A CPI approach using Radiation Awareness and Evidence Based Medicine to Achieve Appropriate Use of Medical Imaging Examinations

Volume 1

James E. Nol

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School of Biomedical and Health Sciences

University of Western Sydney

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DEDICATION

I DEDICATE THIS RESEARCH STUDY TO MY SONS JAMES AND ELIE AND THE CHILDREN OF THE WORLD IN AN ATTEMPT TO CREATE A SAFER HEALTH CARE SYSTEM BY ENCOURAGING THE RESPONSIBLE USE OF TECHNOLOGY.

James E. N d

“THE FOUNDATION OF EVERY STATE IS THE EDUCATION OF ITS YOUTH.”

DIogenes
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Declaration

I hereby declare that this thesis is my own work and to the best of my knowledge it contains no materials previously published or written by another person, except where due acknowledgement is made. I have not submitted this material, in either full or in part, for a degree at this or any other institution.

James E. Nol
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ABBREVIATIONS

Ankle, Knee and Spine examinations (Category ‘B’)

Area Health Services (AHS)

Clinical Practice Improvement (CPI)

Control Site (Hospital ‘C’)

Emergency Department (ED)

Evidence Based Medicine (EBM)

First preliminary study site (Hospital ‘A’)

General Practitioner (GP)

Intervention Site (Hospital ‘B’)

Kidney Ureter and Bladder examination (KUB)

Medical Radiation Scientist (MRS)

Medial Officer (MO)

Quality Coordinator (QC)

Radiology Information System (RIS)

Remaining examinations (Category ‘C’)

Rollout Site (Hospital ‘D’)

1
Skull, Ribs, Nasal Bone and KUB examinations (Category ‘A’)

Team leader (TL)
ABSTRACT

A prospective intervention study, using clinical practice improvement (CPI) methodology, was undertaken to reduce unnecessary x-ray examinations in the early management of patients presenting to the Emergency Department (ED). This was achieved through raising the awareness of medical and allied health staff to medical radiation by means of clinical education and implementing evidence based diagnostic imaging requisition.

The main study was conducted in the ED of a public hospital located in the western Sydney, Australia. A second hospital within the area health service, with similar bed size, activity levels and demographics, was used as the control site.

The first phase intervention raised the awareness of the health professionals to medical radiation. The second phase intervention used CPI methodology to attain efficient clinical practices so as to eliminate unnecessary examinations and requests. A multi-disciplinary CPI Project Team involved in the process of imaging examination requisition was empowered to improve the appropriateness of the requested examination utilisation. This it achieved mainly through the implementation of evidence based clinical decision rules and imaging guidelines. An additional method of validating the outcomes was provided through the simultaneous rollout of the interventions at another hospital within the same area health service.

At the completion of the study, unnecessary examinations such as Skull, Ribs, Nasal Bone and Kidney Ureter Bladder (KUB) requests at the intervention Hospital site were significantly reduced by 92.6% (p<0.0001), whereas at the control site Hospital
there was minimal reduction which was found to be not statistically significant (p=0.2110). Other frequently requested examinations such as Ankle, Knee and Spine requests were marginally though significantly reduced at the intervention Hospital by 22.7% (p < 0.001), whereas at the control site Hospital the reduction was similarly found to be not significant (p=0.1055). Most importantly, the overall x-ray requisition for every 100 ED presentations at Hospital ‘B’ was reduced by 27%.

The results of this study, demonstrated that Radiation Awareness educational programs, targeting medical and allied health staff, will reduce the unnecessary requisition of examinations found not to contribute to the process of the patient’s clinical management. The use of a CPI project approach was found to be important in the process of establishing, implementing and sustaining the achieved improvements, and in particular, the rules and guidelines of evidence based imaging requisition.

Importantly, the study also confirmed that the CPI methodology that had been used for the main intervention was adaptable to other organisations when it was found to have been successfully rolled out at another hospital. This confirmed that the main outcomes of the investigation could be generalised to other health facilities. There was an immediate reduction in the requisition of unnecessary examination similar to the results at the main intervention hospital.

The implementation and adoption of the CPI intervention across the health care system in general could significantly reduce unnecessary x-ray examinations, saving significant health care resources, and sparing patients from potential cancer risks associated with avoidable exposure to ionising medical radiation.
Chapter 1

INTRODUCTION

On 8 November 1895, while experimenting with cathode rays generated in a Crooke’s tube, Dr. Wilhelm Conrad Roentgen discovered a new kind of radiation that caused a small piece of paper coated with barium platinocyanide to glow. As he could not determine how the radiation was carried through space or why it had such penetrating power, he called the radiation X-rays, taking the name from the mathematician’s use of X to denote the unknown quantity in a problem. The formal name given to radiation is Roentgen rays, in honour of the discoverer.

Today, hardly more than a century after its discovery, Radiation Science is part of our culture and way of life, used in our homes and workplaces as well as being the main source of energy in the world. In Medicine, Radiation Technology is an essential diagnostic tool, used for general radiography, fluoroscopic screening and computed tomographic scanning.

Unfortunately, the use of radiation is accompanied with detrimental side effects where the extreme result could be the manifestation of carcinogenesis causing death (NHRMC, 1986)

1.1 BACKGROUND TO THE THESIS

Imaging examinations have become an essential diagnostic tool in the decision making process for clinical management. The use of Imaging has increased dramatically in the modern health care system. However, the increased utilisation
of imaging services is not fully justified, indeed there is extensive literature supporting the notion that a large number of unnecessary and inappropriate diagnostic imaging examinations are requested instead (Two literature reviews are included as Appendices 1 & 2). A substantial number of Imaging examinations requested by clinicians have been reported to have no value in the clinical management process (McCaig, 1992; Stiell et al., 1992; Tasu et al., 2001; Thanni, 2003; Anfossi et al., 2003). Published research shows a large inter-clinician variation for utilisation of imaging examinations of the order of between two to six times (Leurquin, 1995; Stiell et al., 1997; Verstappen, 2004; Mogyorosy and Mogyorosy, 2006).

Over-utilisation of x-ray examinations has negative ramifications on both the health care system and the patient. Over-utilisation affects the health care system by wasting scarce resources and creating unnecessary constrictions or ‘bottlenecks’ in the system. This in turn represents poor use of the valuable time of Medical Radiation Scientists (MRS) and Radiologists. Despite a system of triage being in place, unnecessary examinations continue to be undertaken whilst patients requiring a necessary Imaging test wait until a slot is available.

The literature demonstrates that 'time' is a critical component in the clinical management of patients. In extreme cases such as the serious poly trauma, the actions taken within the 'golden hour' often determine survival (Weber & Ertel, 2005; Zabek & Zaczyski, 2007). For any case, whatever the degree of severity, unnecessary examinations represent poor use of time. Undertaking the correct evidence-based examination will assist, since the appropriate course of action is more likely to be taken in a timely manner (Tallon, 2002; Shaw, 2004). The condition of a patient may deteriorate further during the time spent waiting for and during unnecessary
examinations, Time wasted in this way accumulates and affects other patients waiting for an examination and their condition may also deteriorate.

For the financial year 1993/1994, Medicare paid $724 million for diagnostic imaging services in Australia. In the following 12 years this amount has more than doubled to $1,609 millions (Medicare Australia, 2007). In the financial year 2005/2006, 15 million diagnostic imaging examinations, paid by Medicare, were performed at a cost of $1,609 millions, which accounted for 14.7% of total Medicare expenditure (1609/10976). In Australia, Medicare data indicates that CT use alone has increased 140% over the decade 1992-2002 (Dickie & Fichew, 2004).

A further serious implication for the patient is the side effects of exposure to radiation. Exposure to ionising radiation during Imaging examinations should follow the ‘As low as reasonably achievable’ (ALARA) principle and the requisition of an x-ray examination should be considered carefully by the referring officer to ensure that the benefits outweigh the risks. Essentially, if an examination is not going to alter clinical management, then that examination should not be performed.

The complications of most medical treatments or investigations are tangible; however, those of exposure to ionising radiation are often invisible. This current research investigates the causes for the cavalier approach to requesting examinations.

The consequence of these unnecessary x-ray examinations (Cascade PN, 2004; Strzelczyk, 2006) may be expressed as maleficence in the name of beneficence. Clearly, unnecessary imaging examinations waste finite health funds and other resources. This will diminish the capacity of the public health system to provide other services that are required (Doody et al., 2000; Brenner et al., 2001; Wang et al., 2002 Preston et al., 2003).
The most serious consequence to patients undergoing imaging examinations that involve ionising radiation is the increase in the associated cancer risk. It is estimated that up to 3.2% of cancer deaths in a developed country were attributable to diagnostic x-ray examinations (Berrington de Gonzales and Darby, 2004).

A lack of knowledge and awareness of the risks of medical radiation are revealed as major contributors for over-utilisation of x-ray examinations (Quinn et al., 1997; Correia et al., 2005; Thomas et al., 2006; Heyer et al., 2007). In view of this finding, promotion of the relevant radiological knowledge and medical radiation education awareness could play a greater role in the effort to reduce the over-utilisation of diagnostic imaging examinations. A comprehensive search of the literature dating back to 1950 has shown very few published investigations that examined the impact of radiation awareness education with regard to the over-utilisation of diagnostic imaging examination.

In terms of improving systems and processes within health care, several tools and methods have been used. These include procedures such as Total Quality Management (TQM) and Continuous Quality Improvement (CQI), resulting in improvement in practice, leading to greater efficiency together with a reduction in costs (Laurila et al., 2001). Clinical practice improvement (CPI) has more recently emerged as a powerful tool, developed for the implementation of evidence based practice and quality improvement in health care in recent years (Bothner, 2001). CPI has proved to be effective in improving clinical practice performance at different levels and in different areas of healthcare (Conroy et al., 2005; Gassaway et al., 2005; Pruett et al., 2007; Ward et al., 2007). The Department of Health in New South Wales (NSW) has promoted CPI as the main implementation tool used to improve clinical practice performance (Easy Guide to CPI, NSW Health, 2002). This study
aims to analyse the impact of raising medical radiation awareness, specifically, of medical and allied health staff through clinical education. The investigation examines the implementation of evidence based diagnostic imaging requests and the resultant reduction of unnecessary x-ray examinations in the early management of patients presenting to the emergency department.

1.1.2 Problem statement.

There is widespread over-utilisation of imaging examinations that do not contribute to clinical management. This also represents the poor use of scarce resources. There is also little or no understanding by requesting medical officers of radiation hygiene, or of which imaging test is appropriate in order to provide the greatest sensitivity and specificity for a specific condition.

1.2 PRELIMINARY DEFINITIONS OF TERMS

1.2.1 Radiation Awareness Program is an educational tool used to educate staff regarding the biological effects of low doses of radiation from medical examinations, also the negative financial impact on the health system.

1.2.2 Evidence Based Imaging Requisition is the concept where requesting imaging examinations is limited to those cases where the findings of the examinations will have a direct effect on a patients’ clinical management.

1.2.3 Clinical Practice Improvement (CPI) refers to a set of tools designed to improve patient care through process and systems redesign. In the present investigation, the CPI methodology follows the recommendations of the NSW Department of Health (Easy Guide to CPI NSW DOH, 2002). It is used
as the main tool to implement intervention strategies that aim to introduce evidence based diagnostic imaging requisition.

a. The study went through two phases. The first phase went through three stages, focusing mainly on radiation awareness and building a strong reference base of material for Medical Radiation Scientists to use in their discussion with referring medical officers, whereas the second phase (Stage 4) had the full compliment of the Clinical Practice Improvement (CPI) model as set by the Department of Health.

b. It was concluded from this investigation that to improve the requisition process of imaging examinations and to reduce the number of unnecessary requisitions, a radiation awareness program must be complemented with an easily accessible and user-friendly evidence-based clinical management tool integrated into a CPI model, available to Medical Officers “MO” and allied health professionals “AHP”.

1.3 HYPOTHESES

1.3.1 There is an immediate and measurable, significant improvement in the use of appropriate imaging examination request for patients presenting to the ED as a function of the introduction of Radiation Awareness Programs for MOs, Nurses and AHPs.

1.3.2 There is an immediate and measurable significant improvement in the use of appropriate imaging examination request on patients presenting to the ED as
a function of the introduction of evidence based appropriate imaging requisition method.

1.3.3 Clinical Practice Improvement “CPI” is an efficient tool to deliver Radiation Awareness Programs and implement evidence based clinical management strategies.

i. There is an immediate and measurable significant decrease in unnecessary imaging examinations requested on patients presenting to the ED, as a function of the introduction of CPI intervention.

ii. There is an immediate and measurable significant improvement in efficiencies in cost to the Imaging Department, through the use of appropriate imaging examination requests for patients presenting to the ED as a function of the introduction of CPI intervention.

1.4 AIM

The study has two main goals:

1.4.1 Undertake a pre-test and post-test controlled intervention using the CPI model over a 37-month period.

1.4.2 To plan, implement and monitor the CPI model as the independent variable, being the intervention strategy. This involved the development of four sub goals as follows:
1.4.2.1 To develop a clinical practice model for imaging services to ensure the appropriateness of the imaging services delivered to patients presenting to the Emergency Department.

1.4.2.2 To develop and market an educational program and an educational reference to raise the awareness of clinical staff to the radiation effects, the efficiencies gained from requesting appropriate imaging examinations and reducing over-utilisation on the health system.

1.4.2.3 To develop an Educational Reference employing Evidence Based clinical practice to requesting examinations to ensure the appropriate utilisation of imaging examinations in the management of patients presenting to the emergency department.

1.4.2.4 To assess the effects of CPI on reducing unnecessary imaging requisition and on improving the appropriateness of imaging examination utilisation provided to patients presenting to the Emergency Department.

1.4.2.5 To assess the adaptability and generalisability of the CPI model through the rollout in the Emergency Department of another hospital within the area health service.

1.5 PLAN OF THE ANALYSIS

The preliminary problem assessment and confirmation was undertaken in the emergency departments of two hospitals in Sydney, Australia. The need for the study was assessed by conducting surveys, statistical data analysis and a review of radiological reports and medical records. The major study was conducted in the
western region of Sydney. The hospital site where the study was conducted and interventions implemented, was designated the 'Intervention site', B. A second site of similar size, demographics, activity levels and patient groups, and within the same Area Health Service “AHS” was used as the “control site” to compare the effects of the interventions between the two sites. This hospital was designated as site ‘C’.

The study was undertaken over a 37 months period and in two phases; `pre' and `post' the CPI.

The first phase went through three stages. At stages 1 and 2 for the pre-test period, data was collected retrospectively and analysed from records available from the Radiology Information System. No interventional measures were introduced to either group, and staff remained unaware of the major intervention that would follow. After defining an end-date for the initial 17 months pre-test period the Radiation Awareness program was introduced to the experimental group. Stage 3 of phase 1 followed a more aggressive Radiation Awareness campaign while robust educational reference material was provided to MRSs for their use in their discussion with referring officers.

Phase 2 involved the use of CPI. A multi-disciplinary CPI Project Team was formed and instrumental in the process of managing the requisition of imaging examinations. MRSs were empowered to perform a gate keeping function, with the intention of improving appropriateness of the requested examinations and thus the correct utilisation of imaging examinations for patients presenting to the ED within the experimental group.
The study used CPI tools such as 'brainstorming', cause-and-effect diagrams, and flow charts to identify, implement and evaluate the best approaches to improve the use of imaging services.

Phase 2 ended through the rollout of the CPI model at another hospital.

1.6 FRAMEWORK OF THE THESIS

This investigation was developed around a framework that drew on several areas of study in order to establish its objectives.

- The thesis has been divided into six chapters, with chapter four focusing on Phase 1 and chapter five focusing on Phase 2.

- Two important reference materials were developed during the study by the author and Chief Investigator to assist in the education process and provide all staff with a reference guide on radiation safety and the selection of evidence based appropriate imaging requisitions. These two resource materials are quite comprehensive and included as Appendices 1 and 2.

Chapter 2 provides an overview, update and critical appraisal with regard to the literature of over-utilisation of diagnostic imaging examinations employing ionising radiation. The chapter also examines the risks associated with exposure to medical radiation, reviews the role of the Medical Radiation Scientist in initialising and promoting CPI, and discusses the principles of evidence-based medicine and its application to medical imaging requisition in reducing unnecessary examinations. As a literature review, the chapter provides a critical and analytical approach that objectively examines publications in terms of differences of opinion across the past 60 years.
Chapter 3 provides in detail the research methods. It includes an overview of the research design and procedures, the patient population used, the justification for using a quasi-experimental design, and a description of the quality improvement methods employed, such as the educational programs and CPI. The timetable of the investigation is also presented. It is to be noted that chapters 4 and 5 also deal with specific methodological issues.

Chapter 4 describes the steps of Phase 1 and the outcomes of each stage (1, 2 and 3). Results are mainly presented as tables and charts, while raw data is essentially displayed in Appendices 3 and 4. Phase 1 went through three stages; at the end of each stage, a brief discussion and preliminary conclusion is drawn.

Chapter 5 describes the CPI methodology, including the interventions embraced by the team. A description of the data collection and data analysis procedures is also provided.

Chapter 6 incorporates the discussion of the outcomes with respect to the original hypotheses. An examination is undertaken of the significant implications of the findings of the research on improving the appropriateness of imaging examination utilisation. The chapter also draws conclusions with regards to the important outcomes and its contribution to knowledge, including the recommended future action, future scope and strategies for wider dissemination.

The chapters were complemented with the Following:

1 Glossary of terms
2 List of Tables
Appendix 1

Radiation Physics, Biological Effects, and Radiobiology.

The background sciences presented to medical and nursing staff, and to the public as well. It includes educational reference material, developed throughout the project to respond to the questions raised by staff, students and the public during the radiation awareness sessions.

Appendix 2

Evidence based versus current Imaging requisition practices.

This was developed to be used as reference material for MRS and MO’s to assist them in the decision making process of selecting the appropriate imaging, thus avoiding unnecessary examination requisition.

Appendix 3

Preliminary Quantitative and Qualitative Data.

Appendix 4

RIS Data, Hospital ‘B’ & ‘C’ & ‘D’.

Appendix 5

Medical Radiation Scientist’s Survey.
Appendix 6

*Medical Officer’s Survey.*

Appendix 7

Uncovering the causes of unnecessary repeated medical imaging examinations, or part of, in two hospital departments.

Published in the Radiographer, The official Journal of the Australian Institute of Radiography.

Appendix 8

Digital Repeat Analysis; Setup and Operation.

Published in the Journal of Digital Imaging, USA.

Appendix 9

*Radiation Awareness program.*

A Power Point presentation to raise awareness of attendees to the effects of radiation caused by exposure to low doses of radiation and give them an idea of some radiation doses from natural and x-ray examinations.

The presentation was modified throughout the project. The different versions are titled as:

Appendix 9 _1: Word Document Presentation Stage 2.


Appendix 10

RAP Marketing

Media Coverage
Appendix 11

*Educational Website*

Educational material published in the Emergency Department website.

Appendix 12

*CPI Tables not included within the chapters.*

Appendix 13

OPEN ACCESS.

BAXTER,

2005 NSW HEALTH AWARD

Finalist – Winner.

Appendix 14

EVIDENCE-BASED X-RAY ORDERING.

BAXTER,

2004 NSW HEALTH AWARD

Finalist
Chapter 2

LITERATURE REVIEW

2.1 INTRODUCTION

This review provides an overview, update and critical appraisal with regard to the literature of over-utilisation of diagnostic imaging examinations employing ionising radiation. Clearly, there is an impact from such over-utilisation on both the health system and patients, thus in order to conduct this research it is both germane and critical to comprehensively review the available work. Not only are there risks associated with exposure to medical radiation, such as developing cancer, altering the function of organs, causing genetic mutation and many other effects, there is also an impact on workflows, resulting in the reduced efficiency of MRSs due to unnecessary examinations. Ultimately, there is an impact on funding within the health care system. Thus, the major influencing factors concerning the current situation with regard to the requisition of radiographic examinations will be addressed. The review also addresses the role of the MRS in initialising and promoting clinical practice improvement (CPI) and as the “gatekeeper” or arbiter, in preventing the unnecessary use of medical radiation. One of the major gaps was the dearth of work regarding radiation awareness campaigns.

This review also discusses the principles of evidence-based medicine and its application to medical imaging requisition in reducing unnecessary examinations. CPI is a widespread and powerful tool for quality improvement in health care. Its
principles and applications in health care are discussed. However, there was a major
gap found with regard to the use of CPI in the context of imaging. Very few
publications were found on the over-utilisation of imaging, though there was fairly
substantial work in other areas, such as pathology.

The literature review was vital in terms of defining and characterising the extent and
nature of the problem, and the important connection between itself and the current
study.

The literature review was undertaken using MEDLINE, CINAHL, EMBASE and the
Cochrane Library databases from 1965 through Feb 2007.

2.2 CURRENT RADIOGRAPHY REQUISITION

2.2.1 Facts of current diagnostic imaging requisition

Conventionally, diagnostic imaging examinations are requested for both clinical and
non-clinical reasons, including medico-legal, lack of confidence, and social or patient
expectation (Cameron et al., 1999; Wilson et al., 2001; Neale, 2004). These
invariably represent misuse of imaging service and MRSs by over-requisition, or
indeed the inappropriate use of non-specific and non-sensitive examinations (Levine
et al., 1997; Thanni, 2003).

There is an absence of published texts or articles that coherently and systematically
review these radiographic examinations. A thorough and systematic review of these
examinations is beyond the scope of this work.

There is a large variation between doctors for the use of both laboratory and imaging
requests. (Leurquin, 1995; Malcolm, 2000; Verstappen, 2004).
Mogyorosy and Mogyorosy (2006) reviewed the available research results in order to identify evidence of variation in primary care in the requisition of diagnostic requests. There is a significant (2 to 4 fold) variation in laboratory requests between countries, as well as between regions and praxis. There is larger (10 to 20 fold or more) variation between regions and praxis in the case of diagnostic requests where the clinical usefulness is deemed to be uncertain.

The over-utilisation or unnecessary requisition of diagnostic imaging examinations, have been extensively studied and published (Appendix 2). For example, the ankle radiographic series and cervical spine series are the two most commonly requested musculoskeletal examinations in EDs (Gratton et al., 1990). Doctors almost always refer patients with this problem for radiography to exclude fracture, although such fractures are typically present in less than 15% of cases (Clarke et al., 1983; Montague et al., 1985; Dunlop et al., 1986; Stiell et al., 1992). Most of these patients will have sustained simple injury to ligamentous soft tissue, or a small avulsion fracture of no clinical significance. It is estimated that more than 5 million ankle radiographic examinations are performed annually in Canada and USA (Cockshott et al., 1983).

Conservative estimates indicate that more than 1,000,000 blunt trauma patients who have the potential for sustaining a cervical spine injury are seen in EDs in the United States each year (Hoffman et al., 2000). About 800,000 cervical spine radiography series (CSR) are performed annually. Virtually all patients with trauma to the neck are requested for imaging by emergency doctors. Among those patients presenting with intact neurological status (arriving either by walking or ambulance), the incidence of acute fracture or spinal injury is less than 1% (McCaig, 1992). Stiell et
al. (1997) assessed the variation of CSR requisition in the EDs in 6 teaching and 2 community hospitals in Canada for alert, stable adult trauma patients. There was considerable practice variation among well-trained emergency physicians, with radiography rates ranging as much as 6-fold, from a low of 15.6% to a high of 91.5%. None of the institutions with low requisition rates missed any patients with cervical spine injury.

### 2.3 IMPLICATIONS OF INAPPROPRIATE IMAGING REQUESITION

#### 2.3.1 Cancer risks associated with medical radiation

One of the most serious consequences of unnecessary radiological requisitions is the potential cancer risks associated with ionising medical radiation. The biological effects of low levels of radiation have been investigated and debated for more than a century. The risk of cancer induced by radiation is the primary consideration of biological effects associated with diagnostic radiography procedures.

Ionising radiation has the potential to disrupt the structure of organic molecules in cells (Tubiana et al., 1990). Little question exists that intermediate and high doses of ionising radiation produce deleterious consequences in humans, including, but not exclusively, cancer (Pollycove & Feinendegen, 1999; Dickson et al., 2005). It is universally accepted that there is no safe level of radiation and even a single low dose exposure carries an associated risk and this risk increases with the dose received (Berrington de Gonzales and Darby, 2004).

Historically, the pioneer studies were essentially incidence reports resulting from medical radiation, such as the establishment of the direct relationship between x-ray
exposure and some of harmful consequences (Thomson, 1898; Rollins, 1901). There were reported deaths of several x-ray pioneers, including that of radiologist Ironside whose death was attributed to x-ray exposure (Leonard, 1907; Thomas, 1995). It is likely that both Marie Curie and her daughter died as a result of x-ray exposure from the mobile radiographic units (Coppes-Zantinga & Coppes, 1998).

Most information of cancer risks induced by radiation is based on the epidemiological studies from atomic bomb survivors, patients irradiated for diagnostic and therapeutic purposes, and those working in radiation related professions and industries (Ashmore et al., 1998; Brenner et al., 2001).

It is estimated that there were 440 excess solid cancer deaths associated with the radiation exposure in the cohort of atomic bomb survivors in Japan. This was reported in the 47-year follow-up (Preston et al., 2003). The excess solid cancer risks appear to be linear with respect to dose, including doses in the 0 to 150mSv range. Although the atomic bomb survivor analyses have often been considered as high-dose studies, the mean dose in the cohort was actually only 200 mSv, with >50% of individuals in the cohort having doses <50 mSv. Those exposed in childhood had 1-1.8 times the estimates for those aged 30 (Stevens et al., 1991; Darby et al., 1992).

For children under age 5 years exposed to fallout in Nordic countries, the estimated fallout bone marrow dose was 1.5 mSv. The incidence of leukaemia increased with RR = 1.11 with 95% CI = 1.00-1.24 (Stevens et al., 1991; Darby et al., 1992).

Several research studies have been conducted of nuclear industry workers from UK (Kendall, 1992; Muirhead, 1999), Canada (Ashmore, 1998), and USA (Gilbert et al., 1989; Cardis et al., 1995). The evidence revealed an association between radiation
exposure and mortality from cancer, particularly significant for leukaemia and multiple myeloma.

Investigation of risks of cancer from medical radiation was published with data derived from radiologists and MRSs working in UK (Smith and Doll, 1981), the USA (Smith & Doll, 1981; Doody et al., 1998), Japan (Yoshinaga et al., 1999), and China (Wang et al., 2002). The mortality from cancer for these professionals was found to be relatively higher than those of the normal population. This was especially the case for lymphatic and haematopoietic cancers, in professionals with higher cumulative exposure. Breast cancer was relatively higher for females with higher cumulative exposure. However, these studies are retrospective. Many of the subjects would have been working during times when regulations were less strict and protection guidelines were less sophisticated. Thus, there is need for these studies to be performed on workers subjected to up to date stricter regulation. Technology has improved greatly in terms of dose reduction techniques such as pulsed fluoroscopy, half dose integration and the ability to alter collimators or gantries without releasing radiation by utilising last image hold techniques.

Studies of irradiated patients for diagnosis with higher exposure and therapy reveal greater cancer risks than the general population. These findings suggest the breast, thyroid gland, and bone marrow to be among the most sensitive tissues to the carcinogenic effect of medical radiation (Darby et al., 1987; Boice, 1991; Ron et al., 1995; Howe and McLaughlin, 1996; Doody et al., 2000).

Radiation risks for irradiation in utero have been extensively studies (Mole, 1990; Muirhead et al., 1993; UNSCER, 1993; Doll and Wakeford, 1997). The association between the low dose of ionizing radiation received by the foetus in utero from
diagnostic radiography, and the subsequent risk of cancer in childhood provides
direct evidence against the existence of a threshold dose below which no excess risk
arises, and has led to changes in medical practice. Though, this change in practice
may also be as a result in the development and availability of ultrasound.

These epidemiological studies provide good evidence showing an increase in risk of
cancers at acute radiation dose $> 50$ mSv, and reasonable evidence for an increase of
risk for some special type of cancers at doses above $5$ mSv. With most modern
radiological examinations, a single procedure produces exposure in the range from $1$
to $30$ mSv (Wall & Hart, 1997; Berrington de Gonzalez & Darby, 2004).

The total population dose of radiation from medical diagnostic procedures is
increasing worldwide. In the USA, the rate of radiography examinations increased
from 670 to 962 per 1000 population from 1970 to 1996 (Shapiro, 2002). In Japan,
the rate has reached to 1477 in 1996 (Berrington de Gonzalez & Darby, 2004). In
Australia, Medicare data indicate that CT use alone has increased 140% over the

Generally, protracted radiation exposures are associated with lower risks than those
of acute exposures to the same total dose for cancer (NCRP, 1980; Brenner, 1999).
Epidemiological studies also show that for radiation exposure over prolonged period,
there is no doubt that there is an increased risk of cancers with protracted dose $>100$
mSv, or that there is increased risk of cancers at protracted dose above $50$ mSv.

For lower dose exposure, it is difficult to estimate the increase of risks of cancers by
epidemiological study (Brenner & Sachs, 2006). Compared with higher dose studies,
the cancer risks associated with lower dose radiation are likely to be lower. It would
require an extraordinarily large sample population to undertake a lifetime follow-up
to maintain statistical precision and power. If the excess cancer risk were proportional to the radiation dose, and if a sample size 500 persons were needed to quantify the effect of a 1000 mSv dose, then a sample size 50,000 would be needed for 100 mSv dose, and about 5,000,000 for a 10 mSv dose (Pochin, 1976; Land, 1980). Thus, it is almost impossible to conduct an epidemiological study of cancer risks associated with radiography examinations.

Due to practical reasons, all the cancer risks associated with medical radiography examinations are estimated by extrapolation, with the assumption that small doses of radiation can cause cancer, as experimental and epidemiological data do not suggest a threshold below which radiation does not cause cancer.

It is estimated that about 0.5 to 3.2% of cancer deaths were attributable to diagnostic radiography (Doll and Peto, 1981; Kaul et al., 1997; Berrington de Gonzales and Darby, 2004).

In addition to the quantitative cancer risks per Sievert, each cancer fatality that is prevented is estimated to save 17.5 years of life, (ICRP, 1991). Whilst there is little information available on determining the lifetime costs of cancer deaths, nevertheless this has been done. For example (Avritscher et al., 2001; Avritscher et al., 2006) achieved this for bladder cancer by reviewing medical records of bladder cancer patients then examining the resources used during management of bladder cancer by unit charges. Costs using the Medicare cost-to-charge ratio with adjustment for inflation provided a final U.S. dollar cost. The investigators determined the average cost of bladder cancer was $65,158.

Whilst such extensive work may be beyond the scope of this particular research, it demonstrates that the cost analysis of the treatment of cancers and other body...
malfunctions caused as a result of exposure to unnecessary radiation and over-utilisation of x-ray examinations is possible and could be determined.

Brenner et al. (2001) estimated the lifetime cancer mortality risks attributable to radiation from CT radiation in a 1-year-old are 0.18% for abdominal CT and 0.07% for head CT. They reported that about 500 of children may ultimately die from cancer attributable to radiation from these examinations in the USA., Despite the high sensitivity of CT, concern was raised by the National Radiological Protection Board (NRPB, 2005) in the UK during the early 90’s, as they noted that CT though making up only 3% of the total examinations performed, resulted in 30% of the total dose of imaging examinations. A more recent study found that CT accounts for 13% of all diagnostic imaging procedures but is estimated to be responsible for more than 70% of the collective radiation dose delivered to patients (Mettler et al., 2000; Dixon and Goldstone, 2002).

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 1993) first proposed the linear no-threshold (LNT) theory in 1958. Despite the widespread adoption of this theory, it must be pointed out that the results of many scientific investigations do not support LNT (Bond et al., 1996; Edwards & Bouffler, 2005; Tubiana et al., 2006). Studies of the relationship between environmental radon concentrations and lung cancer even contradict this theory, clearly suggesting a “hormetic” effect (Cohen & Colditz, 1994). This is by no means an isolated report and there are many others indicate that low-dose ionizing radiation is not only a harmless but often has a beneficial or hormetic effect (Parsons, 2003; Higson, 2004). The concept of radiation hormesis is usually applied to physiological benefits from low LET radiation in the range of 1-50 cGy total absorbed dose.
(Macklis, 1991). Ironically, it has been even suggested that about one third of all cancer deaths could be preventable by increasing exposure those individuals to low dose radiation (Becker, 2007; Muckerheide, 2007). However, since many patients undergoing examinations involving ionising radiation are children or young adults and given their increased sensitivity (Mazonakis et al., 2004), despite the contra evidence to LNT, a cavalier attitude to radiation hygiene would be both unreasonable and unacceptable. Though, further work is required in this area. In summary, the epidemiological studies suggest that for an acute exposure 10-50 mSv and for a protracted exposure 50-100 mSv, there is reliable evidence of increased cancer risk in human (Chadwick et al., 2003). Most single diagnostic radiography examinations produce doses in the range 1-30 mSv (Damilakis et al., 2003; Gogos et al., 2003; Ramli et al., 2005). These provide a firm basis to extrapolate possible cancer risks from still lower dose radiation. Experimentally grounded and quantifiable biophysical arguments support that a linear extrapolation of cancer risk estimation appears to be the most appropriate methodology (Wheldon et al., 2000). It is generally accepted that there is no threshold of radiation dose for excess cancer risk and even the smallest amount increases the risk of cancer (Breckow, 2006). Regardless of any evidence supporting radiation hormesis, radiation protection principles such as ALARA should be enforced in the daily practice.

2.3.2 Clinical implications

An excessive number of referrals not only utilises resources, but can also lead to adverse outcomes for patients. For example, it has been estimated that with 10 requests for a healthy person there will be a 40% chance of a false-positive result,
requiring further investigation and follow up, thus utilising even more time and money (Petra Axt-Adam et al., 1993).

False-positive results from unnecessary requests may also result in costly and on occasion, harmful interventions (Griner and Glaser, 1982). Test results may misdirect doctors and patients into a “clinical wild goose chase” through a series of unnecessary diagnostic procedures, and in some instances surgery (Gama et al., 1992).

General practitioners (GPs) frequently request “blood tests” when a patient presents with an unexplained complaint (Van Bokhoven et al., 2006). Due to the low prevalence of serious pathology in general practice, the risk of false-positive request results is relatively high. This may result in unnecessary further diagnostic tests, leading to effects such as patient anxiety, high costs, somatisation and morbidity.

The false-negative results from misuse of insensitive radiography examinations can have serious consequences. For example, despite the low sensitivity of the CSR in detecting blunt cervical spine fractures almost all those patients are referred for plain cervical spine radiography although up to forty-two to seventy-eight percent (42% to 78.4%) of blunt cervical spine fractures may be missed by CSR (Nunez, 1996; Gale et al., 2005).

Inefficiencies in utilisation of imaging services occur as a result of inappropriate requests, which in turn increase the workload unnecessarily. Increased imaging workloads contribute significantly to poor workflow within an organisation by burdening the system with unnecessary examinations, introducing delays in reporting in addition it reduces the productivity of MRSs. For example Daffner (2000) in his study demonstrates that the routine practice of CSR for blunt cervical spine trauma
patients takes an average of 32 min taking the valuable MRS time away from other patients genuinely requiring an imaging examination. Achieving streamlined imaging workflow through the elimination of unnecessary requests would allow for faster availability of imaging reports and thus enhancing the potential of rapid diagnosis to initiate clinical intervention.

Over-reliance and over-utilisation by clinical staff on tests such as in-vitro laboratory diagnostics may lead to a deterioration of skills in history taking and physical examination (Isouard, 1996); this can also be expected to have implications for over-utilisations of imaging examinations.

2.3.3 Economic implications

The over-utilisation of requests results in wasted resources. The appropriate allocation of society's resources devoted to health care has been the subject of significant debate. In 1965, the United States devoted 5.9% of its gross national product to health expenditures (Moskowitz, 2000). By 1995, this figure had risen to approximately 14%. It is estimated that expenditures will increase to approximately 17% of the gross national product by 2007. It has been estimated that medical imaging uses approximately 8% of health care dollars. Government health care expenditures have grown more rapidly than the economy in all developed countries. Between 1970 and 2002 these expenditures per capita grew at almost twice the rate of gross domestic product (GDP) per capita in 10 countries studied: Australia, Austria, Canada, Germany, Japan, Norway, Spain, Sweden, the United Kingdom and the United States (NCPA, 2006). In Australia in 2002, total health expenditure as a proportion of GDP (9.3%) was the ninth highest in the OECD (AGDHA, 2006). It was higher than the average for all OECD countries (8.5%). In Australia, diagnostic
imaging by MRSs under Medicare had increased from 4,685,384 in 1993 to 14,921,662 in 2006 (Medicare Australia, 2006). Based on the Australian Medicare figures, taking the lowest imaging fee per examination, (as per the Australian Medicare benefits schedule fee), the estimated yearly cost of unnecessary examination would almost be $148 million a year (Medicare statistics, April 2007).

It was estimated that the total professional and technical cost of performing 5 million ankle radiographs annually in North America was $500 million in 1990’s, although less than 15% of the cases presented with a fracture (Stiell et al., 1993). Low back pain (LBP) is the second most common complaint among patients presenting to primary care physicians, with 4 of every 5 people experiencing low back pain at some point in their lives in the USA (Brant-Zawadzki et al., 2000). Lumbar spine radiography examination (LSRE) is still included as a standard examination for patients presenting with LBP. The effectiveness of LSRE has been questioned for long time. In the United Kingdom, some 5% (£81.6 million) of the direct health care cost of LBP is spent on LSRE (Maniadakis and Gray, 2000). Vader et al. (2004) studied the use of and resultant exposure from plain lumbar spine radiography in Switzerland, indicating the estimated number of LSRE is 39 per 1000 inhabitants per year.

2.4 INFLUENCING FACTORS

There are many influencing factors that result in the requisition of unnecessary examination. The main factors identified include, lack of knowledge and awareness of medical radiation, fear of medical litigation, influence or expectation of the patient, financial incentives and payment structures, and most importantly, the lack
of appropriate clinical training in diagnostic strategies required to manage a clinical condition.

2.4.1 Lack of awareness and knowledge of radiation

There are documented reports supporting the premise that clinicians, and even some radiologists, generally lack the awareness and knowledge of radiation exposure from medical diagnostic procedures and the associated risks (Correia et al., 2005). They are generally unaware of the environmental impact, including the biological risks from exposure to ionising radiation, for procedures they prescribe and/or perform daily.

There are studies that identify some unnecessary exposure to radiation to be as a result of the behaviour of MRSs. MRSs may take shortcuts when performing examinations, providing a less reliable examination and exposing the patient unnecessarily to additional radiation. Nol et al. (2005 & 2006) identified that poor training and knowledge resulted in avoidable exposures and repeat examinations by MRSs. The method of overcoming this was through education, training, and raising awareness to the risk of exposure to radiation.

These studies also support the concept that patients are not provided with information regarding the risks, benefits, and level of radiation dose received from these procedures.

For example, Quinn et al. (1997) studied radiation protection awareness in non-radiologists employing an anonymous questionnaire. An underestimation of radiation dose was made by all respondents (p<0.001). The majority of respondents were not aware that patients do not have an annual dose limit and the majority did not know
the relative radio-sensitivity of different organs. It was shown that despite the POPUMET (Protection of Persons Undergoing Medical Examination or Treatment) regulations the majority of clinicians have not received adequate radiation protection teaching and that even if a course had been attended, overall knowledge was still poor. Quinn and his colleagues proposed that formal compulsory teaching at undergraduate level may correct this in the future.

Published data demonstrate there to be considerable thirty-eight percent (38%) to fifty percent (50%) differences in effective radiation doses from left and right lateral lumbar spine views of radiography examinations (Hard et al., 1994; Hard et al., 1996). Nicholson et al. (1999) investigated the awareness of imaging staff to the radiation dose differences in four London hospitals, including 15 radiology consultants, 10 radiology registrars, 10 senior MRSs, and 40 junior MRSs. Only one respondent knew the dose difference and correctly identified the approach that results in lower effective dose.

There is an increasing awareness of the potential risks associated with ionizing radiation employed in medical imaging, especially following recent publicity regarding radiation risks in children. Thomas et al. (2006) investigated radiation dose awareness among paediatricians. This study demonstrated the awareness of radiation protection issues amongst paediatricians to be generally low, with widespread underestimation of relative doses and risks. When estimating the effective doses of various paediatric radiological investigations in chest radiograph (CXR) equivalents, eighty-seven percent (87%) of all responses and ninety-four percent (94%) of CT estimates, were underestimated. Only fifteen percent (15%) of respondents were familiar with the “As low As Reasonably Achievable” (ALARA) principle. Only
fourteen percent (14%) of paediatricians recalled any relevant formal teaching during their specialty training.

CT accounts for just thirteen percent (13%) of all diagnostic imaging procedures but is estimated to be responsible for more than seventy percent (70%) of the collective radiation dose delivered to patients (Mettler et al., 2000; Dixon and Goldstone, 2002). Lee et al. (2004) studied the awareness level concerning radiation dose and possible risks associated with CT among patients, ED physicians, and radiologists. In this study, all the physicians and radiologists were unable to accurately estimate the dose for one CT scan compared with that for one chest x-ray. Only nine percent (9%) of the physicians and three percent (3%) of the patients believed that there was increased risk associated with CT scan. Regardless of their professional knowledge and experiences, only forty-seven percent (47%) radiologists believed there was increased risk. Only seven percent (7%) of ED patients were informed about the risks and benefits of their CT scan, although twenty-two percent (22%) physicians reported that they had provided such information to their patients. Similarly, Heyer et al. (2007) assessed the knowledge of non-radiological physicians concerning radiation exposure during normal chest x-rays and chest CT. It was demonstrated that there was little ability to correctly estimate radiation dose from examinations of the thorax, especially of CT examinations, indeed this posed substantial difficulties for non-radiologists regardless of the length of professional experience and field of clinical training. This group went on to suggest that in light of the increase in use of radiological examinations, there is a need for targeted adaptation of medical school teaching content, with promotion of pertinent continuing radiological education.
2.4.2 Medical litigation

Health care has been reported to be in the midst of a medical litigation crisis that may well deteriorate further before there is a significant improvement (Cohen et al., 2005). Seventy-seven percent (77%) of all Irish doctors from trainees to consultants commented they fear a legal complaint according to one study (Birchard, 2004). The frequency of claims against consultants is projected to increase from 200 to 210 per 1000 consultants. The Irish government stated that the cost to cover doctors in case of litigation in the health system has tripled in 10 years (Saunders, 2001).

The fear of medical litigation has been highlighted as a contributing factor to the unnecessary use of requests with clinicians sometimes requesting diagnostic requests in order to reduce the risk of malpractice liability (Cameron et al., 1999; Neale, 2004). Of course, for the referring doctor the concept of avoiding malpractice also results in avoiding mistakes and thus improving patient care. The transient nature of the relationship between the doctor in the ED and the patient, make it more likely that a patient will bring a complaint or malpractice suit against an unfamiliar doctor (Lloyd, 1986). Although the defensive use of diagnostic requests may improve clinical outcomes for some patients, it worsens clinical outcomes for others. Moreover, defensive requesting worsens the expected outcomes of all patients whose clinical strategies are altered. Clinicians need to realise that defensive requesting may reduce the overall quality of patient care (DeKay and Asch, 1998). According to Sox (1989) the concern of the doctor is with avoiding mistakes that could cause harm to the patient and result in a lawsuit (Sox, 1989).

For many doctors, a request for an imaging test is an easy way to avoid mistakes, even if there is little chance of a result that would change the management of the
patient. Allison (1993) reported that obstetricians in one region dramatically increased the number of requests for diagnostic examinations over the five years prior to their study. The single most attributable factor to requesting inappropriate tests was identified to be the fear of litigation (Allison, 1993). However, such a belief may often be mistaken. Requests with a high level of false negatives is no insurance against missing pathology, and requests with a high a false positive rate may lead to an incorrect positive result.

Birbeck et al. (2004) surveyed 595 US neurologists, utilising demographic information, attitude scales, and clinical scenarios to evaluate the influence of non-clinical factors; that is malpractice concerns and reimbursement, on decisions taken with regards to requesting tests. The study revealed that malpractice concerns and receipt of reimbursement, to be associated with a higher likelihood of request requisition. Neurologists in this survey estimated on average that 8 neurologists per 100 (median = 5) in their state would be sued by patients or insurance companies within the next year.

2.4.3 Effects of financial incentives and payment structures

Financial interests or incentives and payment structure have always been an important factor influencing the requisition of imaging tests (Spettell et al., 1998). There is extensive literature showing that non-radiologist physicians with a financial interest in the diagnostic imaging of their patients request more imaging than colleagues in the same specialty without financial interest. New possibilities for self-referral and a proliferation of “joint ventures”, emerged from collaborations between medicine and industry, with a growing environment of business-type competition, and acceptance of a for-profit orientation, in the 1980s have all further accentuated
and compounded the issue. (Gray, 1986; Mitchell, 1995; Spettell, 1998; Greeson, 2004). Common self-referral examples are obstetricians (or their staff) performing ultrasound examinations, internists performing and interpreting chest radiography, and orthopaedic surgeons performing and interpreting musculoskeletal radiography. More commonly, physicians refer patients to their own imaging facilities or the facilities of their organisation.

The largest studies regarding the prevalence of referral of the patient by a clinician to their own imaging facility utilised the complete national Part B Medicare data from 1989 and 1993 (Leven, 1994). This data covered primarily the elderly and was estimated to reflect one third of imaging performed in the United States. Seventy percent (70%) of radiographic and sixty-three to eighty-four percent (63%-84%) of ultrasound examinations in private offices and imaging centres were self-referral and these examinations accounted for sixty to eighty-two percent (60%-82%) of the total charges for these procedures. Non-radiology physicians who have an X-ray machine in their consulting rooms perform as many as four to five times as many examinations per patient as physicians in the same specialties managing patients with the same conditions, though referring them to radiologists for imaging (Aranovitz, 1994).

Kouri et al. (2002) carried out a literature review of doctor self-referral for diagnostic imaging. The empiric literature reveals that self-referral constitutes approximately sixty to ninety percent (60%-90%) of non-hospital radiography requisition. Non-radiologists performing their own imaging, are at least 1.7-7.7 times as likely to request imaging as non-self-referring physicians in the same specialty that see patients with the same conditions. When self-referral involves an external facility in
which the referring physician has a financial interest, imaging is increased by as much as fifty four percent (54%), depending on the modality. The limited evidence available generally indicates that, increased financial incentives such as those in self-referral, may lead to more requests and that self-referral involves over-utilisation.

The impact of non-clinical factors on GPs’ requisition patterns for magnetic resonance imaging/computed tomography for 4,372 patients presenting with a headache was examined (Couchman et al., 2004). It was found that, at their first encounter, patient's insurance status under the health care system's Health Maintenance Organization had statistically significant associations with the likelihood of imaging requests.

Litt et al. (2005) compared the relative use of bilateral versus unilateral extremity radiographic examinations when patients are referred to radiologists for imaging (radiologist referred) versus studies performed in the referring physician's office (self-referred). The rate of self-referred bilateral examinations was 2.21 times higher per 100 office visits than the rate of radiologist-referred bilateral examinations. Combined bilateral and unilateral use by self-referrers was 1.86 times higher than use by radiologist-referrers. Self-referring podiatrists and rheumatologists requested bilateral studies up to 3.25 times more frequently than did their radiologist-referring colleagues.

2.4.4 Influence of the patient

Patients' perceived need or preferences for diagnostic requests also plays an important role in influencing doctor's requisition behaviour,
Requisition of ankle radiographs is influenced by the nature of ED practice (Long, 1985; Lloyd, 1986). Patients, suffering pain and anxiety have brief encounters with busy doctors whom they have not seen before and who will not be following their care. Furthermore, Doctors frequently believe that patients expect radiography.

The patient's role on imaging referral when presenting as outpatient treatments for respiratory problems and low back pain was investigated by Wilson et al. (2001). Patients were found to communicate their wishes to physicians, either directly or indirectly, regarding radiological examinations they believe are necessary. Differences in physicians' adherence to guidelines regarding imaging utilisation may in part reflect variations in patients' perceived need for those examinations. They suggest efforts to educate patients regarding situations where radiological studies are actually medically indicated may have an important role, complementary to image requisition guidelines.

Van Der Weijden et al. (2003) studied Dutch general practitioners' request-requisition behaviour for patients presenting with unexplained complaints. On average, thirteen percent (13%) of consultations involved complaints considered as unexplained by GPs. The Dutch College of General Practitioners (DCGP) recommends a watchful, waiting attitude regarding the requisition of requests for unexplained complaints. However, in their study, unexplained complaints were positively related to request requisition (adjusted odds ratio [OR] = 2.4, ninety percent (95%) confidence interval [CI] 1.1-5.3), despite the DCGP's recommendation. Patients' expectations regarding request requisition, exerted further influenced (adjusted OR = 4.1, 95% CI 2.2-7.6).
2.4.5 Training of diagnostic strategies

The selection of diagnostic strategies for patients presenting to the ED may appear to be relatively straightforward. However, the process for the development and selection of appropriate imaging examinations strategies for patients presenting to ED has proved over time, to be poorly undertaken by some clinicians. According to some investigators, the problem appears to be related to the lack of training given to medical students on the principles that underlie clinical decision making (Isouard, 1996). The argument proposed is that most of the energy expended in the education of medical students and house officers is directed into teaching a huge body of knowledge and methods for gathering and interpreting data, with little or no attention being given to the principles that underlie clinical decision making (Isouard, 1996).

However, the ability to make rational decisions that lead to optimum therapeutic outcomes is one of the chief characteristics of an outstanding clinician. Medical Imaging examinations should only be requested when the information available from the history, physical examination, and previous imaging examinations is insufficient to handle the questions at hand. The requisition of a specific and high sensitivity imaging examination should therefore be undertaken on the assumption that the resulting data would appreciably lower the clinical uncertainty and significantly change the pre-exam probability that the suspected medical condition is present (Black et al., 1991).

Low sensitivity examinations should not be requested for the purpose of confirming a finding (NHRMC, 1986). Not every examination traditionally employed is a valid tool to diagnose an illness. For example, kidney, ureter, and bladder (KUB) radiography is traditionally used as the first imaging modality for patients with first-
time episodes of renal colic. However, current studies have revealed that KUB has only a sensitivity of forty two to fifty nine percent (42% to 59%) for the detection of calculi, and specificity around seventy seven percent (77%) (Levine et al., 1997; Anfossi et al., 2003).

Acquisition of diagnostic knowledge and improvement of patient health often are mutually exclusive goals. The majority of clinical conditions permit the pursuit of perfect diagnostic knowledge (Isouard, 1996). Occasional medical disasters occur because physicians underestimate the patient's functional reserve or the cumulative toll exerted by performing multiple tests (Isouard, 1996). In emergency situations or with serious illness, the maximum amounts of knowledge that can be accumulated maybe less than perfect (West and West, 2002). Insufficient knowledge of request sensitivity and specificity has been identified as a major reason for the poor use of laboratory tests (Isouard, 1996). The same principle applies to imaging. If two or more examinations are available for the diagnosis of certain ED presentation, the one with the highest sensitivity should generally be selected if it is important to rule out disease, and the one with the highest specificity should be selected if it is most important to confirm the presence of disease (Black et al., 1991). However, in some medical conditions, it is unnecessary to obtain confirmation, especially when a confirmed diagnosis does not lead to a change in clinical management; for example, as shown in Appendix 2.9, the management of rib fractures remain the same regardless of x-ray confirmation.
2.5 CURRENT ROLE AND PROFESSIONAL STATUS OF MEDICAL RADIATION SCIENTISTS

In the early years of radiation medicine there was no clear distinction between radiography and radiology and the terms were used interchangeably (Larkin, 1983). The early non-medical x-ray workers or MRSs were responsible for the care of their patients, the operation of the x-ray equipment and, significantly, for the report of radiographs. This recognised implicitly their specialised knowledge and skills, as well as their responsibility and accountability to patients and to the wider society in which they practised. These were powerful indicators of autonomy and established the first MRSs as practitioners in their own right and radiography as a profession. However, within ten years of x-ray discovery, moves were made to establish boundaries between the medical and non-medical practitioners (Arthur and Muir, 1909). Subsequently, radiography was gradually changed to mean the production of medical radiograph and was practised by non-medical qualified or technical personnel under complete control of the medical profession.

The traditional view of the MRSs or as previously known as the Radiographer was that of the technician “pushing the buttons” in order to produce an image, with no role in science or decision making processes. They are expected to perform an examination simply because it has been requested by a doctor, without any reasoning regarding whether it is appropriate or the correct test for that condition. Due to the hierarchical structures and medical dominance in the health workforce, the culture does not allow MRSs to question the justification for an examination (Germov, 2002; Grbich, 2004). Furthermore, taking on the role of an educator to teach requesting medical officers was not viewed as acceptable. The Medical profession dominance of
radiography was evident not only in the field of education but also in relation to the pay and conditions of employment of MRSs.

The dimensions of medical dominance in health care system are apparent across western countries including Australia. The dominance is reflected in wider society and specifically in government policy orientation in the provision of resources for research, technology and care in MRS. It is also apparent in the hierarchical structures and the division of health labour within the health system by medical profession, including medical knowledge and research (Grbich, 2004). The dominance in this sense refers to both visible and hidden methods in which power organises change and continuity in health policy and practice. In recent years, the medical profession dominance in health care system has been challenged by society as well as the broader democratic processes of lay people regarding medicalised care and the general definitions of risks associated with health treatment based on the medical model (Reddy, 1996). The challenge is also derived from the shift of the health care system to the more privatised, market-driven and managed care of today (Germov, 2002).

The re-establishment of radiography as a profession was slow. One major step was taken in 1960 with the introduction of the Professions supplementary to the Medicine Act (PSM) with radiography recognised by status (Moodie, 1970). The professionisation of radiography is progressing steadily; although it is well evidenced in the literature that the current professionalisation of MRSs has developed under the influence of professional dominance of radiologists. This has constrained MRSs from achieving their full potential (Larkin, 1978; Daly and Willis, 1994; Ryan et al., 1996).
Changes in the education and role extension are changing the professional status of MRSs as well as for other health professionals, challenging the boundaries of their relationships with doctors (Wick, 1999; Smith and Baird, 2007). MRS education in Australia is of a high standard. Most of the eight universities offering undergraduate degrees also offer postgraduate programs in diagnostic imaging. Three universities currently offer postgraduate courses specifically in image interpretation. A survey by Egan (2005) indicates that 74.5% of MRSs working in public hospitals of NSW have postgraduate qualifications. In some hospitals, majority of MRSs possess postgraduate qualifications.

As identified by Finch (1997), there are substantial variations between the levels of responsibilities of MRSs between different countries and imaging modality groups including:

- is told exactly how to position the patient for each projection
- follows defined and precise protocols only adapting under direction
- usually follows protocols, but may adapt them without permission
- may make independent decisions about the adaptation of projections, or about the performance of further projections
- may assess and question the diagnostic need for examination
- may suggest the other imaging modalities are more appropriate
- may describe the radiographic appearances on an image to a clinician at his or her request
may give an opinion about the diagnosis to the referring clinician

Professionalisation opportunities for MRSs have been boosted in the USA with the establishment of the positions of mid-level radiology practitioner assistant (RPA) and, more recently, radiologist assistant (RA). Although they still work under the supervision of radiologists, both RPAs and RAs have extended clinical roles with regard to “patient assessment, patient management and a broad range of radiology diagnostic and interventional procedures (CBRPA, 2007). They may be certified to perform procedures traditionally performed by radiologists and to provide technical reports to assist radiologists and referring medical officers. However, the supervising radiologists retain the responsibility for final image interpretation, diagnosis and issuing of written reports.

In Australia in the last two decades, the role of MRS has undergone a radical change. The profession has moved from hospital certificate into higher education, from a college diploma to university degree. Moreover, an additional mandatory year for professional development has been introduced, to ensure a high standard within the profession. Since these changes, the profession has moved forward with many postgraduate degrees undertaken including Masters and PhD. These include areas of role extension that blur the traditional boundary between professions, such as a Masters degree in image interpretation. This area until recently was the restricted domain of the radiologist. MRSs have become a trusted source of knowledge and expertise that medical officers and even radiologists rely upon. The hierarchy and relationships have altered in recent years to the extent that the radiologist no longer enjoys a position of unquestioned authority. MRSs are becoming professionally differentiated and autonomous. They need no longer demonstrate obedience to the medical
profession. Obedience to dominant professions and its dangers within the hospital environment has been the subject of important research in Psychology (Hofling et al., 1966). The MRS would not perform an examination that is unnecessary and potentially harmful.

Today the role of the MRS is changing to become the instigators, promoters, and gatekeepers of imaging practices. The role was and still is beset with enormous challenges due to the dominance of the medical profession and the hierarchical structures in current health system. Furthermore, image interpretation has become the major thrust of role extension for MRSs. This represents the pinnacle of hierarchical levels of responsibilities within a cultural context. Not only the educational aspects, but also the economic, political and socio-cultural contingencies have to exist to support and embrace such a level of responsibility.

The steady increase in the incidences of chronic diseases and in hospital admission rates due ageing of population has an impact on the global health workforce (Duckett, 2005). The current practice and health workforce models cannot meet the future health care needs of the population. Hence, there are increasing calls to redesign health care workforce based on models involving “task transfer” as a key component (Brooks et al., 2003; Joyce et al., 2004).

In their study, Espinosa and Nolan (2000) found that missed radiological diagnoses were reduced from three percent to less point three percent (3.0% to 0.3%) when accident and emergency radiographs were viewed by radiologists within 12 hours of the examination being performed, as opposed to non-radiologist physicians. While such a quality improvement would be desirable, it is unlikely that EDs can expect
radiologists always to be available to provide a service of this standard, considering the workforce shortage.

The role expansion of MRSs has even progressed further in the UK. Within the National Health for postgraduate-trained MRSs, it is now common to have MRSs educated with the credentials to report on musculoskeletal, chest and abdominal plain radiographs, as well as reporting on other imaging modalities. They also perform various other extended clinical roles (Brealey et al., 2003; Price et al., 2007). A survey of National Health System (NHS) Trusts found that MRSs were reporting plain film examinations of the appendicular skeleton at 81 of the 177 Trusts surveyed and of the axial skeleton at 70 Trusts. They also conduct barium enemas and ultrasound examinations at 78 and 146 Trusts, respectively (Brealey et al., 2003). It also found that there was no statistically significant difference between the reporting accuracy of clinical specialist MRSs and consultant radiologists when reporting on plain radiographic examinations requested by accident and EDs or general practitioners (Brealey et al., 2005). A meta-analysis of 12 studies found that MRSs report plain film radiographs in clinical practice with ninety two percent (92.6%) sensitivity and ninety seven percent (97.7%) specificity compared with radiologists (Woodford, 2006). With selective training of MRSs in image interpretation, there was no significant difference in their reporting accuracy compared with that of radiologists. Benefits have been claimed in terms of reduced patient waiting times, freeing up radiologists for other duties, cost-effectiveness, and greater potential for recruitment and retention of MRSs, with higher levels of job satisfaction.

Based on evidence from overseas experiences, it has been documented that MRSs are capable of accurately reporting on plain radiographic images in clinical practice, it
would seem feasible to teach senior, experienced MRSs to provide reports that would help referring medical practitioners to identify abnormalities in Australia. Cook et al. (2004) reported an investigation into the accuracy and effectiveness of 2 senior Australian MRSs in reporting of appendicular musculoskeletal radiographs in the adult trauma situation in a large Queensland teaching hospital. The study of 540 patients referred from the ED department demonstrated high rates of diagnostic accuracy with a sensitivity of ninety eight percent (98.00%) and specificity of ninety nine percent (99.11%) in the assessment of appendicular musculoskeletal radiographs.

Similar professionalisation changes are also happening to other health professions. For example, the Nurse Practitioner role was widely developed in the USA (Griffin and Melby, 2006) and their task include completing physical examination, prescribing and dispensing medication, minor surgery, maintaining independent caseloads and referring to a doctor when required. Senior nurses are now being recruited to senior management positions in large private and public hospitals. Their roles in relation to nursing have expanded into areas formerly in the domain of the doctor (Adamson and Harris, 1996). In Kenny and Adamson’s survey, fifty six percent (56%) of physiotherapists, there were incidences of refusing a doctor’s instruction or recommendation on six or more occasion in the previous year, compared to thirty five percent (35%) of psychologists, 30% of occupational therapists, seventeen percent (17%) of nurses and eleven percent (11%) of speech pathologists. The strong resistance to doctors and better autonomy of physiotherapists are probably related lack of direct supervision from doctors and a degree of biomedical knowledge. The skills utilised are unknown to doctors, or unchallenged by doctors’ expertise. The case of physiotherapy is a useful example of
how a health profession gains and sustains autonomy from medical dominance. The other examples of health professions that have restricted recognition by the medical profession are nutritionists, psychologists and social workers. Nutritionists have struggled for autonomy from medical control in Australia though an emphasis on an education strategy directed towards the importance of cultural and social aspects of good nutrition (Duff, 1990).

2.6 EVIDENCE-BASED MEDICINE

2.6.1 Evidence-based medicine (EBM) is a high profile topic in modern medical practice and has changed medical practice and its delivery in recent decades. EBM is regarded as possibly the top medical milestone (Browning, 2007). Sackett and colleagues (1996), define evidence-based medicine as the “conscientious, explicit and judicious use of current best practice evidence in making decisions about the care of individual patients” (Sackett et al., 1996).

The practice of evidence-based medicine refers to the integration of individual clinical expertise with the best available external clinical evidence determined by systematic research. EBM is the use of critical thinking, or “healthy scepticism” in medicine. Individual clinical expertise refers to the proficiency and judgment that individual clinicians acquire through clinical experience and practice. Increased expertise is reflected in many ways, but especially in more effective and efficient diagnosis, also in the more thoughtful identification of conditions, together with compassionate awareness of individual patients' predicaments, rights, and preferences in making clinical decisions about their care. Best available external clinical evidence refers to clinically relevant research, often from the basic sciences of medicine, but especially from patient centred, clinical research into the accuracy and precision of
diagnostic requests (including the clinical examination). However, it also refers to the power of prognostic markers, and the efficacy, safety of therapeutic, rehabilitative, and preventive regimens. External clinical evidence both invalidates previously accepted diagnostic tests and treatments. This results in their replacement with newer tests that are more powerful, more accurate, more efficacious and safer.

EBM health care involves the more formal integration of the best research evidence with clinical expertise and explicit acknowledgment of patient values, in clinical decision making, as compared with conventional practice.

During the past decades, many health care disciplines have increasingly adopted the principles and practice of evidence-based health care (Raslich et al., 2007; Shuval et al., 2007). Regardless of the place of EBM in medicine, this “movement” has served an important role in moving clinicians into a more scientific (albeit empirical) and transparent realm (Mayer, 2006). This is especially so when various request requisition protocols or evidence-based guidelines and educational programs have been set up to improve behaviour when requesting clinical requests (Emerson, 2001; Moskowitz, 2000; Sanders, 2001; Stafford, 2001). For example, Verstappen et al. (2003) studied the effect of a practice-based strategy on request requisition performance of primary care physicians. The mean total number of requested requests per 6 months per physician was reduced from baseline at follow-up by twelve percent (12%). It demonstrated that the practice-based, multifaceted strategy using guidelines, feedback, and social interaction resulted in modest improvements in request requisition by primary care physicians.

Neilson et al. (2004) conducted a study on the impact of peer management on request, requisition behaviour through a resource utilisation committee (RUC). This
was with regard to favourable modification of this behaviour in a large academic medical centre, with an inpatient care provider order entry (CPOE) system and database of requested requests. Voluntary reduction of requesting beyond 72 hours decreased requests for metabolic panel component requests by twenty four percent (24%) (P=0.02) and electrocardiograms by fifty seven percent (57%) (P=0.006). Similarly, Phan et al. (2006) examined the effectiveness of an automated, stratified system of radiological request requisition, known as “Traffic Lights”, in reducing the number of unnecessary requests and their associated costs. The system involves stratification of radiological requests into three groups, denoted by red, amber and green colours. “Red” requests must be authorized by a consultant. ”Amber” requests must be signed by a registrar or authorized by a consultant. ”Green” requests can be requested directly by residents or interns. The average monthly reduction for all the imaging methods was thirteen percent (13.8%) in the number of requests and fifteen percent (15.1%) in the associated costs of these requests. The reductions were statistically significant for both the number of requests (P=0.01) and costs (P<0.01). In addition, analysis of data 20 months immediately after the introduction of “Traffic Lights” showed a consistent reduction in the total number of requests.

The effect of a controlled feedback intervention on laboratory request requisition by community physicians was studied by Bunting et al. (2004). During the 2-year intervention, intention-to-treat analysis showed that utilisation decreased significantly in the intervention group compared with the controls [relative reduction of 7.9% (P<0.0001); absolute reduction of 0.22 requests/visit (95% confidence interval, 0.20-0.24)]. They concluded that a multifaceted education and feedback strategy can significantly and persistently decrease laboratory utilisation by practicing community physicians.
Excessive pathology requests are particularly prevalent with patients presenting for elective surgery. Macpherson et al. (2005) tried to reduce requisition of inappropriate pathology requests in surgical patients attending the pre-admission clinic (PAC). This was attempted through the introduction of a protocol-based request requisition system and the creation of an environment where such improvement can be sustained. Following the introduction of pathology request protocols, the requisition of all but one of the eight requests was statistically significantly reduced. In particular, requisition of coagulation studies was reduced from twenty two percent (22.5%) to thirteen percent (13.8%) and electrolytes, urea and creatinine from sixty five percent (65.2%) to forty eight percent (48.25%) of patients (both P<0.0001). Average number of requests performed per patient declined from 2.48 to 1.88 in pre-admission.

The effect of price information on requisition behaviour and patient outcomes in a paediatric ED was studied by Hampers et al. (1999). It was found that providing information on cost was associated with a significant reduction in charges by twenty seven percent (27%) for requests on paediatric ED patients with acute illness that did not require admission. This decrease was associated with a slightly higher rate of unscheduled follow-up, but no difference in subjective outcomes or family satisfaction.

Some clinicians demonstrate ambivalent and contradictory attitudes towards EBM (Grahame-Smith, 1995; Haggard, 2007; Kitto et al., 2007). Criticism has ranged from evidence-based medicine being “old hat” to it being a “dangerous innovation”, perpetrated by the arrogant to serve cost cutters and suppress clinical freedom. The major concern is the translation of scientific knowledge and practice from one
context to another. Firstly, when knowledge practices shift they often become altered in practice, secondly, the success of the translation involves a displacement of existing knowledge practices (Latour, 1987). A recent systematic review of the effectiveness of guideline dissemination and implementation in health professional settings supports this approach (Grimshaw et al., 2004). The evidence pertaining to the diffusion and adoption of guidelines for practice does not take into account the effects of differing contexts and practice circumstances on these processes.

Likelihood ratios (LRs) have been found as a very useful indicator of a test's diagnostic strength. Each test has two LRs, with one corresponding to a positive test and the other to a negative test. As the positive LR increases, the test becomes a stronger positive predictor, and as the negative LR decreases, the test becomes a stronger negative predictor. There have been numerous lists published of likelihood ratios. As such these have proved to be useful tool in facilitating clinical decision making that is evidence based

2.6.2 Implementation of EBM in medical imaging has received increasing attention in medical imaging; however, compared to therapeutic medical disciplines, EBM radiological publications are still underrepresented (Dodd et al., 2004; Puig et al., 2006; Staunton, 2007).

2.6.3 Evidence-based imaging guidelines, clinical decision rules, and related educational programs are the most common applications of EBM in medical imaging. Guidelines are defined as “systematically developed statements to assist practitioner and patient decision with regard to appropriate health care for specific clinical circumstances” (Field, 1992). The imaging guideline aims to assist clinicians determine when it is appropriate to use imaging and which imaging modality should
be used first. Correct utilisation of the guideline should lead to a reduction in the number of imaging requests required to reach a diagnosis without adverse patient outcomes.

Developing a definition that describes evidence-based requisition and its role in the management of trauma patients presenting to the ED is the first step. This leads to objective analysis of the difference between the two approaches and assesses the impact of the interventions, in addition to the methods of improving clinical management practices.

In this study, evidence-based requisition was essentially regarded as the effective and efficient use of imaging examinations in attaining the best possible health outcomes for the patient. It involved the clinical team maximising its use of the various decision making tools, substituting invasive examinations with lower radiation dose examinations and integrating information derived from diagnostic requests with clinical judgment.

Evidence-based clinical management relies on scientific methods of assessing the value of each request for the clinical management of different trauma cases. The next definitions are with respect to the tools used in understanding the significance of each examination and its reliability for the process.

Evidence-based radiography requisition has many positive aspects, in addition to affecting the clinical management of the patient; it might actually change the whole outcome of the treatment process. The time expended on the unnecessary examination might be critical to the patient and the surrounding environment. For example, the time deemed to be “wasted” on the logistics of moving patients to and from the imaging department consumes scarce resources. Nurses and transport staff
will be occupied with that patient, whilst another, in real need of an imaging examination, must wait. Such delay might be detrimental and could in extreme cases result on increased morbidity or mortality.

A patient might require an urgent medical intervention; however, during time spent with unnecessary visits to imaging departments, prior to the appropriate examination being performed, their condition could deteriorate. Whilst following evidence-based decision making approach, that patient could have begun or even completed treatment and been discharged, or admitted as appropriate. There are other benefits such as pain management being given earlier with improved comfort. The hospital is better placed to “free up” resources and therefore able to deal with more patients during that time, therefore reducing waiting time. Over-utilisation certainly consumes resources that might otherwise have been used for other aspects of the patient’s care (Zilva et al., 1993).

Whilst the problem of overuse of requests is often studied, the equally important issue of under-utilisation of MRSs is rarely investigated (Schroeder, 1987). An evidence-based approach where requesting medical officers consult charts, decision trees and staff specialists would result in neither under nor over-utilisation of imaging resources. It was argued that request “under-utilisation” often occurred because of poor training and knowledge in request examinations. The evidence-based approach will benefit the patient and the institution. Patients will not only be spared exposure to unnecessary examinations, but also will receive the appropriate diagnostic requests. The hospital will benefit by cost reduction when non-evidence-based approaches is reduced or abolished.
Sometimes under utilisation of imaging investigations does occur, due to high cost or the unavailability of a “special” modality that possesses both high specificity and high sensitivity, such as computed tomography “CT”, ultrasound “US”, or magnetic resonance imaging “MRI”. Instead, imaging examinations are effectively misused with the selection of relatively low sensitivity and low specificity examinations, simply because the appropriate modalities are available. Under-utilisation of appropriate and necessary examinations will result in poor clinical outcomes for those patients being treated. Although the overall number of requested examinations may be reduced through the introduction of various strategies, it is essential that the examinations that are subsequently requested are in fact those appropriate for best patient care. As described by Burke (1995). Decreased utilisation is not synonymous with appropriate use. The real danger with examination reduction is that necessary as well as unnecessary examinations might be eliminated.

There are a number of reports of successful implementation of evidence-based imaging guidelines and clinical rules. For example, Moskowitz et al. (2000) studied the number and type of radiographic imaging studies performed a year after these guidelines were set in place in 1997 and compared them with the findings of the year prior to the guidelines being established (1995) together with pre guideline trends. The number of radiographic examinations per 1000 of those enrolled decreased 20-25% from the previous trend. Non-radiologists' share of the total fell from 39% to 15%. The conclusion being that guidelines can effect change in the location and number of radiological examinations performed. This leads to an improvement in the quality of the studies and a decrease in both radiation dose and cost. No decline in quality of care appears to result from this despite claims by opponents to such changes that with widespread use, serious quality impairment would occur.
Davini et al. (2002) studied the use of EBM to build radiological guidelines on patients presenting with minor head injury to reduce the widespread, unjustified use of conventional skull radiographs. The results indicate that employing EBM in guideline creation, results in obtaining a greater adhesion to guidelines by the users involved in management of the patient. In particular, this occurs if the guideline is a product of large scale contribution and where it is supported for all additional procedures that can be usefully implemented.

Giovagnoni et al. (2005) evaluated the role of diagnostic imaging modalities in the follow-up of patients after surgery for solid cancer, using an EBM approach. There was assessment of the possible discrepancies between the EBM model and the clinical protocols currently used for the follow-up of treated patients. Comparison was undertaken of the real costs of the radiological examinations performed for follow up after surgery and the theoretical costs that would have been incurred, had the patients been followed up according to the theoretical EBM approach. A significant difference was found between the real costs of the follow-up programs implemented and the theoretical costs derived from the guideline recommendations (an excess of 99.06% for lung cancer, and 93.6% for colon cancer), leading to a more rational use of resources.

Another successful implementation of evidence-based imaging requisition is the prominent Ottawa Ankle Rules (OAR). These attempted to reduce unnecessary ankle radiography and increase the diagnostic yield of ankle x-ray examinations in EDs (Stiell et al., 1993). A sensitivity of 100% for fracture detection with CI (95% confidence interval (CI), 0.97 to 1.0) has been validated in different countries and clinical settings (Stiell et al., 1993; Salt et al., 1997; Mann et al., 1998; Bachmann,
2003). The potential reduction in radiography was estimated to be 30-40% (Solomito et al., 1994; Auleley et al., 1998; Pijnenberg et al., 2002; Bloomberg, 2003) with CI (95% CI, 0.97 to 1.0). In Bachmann’s study, the pooled negative likelihood ratios for ankle and mid-foot were found to be 0.08. Applying these ratios to a 15% prevalence of fracture gave a less than 1.4% probability of actual fracture.

It may seem that a fracture may occasionally be missed. Nevertheless, such a missed fracture would be relatively trivial and the likelihood of morbidity for the patient would be very small. The rapid application of a few simple clinical variables indicates those patients that are at negligible risk for a fracture need not undergo radiography. One attendant clinical benefit would be decreased waiting times for patients discharged without radiography. In addition, patients could be sent directly to the imaging department by triage nurses trained to employ the rules. The other benefit would be cost savings to the health care system.

As an example, the research of Bachmann et al. (2003) supported the Ottawa ankle rules as an accurate tool for excluding fractures of the ankle and mid-foot. The pooled negative likelihood ratios for both regions were found to be 0.08. Applying these ratios to a 15% prevalence of fracture gave a less than 1.4% probability of actual fracture, with a resulting sensitivity of almost 100% and a modest specificity. The authors concluded that its use should reduce unnecessary radiographs by 30-40%.

The transportability of decision rules between countries and among related populations has been questioned by the studies conducted in USA, New Zealand, Scotland and Singapore due to a high false-negative rate (Lucchesi et al., 1995; Perry et al., 1999; Tay et al., 1999). However, these studies have been criticised for their
design and the lack of trained physicians in the correct application and interpretation of the OAR, thus leaving their conclusions open to question (Stiell et al., 1996).

In recent years, there have been dramatic changes in the imaging of patients with suspected cervical spine injuries with an evidence-based approach. Efforts have been made in developing and establishing study methods of improving selection of patients who truly are at risk and need imaging, based on a list of clinical and history-based indicators related to high risk for C-spine injury (Mirvis, 1989; Vandemark, 1990). The popular NEXUS criteria created by the National Emergency X-Radiography Utilization Study and the Canadian C-spine Rule have demonstrated sensitivity of 99 to 100% in predicting cervical spine fracture (Hoffman et al., 2000; Stiell et al., 2001; Touger et al., 2002; Kerr et al., 2005). Requisition of X-ray procedures could be reduced by 25 to 58.2%.

Optimisation of diagnostic imaging requisition and promotion of appropriate utilisation may require multifaceted intervention throughout the health system including changes in regulation, licensing, available capacity, and reimbursement / incentive systems. Continuous medical education as well as improved patient information may play an important role.

Excessive referral for imaging is one of the major factors in the unnecessary high medical radiation received by patients. Imaging guidelines have been regularly produced and updated for clinical education for medical practitioners. Kerry et al. (2000) showed that introduction of radiological guidelines into general practices together with feedback on referral rates reduces the number of GP radiological requests over one year; In addition, there was exploration of GPs' attitudes to the guidelines. Forty three thousands seven hundred and seventy eight radiological
examinations were requested during a two years period. The practices that received the guidelines demonstrated a significant 20% reduction in requests for spinal examinations as compared with control practices (P<0.05).

2.7 CLINICAL PRACTICE IMPROVEMENT (CPI)

One of the outstanding dilemmas of our current health care systems is the chasm or the substantial gaps between what is known to be achievable and what is achieved in practice; the failure to implement that which evidence-based medicine actually supports (CQHCA, 2001). For example, in the USA, fewer than 50% of patients hospitalised for ischemic heart disease were discharged with a treatment that current evidence would support (Allison et al., 2000). Obviously, continuing education can narrow the gap and is the key for implementation of evidence-based medicine.

Traditional methods of evaluating continuing education have focused on end-of-session feedback and/or requests related to the learning experience, such as the "happiness index" (individuals' perceptions of objectives, content, faculty, and facilities at the end of a learning activity) (American Nurses Credentialing Centre, 1996). The goal of continuing education is to produce new behaviours (Fox, 1996). New behaviours incorporated into practice over time result in new processes or methods of providing care. To investigate the effectiveness of continuing education, the behaviour and outcome changes must be assessed.

Although traditional methods provide valuable data and have their place in the continuing education process, none provide information related to the goal of increasing the ability of the learner to provide quality care. The focus is on uniquely quantifiable facts collected at one point in time and do not take into account the
processes of reflective thinking, innovation, creativity, and change. Dickerson (2000) used another approach, a CQI framework and associated statistical process control tools provided to assess both processes and outcomes of continuing education. The CQI method has evolved from the total quality management (TQM) framework, the roots of which can be traced to J.C. Penney in 1913 (Dickerson, 2000), Walter Shewhart in the 1920s (Cartin, 1993), and more recently Deming (Anschutz, 1995).

The CQI model focuses on customer satisfaction, teamwork, process improvement, empowerment, and strategic planning, together with parameters of organisational growth. This process promotes orderly and systematic analysis of existing patterns, emphasizes positive aspects of organisational activities, provides evidence of where changes need to be made, and demonstrates outcomes of process improvement activities.

Statistical process control tools such as flow charts, histograms, pareto charts, and control charts are usually used to compile and analyse process and outcome data. These tools allow for individualisation of factors unique to particular situations. In many cases, they can be used with existing databases to offer new ways of viewing information and provide a foundation from which strategic planning can occur. The CQI model offers a stimulating option to continuing education/staff development educators looking for creative and beneficial ways to evaluate educational activities.

The TQM model also offers a framework for organisational wide improvement, including the area of clinical and diagnostic services. Isouard (1999(a)) found that the introduction of a TQM model improved the appropriateness of clinical pathology test ordering in acute myocardial infarction. Using the TQM framework in several
investigations, Isouard reported improved quality of test utilisation and better patient care (Isouard 1998; Isouard 1999(b); Isouard 1999(c); Isouard 2000).

Similar to CQI, CPI is one of other popular tools being developed and used for implementation of evidence-based practice and quality improvement in health care. CP is rooted in Deming’s system of profound knowledge of four interrelated elements: appreciation for a system, knowledge about variation, theory of knowledge, and psychology (Deming, 1994). CPI is the application of the scientific method to the day-to-day practice of medicine. The objective of CPI is simply to spread innovation in order to improve a particular outcome or process, through changing the processes within the current system. Proof of a causal relationship between a particular intervention and improvement, is not essential and should not be allowed to “divert” the project. Demonstration of measured improvement is essential, often with multiple and even simultaneous interventions to that system of care. There are three outcomes from any improvement activity, which are, clinical benefit or reduction of harm, cost, or satisfaction from the patients' perspective.

The basic CPI principles share common ground with other management improvement approaches. However, it is important to note that there is a scientific basis for this knowledge and that the chronological order of actions is logical. Figure 2.1 summarises the concept and methodology of a typical CPI program.

**Figure 2.1** Cycle of sequential steps involved in CPI
The CPI approach presents three major advantages (Bothner, 2001). Firstly, a scientific bottom-up approach places accountability for practice improvement and outcomes on local clinicians. CPI supports caregivers in making their own decisions about optimal care based on objective statistical evidence gathered in the routine, everyday practice of medicine. Secondly, CPI measurement encompasses a comprehensive view of the care management process: patient characteristics, process steps, and outcomes. All three classes of data are considered simultaneously. This comprehensive measurement framework provides a basis for meaningful analyses of significant associations, as well as relationships between process and outcome. Thirdly, the CPI methodology focuses on deployment and application.

CPI has proved to be effective in improving clinical practice performance at different levels and different areas in health care (Lucas et al., 1995; Conroy et al., 2005; Gassaway et al., 2005; Pruett et al., 2007; Ward et al., 2007).
Horn (1995) reported that application of CPI not only improved quality but also decreased cost in managed care. According to the author, CPI can be employed in all health care settings inpatient or ambulatory, large or small. For example, Weiss (1996) applied CPI in the management of the patient with chronic asthma. The results indicated that this tool was appropriate for use in physician offices for both longitudinal and aggregate analysis of asthma patient outcomes, and for developing educational materials for both patients and health professionals. In 1997, Horn and colleagues successfully implemented CPI methodology in overcoming obstacles to effective treatment in 13,000 depression patients with otitis media, arthritis, hypertension, asthma, or ulcerative disease. In addition, cost-containment strategies in this study appeared to markedly limit psychiatric referral, frequency of visits and use of serotonin selective reuptake inhibitor treatment. Shafer et al. (2002) studied the effect of a CPI intervention on Chlamydia screening among adolescent girls. They found that implementation of this clinical practice intervention in a large health maintenance organization system is feasible, and it significantly increased the chlamydia trachomatis screening rates for sexually active adolescent girls during routine checkups. Marogna and Massolo (2003) observed sublingual immunotherapy in the context of a CPI program in the allergological setting to assess the efficacy and safety of sublingual immunotherapy in a CPI program carried out in allergology. In addition to being efficient and particularly safe, this method has an unfailing protective effect against the development of asthma and new allergic sensitizations.

The inefficiencies in the delivery mobile radiography of hospital-based health care are well known, no matter whether in the United States or Europe (Kamat et al., 1999). Their application of mobile CQI could result in drastic cost reductions (ranging from 40-75% at the institutions studied). Laurila et al. (2001) studied the
efficacy of CQI compared to ordinary management in an on-duty imaging department. It was found that CQI was an effective method for improving the quality of performance of an imaging department compared with ordinary management methods.

The need for CPI or similar quality improvement programs is unarguable. The question is why has it not happened already, or if it is occurring, why so slowly? The answer to this question lies in the difficulty of the task. Spontaneous adoption of CPI in practice is uncommon.

There are many barriers to effective implementation of CPI. Mortimer and Ward (2002) classify these barriers into three groups: system barriers, evidence barriers, and individual barriers. The common system barriers include problems with organizational culture, management, misuse of the theory and practice, team and cost issues (Messner, 1998). The most important appears to be ingrained philosophies and “mindset” prevalent in the organisation itself. Evidence barriers, concern the block between obtaining robust clinical evidence and its introduction into clinical practice. A widely quoted article by Antman et al. (1992) documented a 13-year delay between obtaining adequate evidence of the utility of streptokinase in myocardial infarction and its widespread use.

Many practitioners believe that their practice is evidence-based. It may, however, be grounded in lessons learned in the past, opinions of colleagues or pharmaceutical representatives, or out-of-date texts. Many have not learned the techniques of framing a meaningful clinical question effectively and efficiently tracking down the best evidence, and then critically appraising the literature to provide a solution. Cabana et al. (1999) reviewed published studies examining barriers to adherence to
clinical practice guidelines and demonstrated that these could be resolved into domains of knowledge, attitudes and behaviour. They showed that practitioner knowledge of, and familiarity with, guidelines might be impaired by poor accessibility, the sheer volume of information and lack of time available to keep informed.

2.8 CONCLUSION

The over-utilisation of diagnostic radiography examinations has been a significant concern that has for several decades been extensively investigated and reported throughout the literature. Currently, millions of unnecessary and obsolete, or inappropriate radiography examinations are performed around the world. These examinations not only place pressure on an already tightened health care budget, but also result in inefficiencies in service delivery.

One of the most serious consequences of unnecessary radiological requisition are the risks associated with ionising medical radiation. Patients are potentially at risk, of being exposed to avoidable and potentially harmful radiation. The epidemiological studies suggest that for an acute exposure 10-50 mSv and for a protracted exposure 50-100 mSv, there is reliable evidence of increased cancer risk in humans. Many single diagnostic radiography examinations produce doses in the range 1-30 mSv. These provide a reasonably firm basis to extrapolate possible cancer risks from still lower dose radiation. Many experimentally grounded and quantifiable biophysical arguments support that a linear extrapolation of cancer risk estimating appears to be the most appropriate and reasonable methodology. It is generally accepted that there is no threshold of radiation dose for cancer risk and even the smallest exposure may
increases the risk of cancer. The radiation protection principle ALARA should be enforced in daily practice.

Various issues have been shown to be linked to the over-utilisation of diagnostic imaging examinations. The most common contributors include fear of medical litigation, the influence from the patient, financial incentives and payment structures, and lack of proper training in the correct diagnostic strategies required to manage a clinical condition. Finally, and of critical importance, is the lack of knowledge and awareness of the side effects of exposure to medical radiation.

Published material is available to support appropriate referral in relation to minimising dose. The NHMRC publication (Recommendations for Minimising Radiological Hazards to Patients, 1986) clearly states that one primary aim is to “remind clinicians of their responsibilities in the careful selection of patients”. It goes further to suggest ways of “reducing radiation exposure”, “methods of carrying out procedures efficiently” with “minimum radiation exposure”. Later documentation published by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA, 2001) maintains and updates the theme that exposures should be subject to “the principles of justification and optimization”, with the physician responsible for the patient determining appropriate medical care. Yet the current situation with over utilisation continues even with the plethora of guidelines and codes of practice that exist.


Increasing concerns with regard to cancer risks associated with medical radiation and the struggling health budget have lead to a focus on implementations of evidence-based medicine in medical imaging such as, imaging guidelines and clinical decision rules. These have been increasingly introduced in medical imaging requisition. Some successful implementations such as the Ottawa Ankle Rules and NEXUS rules have demonstrated significant reduction in unnecessary and inappropriate uses of diagnostic imaging examinations. Unfortunately, although lack of awareness of medical radiation has been revealed as one of the major contributors of over requesting radiography examinations, there are no publications studying the impact of raising awareness of medical radiation on the over requisition of radiography examinations.

An outstanding dilemma of the current health care systems is recognised as the substantial gap between what is known to be achievable and what is actually achieved in practice; the failure to implement that which evidence-based medicine in fact supports. Continuing education has been proven to provide a tool for narrowing or overcoming this gap and a key for implementation of evidence-based medicine.

Lee et al. (2007) looked at efforts to improve both efficiency and effectiveness in managing the pressure areas of spinal cord injured patients. They believe that for improvement to become a standard component in clinical practice, the cost focus of management and the patient centred approach of the clinician need become more congruous. This research does represent such an alignment, since it has both patient advocacy and cost containment at its core in examining over-utilisation.
To improve the efficiency of continuing education, CPI and similar programs such as CQI have been developed and introduced into continuing education in health care during the past decades. Compared to the conventional continuing education approach, CPI and CQI assess both processes and outcomes of continuing education. Applications of these programs in different health care fields including medical imaging have proved to be a great success.

This literature review suggests that using CPI procedures in ED to raise awareness of medical radiation is an important tool in implementing evidence-based imaging requisition.
Chapter 3

METHODOLOGY

3.1 INTRODUCTION

This chapter aims to describe the design of the study. The study employed a multi-stage approach throughout the investigation. This comprised appraisal and review of each element using problem identification methods prior to moving forward to the next stage where a team based approach was employed in order to design the interventions.

A preliminary problem identification study was undertaken in two public hospitals located in two different Area Health Services (AHS) designated as Hospital ‘A’ and Hospital ‘B’. A control site, Hospital ‘C’, was used to measure and compare the outcomes of the interventions at Hospital ‘B’ and assist in validation. Hospital ‘C’ is located in the same AHS as Hospital ‘B’. Hospital ‘C’ has similar demographics and hospital activity levels, and employs the same radiology information system (RIS) as Hospital ‘B’.

Once the major intervention had been completed and evaluated in terms of set targets and key performance indicators (KPIs) for the CPI project, the intervention procedure itself was further tested and validated through the rollout at another site, Hospital ‘D’. Importantly this was to provide information on the adaptability and generalisability of the intervention across other organisations. Hospital ‘D’ was selected because it was a sister site of Hospital ‘B’. Each of these two hospitals operated under a common administration, including the same heads of the
Emergency and Imaging Departments. Hospital ‘D’ is a larger sized hospital with greater imaging capabilities. Unlike Hospitals ‘A’, ‘B’ and ‘C’ Hospital ‘D’ had a Computed Tomography (CT) service when the study had first commenced, whereas Hospital ‘B’ had acquired the CT service at stage 4 (Operational September 2003), and Hospital ‘C’ had acquired the CT service at the end of Stage 4 (operational November 2004).

The study was subject to pre-test data analysis prior to intervention with a final post-test analysis being performed ultimately.

The first section outlines the early stages of the study, commencing with developments such as the formation of the team, Brain storming sessions, survey questionnaire and the preliminary problem identification methods. The first survey undertaken in Hospital ‘A’, examined Medical Radiation Scientists (MRS) and their perception regarding how the service is utilised. A similar survey was conducted at Hospital ‘B’.

Following the first intervention, another survey was tailored targeting referring Medical Officers (MO) at Hospital ‘B’, in order to gain an understanding of the reasoning behind their referral pattern. The preliminary problem identification study describes the qualitative methods used. Data was acquired from the RIS together with a review and analysis of Radiologist reports.

The third Section describes the third and final stage of Phase 1, including Preliminary and post intervention data analysis.
The final section of this chapter describes Phase 2 of the study, which employed the tools of Clinical Practice Improvement (CPI) as set by the Department of Health of New South Wales (Easy Guide to CPI, 2002).

3.2 RESEARCH DESIGN

The research design comprises a non-equivalent, Pre-test / Post-test control group quasi-experimental design. Initial data collection was undertaken at the baseline (Pre-test) prior to three separate interventions taking place, and then again following that intervention (Post-test). The impact of the intervention was further validated through the introduction of a rollout phase of the intervention at a larger sized site. The study employs demonstrated equivalent populations attending the EDs at the two hospitals (experimental and control). The study conforms to fundamental experimental theory by allowing adequate control over major threats to internal and external validity.

The research design for this cohort study is shown in Figure 3.1. The diagram shows the various aspects of the research design, including the relationships between the various cohort groups and the timelines for each stage. This includes the preliminary investigation (Hospital ‘A’), the intervention (Hospital ‘B’), the control (Hospital ‘C’) and the rollout (Hospital ‘D’). In terms of the intervention process, there were a series of three separate interventions involved (X1, X2 and X3).
Figure 3.1 The non-equivalent quasi-experimental research design.

P1

P2 → M1 → X1 → M3 → M5 → X2 → M7 → M9 → X3 → M12
M2 → M4 → M6 → M8 → M10 → M13
M11 → X4 → M14

P1, preliminary investigation, Hospital ‘A’
P2, preliminary investigation, Experimental Group Hospital ‘B’
M1, measurement Pre-Intervention Experimental Group Hospital ‘B’
M2, measurement Pre-Intervention, Hospital ‘C’
M3, measurement Post-Intervention, Hospital ‘B’
M4, measurement Post-Intervention, Hospital ‘C’
M5, measurement Pre-Intervention Experimental Group Hospital ‘B’
M6, measurement Pre-Intervention, Hospital ‘C’
M7, measurement Post-Intervention, Hospital ‘B’
M8, measurement Post-Intervention, Hospital ‘C’
M9, measurement Pre-Intervention Experimental Group Hospital ‘B’
M10, measurement Pre-Intervention, Hospital ‘C’
M11, measurement Pre-Intervention, Hospital ‘D’
M12, measurement Pre-Intervention, Hospital ‘C’
M13, measurement Post-Intervention, Hospital ‘D’
M14, measurement Post-Intervention, Hospital ‘D’
X1, X2 and X3, three interventions, Hospital ‘B’
X4, rollout of the CPI intervention to Hospital ‘D’
According to Polgar and Thomas (1997), there are several threats to internal validity in quantitative research. These include population selection, history, maturation changes, practice effects, instrument error, and attrition.

In terms of the current investigation, the use of the quasi-experimental design and the accompanying method of implementation contributed greatly to reduce the threat to internal validity. Since the two patient groups comprised the total populations presenting to the ED, the methodological issues often associated with sample size and random selection were not evident. In addition, the use of hospitals within the same area health service allowed for the inclusion of populations with similar demographic and cultural profile and characteristics. Hospitals were able to be chosen that demonstrated similar levels of activity and service delivery, and under the same central area health administration.

The scientific method included a parallel control group and an additional population group for further validation. The rollout of the intervention to Hospital ‘D’ was undertaken to validate the findings of the main CPI project in another equivalent setting. The latter was in the form of the intervention being simultaneously rolled out using pre-test and post-test controlled conditions. The research design conformed to fundamental experimental theory by allowing adequate control over major threats to internal and external validity.

The use of an equivalent control group, an accompanying rollout group, and use of total and equivalent populations were specific strategies employed by the Chief Investigator to remove the confounding and extraneous variables threatening internal validity. The threat of ‘history’ (any event other than the independent variable that
may affect the dependent variable) was countered through the control and rollout
groups, which would presumably be equally susceptible as the experimental group.

In addition, the threat of ‘maturation’ (processes within the respondents that change
as a function of time) was similarly controlled through the addition of the control
group. The threat of ‘testing’ (the effect of being measured on retest results) was
similarly not an issue since different patients were used at the pre intervention and
post intervention stages.

3.3 METHOD: PHASE 1

3.3.1 Stages 1 and 2, the preliminary problem identification study

Phase 1 employed a traditional approach to quality improvement through using the
established model for CPI. This standard CPI process of identifying problems and
determining remedial actions is accepted practice within this health service. The
model was adopted by the Medical Administration unit of the Hospital. Through this
process, continuous education was incorporated, and an evaluation undertaken at the
end of each session using the happiness index. The results of the survey were then
forwarded to the research team for consideration in terms of improving subsequent
intervention strategies.

Stage 1 involved the assembly of a small team comprising the following staff:
Radiologist, Deputy Chief Medical Radiation Scientist (MRS) and a senior MRS.
Their initial task was to gain an understanding of the routine issues facing MRS.
They undertook Brainstorming sessions, designed and delivered questionnaires to
MRS at Hospital ‘A’ & ‘B’ (Appendix 5). The Chief Investigator and the Radiologist
were assigned the task of planning and performing the quantitative and qualitative
data analysis. The Chief Investigator was responsible for the development of the radiation awareness program (RAP).

Radiology Information System (RIS) data was examined in order to identify the number of normal reports from all patients presenting to the ED referred for relevant examinations. The data was exported from the RIS into an Excel Spreadsheet for interpretation. This data was then sorted into different examination categories such as Skull, Ribs and other areas and eventually displayed in tables and charts.

In addition, a review of the clinical management process was undertaken by examining the medical records of relevant patients. In order to maintain confidentiality, identification and demographic data were neither examined, nor documented. This qualitative approach was used solely for the preliminary stages 1 and 2 at Hospitals ‘A’ and ‘B’.

This work was required to establish whether the relevant examinations were requested and to determine frequency. Furthermore, the qualitative data and case analysis was required to confirm or refute claims that the relevant examinations were indeed obsolete, based on the value of the radiologist report to the clinical management of the patient.

Following this, the next key steps were determined by the project team to:

- Prepare educational presentation and gather reference material.
- Commence the educational program by presenting lectures to MRS, with expansion of the RAP audience to include MOs and allied health professionals
- Seek and gain the support of hospital staff and commence the search for a champion to lead the project.
3.3.2 Data Collection and Analytical Analysis

The first set of data was collected from the RIS of Hospital ‘A’. Radiology reports were then assessed and results recorded either as normal or abnormal. The patient’s medical records were subject to examination in those cases with abnormal findings.

The second set of data was collected from Hospital ‘B’ of patients presenting to the ED. Skull, Cervical Spine, Rib and Pelvis examinations were evaluated by review of radiology reports. Examinations with a suspicion of pathological or trauma findings were subject to further scrutiny with a complete radiological history and review of clinical records.

The aim of the preliminary data acquisition was to analyse the extent of over-utilisation, determining the value of the requested examination and the results obtained.

At the post intervention period of Stage 2 a Continuous Quality Improvement (CQI) approach was employed using statistical process control tools. Data was translated to tables and run charts. The data was analysed using the Statistical Package for the Social Science (SPSS). The statistical associations among variables used in chapters 4 and 5 were compared using student’s t-test. Mean referrals, percentage differences, p values and 95% confidence intervals were calculated. Statistical comparisons were undertaken for data pre and post intervention at Hospital ‘B’ and ‘C’. The unpaired t-test was used to compare the pre and post interventions. A level of \( p = 0.05 \) was considered to be statistically significant. Similar data collection and analytical methods were employed during Stages 3 and 4.

Monthly statistical data of examinations requested from ED of the selected examinations are shown in Appendix 3.
Data from Hospital ‘C’ was also extracted from the RIS providing comparative statistics to demonstrate the differences between the research and control sites.

3.3.3 Educational Tools

The chief investigator developed the initial material for the presentations, employing reference material drawn from the National Health and Research Commission (NHMRC Canberra, 1986) and the International Commission of Radiation Protection (ICRP, 1991). Radiation safety materials were obtained from the radiation physics department in teaching hospitals.

Presentations were organised for junior MOs and registrars as part of their hospital orientation. Special workshops tailored for nurses and allied health professionals, were conducted. As a result of the feedback, the program was extended to cover safety precautions.

The educational program was developed to include radiation physics, the basics of ionisation of molecules, Radiobiology and the alteration and mutation of the genetic structure of DNA.

The first draft was presented at the University of Western Sydney Research Forum.

Extension of the radiation awareness program was undertaken to cover the entire hospital in the form of a radiation safety day. An invitation was extended to the community through high schools in the region. The program was replicated and delivered at all hospitals within the AHS.

3.3.4 Survey Questions

A questionnaire was designed for MRS staff to obtain information and insight regarding their overall perception of over-utilisation. The questions in the survey were developed from the feedback and general complaints received by the chief
investigator from MRS staff concerning over-requisition of imaging examinations. All junior and senior MRSs from each hospital were surveyed. The questionnaire can be found in Appendix 5.

### 3.3.5 Survey Post educational program

As described in Chapter 2.7 the study in its early stages, employed a questionnaire designed to obtain post educational session feedback in order to assess customer satisfaction and knowledge. The questionnaire was designed to provide researchers with an indication of any issues in the system requiring improvement. It was also used to assess the level of radiation hygiene knowledge possessed by MOs and the impact of this on their behaviour in requesting imaging examinations and therefore over-utilisation. The questionnaire also assisted the development of the radiation awareness program, which was subsequently used to address the needs of MOs. A copy of the survey can be found in Appendix 6.

### 3.3.6 Radiation Management Tools

Stages 1 and 2 were designed and implemented by a small team, which also proceeded as follows:

a. Identify the main problems by performing a Quantitative Data Analysis; identify the number of the requisition of examinations considered to be of no value and outdated as discussed in Appendix 2. This task was performed by the Chief and Senior MRS.

b. Identifying the value of the requested examinations by performing Qualitative Data Analysis; reviewing the radiologist report of all requested examinations and analysing the clinical records of those patients with a positive finding. This was performed in order to assess the
contribution of the examination to the clinical management process. The Radiologist performed this task together with the Chief MRS. The Radiologist provided clinical input.

c. Development of the RAP for MOs during their hospital orientation program.

3.3.7 Stage 3, Main Radiation Management Intervention

The team reviewed the process of the intervention methods. As a result the team had identified the need of getting an administrative officer on board in to take ownership and responsibility for records maintenance, organising the RAP, and marketing the event within the hospital and externally through local media and newspapers. It was also identified that there was a need for the inclusion of a senior nursing representation on the team in order to obtain the nursing perspective and to promote the project to nurses. In addition, it was determined that at this stage a representative from the university should be included in order to monitor quality and the integrity of the processes.

The literature review in chapter 2 identified that the requisition of imaging examinations is influenced by a variety of disciplines and professions within the health care system. It was therefore, decided to extend the delivery of the education program to those professional groups, including MOs, Nurses, the professions allied health and administrative staff.

The literature review also identified that patients, or their relatives, may demand an x-ray without understanding, regardless of the clinical need or not. Some MOs automatically comply in order to placate the patient, or to demonstrate that something tangible is being done. The team therefore, determined that the
‘consumer’ needed some education in radiation hygiene in order to assist in reducing such pressure on junior MOs. The educational program was expanded to encompass public and private high school students. The team believed that students, when properly educated, would be well placed to promote the message to parents and the rest of the community.

3.3.7.1 Team Reformation

At Stage 3 the team was expanded to include an senior academic from the university, a registered nurse and a clerical staff member. The variety of disciplines now represented within the team provided further insight and additional perspectives to the problem and the efficacy of the interventional tools.

3.3.7.2 Addressing the New Team

1) Presentation of all the latest material to the team.

2) Presentation of the radiation awareness lecture to the new members during the first meeting.

3.3.7.3 Brainstorming

As an essential component of CPI, brainstorming was employed at various stages of the process. Through this process, the Team Leader assumed responsibility to ensure that all members of the team were able to voice their thoughts and that all input was considered by the group. In the first brainstorming session discussions lead to the following strategies to be developed:

1. Further review and modification of the radiation awareness presentation.

2. A target was set to coordinate the presentations for delivery within two weeks to the following professional groups:
i. MOs

ii. Nurses

iii. Allied Health Professionals

iv. Key executives and senior staff of the hospital and the AHS

v. Radiation Awareness Day advertised in local papers inviting the public

vi. Invite high school students to attend the Radiation Awareness day.

vii. Interviews were arranged with local radio stations and newspapers.

viii. Image interpretation lectures were prepared by the Chief MRS and presented by the Radiologist in order to enhance the relationship of the department with other groups within the hospital.

ix. Preparation of an evidence based clinical management educational reference by the Chief MRS and a senior MRS, to assist staff in selecting the examination of choice.

The team understood that the project was encountering a major difficulty in sustaining the reduction in the number of examinations and over-utilisation. This centred around the resistance of MOs in listening and consulting with health care workers from other disciplines (as discussed in Chapter 2). The solution and strategy of the team was to identify authority figures during the RAPs from whom support for the project could be secured.
3.4 METHOD PHASE 2

3.4.1 Stage 4, Clinical practice Improvement CPI

As discussed in section 2.7, Clinical Practice Improvement (CPI) was selected as the preferred method because of its established successful clinical application in improving quality. In addition, it was the recommended method by the NSW Department of Health (DOH) and the Area Health Service of Hospital ‘B’.

The methodology used in Phase 2 was undertaken in accordance with the ‘Easy Guide to Clinical Practice Improvement’ published by the NSW Department of Health (2002). The educational program remained the same during phase 1 stage 3. Systematic analysis of the data was employed in a similar to that used in stage 3 in order to monitor progress. The study followed two approaches set by the NSW Department of Health. These being firstly, the Clinical Practice Improvement (CPI) model employed to improve the process of care and service delivery and secondly the Root Cause Analysis (RCA). The latter being employed to understand ‘the event’ and ensure that the investigation reviews all known causes of issues. Figure 3.2 demonstrates the steps associated with both CPI and RCA and provides a guide to their appropriate use.
3.4.2 CPI Strategy

As discussed in Chapter 2.7 the study at Phase 2 incorporated CPI methods (Easy Guide to CPI, 2002, p4) and was aimed at addressing the following:

- What are we trying to accomplish?
• How will we know that a change is an improvement? What parameters do we need to measure?

• What changes can we make that will result in an improvement?

As shown in figure 3.3 the CPI Improvement model operates upon a ‘trial and learning’ method referred to as the PDSA cycle. In this cycle the team plans a change, conducts a trial of the proposed change, evaluates the impact of the trial and then implements the changes that have been proven effective.

**Figure 3.3 The CPI Model**

![The Clinical Practice Improvement Model](Image)

**Source: Easy Guide to CPI 2002 p4**

As discussed in chapter 2.7 the improvement process goes through five phases. The different phases, highlighting the role of PDSA cycles at the intervention phase are
described in Figure 2.1.

3.4.3 Project Phase

The CPI steps were undertaken through a series of phases. The project phase started with the team leaders meeting which determined new team members. The first task of the new team was to gain a comprehensive understanding of the side effects of exposure to radiation and gaining full commitment by attending a RAP prior to commencement of the project.

Once that was established, the team focused on defining a Mission Statement and setting a target goal.

Comprehensive data measurement was undertaken to monitor progress and highlight the impact of the interventions.

3.4.3.1 Initial Decision of the Process That Needs Improvement

Following the CPI model, it was essential to decide on the process that is required improvement. There was consensus at team meeting that the problem existed and agreement that further interventions would be required.

3.4.3.2 Team Selection and role of each member.

Team formation followed the CPI guidelines. The project team comprised the following members and attributes:

- **Clinical Director of ED;** The role of the Clinical Director was that of ‘Team Leader’ for the project. As an Emergency Specialist, he was able to provide a strong case for eliminating inappropriate imaging examinations, and to focus on an evidence based approach.
- **Quality Coordinator:** The role of the Quality Coordinator was largely to ensure that the overall process adhered to the principles and methodology of CPI. This included providing advice and training on CPI to team members as needed. The Quality Coordinator was also responsible for scheduling meetings and circulating the appropriate documentation. The coordinator’s previous experience and background with quality and quality systems was utilised in the development of tools and the presentation of data.

- **Senior Emergency Registrar:** The role of senior ED registrar was to provide both practical and clinical input applicable to patients presenting to ED. In addition, this member was also able to provide information on possible reasons behind requesting examinations not supported by Evidence based clinical management.

- **Two Junior MOs:** The team membership role of the junior MO was similar to that of the senior registrar, including the provision of practical input to the process, especially with regard to issues that affect day-to-day workflow.

- **Nursing education:** The role of the nurse educator was to liaise and assist in the training of Nurses and other professionals in both radiation hygiene and the proposed guidelines. 

- **Registered Emergency Nurse:** The role of the registered nurse was to represent Nurses and provide input on issues that affects workflow and staffing issues within the ED, as well as providing information on feedback or any observed behaviour from patients or their relatives.
• **Medical Radiation Scientist (MRS)**; The role of the MRS was to represent the concerns of other MRS’s and provide input on issues that affect workflow and staffing issues within the Imaging Department.

• **Assistant Chief MRS**; The role of the assistant chief MRS was to provide input on factors affecting the imaging department and training issues, as well as maintaining and providing the statistical data required.

• **Chief Investigator**; The role of the chief investigator was to coordinate the research aspects of the project, including the ongoing development and delivery of the educational material and ensuring adherence to the procedures set as interventions.

With the exception of Junior MOs, the team remained unchanged for the duration of the project. Junior MOs were replaced at the end of their term with members from the incoming cohort.

### 3.4.3.3 Mission Statement and Target

The initial meeting of the project team defined the problem and determined a plan to move forward. Team members were provided with all relevant background information in order to be fully conversant with the issues.

A mission statement was then prepared. According to the Easy Guide to CPI (2002), (p8), the mission statement should be **SMART**, that is, it should be:

- **Specific** - **Measurable** - **Appropriate** - **Result oriented**, and **Time scheduled**.

The mission statement set target goals to reduce over-utilisation of the different category examinations.
3.4.3.4 Data Measurement

A range of data was required at the different stages of the process. Data analysis as set in 3.3.2 was followed throughout the project to monitor progress. Data analysis at Phase 2 included:

- Annual Imaging cost Analysis. Specific to Phase 2
- Number of examinations requested of the categories set in 3.3.2.
- Number of ED requisitions per the number of total patient admissions to ED.

3.4.4 Diagnostic Phase

As shown in 5.2.3.6 the diagnostic phase went through several steps:

- Brain storming sessions were conducted to identify the problem and the causes of over-utilisation, using a democratic team based approach where every member was given eight blank ‘sticky notes’ to describe the causes from their perspective. This allowed the present issues from all participants to be addressed.

- The results were then grouped under agreed definitions and presented in a table format.

- The Results from the brainstorming table were presented in a Pareto chart.

- To define the goal and reduce the diverse range of issues proposed; a democratic process of voting was employed. This allowed the ranking of the importance of each point. The team focused on the most important issues, the least important points were disregarded.
• A further meeting was held to discuss the reduced list. The issues were summarised in open discussion and defined under categories.

• Results were presented using Cause and Effect diagram categorising and displaying the causes in different categories.

Many health care professionals desire to determine on the solution to a problem early in the improvement process and before the real problem is accurately identified (Easy Guide to CPI, 2002 p9). It is important to follow the process carefully in order to avoid reaching conclusions or solutions prematurely and thus ultimately identify the most appropriate interventions.

The Diagnostic Phase needs to follow the CPI steps as described in Figure 3.4

**Figure 3.4 Diagnostic Phase**

Source: Easy Guide to CPI 2002 p9

There are few tools that can be utilised during the diagnostic phase such as process map, brainstorming, Pareto Chart and Cause & effect diagrams. Each tool utilised will be discussed in chapter 5.
3.4.5 Intervention Phase and Implementation Methodology

As shown in 5.2.3.7, after refining the cause and effect the Intervention Phase went through a few steps:

- A brainstorming session was conducted to propose interventions.
- Refining and agreeing upon interventions to be implemented.

This followed the PDSA cycle where the team planned the methodology of the interventions, such as the continuance of the RAP at each MO orientation and a more aggressive approach to deliver RAPs for allied health and the community. A further measure was building the educational website and the promotion of this together with the elimination of the paper requisition to a controlled electronic system as described.

In a second PDSA it was decided to give MRS staff more support in their gatekeeping role. This was achieved by providing access to the Chief Investigator and the Team leader when faced with difficult situations. As an example, if an MO refuses the advice of an MRS, the MRS would have the option of calling the Chief Investigator. The Chief Investigator in turn could decide to contact the Team leader for his direct involvement if the issue remained unresolved. Figure 3.5 provides a description of the Interventions phase as set by the CPI guidelines.
3.4.6 Impact and Implementation Phase

The impact and implementation phase is the one of the most important phases. It must ensure that changing a system does not cause systematic damage that may affect patient care. It must also assess the outcomes and the extent of the improvement if it has occurred.

Figure 3.6 provides a description of the Impact and Implementation phase as set by the CPI guidelines.
3.4.7 Sustaining and improvement Phase

According to the CPI guidelines Standardisation, Documentation, Measurement and Review, Training and education, are essential points that are required to sustain an improvement (Easy Guide to CPI, 2002 p13).

3.4.7.1 Standardisation

The team reached a consensus on standardising workflow processes. The first point was to employ a consistent style in delivering the RAP. The second point was to ensure that manual requisition forms are eliminated from the system, including the system in the larger sister hospital, where the same electronic requisition system is employed.

The same workflow and procedures were adopted at both sites including the role of the MRSs as the gatekeepers. The new ED website was also highly promoted at both sites.
3.4.7.2 Documentation

The Quality Coordinator with the help of the Senior MRS, undertook the role of documenting all the steps and outcomes, using power point presentation tools to present all the steps and the charts from the RIS data using the Minitab statistical package.

Documentation also included the educational package as employed on the website as a reference material.

3.4.7.3 Training and Education

The team decided to implement RAPs across the AHS, employing a consistent style of delivery, which comprised using the same content presentation during all sessions and to have all presentations delivered by the same presenter. The team also standardised the educational process of the clinical pathway by displaying the educational material on the website. The team leader undertook the responsibility to engage with every new cohort of MOs. He used a tutorial style medical officers forum in the setting of the guidelines. Figure 3.7 is a description of the improvement phase carried out to sustain change as set by the CPI guidelines.
3.4.7.4 Sequence of Events for the CPI Phases

After the initial meeting of the project leaders, the following steps were taken:

- The Clinical Director of ED was invited to join the team and was briefed on the project.
- A venue and forum was organised for the Chief MRS to present the radiation lecture.
- First meeting was called to set out the rules.
- Pre project data collection and analysis was performed.
- A ‘Brainstorming session’ as per the CPI guidelines.
- The issues identified were then sorted and entered into an excel spreadsheet (Table A5.2).
• The list of issues was then reduced to those deemed most important (Table A5.3 – A5.4).

• A democratic team based approach of further selecting the most important issues was employed. These outcomes are listed in Table A5.5 and in Table A5.6.

• The outcome of the votes on the issues list was calculated and entered into a Pareto Chart (Table A5.7).

• These were then transposed into a Pareto chart (Figure 5.2) and Cause and Effect Fishbone (Figure 5.3).

• Setting a target goal (Table A5.1) allowed identification of the different categories of requested examinations and setting the protocols of each category.
  
  o Category ‘A’, never to be requested.

  o Category ‘B’, apply algorithm before requesting.

  o Category ‘C’, all remaining examinations where referring officers are required to assess importance of an examination prior to requisition.

  o The elimination of all batch requisitions such as imaging trauma series.

• MRS receiving the requisition to check and discuss validity of requestion
3.4.7.5 Primary actions

- The Clinical Director of ED was to set up a website stating the new rules of requesting examinations

- Continuing with the ongoing RAP

- The chief and senior MRS to review supporting literature review

- The Assistant MRS to collect data continuously and monitor progress with the Quality Coordinator.

3.4.7.6 Follow up actions

- Reinforce project guidelines,

- Increase the level of MRS involvement as the gatekeeper,

- MRS on duty to have direct access to the Clinical Director of ED to report,

- Extend the educational program to include high school students,

- Roll out of Project to a larger size Hospital ‘D’, attached to Hospital ‘B’.

3.4.7.7 Main Interventions:

- Web design software, to make guidelines available to all staff via the AHS intranet

- Setting the protocols

- Alteration of the electronic requisition form to remove auto selection of imaging series, in addition to removal of Category ‘A’ examinations from
the selection list

- Continue the training sessions during the MOs orientation sessions

- Continue Radiation Awareness Program to hospital staff and the public

- Assign MRSs on duty the role of ‘gatekeepers’ to monitor unnecessary requisitions

- Imaging to expand and refine imaging protocols and justifications, using evidence based approach.

3.4.8 Stage 4, Rollout of the CPI Project

Once the CPI intervention had been implemented and validated at Hospital ‘B’, the decision had been made to rollout the same intervention one month later at the relatively larger sister site Hospital ‘D’. Hospital ‘D’ operated under the same administrative arrangement as Hospital ‘B’. It had the same Director of ED and the Chief MRS. It should be noted that at Hospital ‘D’ there had not been any formal interventions taken place up to Stage 4 in terms of the present investigation. In addition, a preliminary retrospective analysis of the data over the previous 14 month period at Hospital ‘D’, indicated a similar level of Category ‘A’ examinations being referred to that of control Hospital ‘C’.

The team had also determined that implementing the project at Hospital ‘D’ would have been an effective measure of the adaptability of the project at larger size hospitals where more advanced technologies were available.
3.5 COMPARATIVE HOSPITAL PROFILE AND ACTIVITY LEVELS

Hospital ‘B’ was selected as the intervention site because both the Chief Investigator and the Senior Radiologist moved from Hospital ‘A’ to new positions at that health service. All the preliminary investigations were repeated using similar methods. A control site (Hospital ‘C’) was also selected to compare the impact of the interventions. Hospitals ‘B’ and ‘C’ also proved to be appropriate selections because of their similar characteristics. The hospitals were of similar size and shared similar activity levels. As shown in Table 3.1, the pre intervention and post intervention statistical data for each hospital demonstrated similar levels of activity in terms of number of beds and bed occupancy, admissions and attendances, average available beds and length of stay.
Table 3.1 Selected activity levels for Hospitals ‘B’ and ‘C’

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Hospital ‘B’</th>
<th>Hospital ‘C’</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pre-intervention</strong>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Admissions (including Live Births)</td>
<td>16,532</td>
<td>13,734</td>
</tr>
<tr>
<td>Total patients treated</td>
<td>17,077</td>
<td>13,911</td>
</tr>
<tr>
<td>Average Available Beds</td>
<td>159</td>
<td>112</td>
</tr>
<tr>
<td>Daily Average Occupied Beds</td>
<td>131.0</td>
<td>103.8</td>
</tr>
<tr>
<td>Adjusted Daily Average</td>
<td>200.2</td>
<td>135.2</td>
</tr>
<tr>
<td>Length of Stay, days</td>
<td>3.1</td>
<td>3.0</td>
</tr>
<tr>
<td>Bed Occupancy Rate, %</td>
<td>91.2</td>
<td>92.6</td>
</tr>
<tr>
<td><strong>Post-intervention</strong>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Admissions (including Live Births)</td>
<td>16,992</td>
<td>15,2</td>
</tr>
<tr>
<td>Total patients treated</td>
<td>17,111</td>
<td>15,362</td>
</tr>
<tr>
<td>Average Available Beds</td>
<td>167</td>
<td>138</td>
</tr>
<tr>
<td>Daily Average Occupied Beds</td>
<td>154.4</td>
<td>120.3</td>
</tr>
<tr>
<td>Adjusted Daily Average</td>
<td>226.2</td>
<td>149.5</td>
</tr>
<tr>
<td>Length of Stay, days</td>
<td>3.6</td>
<td>3.1</td>
</tr>
<tr>
<td>Bed Occupancy Rate, %</td>
<td>100.3</td>
<td>86.4</td>
</tr>
</tbody>
</table>

* Pre-intervention period, May 2001- April 2002; ** Post-intervention Period, October 2003- September 2004; Differences between Hospitals ‘B’ and ‘C’ are not significant, except for the Adjusted Daily Average (p< 0.05).

It should be noted that the catchment areas for both Hospitals ‘B’ and ‘C’ had similar distribution in terms of ethnic diversity and demographics. The patients in each
group that presented to the EDs were also of similar age and gender. In addition, each hospital had four Operating Rooms, an Intensive Care Unit, a Cardiac Care Unit, Children’s Ward, Surgical capacity, and limited Imaging interventional capabilities and Ultrasound Services. One difference, however, was the presence of a delivery ward only at Hospital ‘C’.

Statistical data employed for the main investigation, comprised of the ‘whole’ population presenting to the Emergency Department for the defined period rather than a sample being collected from attendees.

3.6 ETHICS

The Chief Investigator received written correspondence from the AHS Human Ethics Committee confirming that the study did not require formal ethics approval. The methods of accessing and handling of patient results and data meant that anonymity and privacy were assured. Whilst it was necessary to access confidential patient records by radiologists, confidentiality was ensured.
Chapter 4

RESULTS AND INTERVENTIONS PHASE 1 (RAP)

4.1 INTRODUCTION

This is the first of two chapters which provides the results for the investigation (chapters 4 and 5). It presents the results and discussion of data from the first stages of the preliminary problem identification and then through to the two stages of the implementation of the intervention, the Radiation Awareness Program (RAP). This chapter specifically presents the findings of the preliminary problem identification process at Hospital ‘A’ (Stage 1) and at Hospital ‘B’, the first intervention and subsequent outcome (Stage 2). This process then presents the results and discussion of data from the development of the interventions adopted (Stage 3). The chapter also includes some brief methodological considerations and in particular relating to the surveys and the interventions. Each section concludes with a discussion of the results with particular reference to the relevant literature. However, formal conclusions are reserved for chapter 6. The results from Hospital ‘C’ were used as a control to compare and contrast the outcomes of the interventions at Hospital ‘B’, the only site at which interventions were introduced. Table 3.1 in chapter 3 provides the comparative details of the demographic and patient characteristics of these two hospitals.
4.2 RADIATION MANAGEMENT STAGE 1 HOSPITAL ‘A’
(Medical Imaging Utilisation Analysis- Preliminary Data)

4.2.1 Background
It was found that there were two main factors contributing to the unnecessary
exposure of patients to ionising radiation. The first factor was the use of inadequate
techniques leading to the production of diagnostically poor quality images. As a
consequence, the examination or part examination would need to be repeated. This
would potentially expose patients to radiation a second time and waste valuable time.
The two publications from these research findings are found in Appendices 7 and 8).

The second main contributing factor was the requisition of unnecessary examinations
by referring MO’s. The study was undertaken as a result of the feedback received on
a regular basis from Medical Radiation Scientists (MRS) regarding the workload
placed upon them by unnecessary examinations. The majority of such examinations
requested were for asymptomatic patients. Most of those requests resulted in a
normal report. In light of the literature review performed in chapter 2 (2.2 current
radiography requisition), it can be anticipated that over-utilisation within such a
system as Hospital ‘A’ will certainly exist. Thus in order to confirm the problem
statement in 1.1.2 and to ascertain the real extent and impact of over-utilisation, a
special team was established to conduct a preliminary study to confirm or negate the
existence of the problem.

4.2.2 Team Formation and Inaugural Meeting
The initial team consisted of a Senior Radiologist, a Senior MRS and a MRS. Formal
meeting sessions were undertaken that focused on assessing and identifying the
issues in terms of utilisation of medical imaging. It was decided that in the first
instance it would be necessary to survey MRSs to establish the extent of the problem. It was also determined that, statistical data from the Radiology Information System (RIS) should be used to separate normal reports from those examinations having abnormal reports. Reports with abnormal findings would then be investigated individually to determine its clinical value.

4.2.3 Medical Radiation Scientist Survey

The survey was designed to examine the concerns raised by the MRSs since up to this point; these were simply anecdotal in nature. A brief questionnaire was designed following consultation with departmental senior MRSs. The questions were formulated to address the nature of the unnecessary examinations, and in effect to establish whether or not a problem existed, and if so, to what extent. Questions were developed to identify the general perception held regarding the requisition of unnecessary examinations, the extent of it and to determine the likely causes. It was also decided to investigate the level of confidence held by MRS staff when dealing with requisitions which they felt were not justified. The questionnaire also aimed to identify the examinations that are perceived to be requested unnecessarily.

The content of the survey (as outlined in chapter 3.2.2 and Table 4.1) was approved during the course of the second team meeting.

The results of the survey are found in Table 4.1. The questionnaire was administered to nine MRSs, of which there were 8 responses.
Table 4.1 Summary: responses received from the MRS Survey for Hospital ‘A’, Stage 1

<table>
<thead>
<tr>
<th>No.</th>
<th>Question</th>
<th>Response</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Do you believe Medical Officers request unnecessary examinations?</td>
<td>Yes</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>(If Q 1 yes), What percentage you believe they overuse imaging services?</td>
<td>75%</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50%</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25%</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Do you question referring Medical Officers when you see an unjustified requisition?</td>
<td>Yes</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>In your opinion what are the reasons behind the unjustified requisitions?</td>
<td>Medico-legal</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Show something being done</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inexperienced Medical Officer</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Patient request</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Family request</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unavailability of proper modality</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Following protocol</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>In your opinion what examinations are requested unnecessarily?</td>
<td>Skull x-rays</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Facial bones</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chest and Ribs views</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cervical and Lumbar Spine</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shoulder and ankle</td>
<td>6</td>
</tr>
</tbody>
</table>

Survey Questionnaire available in Appendix 5.

4.2.4 Data analysis

Six months of data were extracted from the RIS database and imported into a Microsoft Excel Spreadsheet. In order to conduct qualitative analysis as well as the quantitative analysis, the extracted data included patient’s name and Medical Record Number, Imaging Accession Number and the type and date of the examination. In
compliance with the AHS guidelines in maintaining patient privacy strict measures were introduced to maintain patient privacy. By this procedure, raw data was archived under a security protected file. Patient’s personal data were not included in any of the tables within the published manuscript. During the second meeting, it was decided that the report should identify the percentage of normal cases in relation to the clinical findings.

Due to the large amount of data (cases), it was decided to focus the search on all Radiographic examinations of Skull, Facial bones, Ribs, Cervical and Lumbar Spine, Shoulders and Ankles. The selection of these particular examinations was based on the data received from the survey of MRS and the deliberations of the team. Not all suggested examinations from the survey were put forward for inclusion in the analysis; only those that had the full agreement of all members of the team were included.

All reports from the nominated examinations were copied and sorted into two groups. All examinations without pathological or trauma findings were classified as ‘normal’ findings and those with anything other than normal were classified as ‘questionable’.

In instances of examinations with any suspicion of a pathology or trauma, further analysis was undertaken by the team. In these cases, a complete radiological history was obtained and a thorough analysis was undertaken, which involved the review of clinical records for some of these patients.
4.2.4.1 Data analysis Results and Discussion - Hospital ‘A’

As shown in Table 4.2, results from the data collected demonstrated that the department has performed 10,047 cases with 8,623 being general radiographic examinations. The remainder was a mix of Ultra Sound and fluoroscopic procedures.

Table 4.2 Referrals from ED*, 12 months. Stage 1, Hospital ‘A’

<table>
<thead>
<tr>
<th>Body Region</th>
<th>No of Examinations**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total ED Referrals</td>
<td>10,047</td>
</tr>
<tr>
<td>Skull</td>
<td>462</td>
</tr>
<tr>
<td>Spine</td>
<td>378</td>
</tr>
<tr>
<td>Thoracic Cage</td>
<td>4,158</td>
</tr>
<tr>
<td>Abdomen</td>
<td>684</td>
</tr>
<tr>
<td>Extremities</td>
<td>2,941</td>
</tr>
</tbody>
</table>

*ED – Emergency Department.

**12 months period.

Due to the large number of examinations in question, it was decided to closely analyse 6 months of continuous data. Radiology reports of all examinations were analysed and classified as shown in Table 4.3 and Figure 4.1. Normal reports were separated from those with abnormal reports. Furthermore, abnormal findings were subjected to further analysis, including the senior radiologist reviewing the patient’s clinical records in order to attain further germane information.
### Table 4.3 Referrals from ED, selected examinations. Stage 1, Hospital ‘A’

<table>
<thead>
<tr>
<th>Body Region</th>
<th>No of * Exams</th>
<th>No of Normal - %</th>
<th>No of Finding - %</th>
<th>No of Fractures - %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skull</td>
<td>241</td>
<td>229 - 95</td>
<td>12 - 5</td>
<td>2 - 1</td>
</tr>
<tr>
<td>Facial Bones</td>
<td>169</td>
<td>151 - 70</td>
<td>18 - 30</td>
<td>9 - 15</td>
</tr>
<tr>
<td>Ribs</td>
<td>102</td>
<td>94 - 92</td>
<td>8 - 8</td>
<td>8 - 8</td>
</tr>
<tr>
<td>Cervical Spine</td>
<td>198</td>
<td>189 - 95</td>
<td>9 - 5</td>
<td>2 - 1</td>
</tr>
<tr>
<td>Lumbar Spine</td>
<td>132</td>
<td>103 - 78</td>
<td>29 - 16</td>
<td>6 - 6</td>
</tr>
<tr>
<td>Shoulder</td>
<td>205</td>
<td>162 - 79</td>
<td>43 - 21</td>
<td>28 - 14</td>
</tr>
<tr>
<td>Ankle</td>
<td>381</td>
<td>300 - 79</td>
<td>81 - 21</td>
<td>32 - 8</td>
</tr>
</tbody>
</table>

**6 months period analysed.**

*No of Fractures are mainly suggestive and not confirmed*

### Figure 4.1  Referrals from ED, Normal Versus Positive Reports of Selected Examinations. Stage 1, Hospital ‘A’ as per Table 4.3.
4.2.4.2 Description and Discussion of Results

The findings of this section of the preliminary study, confirm that the problem of over-utilisation of imaging examinations does indeed exist and as defined in the initial Problem Statement of 1.1.2. Furthermore, this varies in extent from one examination to another.

4.2.4.3 Skull

As shown in Table 4.3, 95% of the Skull radiographic examinations had normal reports (where pathology or fracture was not demonstrated). Of the 5% positive cases, only less than one percent had fractures relating to the patients’ current clinical presentation. Although there had been positive findings of the x-ray examination, both cases were referred for Computed Tomography (CT). Although positive findings had been reported on the plain x-ray examination, both cases required a CT scan to be performed in order to determine the presence and extent of any management altering pathology, for example extra-dural haemorrhage. This means that ultimately the X-ray examination served no real purpose, wasting resources and exposing the patients to unnecessary radiation exposure.

According to the examining Radiologist at the time of reporting, only 4% of cases had some findings. However, these were unlikely to be related to the current clinical presentation, and therefore the examinations would not contribute to the clinical management to initiate treatment.

4.2.4.4 Facial Bone

As shown in Table 4.3, there were more positive Facial Bones than Skull examinations. One hundred and sixty nine cases were examined. Thirty percent (30%) had a finding that was commented upon by the Radiologist, 11% of these
being indicative of fracture. The other cases demonstrated signs of fluid or oedematous tissue. Five percent (5%) of patients with a fracture were referred for further investigation by CT. Following this, together with all patients reported as having fractures, they were referred back to their general practitioners for follow up.

4.2.4.5 Ribs Views

As shown in Table 4.3, 92% of the 102 Ribs examinations had no indication of any fracture. Eight percent (8%) of the cases demonstrated a hairline fracture. A review of the clinical records revealed that all were discharged on the day of admission with a prescription for ‘painkillers’ and referral to their general practitioners. The team determined that it appeared that knowledge of the fracture did not contribute to the clinical management, and that the treatment essentially remained unchanged regardless of the finding of the fracture. The view of the team was that a simple chest radiograph would have yielded the same information. However, in terms of radiation exposure, if the latter approach had been adopted, the patient would have received the same radiation dose as a chest radiograph, approximately 0.16 mSv, as compared to approximately 4 mSv, the average received for rib radiographs.

4.2.4.6 Cervical Spine

As shown in Table 4.3, 95% of the total Cervical Spine examinations had normal reports with no indication of any trauma or pathological findings. Four percent (4%) demonstrated the presence of a variety of pathologies though only one percent (1%) was suggestive of the presence of a fracture. Both of these cases were referred for CT examinations in order to determine whether there was a need for referral to a specialist opinion. Odontoid Views are one of the most frequently repeated examinations especially when obtained by a junior MRS (Nol et al., 2006). The team
determined that a plain lateral ‘Shoot through’ view would have been more than satisfactory to exclude dislocated vertebrae. CT examination is of a value where the index of suspicion is high and would have saved the patient the consequences of the unnecessary exposure to an imaging examination involving ionising radiation.

4.2.4.7 Lumbar Spine

As shown in Table 4.3, 78% of the total Lumbar Spine x-ray examinations performed had normal reports without trauma or pathology being detected. Seventeen percent (17%) of the cases had some pathological findings such as Schmhorl’s nodes or degenerative changes. Only 5% of those cases demonstrated fractures such as compressed vertebrae. Sixty seven percent (67%) of the six cases with fractures findings were referred for CT. Following this they were referred on to their general practitioner for follow up. The other two patients were discharged and referred to their general practitioner.

4.2.4.8 Shoulder Examinations

As shown in Table 4.3, 79% of patients who underwent shoulder x-ray examinations had clinically normal reports. In total, 21% of all radiographic shoulder examinations demonstrated findings of trauma such as fractures or dislocation. Some cases demonstrated fracture of the clavicle. It was the view of the team that had these patients had been subjected to an evidence-based clinical examination; the majority of those undergoing Radiography with subsequent normal findings would not have been referred for Radiographic examination.

4.2.4.9 Extremities / Ankle

As shown in Table 4.3, 2,941 patients had general extremity examinations. Due to the large number of radiographic examinations, it was decided to limit the study at
this stage to examinations of the ankles. As shown in Table 4.2, 381 patients had ankle x-ray examinations. Of these, 79% had normal reports, with 21% of cases reporting fracture, dislocation or oedematous bruising. Ankle radiographs had the highest positive findings of all radiographs of extremities that were undertaken. However, the number of normal reports amongst these was observed to be extremely high, comprising 79% of all ankle examinations. It was the view of the reporting radiologist that this outcome demonstrated that insufficient training was given to referring MOs. In addition, with extremity examinations, there was a lack of any caution exhibited regarding the risks from radiation.

4.2.5 Intervention

It was clear from the analysis and interpretation of the preliminary data that there was a significant issue in terms of unnecessary imaging examinations. Based on these data, the team determined that the problem could be attributed to a number of factors, including a poor awareness of the side effects of radiation and a general lack of understanding regarding the impact of over-utilisation on the health system (including impact on resources, the organisation of services and workflow).

It was the unanimous decision of the team to prepare a structured Radiation Awareness Program (RAP). This would provide an opportunity to educate referrers as to the recommendations of the National Health and Medical Research Council (NHMRC, 1986) and the International Commission of Radiation Protection (ICRP, 1991). It would also support discussion on the actual usefulness of examinations and their role in the recommended clinical path.

It was also determined that the presentation should be incorporated as part of the orientation program for each new cohort of MOs at the hospital.
At the conclusion of the preliminary problem identification Stage 2 members of the research group (the author as the doctoral candidate, and the Senior Radiologist) secured new employment in similar positions in the adjoining Area Health Service. The study was relocated from Hospital ‘A’ to the new place of employment, Hospital ‘B’. It was decided to continue with the research project at Hospital ‘B’. Thus, the planned intervention did not proceed at Hospital ‘A’.

4.2.6 Conclusion of Stage 1

The analysis of the radiology reports confirmed that the problem of over-utilisation to be present. The analysis confirmed over 80% of the requested examinations resulted in normal reports. Furthermore, they made no contribution to the clinical management of the patient. The pattern differed between examinations, with in excess of 95% of Skull examinations found to be unnecessary, whereas 79% of ankle examinations were normal. However, though there were a higher percentage of positive findings for some examinations, the investigation confirmed that not all of those examinations were absolutely necessary. The team reported that several of the cases involving bruising and some with hairline or minor stable fractures, could have been diagnosed through appropriate clinical examination alone.

As stated earlier, during this period two members of the research group secured new employment in similar positions in the adjoining Area Health Service. The study was thus relocated from Hospital ‘A’ to the new place of employment, Hospital ‘B’. It was determined that the research project would continue at Hospital ‘B’, this now being termed Stage 2 of the research investigation.
4.3 RADIATION MANAGEMENT STAGE 2 HOSPITAL ‘B’
(Medical Imaging Utilisation Analysis - Preliminary Data and 1st Intervention)

4.3.1 Background

It was decided to proceed with the research project using the methodology previously undertaken with success at Hospital ‘A’. As mentioned earlier in 4.2.6, the Senior Radiologist and I, the senior MRS, relocated from Hospital ‘A’ to ‘B’. A new team at Hospital ‘B’ was established to take part in this process. It was also decided to collect a new set of preliminary data from Hospital ‘B’. This site was located in the adjoining health service to that of Hospital ‘A’. In addition, in Stage 2 the hypothesis that radiation awareness would reduce inappropriate requests could be tested.

4.3.2 Team Formation and initial meeting

The new team assembled at Hospital ‘B’ consisted of a Senior Radiologist, SMRS and MRS. The initial encounter provided a suitable forum in which to determine the purpose and aims of the team. The Senior Radiologist and the SMRS, through their previous experience at Hospital ‘A’, were able to convey their previous experience and effectively communicate the outcomes to the new team, relating these to the current situation at Hospital ‘B’.

It was determined to adopt the same initial process of surveying MRSs in order to investigate and define the extent of the problem of over-utilisation of medical imaging. As for Hospital ‘A’, it was decided to collect and analyse data from the RIS at Hospital ‘B’.
4.3.3 Medical Radiation Scientist Survey

The survey used was identical to that employed in Stage 1. It was designed to examine the concerns of MRSs and to examine the nature of unnecessary examinations, through determining the general perception, the likely causes and the level of confidence of MRS staff in dealing with or being confronted with such cases.

The survey designed at Stage 1 was presented for discussion and subsequently approved to be used for this hospital.

The results of the survey are summarised in Table 4.4. The methods are discussed in the Methodology chapter 3.2.2. Of the nine MRS staff surveyed, there were six completed surveys returned.
Table 4.4 Summary: responses received from the MRS Survey for Hospital ‘B’, Stage 2

<table>
<thead>
<tr>
<th>No</th>
<th>Question</th>
<th>Response</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Do you believe Medical Officers request unnecessary examinations?</td>
<td>Yes</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>(If Q 1 yes), What percentage you believe they overuse imaging services?</td>
<td>75%</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50%</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25%</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Do you question referring Medical Officers when you see an unjustified requisition?</td>
<td>Yes</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>In your opinion what are the reasons behind the unjustified requisitions?</td>
<td>Medico- legal.</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Patient Request.</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Family request.</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Use of radiation not seen as a hazardous tool.</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>To show that something is being done.</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unavailability of proper modality.</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Following protocol.</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inexperienced Medical Officer.</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>In your opinion, what examinations are requested unnecessarily?</td>
<td>Chest and Ribs.</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Skull x-rays.</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shoulder.</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ankle.</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cervical and lumbar spine.</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pelvis.</td>
<td>4</td>
</tr>
</tbody>
</table>

Survey Questionnaire available in Appendix 5.

4.3.4 Data Analysis

The combined findings of this MRS survey, in addition to the data from Hospital ‘A’, contributed to the team excluding locality specific examinations such as Facial Bones, which were more prevalent at Hospital ‘A’. The outcomes of the study at Hospital ‘A’ influenced the team in focusing on those examinations identified as having very low percentages of positive findings. Overall, there were a high percentage of normal reports. These comprised Skull, Ribs, Cervical and Lumbar Spine examinations. The team determined that studies with high rates of positive findings demonstrating some form of pathology, such as Shoulder and Ankle, were
to be excluded at this stage, but reviewed at a later stage. It was believed that the revelation of the high frequency of negative findings together with the associated radiation burden for each examination would have an important impact on referring MOs and specialists. Pelvis examinations were included at Stage 2 since this was an area of concern identified in the MRS survey at Hospital ‘B’. Similar to Hospital ‘A’, the investigation was performed in order to identify the rate of normal cases with respect to those with findings of pathology or trauma.

All reports from the nominated examinations were separated into two groups. Those without pathology or trauma were classified as ‘normal’ findings. Imaging Examinations with any degree of an abnormal finding reported were subject to further investigation involving review of the patient’s medical records. The complete radiological history was obtained and a thorough analysis was conducted. The clinical records were reviewed by the chief investigator and the senior radiologist.

4.3.4.1 Data analysis Results and Discussion - Hospital ‘B’

As shown in Table 4.5, the Radiology Department performed 11,463 general radiographic examinations of patients that presented to the Emergency Department (ED).

Table 4.5 Referrals from ED, 12 months. Stage 2, Hospital ‘B’

<table>
<thead>
<tr>
<th>Body Region</th>
<th>No of Examinations*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total ED Referrals</td>
<td>11,463</td>
</tr>
<tr>
<td>Skull</td>
<td>300</td>
</tr>
<tr>
<td>Rib</td>
<td>163</td>
</tr>
<tr>
<td>Cervical Spine</td>
<td>302</td>
</tr>
<tr>
<td>Lumbar Spine</td>
<td>203</td>
</tr>
<tr>
<td>Pelvis</td>
<td>163</td>
</tr>
</tbody>
</table>

* 12 months period
Due to the large number of examinations in question, it was decided to closely analyse 6 months of continuous data. Radiology reports of all examinations were analysed and classified as shown in Table 4.6 and Figure 4.2. Normal reports were separated from those with abnormal reports. Furthermore, abnormal findings were subjected to further analysis, including the senior radiologist reviewing the patient’s clinical records in order to attain further germane information.

Table 4.6 Referrals from ED, selected examinations. Stage 2, Hospital ‘B’

<table>
<thead>
<tr>
<th>Body Region</th>
<th>No of * Exams</th>
<th>No of Normal - %</th>
<th>No of Other Findings - %</th>
<th>No of ** Fractures - %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skull</td>
<td>145</td>
<td>139 - 96</td>
<td>6 - 3</td>
<td>2 - 1</td>
</tr>
<tr>
<td>Ribs</td>
<td>90</td>
<td>80 - 89</td>
<td>10 - 3</td>
<td>7 - 8</td>
</tr>
<tr>
<td>Cervical Spine</td>
<td>62</td>
<td>49 - 92</td>
<td>13 - 7</td>
<td>2 - 1</td>
</tr>
<tr>
<td>Lumbar Spine</td>
<td>106</td>
<td>100 - 94</td>
<td>6 - 5</td>
<td>1 - 1</td>
</tr>
<tr>
<td>Pelvis</td>
<td>76</td>
<td>68 - 89</td>
<td>8 - 7</td>
<td>3 - 4</td>
</tr>
</tbody>
</table>

*6 months period analysed.

**No of Fractures are mainly suggestive and not confirmed
4.3.4.2 Description and Discussion of Results

As with Hospital ‘A’, the findings of this section of the preliminary study confirm that the problem of over-utilisation of imaging examinations does indeed exist and as defined in the initial Problem Statement of 1.1.2. Furthermore, similar to the results from Hospital ‘A’ the extent of over-utilisation varies from one examination to another as shown in Table 4.6 and the following sections.

4.3.4.3 Skull

As shown in Table 4.6, 96% of the Skull radiographic examinations had normal reports (where pathology or fracture was not demonstrated). Four percent (4%) had pathological findings, with only 1% having a confirmed fracture related to the current presentation of the patient to the ED. Only one case had findings suggestive of a fracture. Despite the findings of the radiographic examination, both cases were referred for further investigation with CT.

In the remaining three per cent (3%) of examinations, there was some degree of suspicion, though the examining Radiologist subsequently found that these were not
conclusive. Though a fracture could not be excluded, it was the opinion of the examining Radiologist that the examination did not have contributed to the patient’s clinical management. In such cases, other modalities with higher sensitivity and specificity are indicated, such as CT or Magnetic Resonance Imaging (MRI).

### 4.3.4.4 Ribs Views

As shown in Table 4.6, 89% of the total Rib examinations had no indication of any fracture. Whereas eleven per cent (11%) of total cases demonstrated pathology, only eight per cent of total cases were suggestive of hairline fractures. The clinical records of those patients revealed that all were discharged on the day of presentation. They were prescribed painkillers with referral to their respective general practitioners. Similar to the outcome at Hospital ‘A’, the confirmation of the presence of the fracture did not contribute to the clinical management of the patient, with treatment remaining unchanged. All patients were given analgesics and discharged on the same day. The team determined that a simple chest radiograph would have provided the same information with a lower radiation dose (Appendix 2.9).

### 4.3.4.5 Cervical Spine

As shown in Table 4.6, 92% of the Cervical Spine examinations had normal reports with no indication of any trauma or pathology. Seven percent of the cases demonstrated the presence of a range of pathologies; only 1% of those suggested a fracture. Both cases were referred for CT to determine whether the patient required referral to a specialist. The team determined that plain film lateral radiography (horizontal beam lateral ‘shoot’ through) would have been appropriate to exclude findings such as dislocated vertebrae (Appendix 2.7). The team determined CT examination to be the examination of choice where there is a high index of suspicion.
and in such cases CT would have prevented the negative impact of unnecessary testing on both the patient and the system.

### 4.3.4.6 Lumbar Spine

As shown in Table 4.6, 94% of the Lumbar Spine x-ray examinations were reported as normal, where no trauma or pathology was detected. Five percent of the cases had some pathological findings such as degenerative changes or osteoporosis. Only one percent of those were shown to have fractures such as compressed vertebrae. Three percent (3%) of those with positive findings were referred for CT examination prior to referral to their general practitioners. Two percent (2%) of the patients were discharged with referral to their general practitioner.

### 4.3.4.7 Pelvis

As shown in Table 4.6, 89% of the radiographic examinations of the pelvis had normal reports, while 11% had pathological findings; fractures and hip prosthesis. Clearly, a finding of 89% of normal reports confirms the presence of extensive over-utilisation and warrants intervention.

### 4.3.5 Intervention

The analysis and interpretation of the preliminary data, including the findings shown in Table 4.6, confirms a significant problem of over-utilising imaging examinations. The team determined from the data analysis that the problem was attributable to several factors, including the lack of awareness of the side effects of radiation on patients’ together with a generalised lack of understanding regarding the impact of over-utilisation on the health system. This supports the overall research investigation, and confirms the underlying problem that is built into the Hypothesis. In accordance
with Hypothesis 1.3.1, an intervention was developed by the team in the form of a RAP. This Program was designed to reduce the unnecessary examinations.

The outcomes of the preliminary study conducted at Hospital ‘B’ were similar to those conducted at Hospital ‘A’. The data analysis also supported the need that MRS staff required additional training and support to assist them in dealing with junior MOs deemed to be requesting unnecessary examinations.

Following review of the situation, the team unanimously decided to continue with the RAP in order to promote the ICRP and NHMRC recommendations. It was recommended for inclusion specific information on the doses associated with the various examinations employing ionising radiation. It was determined that the RAP presentation should be delivered to each new cohort of MOs during their orientation program. In addition, the presentation was also to be given to other professional groups such as nurses.

4.3.6 Educational Material of the Awareness Program

The Chief investigator prepared the educational material for the presentations. References were sourced from the National Health and Medical Research Council (NHMRC, 1986), the International Commission of Radiation Protection (ICRP, 1991), and a selection of radiation physics books (Curry et al., 1990; Selman, 1980). It was decided to demonstrate the radiation doses received by patients at Hospital ‘B’ when referred for the various examinations. Radiation doses of examinations carried within the Imaging Department were measured using the Nero 4000 radiation testing equipment.

The presentation comprised of practical rather than simply theoretical information and included aspects from the surrounding environment in order to demonstrate the
impact of this topic in everyday life. This approach also engaged the attention of the audience, making them aware of radiation risks in the environment, rather than just focusing on those encountered in the workplace. The presentation included information on the effects of radiation exposure from such sources as microwave ovens. It focussed on the safety aspects and the duties of the MRS as a trusted professional with a major role in improving public health safety through reducing radiation doses to the patient.

The RAP was established during Stage 2. At Stage 3, as a result of feedback from participants in the previous program, modification was undertaken to include topics such as radiobiology. Some adjustment was made in order to make the program more accessible to the range of healthcare professionals attending presentations.

Table 4.7 outlines the first RAP as detailed in Appendix 9_1, and lays down the context and rationale behind each slide in the presentation.
<table>
<thead>
<tr>
<th>Slide No.</th>
<th>Title / Content</th>
<th>Objectives and learning outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction</td>
<td>Purpose of the study and value to staff, patients and the public</td>
</tr>
<tr>
<td>2-4</td>
<td>Definition of radiation types and sources</td>
<td>Gives the audience an understanding of the basics of radiation and to understand the relationship of x-rays to familiar sources such as ultraviolet and electricity.</td>
</tr>
<tr>
<td>5</td>
<td>Doses received from natural radiation and its assumed benefits</td>
<td>Doses from natural sources have been set as the maximum occupational permissible dose (MOPD).</td>
</tr>
<tr>
<td>6</td>
<td>Negative impacts of radiation</td>
<td>To give the audience an understanding of the side effects of high and low doses.</td>
</tr>
<tr>
<td>7-14</td>
<td>Artificial radiation- examples and side effects of exposure</td>
<td>To familiarise the audience with radiation in building a knowledge base from their daily life.</td>
</tr>
<tr>
<td>15</td>
<td>Introduction to radiation in health</td>
<td>Give the audience an understanding of the strength of x-rays used in health and its relationship with non-ionising radiation.</td>
</tr>
<tr>
<td>16</td>
<td>The permissible Occupational Dose</td>
<td>The scale of the problem of excess radiation.</td>
</tr>
<tr>
<td>17-20</td>
<td>The effects of Radiation</td>
<td>Tabled list of the side effects.</td>
</tr>
<tr>
<td>21</td>
<td>Low Dose Radiation</td>
<td>Effects from low doses.</td>
</tr>
<tr>
<td>22</td>
<td>Radiation doses during Skull radiography</td>
<td>The doses received from a Skull examination compared with MOPD.</td>
</tr>
<tr>
<td>23</td>
<td>High Radiation Doses- Lumbar Spine examinations</td>
<td>Lateral lumbar Spine requires the highest radiation dose for being the thickest part of the human body.</td>
</tr>
<tr>
<td>24</td>
<td>Single exposure of different regions of the body</td>
<td>A list of few other examinations to give referring MO’s an understanding of the different doses.</td>
</tr>
<tr>
<td>25-28</td>
<td>Safety and the use of guidelines</td>
<td>Safety requirements and the minimum knowledge required by MO’s</td>
</tr>
<tr>
<td>29</td>
<td>The hidden dangers</td>
<td>What we see is not what really occurs. Radiation being invisible, old radiation protection practices might in some cases do more harm than good.</td>
</tr>
<tr>
<td>30-31</td>
<td>Simple protective measures and safety techniques used by MRSs</td>
<td>Safe work practices to apply the ALARA principles.</td>
</tr>
<tr>
<td>32-37</td>
<td>Recommendations and guidelines- *NHMRC and ICRP</td>
<td>Target</td>
</tr>
<tr>
<td>38</td>
<td>Questions and discussion</td>
<td></td>
</tr>
</tbody>
</table>

* NHMRC- National Health and Medical Research Council;  
* ICRP- International Commission of Radiation Protection;  

Presentation available in Appendix 9_1.
4.3.7 Post Presentation Feedback Survey

A post presentation feedback survey as described in 3.2.5 was administered to referring MOs during their orientation session. The survey also examined levels of awareness of radiation dose and the side effects of radiation. A summary of the responses received is shown in Table 4.8.

4.3.7.1 Medical Officers Survey – Results

The Survey was administered to 43 MOs between May 2002 and April 2003, during their orientation to the hospital and the Imaging Department. Orientation to the Imaging Department included the RAP. Sixty-two percent (n= 27) of attendees returned the completed questionnaires. The design of the survey is found in 3.2.5 and responses are shown in Table 4.8.
### Table 4.8 Responses received from the Medical Officers Survey for Hospital ‘B’, Stage 2

<table>
<thead>
<tr>
<th>No</th>
<th>Question</th>
<th>Response</th>
<th>No.</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Radiation Safety. Was it included in the formal medical training course?</td>
<td>Yes</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td>27</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>Have you been introduced to the occupational permissible radiation doses?</td>
<td>Yes</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td>27</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>Do you have an idea of the approximate Radiation doses of the different Medical Imaging Examinations?</td>
<td>Yes</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td>27</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>Do you think you have enough knowledge about radiation safety and radiation doses?</td>
<td>Yes</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td>27</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>After today’s Presentation, do you think you need further training on radiation safety or radiation doses?</td>
<td>Yes</td>
<td>16</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td>11</td>
<td>41</td>
</tr>
<tr>
<td>6</td>
<td>Do you consider radiation dose to be a limiting factor to request an x-ray examination. Please list few points.</td>
<td>Yes</td>
<td>27</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Comments</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>May you please name your last clinical placement before Hospital ‘B’?</td>
<td>8-</td>
<td>Westmead</td>
<td>(2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1-</td>
<td>RPA</td>
<td>(5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2-</td>
<td>Concord</td>
<td>(4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3-</td>
<td>St George</td>
<td>(3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4-</td>
<td>RNS</td>
<td>(5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5-</td>
<td>Liverpool</td>
<td>(6)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6-</td>
<td>Gosford</td>
<td>(1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7-</td>
<td>Dubbo</td>
<td>(1)</td>
</tr>
<tr>
<td>8</td>
<td>Are there differences in protocols and guidelines of requesting imaging examinations amongst the different hospitals where you have done your clinical placements? If yes, can you name some of the differences?</td>
<td>Yes</td>
<td>17</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td>10</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>Comments were:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Easy access to modalities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nurse initiated</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nurse fills the form for you</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Do you agree with the use of set ordering protocols such the “trauma series? Why? Why not?</td>
<td>Yes</td>
<td>18</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td>9</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Comments were:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yes fast track process</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yes don’t take chances</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>No unnecessary</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Do you find it difficult to request high end modality examinations such as CT/US or MRI in comparison with general X-ray?</td>
<td>Yes</td>
<td>14</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td>13</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>Comments were:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nurse initiated</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Usually form is pre filled by nurse to speed up process</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Do you always request the examinations for your patients, if not please specify?</td>
<td>Yes</td>
<td>14</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td>13</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>Comments were:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nurse initiated</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Usually form is pre filled by nurse to speed up process</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Have you been faced with situations where you had to request an examination for non-clinical purposes?</td>
<td>Yes</td>
<td>21</td>
<td>78</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No</td>
<td>6</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Comments were:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yes Medico legal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yes unavailability of proper modality</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yes patient request</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yes Family request</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yes Following protocol</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Survey Questionnaire available in Appendix 6.

In addition, all participants to the sessions were handed an evaluation survey to rate the session. This provided the team with comments and suggestions to improvement the sessions. This evaluation returned a high approval average rating of 4.5 (max 5.0,
the number of comments provided was notably high. The main suggestions made being requests for detailed information on radiation dose and the biological effects of radiation as this would be beneficial.

4.3.7.2 Medical Officers Survey – Discussion

As shown in Table 4.8, the results were a clear indication that the effects of radiation and dosage were not considered when requesting an x-ray examination. As shown by the unanimous negative response from MOs for Q1- Q4, they lacked knowledge on radiation safety and dose, including the occupational permissible doses. Radiation safety had not formed part of their training. However as shown in the response of Q5, surprisingly only 59% percent believed that more training is required.

For most MOs, the effects of exposure to radiation were not part of the decision-making formula during the process of requesting an imaging examination, pregnancy being the only exception (Table 4.8 Q6). Post RAP discussions with attendees revealed that surprisingly MOs could not reconcile the fact that if there are dangers from exposure to radiation during pregnancy, then there is likely to be risk associated with radiation exposure to other patients.

As shown in Table 4.8 Q8, a small number of respondents agreed that requesting ‘blanket orders’ of imaging trauma series to be a positive approach especially with regard to reducing ED waiting time. This was likely to be due to a number of factors, including that the belief that this would result in fast track patient management, provide protection from medico-legal issues, and reduce potential criticism from senior colleagues. There were a considerable number of responses admitting that request forms were pre-signed and actually completed by nurses or other staff. Two respondents indicated that examinations are actually requested by nurses.
The survey also revealed reasons other than clinical need, for requesting examinations. As shown in Table 4.8 Q12 other factors such as pleasing or placating the patient and their family and protection from medico-legal litigation were provided as responses. It was also highlighted that in some instances due to the unavailability of high-end modality examinations such as CT and US, requisitions were substituted with low sensitivity radiographic examinations Table 4.8 Q10 and comments in Q12.

4.3.8 Post Implementation Sequence of Events and Results

Sixteen months of new data collected from January 2002 - April 2003 were extracted from the RIS database and imported to a Microsoft Excel Spreadsheet. At this stage, it was decided that it would be beneficial for the data to be employed to analyse referral patterns, rather than detailed analysis of reports in order to observe any change occurring as a result of the intervention.

As shown in Table 4.9, data collected from the RIS revealed the department to have performed 16,072 general x-ray examinations on patient’s presenting to the ED.

The detailed list comprised Skull, Rib, KUB and Nasal Bones. Monthly totals were classified under ‘examination categories’ and results documented using a chart format.

There were 291 Skull x-rays, 248 Ribs examinations, 79 nasal bone examinations and 260 KUB’s requested.

Monthly referrals for Hospitals ‘B’ and ‘C’ are in (Appendix 4), showing the number of the monthly requested examinations. Results were translated to run charts to present the level of activity to the team in figures 4.3, 4.4, 4.5 and 4.6.
Figure 4.3 Skull Referrals from ED. Pre & Post Stage 2 Hospitals ‘B’ & ‘C’

Figure 4.4 Ribs Referrals from ED. Pre & Post Stage 2 Hospitals ‘B’ & ‘C’
Figure 4.5 Nasal Bone Referrals from ED. Pre & Post Stage 2 Hospitals ‘B’ & ‘C’

Figure 4.6 KUB Referrals from ED. Pre & Post Stage 2 Hospitals ‘B’ & ‘C’
4.3.9 Raw Data Analysis

Data from Appendix 4 were translated to run charts (Figure 4.3 to 4.6) and presented to team members on a monthly basis to show the variation in the outcomes. At the end of Stage 2 the team recommended that further analysis be undertaken to address the variation and inconsistency in the overall reduction of requested examinations, and to highlight the impact of the different presenters as well as the impact of ceasing RAP during the MOs orientation.

Data from Appendix 4 were further analysed by calculating mean referrals per 100 ED presentations, and as shown in Tables 4.9 and 4.10 for Hospitals ‘B’ and ‘C’ respectively. Furthermore, Tables 4.9 and 4.10 were further grouped into three equal four monthly periods where different RAP methods were employed. For the purpose of statistical comparison pre and post intervention, mean referrals were determined.
Table 4.9 Referral from ED (Category ‘A’), pre and post Stage 2, Hospital ‘B’.

<table>
<thead>
<tr>
<th>Body region</th>
<th>Pre- any Intervention*</th>
<th>Post- Interventions**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. Referrals - Referrals</td>
<td>Mean***</td>
</tr>
<tr>
<td>Skull</td>
<td>275 - 1.0666</td>
<td>188 - 0.6900</td>
</tr>
<tr>
<td>Ribs</td>
<td>208 - 0.8065</td>
<td>169 - 0.6202</td>
</tr>
<tr>
<td>Nasal</td>
<td>53 - 0.2055</td>
<td>60 - 0.2202</td>
</tr>
<tr>
<td>KUB</td>
<td>205 - 0.7949</td>
<td>185 - 0.6789</td>
</tr>
<tr>
<td>Total</td>
<td>741 - 2.8734</td>
<td>602 - 2.2094</td>
</tr>
</tbody>
</table>

* May 2001 – April 2002, Total number of ED referrals = 12,066; Total number of ED, Presentations = 25788
** May 2002 – April 2003 (Total of 3 RAP’s), Total number of ED referrals = 11,889; Total number of ED Presentations = 27246
*** Mean Referrals per 100 ED Presentations.
(x) Negative Result
Table 4.9.1 Referral from ED (Category ‘A’), pre and post Stage 2, Hospital ‘B’. 1st RAP.

<table>
<thead>
<tr>
<th>Body region</th>
<th>Pre- any Intervention*</th>
<th>Post- Intervention**</th>
<th>% Difference (95% CI)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. Referrals - Referrals</td>
<td>Mean***</td>
<td>No. Referrals - Referrals</td>
<td>Mean ***</td>
</tr>
<tr>
<td>Skull</td>
<td>275 - 1.0666</td>
<td>39 - 0.4419</td>
<td>-58.6 (55.7 – 61.5)</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Ribs</td>
<td>208 - 0.8065</td>
<td>54 - 0.6119</td>
<td>-24.1 (22.1 – 26.1)</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Nasal</td>
<td>53 - 0.2055</td>
<td>18 - 0.2039</td>
<td>-0.78 (0.63 – 0.93)</td>
<td>0.9894</td>
</tr>
<tr>
<td>KUB</td>
<td>205 - 0.7949</td>
<td>49 - 0.5553</td>
<td>-30.1 (27.5 – 32.7)</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Total</td>
<td>741 - 2.8734</td>
<td>160 - 1.8132</td>
<td>-36.9 (34.5 – 39.3)</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

* May 2001 – April 2002, Total number of ED referrals = 12,066; Total number of ED Presentations = 25788

** May 2002 – August 2002 (1st RAP Lecture by Chief Investigator), Total number of ED referrals = 4,114; Total number of ED Presentations = 8824

*** Mean Referrals per 100 ED Presentations.

Figure 4.7 Referral from ED (Category ‘A’), pre and post Stage 2, Hospital ‘B’. 1st RAP
**Table 4.9.2** Referral from ED (Category ‘A’), pre and post Stage 2, Hospital ‘B’. 2\textsuperscript{nd} RAP.

<table>
<thead>
<tr>
<th>Body region</th>
<th>Pre- any Intervention*</th>
<th>Post- Intervention**</th>
<th>% Difference (95% CI)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. Referrals - Mean***</td>
<td>No. Referrals - Mean ***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skull</td>
<td>275 - 1.0666</td>
<td>64 - 0.6887</td>
<td>-35.4 (34.1 – 36.7)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Ribs</td>
<td>208 - 0.8065</td>
<td>52 - 0.5596</td>
<td>-30.6 (29.6 – 31.6)</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Nasal</td>
<td>53 - 0.2055</td>
<td>16 - 0.1721</td>
<td>-16.2 (15.6 – 16.8)</td>
<td>0.2825</td>
</tr>
<tr>
<td>KUB</td>
<td>205 - 0.7949</td>
<td>72 - 0.7748</td>
<td>-2.5 (2.2 – 2.8)</td>
<td>0.8981</td>
</tr>
<tr>
<td>Total</td>
<td>741 - 2.8734</td>
<td>204 - 2.1954</td>
<td>-23.6 (22.1 – 24.1)</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>

* May 2001 – April 2002, Total number of ED referrals = 12,066; Total number of ED Presentations = 25788

** September 2002 – December 2002 (1\textsuperscript{st} RAP Lecture by Chief Investigator), Total number of ED referrals =3,931; Total number of ED Presentations = 9292

*** Mean Referrals per 100 ED Presentations.

**Figure 4.8** Referral from ED (Category ‘A’), pre and post Stage 2, Hospital ‘B’. 2\textsuperscript{nd} RAP
Table 4.9.3 Referral from ED (Category ‘A’), pre and post Stage 2, Hospital ‘B’. No RAP.

<table>
<thead>
<tr>
<th>Body region</th>
<th>Pre- any Intervention*</th>
<th>Post- Interventions**</th>
<th>% Difference (95% CI)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. Referrals - Referrals</td>
<td>Mean***</td>
<td>No. Referrals - Referrals</td>
<td>Mean ***</td>
</tr>
<tr>
<td>Skull</td>
<td>275 - 1.0666</td>
<td>85 - 0.9309</td>
<td>-12.7 (12.1 – 13.3)</td>
<td>0.2526</td>
</tr>
<tr>
<td>Ribs</td>
<td>208 - 0.8065</td>
<td>63 - 0.6900</td>
<td>-14.4 (13.8 – 15.0)</td>
<td>0.5513</td>
</tr>
<tr>
<td>Nasal</td>
<td>53 - 0.2055</td>
<td>26 - 0.2847</td>
<td>+38 (35.9 – 40.1)</td>
<td>0.1053</td>
</tr>
<tr>
<td>KUB</td>
<td>205 - 0.7949</td>
<td>49 - 0.5366</td>
<td>-32.5 (30.8 – 34.3)</td>
<td>0.4856</td>
</tr>
<tr>
<td>Total</td>
<td>741 - 2.8734</td>
<td>238 - 2.6067</td>
<td>-9.3 (8.7 – 9.9)</td>
<td>0.3550</td>
</tr>
</tbody>
</table>

* May 2001 – April 2002, Total number of ED referrals = 12,066; Total number of ED Presentations = 25,788

** January 2003 – April 2003 (No RAP Lecture) Total number of ED referrals = 3,844; Total number of ED Presentations = 9,130

*** Mean Referrals per 100 ED Presentations.
(x) Negative Result

Figure 4.9 Referral from ED (Category ‘A’), pre and post Stage 2, Hospital ‘B’. No RAP
**Figure 4.10** Referral from ED (Category ‘A’), comparing the impact of the different periods within Stage 2. i.e. 1st RAP, 2nd RAP, No RAP. Hospital ‘B’.

![Graph showing referral rates across different body regions and intervention periods]

**Hospital ‘C’ data:**

**Table 4.10** Referrals from ED (Category ‘A’), pre and post Stage 2, Hospital ‘C’.

<table>
<thead>
<tr>
<th>Body region</th>
<th>Pre- any Intervention*</th>
<th>Post- Intervention period**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. Referrals - Mean***</td>
<td>No. Referrals - Mean***</td>
</tr>
<tr>
<td>Skull</td>
<td>231 - 1.2059</td>
<td>232 - 1.1477</td>
</tr>
<tr>
<td>Ribs</td>
<td>188 - 0.9814</td>
<td>155 - 0.7668</td>
</tr>
<tr>
<td>Nasal</td>
<td>79 - 0.4124</td>
<td>65 - 0.3215</td>
</tr>
<tr>
<td>KUB</td>
<td>167 - 0.8718</td>
<td>177 - 0.8756</td>
</tr>
</tbody>
</table>

| Total       | 565 - 2.9496           | 629 - 3.1118               | +5.2 (4.9 – 5.5)       | 0.3344 |

* May 2001 – April 2002, Total number of ED referrals = 9,762; Total number of ED Presentations = 19155
** May 2002 – April 2003 (Total of 3 RAP’s at Hosp B), Total number of ED referrals = 8,406; Total number of ED Presentations = 20213
*** Mean Referrals per 100 ED Presentations.
(x) Negative Result
4.3.10 Discussion

As shown in Table 4.9 there was an overall significant decrease of 23.1% (p<0.01) examinations requisitioned in the 12 months following the first intervention period. The greatest reduction was found for Skull examinations, which were reduced by 35.3% (p<0.001). During this period, the mean number of monthly referrals decreased from 1.06 to 0.69 per month. Similarly, there was a reduction in the frequency of requisitions for Rib examinations by 23.1% (p<0.05). During this period, the mean number of monthly referrals decreased from 0.81 to 0.62 per month.

Further analysis has demonstrated a change in the pattern of requisition following each of the educational presentations undertaken at the regular orientation sessions every four months. Tables 4.9.1, 4.9.2 and 4.9.3 show the pattern of requisitions for each of the four months periods immediately following the orientation sessions. Whereas there had been an overall 23.1% (p<0.01) reduction during the 12 months period following intervention, the reduction was most evident initially with a 36.9% decrease (p<0.001) after the first four months (Table 4.9.1). The reduction was by 23.6% (p<0.01) for the second four months (Table 4.9.2) and 9.3% (p=0.3550) in the final four months (Table 4.9.3).

As shown in Table 4.9.1 and Figure 4.7, the impact was greatest initially, with decreases in referrals for Skull (58.6%, p<0.0001), Ribs (24.2%, p<0.05) and KUB (30.2% p<0.05). The impact declined noticeably following the second orientation session (Table 4.9.2 and Figure 4.8) with reductions not as pronounced. As shown in Table 4.9.3 and Figure 4.9, there was no significant overall decrease in the number of referrals for the final four months.

On evaluation of the intervention, the team attributed the significant variation in
reduction of referrals across the 12 months period to the quality of the presentation provided at each of the orientation sessions. The first session had been presented by the Chief Investigator, the second by another MRS, while no educational presentation was provided at the third and final orientation session for that year. The first session had clearly achieved the greatest change in terms of reduction of unnecessary examinations, while the last period showed elevated levels of referral with a return to pre-intervention rates due to no orientation program being provided. The team determined that the main contributing factors in the first session were the Chief Investigator’s advanced level of knowledge of radiation doses, the effects of radiation at cellular level as well as an understanding of the guidelines set by the NHRMC. Another contributing factor was determined to be the superior presentation skills. The team concluded that for the RAP to achieve the expected outcomes, presenters must be trained to be fully conversant with the RAP subjects, and also receive training to strengthen their presentation skills.

As shown in Table 4.10 although there was slight reduction in referrals from ED at Hospital ‘C’, the overall reduction was statistically insignificant (P=0.3344).

4.3.11 Conclusion
Stage 2 was an extension of Stage 1. Results from Stage 1 were presented to the new members and some modifications were agreed upon to only examine the areas of greatest concern and omit some examinations from the analysis such as Facial Bones, Spine and Extremities. KUB and Nasal Bones were added. In addition, key aspects were identified for further analysis.

As discussed, the findings from the MOs’ survey (Table 4.8) were indicative of the exclusion of Radiation Safety in any formal medical training course, it was also
prevalent that none of the attendees had an understanding of radiation doses received by patients or the level of permissible occupational doses for staffs. The interactive discussion during question time indicated that majority of MO’s have a limited knowledge of radiation effects on living cells and would welcome more training on this topic.

As shown in Table 4.9.2, the data analysis demonstrated an immediate drop in referrals post radiation awareness presentation. For some of the selected regions the number of referrals was reduced by approximately 40% (Table 4.9.2). It also illustrates that the number of examinations continues to fall for the following 3 months and then increased when there was a new intake of MOs.

It was also noted that the style and the assertiveness of the presenter contributes to the expected outcomes. The results of the post Radiation Awareness survey clearly highlighted the existing low levels of knowledge regarding radiation safety and the requirement for a more structured education incorporating continuous awareness programs.

4.4 RADIATION MANAGEMENT STAGE 3 HOSPITAL ‘B’ (2nd Intervention)

4.4.1 Background

In order to effect the immediate and measurable significant improvement as specified in the hypothesis (1.3.2), Stage 3 was implemented. An evidence-based appropriate imaging requisition method was now employed.

The team reviewed the progress of the project, prior to implementation of an evidence-based approach. A more assertive approach was to be employed to effect
better outcomes. An expansion in the membership of the team took place and further modification of the radiation awareness presentation was undertaken.

4.4.2 Team Reformation

The team expanded its membership to include a member from the university as the quality co-ordinator a registered nurse, a senior member of clerical staff. The other members comprised a senior radiologist, a senior MRS, and the Chief MRS.

Following the introduction, the inaugural meeting focused directly on the presentation of the radiation awareness lecture. The new team decided that in order to fulfil the aim, (1.4.2.3) the presentation required an increased scientific content together with an expansion of the general knowledge aspects (Appendix 9_2). Development of appropriate reference material was required in order to support MRS’s in their discussions with MOs when making recommendations (Appendix 2).

It was also determined that a more intensive program should be formulated. However this new program also required stricter adherence to the material by those delivering it as, as the team recognised that the program had not been followed as diligently at Stage 2.

It was also acknowledged that for the project to succeed and the hypothesis to be entirely proved the support and contribution from a Specialist MO (non-radiologist) would be required. Preferably, this would be a specialist from the ED. The content of the RAP is illustrated in Table 4.11. The presentation underwent some extensive change commencing with the layout and sequence of each subject. Slide 1 remained the introduction with the addition of the title “OH&S at WORK & HOME”.

140
Table 4.11 Outline of the Radiation Awareness Program for Hospital ‘B’, Stage 3

<table>
<thead>
<tr>
<th>Slide No.</th>
<th>Title / Content</th>
<th>Objectives and learning outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction with new Title “OH&amp;S at WORK &amp; HOME”</td>
<td>Purpose of the study and value to staff, patients and the public</td>
</tr>
<tr>
<td>2- 4</td>
<td>Definition of radiation types and sources – with addition of the SPECTRUM</td>
<td>Gives the audience an understanding of the basics of radiation and to understand the relationship of x-rays to familiar sources such as ultraviolet and electricity.</td>
</tr>
<tr>
<td>5 -6</td>
<td>Doses received from natural radiation and its assumed benefits (PYE Chart been added)</td>
<td>Doses from natural sources have been set as the maximum occupational permissible dose (MOPD).</td>
</tr>
<tr>
<td>6</td>
<td>Negative impacts of radiation</td>
<td>To give the audience an understanding of the side effects of high and low doses.</td>
</tr>
<tr>
<td>7- 9</td>
<td>Radiobiology</td>
<td>Simple and descriptive diagrams showing alteration in molecular structures and DNA</td>
</tr>
<tr>
<td>10</td>
<td>Cumulative nature of radiation</td>
<td>Explain that radiation doses are cumulative for the life of the exposed subject.</td>
</tr>
<tr>
<td>15</td>
<td>Introduction to radiation in health</td>
<td>Give the audience an understanding of the strength of x-rays used in health and its relationship with non-ionising radiation.</td>
</tr>
<tr>
<td>16</td>
<td>The permissible Occupational Dose</td>
<td>The scale of the problem of excess radiation.</td>
</tr>
<tr>
<td>17</td>
<td>The financial impact of over-utilisation</td>
<td>Gives the audience an understanding of the financial impact of unnecessary examinations.</td>
</tr>
<tr>
<td>18 - 43</td>
<td>Minor changes to previous presentations</td>
<td>The content of the remaining slides is similar as in Table 4.7</td>
</tr>
</tbody>
</table>

NHMRC- National Health and Medical Research Council; ICRP- International Commission of Radiation Protection. Presentations available in Appendix 9.2.

4.4.3 Role Delineation and Setting the Goals and Timelines

Following modification of the presentation, a meeting was organised in order to discuss the changes in the presentation format, assign tasks and responsibilities and devise a schedule for the educational program. These are documented below;

a. Presentation: all changes were approved.

b. It was also proposed to get some comparative data to be used as a control.
c. Role delineation:

d. The Chief MRS to personally deliver all presentation.

e. The Radiologist to work closely with the Chief MRS to provide educational lectures to Junior MOs.

f. The Senior MRS to be in charge of data extraction and formatting.

g. The senior clerical staff to be in charge of managing dates, venues and prepare for the radiation day. Also to work as the public relations officer to communicate with high schools and community representatives.

h. The university representative to coordinate the function of the team and review and analyse data with Chief MRS.

4.4.4 Goals:

Deliver the Radiation Awareness presentation to:

i. All Medical Officers,

ii. Nursing Staff,

iii. Allied Health Staff,

iv. High School students,

v. Community groups,

vi. Target key figures in the hospital to secure a Medical Champion to lead the team,

vii. Radiation Awareness day to be advertised in local papers
inviting the public,

viii. Prepare an interview with local media and news papers.

4.4.5 Timelines:

a. Six Presentations to be delivered within 10 days to staff as well as delivering the RAP to high school students and the public and widely market the project using the media (Appendix 10).

b. Reconvene the team in 2 weeks time

4.4.6 Data Collection

Data were sorted as:

a. January 2002 – May 2003 Pre Stage 3 data, Hospital ‘B’ (data available at Stage 2)


4.4.7 Results

Figure 4.11 Skull Referrals from ED. Pre & Post Stage 3 Hospitals ‘B’ & ‘C’
**Figure 4.12** Ribs Referrals from ED. Pre & Post Stage 3 Hospitals ‘B’ & ‘C’

![Ribs Referrals Graph]

**Figure 4.13** Nasal Bone Referrals from ED. Pre & Post Stage 3 Hospitals ‘B’ & ‘C’

![Nasal Bone Referrals Graph]
4.4.8 Raw Data Analysis

As shown in 4.4.8, data from Appendix 4 were translated to run charts (Figures 4.11 to 4.14) and presented to team members on a monthly basis to show the variation in the outcomes. At the end of Stage 3 the team recommended that further analysis be undertaken to address the variation and consistency in the overall reduction of requested examinations.

Data from Appendix 4 were further analysed by calculating mean referrals per 100 ED presentations, for Hospitals ‘B’ and ‘C’ respectively. For the purpose of statistical comparison pre and post intervention, mean referrals were determined in Tables 4.12 and 4.13. Bar Charts were produced to be presented at the next meeting in Figures 4.15, 4.16 and 4.17.
### Table 4.12 Referrals from ED (Category ‘A’), pre and post Stage 3, Hospital ‘B’.

<table>
<thead>
<tr>
<th>Body region</th>
<th>Pre- any Intervention*</th>
<th>Post- Interventions**</th>
<th>% Difference (95% CI)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. Referrals - Referrals</td>
<td>Mean***</td>
<td>No. Referrals - Referrals</td>
<td>Mean***</td>
</tr>
<tr>
<td>Skull</td>
<td>89 - 0.9720</td>
<td>37 - 0.3899</td>
<td>-59.8 (57.2 – 62.4)</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Ribs</td>
<td>69 - 0.7536</td>
<td>48 - 0.5058</td>
<td>-32.9 (31.6 – 34.2)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Nasal</td>
<td>27 - 0.2948</td>
<td>8 - 0.0843</td>
<td>-71.4 (68.5 – 74.3)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>KUB</td>
<td>67 - 0.7317</td>
<td>44 - 0.4636</td>
<td>-36.6 (34.4 – 38.8)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Total</td>
<td>252 - 2.7522</td>
<td>137 - 1.4437</td>
<td>-47.5 (46.0 – 49.0)</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>

* February 2003 – May 2003, Total number of ED referrals = 3,966; Total number of ED Presentations = 9,156

** June 2003 – September 2003, Total Number of Referrals = 3,904; Total number of ED Presentations = 9,489

*** Mean Referrals per 100 ED Presentations.

### Figure 4.15 Referral from ED (Category ‘A’), pre and post Stage 3, Hospital ‘B’.
<table>
<thead>
<tr>
<th>Body region</th>
<th>Pre- any Intervention* No. Referrals - Referrals</th>
<th>Mean***</th>
<th>Post- Intervention period** No. Referrals - Referrals</th>
<th>Mean ***</th>
<th>% Difference (95% CI )</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skull</td>
<td>56 - 0.8226</td>
<td></td>
<td>57 - 0.8131</td>
<td>-1.15</td>
<td>(0.95 – 1.35)</td>
<td>0.9289</td>
</tr>
<tr>
<td>Ribs</td>
<td>53 - 0.7786</td>
<td></td>
<td>55 - 0.7845</td>
<td>+0.75</td>
<td>(0.71 – 0.79)</td>
<td>0.9163</td>
</tr>
<tr>
<td>Nasal</td>
<td>17 - 0.2497</td>
<td></td>
<td>17 - 0.2425</td>
<td>-2.88</td>
<td>(2.68 – 3.08)</td>
<td>0.9930</td>
</tr>
<tr>
<td>KUB</td>
<td>60 - 0.8814</td>
<td></td>
<td>44 - 0.6276</td>
<td>-28.7</td>
<td>(27.5 – 29.9)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Total</td>
<td>186 - 2.7324</td>
<td></td>
<td>173 - 2.4679</td>
<td>-9.68</td>
<td>(9.28 – 10.08)</td>
<td>0.7110</td>
</tr>
</tbody>
</table>

* February 2003 – May 2003, Total number of ED referrals = 3,457; Total number of ED Presentations = 6,807.

** June 2003 – September 2003, Total Number of Referrals = 2,887; Total number of ED Presentations = 7,010

*** Mean Referrals per 100 ED Presentations.

(x) Negative Result

Figure 4.16 Referrals from ED (Category ‘A’), pre and post Stage 3, Hospital ‘C’.
4.4.9 Discussion

As shown in Table 4.12 and Figure 4.15, there was an overall significant decrease of 47.5% (p<0.0001) in referrals for radiographic examinations requisitioned in the four months following the second intervention period. The greatest reduction was found for Skull examinations, which were reduced by 59.8% (p<0.0001). During this period, the mean number of monthly referrals decreased from 0.97 to 0.38 per month. Similarly, there was a reduction in the requisitions for Rib examinations (32.9%; p<0.001); Nasal bone examinations (71.4%; p<0.0001) and KUB examinations (36.6%; p<0.0001).

On the other hand, as shown in Table 4.13 and Figure 4.16, although there was a slight reduction in referrals from ED at control Hospital ‘C’, the overall reduction was not considered to be statistically significant (P=0.7110).

As shown in Table 4.13, KUB examinations decreased by 28.7% (p< 0.05) at Hospital ‘C’. An investigation was undertaken to identify the potential cause of the
positive outcome. It was discovered that the MRS and clerical staff at Hospital ‘C’ had inadvertently been registering some KUB examinations as Abdomen examinations. This of course affected the data collected. The review showed that if all KUB examinations registered as Abdomen were to have been included with KUB, the results would have shown in fact an increase and not a decrease.

In order to ensure the rigour and integrity of the data collected, abdominal examinations at Hospital ‘B’ were also reviewed. It was determined that staff had been diligent in recording the proper examination.

The results demonstrate that the educational process had an immediate impact on the referral pattern at the intervention Hospital ‘B’. However, the challenge that was ahead for the team was to sustain the achievements, and in particular with every new cohort of MOs. Examining data from the control site, demonstrates that the referral rate for the examinations in question, was reduced only at the site where the intervention took place.

One of the main outcomes of the project was the addition of a ‘champion’ (the Clinical Director of the ED), who embraced the opportunity to take on a major role in the project and fast track its implementation, in order to improve the efficiency and outcomes of the ED.

4.4.10 Conclusion Stage 3

There was a highly significant decrease in the number of unnecessary or selected examinations each time the RAP was delivered. The total number of requested Skull, Ribs, Nasal and KUB Radiography examinations had reduced by 47.5% (p<0.0001). On the other hand, there was no significant change present at the control site (p=0.3344).
The hypothesis outlined in 1.3.1, (that radiation awareness has an immediate and measurable impact) has been proven. Moreover, at this stage the introduction of evidence based reference material has resulted in a further reduction, in line with hypothesis 1.3.2

However, the challenge remained for the team as to how the achievements could be sustained.
Chapter 5

RESULTS AND INTERVENTIONS PHASE 2 (CPI)

5.1 INTRODUCTION

This is the second of two chapters, which provides the results for the investigation (chapters 4 and 5). It presents the findings for the Phase 2 intervention, the Clinical Practice Improvement (CPI) method, which includes intervention based on further radiation awareness (Hypothesis 1.3.1) and evidence based appropriate imaging requisition methods (Hypothesis 1.3.2). The chapter describes and analyses the CPI method in terms of the intervention process undertaken, and the results and discussion of the data obtained. A description of the CPI process and outcomes has been included to allow easier replication of the study by others. Also included are the detailed outcomes of the development of the educational website, where all reference materials displayed are supported by literature, as shown in Appendix 2. Overall, an analysis is undertaken on the impact of CPI on unnecessary imaging examinations tests (Hypothesis 1.3.3i) and on cost efficiencies (Hypothesis 1.3.3ii). The chapter also includes some brief methodological considerations relating to the CPI process. Formal conclusions are reserved for chapter 6.

5.2 CPI PROCESS STAGE 4

5.2.1 Preface

Phase 2 complements the previous stages of the study with the CPI stage, which is the fourth stage. As discussed in 2.7, the CPI process brought together a new Radiation Management Project team that comprised a range of key personnel involved in the process of the requisition of imaging examinations.
The recruitment of a new champion, the Director of the Emergency Department, resulted in the expansion of the selected examinations for review. Examinations were grouped under 2 categories ‘A’ and ‘B’. ‘A’ being the data already used in Stages 2 and 3 (Table 4.3) and ‘B’ being examinations such as Ankle, Knee and Spine (Table 5.5). Such examinations are likely to do more harm than good to patients, due to the unnecessary radiation burden (2.3.1, A7.10.1). They also consume valuable scarce resources.

Although the data from Stage 2 had clearly shown that previous interventions contributed effectively to the reduction in the number of examinations, the team experienced difficulties in sustaining these reductions at the same level. It was the view of the team that with the addition of a clinical leader from the Emergency Department, this would assist in sustaining the reductions in unnecessary examinations. The new member possessed the necessary knowledge and the clinical position of authority to review all imaging procedures and to introduce new guidelines. This increased the likelihood that future requisitions for imaging were appropriate and justified, whilst excluding examinations that added little or no value to the clinical management process. The purpose of the CPI was to establish the viability and benefit of incorporating examination request protocols into clinical practice, requiring all such examinations to be evidence based.

Commencing from a theoretical premise that the reduction in x-ray exposure of patients and the financial savings would individually, or collectively, render the adoption of this practice worthwhile, the questions to be answered included:

- What changes to procedure would bring about the required outcomes with an immediate and measurable significant decrease in unnecessary imaging
examinations requested, and an immediate and measurable significant improvement in efficiencies in cost?

- How can workable protocols be constructed?
- How can ‘buy in’ by appropriate staff to these innovative procedures be obtained?
- Would outcomes of these innovations be beneficial, substantial and sustainable?

The previous interventions (Stages 2 & 3) have shown that radiographic examinations can be reduced in numbers without affecting the quality of patient care.

### 5.2.2 Background

Background factors to the study

- Statistics obtained from the Area Health Service that includes Hospital ‘B’ and Hospital ‘C’, indicates an annual increase over the past five years of four percent in demand for imaging services.

- Annual cost: $546,795 at Hospital ‘B’ Emergency Department as shown in Table 5.1.

- An analysis by the team of the 2002/03 data suggested that x-ray requests did not follow evidence-based protocols. In addition, there were many examinations that did not contribute useful information to the patient’s clinical management. This statement is supported by published randomised controlled trials assessing the benefit of x-rays at various sites as discussed in 2.2, 2.6 and Appendix 2, 2.4 – 2.9.
* Radiation exposure is a cumulative cause of morbidity (Appendix 1.2).

**Table 5.1** Average Annual Imaging Cost to Hospital ‘B’.

<table>
<thead>
<tr>
<th>Hospital ‘B’ 12 months</th>
<th>No of Radiography Exams Referred</th>
<th>Average Radiography Exam Cost as set by HIC</th>
<th>Yearly Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre intervention</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Referrals</td>
<td>22919</td>
<td><strong>$45.00</strong></td>
<td><strong>$1,031,355.00</strong></td>
</tr>
<tr>
<td>ED Referrals</td>
<td>12151</td>
<td><strong>$45.00</strong></td>
<td><strong>$546,795.00</strong></td>
</tr>
</tbody>
</table>

* The average cost of $45.00 was derived from The Health Insurance Commission (HIC) for a general Radiography examination, to cover salary and wages of MRS, Radiologist, capital cost and operating cost. This provides a conservative estimate that incorporates only the Medicare Benefits Schedule. The actual cost to the department could be much higher as other costs for the Imaging Department involved in the examinations have not been included. Calculating the exact cost of imaging examinations is outside the scope of this study.

### 5.2.3 CPI Meetings

The CPI process included a series of meetings discussed in Table 5.2.
### Table 5.2 Summary of the CPI Meetings

<table>
<thead>
<tr>
<th>Meeting No.</th>
<th>Content</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Project Leaders meeting</strong></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Introduction</td>
<td>Set the rules</td>
</tr>
<tr>
<td></td>
<td>RAP</td>
<td>Gain commitment</td>
</tr>
<tr>
<td></td>
<td>Presentation of data</td>
<td>Data from previous stages</td>
</tr>
<tr>
<td></td>
<td>Discussion of the problem</td>
<td>Cause identification</td>
</tr>
<tr>
<td></td>
<td>Tasks for next meeting</td>
<td>Extract more RIS data</td>
</tr>
<tr>
<td>2</td>
<td>Presentation of data</td>
<td>RIS data and number of ED presentations</td>
</tr>
<tr>
<td></td>
<td>Project Target</td>
<td>Setting the goals</td>
</tr>
<tr>
<td></td>
<td>Planning</td>
<td>adoption of CPI tools</td>
</tr>
<tr>
<td>3</td>
<td>Introduction to change process</td>
<td>QC explained the process</td>
</tr>
<tr>
<td></td>
<td>Aim</td>
<td>Rationalise x-ray requisition</td>
</tr>
<tr>
<td></td>
<td>Process Map</td>
<td>workflow defined</td>
</tr>
<tr>
<td></td>
<td>Identify problems</td>
<td>Invite to join the team</td>
</tr>
<tr>
<td></td>
<td>Contributing elements</td>
<td>Invite online requisition manager</td>
</tr>
<tr>
<td>4</td>
<td>Review process map</td>
<td>Process re-mapped approved</td>
</tr>
<tr>
<td></td>
<td>Brainstorming session</td>
<td>Identify the cause to the problem</td>
</tr>
<tr>
<td>5</td>
<td>Process map</td>
<td>Approved</td>
</tr>
<tr>
<td></td>
<td>Issues List</td>
<td>Defined into groups</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Voting</td>
</tr>
<tr>
<td>6</td>
<td>Issues list</td>
<td>Pareto Chart presented</td>
</tr>
<tr>
<td></td>
<td>Finalising issues list</td>
<td>List reduced after discussion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Identify priority issues and set cut-off line</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Discussion</td>
</tr>
<tr>
<td>7</td>
<td>Cause and effect analysis</td>
<td>Minitab Fishbone – presented and approved</td>
</tr>
<tr>
<td></td>
<td>Intervention</td>
<td>Proposed Interventions adopted</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Date set for Intervention</td>
</tr>
<tr>
<td>8</td>
<td>Review</td>
<td>Progress statistical data*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The changes in O-L Requisition</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MRS role</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Material on the website</td>
</tr>
<tr>
<td></td>
<td></td>
<td>How to deal with after hours Locum MOs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Address review outcomes</td>
</tr>
<tr>
<td>9</td>
<td>Inception</td>
<td>Review final intervention</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kick-off implementation</td>
</tr>
<tr>
<td>10</td>
<td>Review</td>
<td>Progress Statistical Data</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Future Scope and sustaining gains</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Monthly meeting for the first 5 months post final intervention</td>
</tr>
<tr>
<td>11</td>
<td>Review</td>
<td>Quarterly meeting</td>
</tr>
<tr>
<td>12</td>
<td>End of Project</td>
<td>Plan future CPI projects of issues arising</td>
</tr>
<tr>
<td></td>
<td></td>
<td>During the project</td>
</tr>
</tbody>
</table>
5.2.3.1 First Meeting - Introduction and Cause Identification

The preparation for the project commenced with a meeting between senior staff specialists from Emergency and Imaging, to discuss the findings. After discussion of the facts and their implications, this group gave their support for a team based CPI project, seeking to identify mechanisms to reduce unnecessary x-ray requisition.

The plan was set by the two key members assisted by the Quality Coordinator (QC) for the health service. An all-volunteer multidisciplinary team was formed, representing senior and junior MO staff, Radiology staff, Nursing staff, the Emergency Data Manager and a QC. The structure of the new team and the role of each member are as described below and as discussed in detail in chapter 3 section 3.3.3;

- Director of Emergency Team leader (TL)
- Quality Coordinator (QC)
- Senior Emergency Registrar
- Two Junior Medical Officers (MO)
- Nursing Officer from Nursing Education unit
- Nursing Officer from Emergency
- MRS
- Assistant Chief MRS
- And Chief MRS assuming the role of Chief Investigator of the CPI project.
Team members remained the same for the duration of the project with the exception of Junior MOs due to their job rotations. New Junior MOs recruited to the team were given an orientation on the project, including the past and current activities and an outline of their role.

As shown in Table 3.2, the first meeting was an introduction to the project. The TL had briefly introduced the project. The QC set some rules and guides on the path and the expected sequence of the project. Furthermore, the QC had explained the importance of keeping all discussions inside the room confidential so staff could have the freedom of expressing their opinions and comments without fear of repercussion. The QC also mentioned the importance of confidentiality to prevent data contamination from unsolicited interventions. It was made clear that no intervention would take place without the endorsement of the team at a meeting.

In addition, the TL stated to members that decisions made by the team would be fully supported and staff empowered if change in roles was one of the outcomes.

The first aim of the leading team was to gain the commitment of the members and to adopt the project and claim ownership. The first step was the delivery of a Radiation Awareness presentation by the Chief MRS. This provided team members with an understanding of the impact of the exposure to radiation.

Results from Stage 3 were presented to team members.

Tasks were set for next meeting,

- The team requested more data to analyse the current percentage of referrals from ED versus number of patients presenting to the ED.
5.2.3.2 Second Meeting - Project Target

The main focus of the meeting was to set and agree on goals. RIS data was provided which demonstrated that the ED is the highest user of imaging services in the hospital. Over 50% of all the x-ray examinations referred to imaging are from ED. It also demonstrated that an average 47% of patients presenting to the ED are referred for imaging examinations (Table 5.7).

In order to reduce the number of unnecessary examinations it was necessary to define the type of examinations in question. Examinations addressed at Stage 3 were labelled as Category ‘A’ examinations, that is Skull, Nasal bones, Ribs examinations and Abdomen (for kidney-ureter-bladder (KUB)) – Category ‘A’ being the examinations that do not assist patient diagnosis and management (RANZCR, 2001; Logon, 1994; Masters 1987; Rohrich 2000).

In addition to Skull, Ribs, Nasal Bones and KUB known as category ‘A’, it was decided to include a new category called Category ‘B’ to include Ankle, Knee and Spine examinations. Similar to Category ‘A’, Category ‘B’ examinations were defined according to published algorithms to provide clinicians’ with choice of investigations (Broomhead and Stuart, 2003; Hoffman, 2000; Stiell, 1996a, 1996b; Waddell, 1996). It was also highlighted that the literature review had reported studies that showed a reduction of about 20% in x-ray examinations when the appropriate algorithm had been followed.

RIS data analysis of examinations requested between January 2002 and May 2003 identified that ED requested an average of 50 Category ‘A’ examinations and an average of 120 Category ‘B’ type Radiographic examinations each month. The team
had determined that the majority of Category ‘A’ and at least 20% of Category ‘B’ examinations could have been eliminated if a decision algorithm was applied (Table 4.3, 4.6, 4.11 & 4.16).

At stages 2 and 3 it had been decided to limit the comparative data analysis to just Category ‘A’ examinations, because the team had not been confident that at this early stage that they could implement the entire strategy. Unlike Category ‘A’ examinations, Category ‘B’ examinations are more difficult to assess and requesting those examinations may be of a clinical value in some cases. Under the direction of the new TL, the Clinical Director, the team had decided that all Category ‘B’ cases should be re-embraced in the re-evaluation, especially now that all educational materials were in place. Although the change was not expected to totally eliminate the numbers of the Category ‘B’ examinations, a considerable decrease would have been anticipated.

Following discussion on the range of examinations that were unnecessary, the team set new guidelines for the categories:

‘A’ never to be requested

‘B’ apply algorithm before requesting

‘C’ assess importance of an examination before requesting

The Team decided on a target to reduce x-rays requested from Hospital ‘B’ ED as follows:

- Category ‘A’ x-rays by 80%

- Category ‘B’ x-rays by 20%
• Overall monthly rate of x-ray requests by over 7%.

Tasks for the next meeting:

• Mapping the process of requesting examinations.

• Issue invitations to all available MOs to attend, and also ensure that a representative for the locum MOs is present.

• Issue an invitation to the Emergency Department Information Systems Manager.

5.2.3.2.1 Guides for X-Ray

The team had determined that examinations under review should be divided into two Categories based on their sensitivity and clinical value in the decision making process.

5.2.3.2.1.1 Category ‘A’

As described in 5.2.4, Category ‘A’ included the following examinations:

• Skull x-ray - for head injury

• Abdomen-KUB (Kidney, Ureter, Bladder) - for Renal Colic

• Chest Ribs views - for rib fracture

• Nasal Bone x-rays - for fracture

It was determined that there should be no x-ray requests for Category ‘A’ since there was no evidence that x-ray examinations of these sites contribute to the diagnosis and management of patients.
Category ‘A’ was supported with a literature review discussing all the relevant examinations in Appendix 2, and it was also supported with educational guidelines on the ED Website in Appendix 11 (Figures 11.1, 11.2, 11.3, 11.4, 11.5, 11.6 and 11.7).

5.2.3.2.1.2 Category ‘B’

As described in 5.2.4 Category ‘B’ included:

- Ankle x-ray - for ankle injury
- Knee x-ray - for Knee injury
- Spine x-ray - for trauma, low back pain & radiculopathy

When considering requesting x-rays of these body regions, clinical assessment and decision algorithms should be applied to determine whether an x-ray would assist diagnosis and management of the condition.

The algorithm was supported with published literature as discussed in Appendix 2 and displayed on the ED website as shown in Appendix 11. Materials in Appendix 11 related to Category ‘B’ were: Figures 11.8, 11.9, 11.10, 11.11, 11.2.2.2, 11.12, 11.2.2.3, 11.13, 11.14, 11.2.2.4, 11.15, 11.16, 11.17. In addition, the team had requested that a table demonstrating the various radiation doses and the yearly occupational dose was displayed on the website in an attempt to attract the attention of the reader and raise their awareness.

5.2.3.3 Third Meeting- Requisition Process Map

After reviewing the new goals, the team discussion focused on the process of requesting radiographic examinations. One of the main tasks in the CPI project was
to construct a flow chart of the existing process (Easy Guide to CPI 2002, p21).

Through a brainstorming session, team members contributed their various issues. A flow chart was constructed. The aim of the process was to (Easy Guide to CPI 2002, p21):

- Understand the current process
- Open criticism of the process
- Identify the complexity of the process and its management
- Identify ‘outcome’ and ‘process’ steps
- Establish process measures
- Simplify the process where required.

A finalised Process Map was drawn and refined at the end of the meeting (Figure 5.1).
Figure 5.1 - Process Map – Process of requesting X-rays at Hospital ‘B’
Following the discussion of the issues, there was an agreement that the goals set in the project target were to be followed even by locums. However, it was suggested that a clear protocol was required.

It was proposed to remove the trauma series and any other grouped requests from the RIS. The Information System Manager agreed to commence preparations for this. However, changes were not to take place until the final decision of an intervention date was set.

Tasks for next meeting:

- Team Leader (TL) to start working on the protocols,
- Chief Investigator to review the reference material. He was to follow some of the recommendations from the Royal Australian and New Zealand College of Radiologists, and the most recent publications (References in Appendix 2),
- Ensure Locum Representative to be present and many MO’s.

5.2.3.4 Fourth Meeting - Brainstorming and Issues list

The objective of the brainstorming session was to generate as many ideas as possible and to list as many issues as possible of issues experienced in the workplace (Easy Guide to CPI 2002, p24). To allow staff to propose objective ideas and to list issues that can be valuable and lead to productive outcomes, it was imperative that all members of the team were well conversant with the background of the project (Easy Guide to CPI 2002, p14). To reinforce the progress of the project, all charts and tables produced in the previous three weeks were presented. These included the outcomes of the preliminary data review from Tables 4.3 and 4.6, where it shows that
over 90% of requested examinations had returned a normal report. A few items from the RAP were revisited especially radiation doses. The QC then proceeded to conduct a ‘Brain storming session’ for the team, with the TL discussing best practices in requesting imaging examinations. The discussion was focused on identifying the problem and the causes of over-utilisation. A democratic approach was used, with every team member provided with six blank “sticky notes” to describe their thoughts on what the causes were.

After the discussion, the “sticky notes” had been collected and grouped under groups based on similarity. After further discussion, six main groups had been identified. It is to be noted that although some members of the team had requested more “sticky notes”, the request was declined. On the other hand, a few members did not fill all their “sticky notes” and were satisfied with listing just three or four issues. The list of issues is found in Appendix 12 and Table 12.2.

The Task set for next meeting was for the QC to present the issues list in a table for further discussion and propose a reduced list.

5.2.3.5 Fifth Meeting - Voting

The meeting had commenced with a review of the set goals (Appendix 12 Table 12.1) and the issues list (Appendix 12 Table 12.2). The QC also presented a reduced and refined list (Appendix 12 Table 12.3) which was approved by the team.

The team undertook a further refining process so that the data could be presented in a Cause-and-Effect Fishbone diagram. After review, duplicates were removed from the list and the list was re-worded (Appendix 12 Table 12.4).

To define the issues, as proposed by the CPI guidelines (Easy Guide to CPI 2002,
p26) formal type of multi-voting was used to narrow or condense the list of issues or options. A process of review took place employing a method of voting taken in order to rank the points according to importance. This ranking allowed focus on the issues determined by consensus to be most important.

Members were given six weighted votes. After the voting process, the discussion proceeded towards proposing interventions.

The meeting was concluded by an open discussion of the received issues. The discussion was conducted to see if there were any surprises, any objections and to seek clarification of those who requested additional votes (Easy Guide to CPI 2002, p26).

Tasks for next meeting:

- QC to present the votes in a table.

5.2.3.6 Sixth meeting – Results (Pareto Chart and Fishbone)

Voting results were presented at the meeting (Appendix 12 Table 12.5) for confirmation by team members as described in 3.8.

After presenting the vote tally the list was revisited, and ranked in order of weighting (Appendix 12 Table 12.6).

Further calculation was required to obtain the results for the Pareto Chart. The calculations are displayed in Appendix 12 Table 12.7.

Results were presented in a Pareto chart and submitted to team members for approval (Figure 5.2).
The next items for discussion were the results within the Pareto Chart. As for all typical CPI processes, there was a need to cull down the number of listed issues that define the causes of the problem (Easy Guide to CPI 2002, p31). The team decided to focus the interventions on issues that attracted at least 8 votes and higher (Table 5.2). All other issues would be reviewed at a later stage when the outcomes of the interventions were under scrutiny.

The main task for the next meeting was for the QC to prepare a cause and effect fishbone diagram. TL and CI to come back with proposed interventions.

5.2.3.7 Seventh Meeting – Finalising Interventions before Implementation

The meeting started with a presentation of the set goals, the adjusted Pareto chart and the Cause and Effect fishbone diagram. The purpose of the diagram was to summarise, organise and categorise the ideas generated in the brainstorming session (Easy Guide to CPI 2002, p28) that would make it easier to follow, thus keeping the team focused on the issues. The Cause an Effect fishbone chart was submitted to the team for confirmation and its content was approved (Figure 5.3).
Figure 5.2 - Pareto Chart of the causes of unnecessary requisition of examinations - CPI

X-Ray Project:
Voting on issues that contribute to unnecessary X-ray Orders

- Poor knowledge of what to request
- Fear of possible medico-legal issues
- Want to get the x-ray done before radiology closes
- To speed up workflow
- Equivocal clinical findings
- Cant be ruled out by clinical assessment
- X-rays are free in public hospitals
- Lack of senior's opinion (more x-rays ordered by junior doctors)
- To show the patient that something has been done
- X-rays are available to see patient
- Wrong protocol for x-ray requirement
- Advised by specialty registrars
- Nurse initiated X-ray, but X-ray not really needed
- You don't get into trouble for ordering a test, only for not ordering one.
- Blanket views ordered, where specifics are required
- Lack of trust in clinical findings
- Inadequate clinical assessment
- To speed up work flow
- Keeps the patient busy until doctor is available to see patient

Voting Tally

Cumulative%
Figure 5.3 - Fishbone diagram for the unnecessary requesting of X-Rays

CAUSES OF UNNECESSARY X-RAY REQUISITIONS

Knowledge
- Poor knowledge of what to request
- Wrong protocol for x-ray requirement
- X-rays are free
- Inadequate instructions
- No sense of cost to patient in terms of rad

Inexperience
- You don't get into trouble for requesting an examination only for not requesting one
- Reassurance for MO
- Fear of trusting clinical findings
- Fear of medico legal issues
- Senior MO not present

Clinical Assessment
- Equivocal clinical finding
- Inadequate clinical assessment
- Blanket views re where specifically
- As advised by specialist
- Requested by 'teams' on in-patients
- GP referral
- Senior MO request
- Nurse initiated x-ray not really
- Rush before radiology close down
- To speed up workflow

Patient
- Keeps the patient busy until doctor is available to see patient
- To show the patient that something has been done
- Reassurance for patient
- Pressure from patient
- Pressure from relatives

External

External
Following the presentation, the meeting focused on the list of required interventions.

The team discussed and approved the proposed interventions with some modifications and an implementation methodology was formulated on the white board. The endorsement of the team was obtained to proceed with the interventions.

Next meeting: kick-off implementation.

5.2.3.8 Eight Meeting- Inception

The meeting focused on reviewing the proposed interventions.

5.2.3.8.1 Implementation Methodology

The range of actions implemented by the team included:

1. Protocols and decision aids were published on the ED website.

2. Hardcopy manuals of protocols and decision aids were made easily accessible in ED.

3. MO meetings were implemented fortnightly to:
   a. Provide and develop staff education;
   b. Review on-going x-ray requisition data and results;

4. Senior MRSs were endorsed to act as ‘gatekeepers’, in order to monitor adherence to the new protocols, and prevent breaches, first by discussing the requisition with the referring MO and 2nd by raising the issues to the team’s attention. This was an area, which required considerable tact and diplomacy, traits that MRS and radiologists are not necessarily trained in. Although few possess these skills naturally, they were important attributes for the non-
physicians empowered with the responsibility to over-rule requested examinations by MOs, and in particular locums.

5. The system for imaging exam requisition in the ED was changed from a paper requisition system to that of a computer based online ‘paperless’ system, equipped with a clinical problem-based system to guide clinicians and direct exam requisition. Menus, dialogue boxes and links within the system software restricted clinicians if attempting to go outside the guidelines. Appendix 12 Figure 12.8 provides a graphic of the electronic requisition main menu and (Appendix 12 Figure 12.9) is a snapshot of the electronic requisition form. The RIS was modified so that all automatic selection of examinations related to body parts or pathology were removed. In addition, Blanket requests were removed; for example, ‘Trauma series’ often used for motor vehicle accident patients. Each individual anatomical area was required to be selected for examination. The team believed that this would ensure that staff consider each request carefully and provide the MRS the opportunity to challenge unjustified cases. Appendix 12 Table 12.10 shows a snapshot of the modified requisition menus as seen by ED staff. Restricted choice is demonstrated.

6. Paper request-forms were removed from ED workstations, enforcing sole access through computer-generated requests.

7. Radiology Department introduced a policy for MRSs to query requests of Category ‘A’ examinations.

8. The project was promoted to medical, nursing and allied health staff. As part of the CPI project, it was highly recommended that team members promote
the project and their achievements to other staff. This would assist in obtaining their support and cooperation, and also help sustain positive outcomes (Easy Guide to CPI 2002, p36).

9. Educational sessions were organised for MO’s where Registrars’ presented evidence for and against inappropriate requisition. Case studies included reviewing patient records to identify whether the x-ray examination assisted the course of patient management. Patients’ identities were always kept anonymous and never included in any of the project records or presentations.

10. RAP was organised similar to previous stages inviting hospital staff, High School students and the public (Appendix 10).

11. Consumer input was sought at all stages and in particular during RAP sessions. The feedback provided valuable insight to medical and nursing staff about consumer expectations.

12. X-Ray requisition guidelines were placed on the ED website for easy reference by referring MOs.

13. A Radiation Dose Guide was placed on the website to inform MOs’ of the levels of Radiation given to patients in comparison with the Occupational yearly permissible dose.

5.2.3.9 Ninth Meeting – Impact and Implementation

The meeting commenced with a presentation summary of the original causes of over-utilisation, and its impact on patients and the system. Target goals were also established. Outcomes were presented for discussion by team members who decided on the way forward. As set in the Easy Guide to CPI (2002, p11) small PDSA cycles
were necessary to assess the outcomes and to propose variation to the implementation if required.

It was also decided that MRSs required more support when dealing with difficult Locum MOs. It was decided that the after hours MRS would have phone access to the Chief MRS at any time and in turn the Chief MRS would have full access to the Team leader if his interference was required.

5.2.3.10 Tenth Meeting – Impact and Implementation (Continue)

As previous, there was an introductory summary to the project and a presentation of run charts.

At the meeting, it was reported that there were two incidents in which the MRS had to call the Chief MRS to report unwarranted requisitioning of examinations. The Chief MRS had in turn requested the Team Leader to interfere. It was reported that the Team Leader had contacted the locum MO and had discussed the clinical requirements. The requisition list was reduced from eight examinations to just two.

At the meeting, it was also decided to fully implement the interventions and publish the outcomes on the website.

It was also decided that in order to sustain the improvements it was essential to spread the culture to the other hospitals within the Area Health Service. The first proposed initiative was for the Chief Investigator to contact other imaging departments to organise RAPs at their sites. The other initiative was for the Team Leader to present the project to the executives and ED Directors in the Area. The third proposed initiative was for the Quality Coordinator to prepare a submission nominating the project for a NSW Health Baxter’s award.
5.2.3.11 Post Implementation Meetings

Monthly meetings were held for five months post last intervention. The purpose was to review the outcomes, enforce compliance and monitor the interventions.

At the final meeting, it was decided that monthly meetings were no longer necessary. The team decided to meet quarterly in future.

February 2005 marked the end of the research. The data from January 2005 were presented to the team. Issues arising, especially from Category ‘B’, were discussed. It was decided to commence new CPI projects to address the issues and to sustain the achievements. The team was congratulated for its successful completion of the project. The research through the CPI projects were: 24 hours Open Access to imaging services (winner of the 2005 NSW Health Baxter’s Award, Appendix 13) Cervical Spine Protocols and Advanced Evidence Based Imaging Requisition.

5.2.4 Pre and Post Intervention Results and Sequence of Events

Sixteen months of data were used as pre-intervention data from January 2001 until April 2002 as a non-contaminated period prior to any interventions. Post intervention data were extracted from the RIS database and imported to a Microsoft Excel Spreadsheet from October 2003 until January 2005. At the CPI stage, it was decided that it would be beneficial to continue with employing the analysis of referral patterns, rather than detailed analysis of reports in order to observe any change occurring as a result of the intervention.

The detailed list comprised Skull, Rib, Nasal Bones and KUB known as Category ‘A’. The additional list included Ankle, Knee and Spine known as Category ‘B’. Monthly totals were classified under ‘examination categories’ and results documented using a chart format.
The post intervention data for Category ‘A’ returned 13 Skull x-rays, 28 Ribs examinations, 12 nasal bone examinations and 26 KUB’s requested. The post intervention data for Category ‘B’ returned 500 Ankles, 372 Knees and 628 Spine examinations. Monthly examination referrals are shown in (Appendix 4) for Hospital ‘B’ and (Appendix 4) for Hospital ‘C’. The results were translated to run charts to present the level of activity to the team (Figures 5.4 to 5.9).

**Figure 5.4** Skull Referrals from ED. Pre & Post CPI Hospitals ‘B’ & ‘C’

![Skull Referrals from ED. Pre & Post CPI Hospitals ‘B’ & ‘C’](image)

**Figure 5.5** Ribs Referrals from ED. Pre & Post CPI Hospitals ‘B’ & ‘C’

![Ribs Referrals from ED. Pre & Post CPI Hospitals ‘B’ & ‘C’](image)
Figure 5.6 Nasal Bone Referrals from ED. Pre & Post CPI Hospitals ‘B’ & ‘C’

Figure 5.7 KUB Referrals from ED. Pre & Post CPI Hospitals ‘B’ & ‘C’
Figure 5.8 Ankle Referrals from ED. Pre & Post CPI Hospitals ‘B’ & ‘C’

Figure 5.9 Spine Referrals from ED. Pre & Post CPI Hospitals ‘B’ & ‘C’
5.2.5 Raw Data Analysis

As shown in 5.2.4, data collected and shown in Appendix 4 were translated into run charts (Figures 5.4, to 5.10) and presented to team members on a monthly basis to show the variation in the outcomes. At the end of Stage 4 the team recommended that further analysis be undertaken to address the variation and consistency in the overall reduction of requested examinations.

Data from Appendix 4 were further analysed by calculating mean referrals per 100 ED presentations, for Hospitals ‘B’ and ‘C’ respectively. For the purpose of statistical comparison pre and post intervention, mean referrals were determined and shown in Tables 5.3, 5.4, 5.5 and 5.6. Bar Charts were produced to be presented to members at the next meeting and as displayed in Figures 5.11 to 5.20.
Table 5.3 Referrals from ED (Category ‘A’), pre and post Stage 4, Hospital ‘B’

<table>
<thead>
<tr>
<th>Body region</th>
<th>Pre- any Intervention*</th>
<th>Post- Interventions**</th>
<th>% Difference (95% CI)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. Referrals - Referrals</td>
<td>Mean***</td>
<td>No. Referrals - Referrals</td>
<td>Mean ***</td>
</tr>
<tr>
<td>Skull</td>
<td>391 - 1.1486</td>
<td>13 - 0.0352</td>
<td>-96.9 (91.6 – 102.2)</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Ribs</td>
<td>260 - 0.7573</td>
<td>28 - 0.0760</td>
<td>-89.9 (85.1 – 94.7)</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Nasal</td>
<td>79 - 0.2301</td>
<td>12 - 0.0325</td>
<td>-85.9 (81.8 – 90.0)</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>KUB</td>
<td>266 - 0.7748</td>
<td>26 - 0.0705</td>
<td>-90.9 (86.3 – 95.5)</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Total</td>
<td>996 - 2.9011</td>
<td>79 - 0.2144</td>
<td>-92.6 (87.7 – 97.5)</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>

* January 2001 – April 2002, Total number of ED referrals = 15,835 – Total number of ED Presentations = 34,331

** October 2003 – January 2005, Total Number of Referrals = 14,336, Total number of ED Presentations = 36,831

Figure 5.11 Referral from ED (Category ‘A’), pre and post Stage 4, Hospital ‘B’. As per Table 5.3
### Table 5.4 Referrals from ED (Category ‘A’), pre and post Stage 4, Hospital ‘C’

<table>
<thead>
<tr>
<th>Body region</th>
<th>Pre- any Intervention*</th>
<th>Post- Interventions**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. Referrals -</td>
<td>No. Referrals -</td>
</tr>
<tr>
<td></td>
<td>Mean***</td>
<td>Mean ***</td>
</tr>
<tr>
<td></td>
<td>% Difference</td>
<td>(95% CI)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skull</td>
<td>291 - 1.1225</td>
<td>223 - 0.8481</td>
</tr>
<tr>
<td>Ribs</td>
<td>238 - 0.9181</td>
<td>214 - 0.8138</td>
</tr>
<tr>
<td>Nasal</td>
<td>102 - 0.3934</td>
<td>66 - 0.2510</td>
</tr>
<tr>
<td>KUB</td>
<td>219 - 0.8448</td>
<td>161 - 0.6123</td>
</tr>
<tr>
<td>Total</td>
<td>850 - 3.2790</td>
<td>1105 - 2.5252</td>
</tr>
</tbody>
</table>

---

* January 2001 – April 2002, Total number of ED referrals = 12,866 – Total number of ED Presentations = 25,922

** October 2003 – January 2005, Total Number of Referrals = 10,654, Total number of ED Presentations = 26,294

---

**Figure 5.12** Referral from ED (Category ‘A’), pre and post Stage 4, Hospital ‘C’. As per Table 5.4
Table 5.5 Referrals from ED (Category ‘B’), pre and post Stage 4, Hospital ‘B’

<table>
<thead>
<tr>
<th>Body region</th>
<th>Pre- any Intervention*</th>
<th>Post- Interventions**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. Referrals - Referrals</td>
<td>Mean***</td>
</tr>
<tr>
<td>Ankle</td>
<td>635 - 1.8496</td>
<td>500 - 1.3575</td>
</tr>
<tr>
<td>Knee</td>
<td>438 - 1.2758</td>
<td>372 - 1.0100</td>
</tr>
<tr>
<td>Spine</td>
<td>737 - 2.146</td>
<td>628 - 1.7050</td>
</tr>
<tr>
<td>Total</td>
<td>1810 - 5.2722</td>
<td>1500 - 4.0726</td>
</tr>
</tbody>
</table>

* January 2001 – April 2002, Total number of ED referrals = 15,835 – Total number of ED Presentations 34,331

** October 2003 – January 2005, Total Number of Referrals 14,336, Total number of ED Presentations 36,831

Figure 5.13 Referral from ED (Category ‘B’), pre and post Stage 4, Hospital ‘B’. As per Table 5.5
Table 5.6 Referrals from ED (Category ‘B’), pre and post Stage 4, Hospital ‘C’

<table>
<thead>
<tr>
<th>Body region</th>
<th>Pre- any Intervention*</th>
<th>Post- Interventions**</th>
<th>% Difference</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. Referrals -</td>
<td>No. Referrals -</td>
<td>(95% CI)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean ***</td>
<td>Mean ***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ankle</td>
<td>481 - 1.8555</td>
<td>396 - 1.5060</td>
<td>-18.8</td>
<td>&lt; 0.0100</td>
</tr>
<tr>
<td></td>
<td>(17.6 – 20.0)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee</td>
<td>446 - 1.7200</td>
<td>300 - 1.1409</td>
<td>-33.6</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td>(31.4 – 35.8)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spine</td>
<td>783 - 3.0206</td>
<td>725 - 2.7572</td>
<td>-8.89</td>
<td>0.24221</td>
</tr>
<tr>
<td></td>
<td>(8.63 – 9.15)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1710 - 6.5967</td>
<td>1421 - 5.4042</td>
<td>-18.0</td>
<td>0.1055</td>
</tr>
<tr>
<td></td>
<td>(17.1 – 18.9)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* January 2001 – April 2002, Total number of ED referrals = 12,866 – Total number of ED Presentations 25,922

** October 2003 – January 2005, Total Number of Referrals 10,654, Total number of ED Presentations 26,294

Figure 5.14 Referral from ED (Category ‘B’), pre and post Stage 4, Hospital ‘C’. As per Table 5.6
Figure 5.15 Referral from ED (Category ‘A’), All Stages for Hospitals ‘B’ & ‘C’

Figure 5.16 Referral from ED (Category ‘A’), All Stages for Hospital ‘B’

Figure 5.17 Referral from ED (Category ‘A’), All Stages for Hospital ‘C’
Figure 5.18 Referral from ED (Category ‘B’), All Stages for Hospitals ‘B’ & ‘C’

Figure 5.19 Referral from ED (Category ‘B’), All Stages for Hospital ‘B’

Figure 5.20 Referral from ED (Category ‘B’), All Stages for Hospital ‘C’
5.2.6 Six Months Pre and Six months Post Study Cost Saving Analysis

As shown in Table 5.7, six-month pre-interventional RIS data were analysed to determine the percentage of ED patients referred to the Imaging Department. Data analysis was formulated in order to calculate the number of patients referred to the Imaging Department for every 100 patient presenting to ED. There were 13,145 presentations to the ED. There were 6,143 patients referred to imaging, which equates to 47% of the total number of patients presented to the ED.

Another six months of data for the post interventional period was analysed. There were 13,306 patients presented to the ED department; where 4,589 patients were referred to imaging which equates to 34% of the total ED presentations. Charts were produced from Table 4.5 in Appendix 4 were presented to the team to monitor the impact of the interventions on reducing over-utilisation (Figure 5.21).

Figure 5.21 Referrals to X-ray per 100 ED presentations pre and post Stage 4, Hospital ‘B’

Table 4.5 in Appendix 4 was further analysed by calculating mean referrals per 100 ED presentations, for Hospital ‘B’. For the purpose of statistical comparison pre and
post intervention, percentages of the total number of referrals per total ED presentations were determined in Table 5.7.

**Table 5.7** Comparison of Referral for medical imaging examinations per 100 ED presentations in Hospital ‘B’

<table>
<thead>
<tr>
<th>No. Referrals</th>
<th>% Referrals /100 ED Presentations</th>
<th>No. Referrals</th>
<th>% Referrals /100 ED Presentations</th>
<th>95% CI of the difference***</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre- Intervention*</td>
<td>6,143</td>
<td>4.669</td>
<td>4,589</td>
<td>34.49</td>
<td>9.42 - 14.99</td>
</tr>
<tr>
<td>Post- last Intervention**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Nov 2001 – April 2002; 13,145 ED presentations.

** Nov 2003 – April 2004; 13,306 ED presentations.

*** 95% Confidence Interval of the difference.

**** % reduction in Referrals/ 100 ED is 26.9%.

**Table 5.8** Cost Saving Analysis for Hospital ‘B’

<table>
<thead>
<tr>
<th>Number of ED Presentations</th>
<th>Number of Referrals to Imaging</th>
<th>Percentage referrals /ED Presentations</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 months Pre-test</td>
<td>14292</td>
<td>6142</td>
</tr>
<tr>
<td>6 months Post-test</td>
<td>13369</td>
<td>4538</td>
</tr>
<tr>
<td>Total % of reduction in Referrals</td>
<td>{(47.00-34) / 47 x %}</td>
<td>= 27%</td>
</tr>
<tr>
<td>Averaged yearly ED Presentations</td>
<td>27661</td>
<td>9404</td>
</tr>
<tr>
<td>Reduced Over-utilisation</td>
<td>Diff</td>
<td>3596</td>
</tr>
<tr>
<td>Estimated Savings, dollars</td>
<td>45 x 3596</td>
<td>= $161,820.00</td>
</tr>
</tbody>
</table>

**Average Medicare Cost per examination = $45.00**
Implementing the model nationwide would have significant economic implications. Table 5.8 demonstrates the savings derived from the project at Hospital ‘B’. This cost analysis is based on Medicare data for 2005/2006 (Medicare Australia 2007). Table 5.9 demonstrates the extrapolation of the estimated benefits in Hospital B as a roll out of protocols of the project nationwide.

**Table 5.9 Potential Annual Savings Nationwide**

<table>
<thead>
<tr>
<th>Total number of Diagnostic Imaging Examinations Nationwide</th>
<th>14,921,662</th>
</tr>
</thead>
<tbody>
<tr>
<td>27% Potential Reduction</td>
<td>4,028,840</td>
</tr>
<tr>
<td>Potential cost saving in Dollars to Medicare:</td>
<td>$1,812,978.00</td>
</tr>
</tbody>
</table>

The data shown in Table 5.9 represents the visible benefits to health costs. In addition, patients could be spared from the radiation exposure resulting from approximately 4,000,000 potentially avoidable x-ray examinations each year. These avoidable examinations not only accentuate the health workforce shortage and the tightened health care budget, but also result in delayed services and reduced efficiencies.

In addition, there would also be other important, though less visible benefits. By extrapolating from the reduction in examination numbers achieved in Hospital 'B', values can be generated for the number of unnecessary examinations and their dollar cost, the unnecessary radiation exposure involved and the potential outcome in terms of increased cancer equivalents due to unnecessary exposure nationwide.

Clearly, an undertaking to conduct this work represents great value, yet it is beyond the scope of this present study. It is suggested that this could form the basis of further study. However, it would prove quite difficult to determine, for example, the cost due
to the increased incidence of cancer as a result of inappropriate usage of x-ray examinations. Several researchers have undertaken some work towards this. Doll and Peto (1981) provided an estimate that 0.5% of cancer deaths in the USA were attributable to diagnostic X-rays. A more recent study, undertaking estimates of the risk of cancer from diagnostic X-rays across the UK and other 14 countries (Berrington de González and Darby, 2004) combined data on the frequency of examination, dose to organs, and risk models appropriate to this area. They demonstrated that 0.9% of cancers could be caused by diagnostic X-rays in the USA (rather than the previous value of 0.5%). Each cancer fatality that is prevented was estimated to save 17.5 years of life, (ICRP 1991). Finally, as previously stated in the literature review, Avritscher et al, determined the cost for a particular cancer (bladder cancer).

At this stage of the project, it was decided the Clinical Practice Improvement (CPI) tool released by the NSW Department of Health in 2002 was to be embraced, in an attempt to create a new system that can be easily maintained and adopted by other organisations.

5.2.7 Rollout of the Intervention at Hospital ‘D’

One month after the implementation of the CPI interventions at Hospital ‘B’, the project was rolled out at Hospital ‘D’. One distinct advantage of Hospital ‘D’ was that of all the hospitals involved in the project, it was the one that had a Computed Tomography (CT) service originally. As previously noted, (Table 4.8) one of the causes identified in the diagnostic phase was the unavailability of CT services. The team’s view was that CT is not a replacement for Skull or Rib examinations. Category ‘A’ examinations as discussed in appendix 2 are regarded as unnecessary
examinations and do not serve any purpose for the patient’s clinical management.

During the implementation meeting, it was also decided to generate data from the RIS so as to measure the impact of the project. Similar data collection and analysis methods were used as for the main intervention study, with a pre- and post-intervention period of 14 months each, presented in Table 5.10 and Figure 5.22.

**Table 5.10** Referrals from ED (Category ‘A’), pre and post (CPI) Rollout Stage 4 for Hospital ‘D’.

<table>
<thead>
<tr>
<th>Body region</th>
<th>Pre- any Intervention* No. Referrals</th>
<th>Mean *** Referrals</th>
<th>Post- Interventions** No. Referrals</th>
<th>Mean *** Referrals</th>
<th>% Difference (95% CI )</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skull</td>
<td>106 - 0.3248</td>
<td></td>
<td>17 - 0.0492</td>
<td></td>
<td>-84.8</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(80.6 – 89.0)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ribs</td>
<td>254 - 0.7785</td>
<td></td>
<td>23 - 0.0666</td>
<td></td>
<td>-91.4</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(87.0 – 95.8)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nasal</td>
<td>76 - 0.2330</td>
<td></td>
<td>17 - 0.0490</td>
<td></td>
<td>-78.8</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(74.9 – 82.7)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KUB</td>
<td>289 - 0.8857</td>
<td></td>
<td>40 - 0.1158</td>
<td></td>
<td>-86.9</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(82.3 – 91.5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>725 - 2.2220</td>
<td></td>
<td>97 - 0.2809</td>
<td></td>
<td>-87.3</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(83.0 – 91.6)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* September 2002 – October 2003, Total number of ED referrals = 15,568; Total number of ED Presentations = 32,627.

** November 2003 – January 2005, Total Number of Referrals = 17,159; Total number of ED Presentations = 34,521.
Figure 5.22 Referral from ED (Category ‘B’), pre and post Stage 4 (CPI) Rollout for Hospital ‘D’

5.2.8 Discussion

As shown in Table 5.3 and Figure 5.11, there was an overall highly significant decrease of 92.6% (p<0.0001) in Category ‘A’ referrals for radiographic examinations requisitioned in the post interventional period of 16 months. The greatest reduction was found for Skull examinations, which were reduced by 96.9% (p<0.0001). During this period, the mean number of monthly referrals decreased from 1.14 to 0.03 per month. Similarly, there were also highly significant reductions in the frequency of requisitions for Rib examinations (89.9%; p<0.0001), nasal bone examinations (85.9%; p<0.0001); and, KUB examinations (90.9%; p<0.0001).

Although relatively not as great a reduction as for Category ‘A’, Category ‘B’ examinations had an overall decrease of 22.7% (p<0.001) in the 16 month post interventional period (Table 5.5 and Figure 5.13). Similarly, there were significant reductions for Ankle examinations (26.6%; p<0.0001); Knee examinations (85.9%;
p<0.001); and Spine examinations (20.5%; p<0.001).

As shown in Table 5.7, the findings of the project went beyond the selected examination in categories ‘A’ and ‘B’ where the overall reduction in referrals per 100 ED presentations was reduced from 46.69% to 34.49% (p<0.001).

As shown in Tables 5.4 and 5.6, although there was a slight reduction in referrals from ED at Hospital ‘C’, the overall reduction of both categories ‘A’ and ‘B’ was considered not to be statistically significant (p=0.0605, and p=0.1055 respectively).

As shown in Table 5.10, the roll out of the project to Hospital ‘D’ had also an immediate impact on the unnecessary requisition of radiology examinations from Category ‘A’. The overall reduction was statistically significant in the average of 87.3% (p<00001).

The combined results at the main Hospital ‘B’ and the rollout Hospital ‘D’ demonstrate that intervention supported by CPI through educational processes using RAP and the introduction to staff of Evidence Based Imaging had an immediate impact on the referral pattern by reducing the over-utilisation of imaging examination significantly.

An analysis of the data from the control site Hospital ‘C’ found that the referral rates in the ‘post- intervention’ period were only slightly reduced and regarded as not being statistically significant in comparison to the pre- intervention phase. On analysis, the CPI team largely attributed the marginal gains from the control group to the flow on success generated within their Area Health Service (AHS) from Hospitals ‘B’ and ‘D’. In particular, Hospital B’s research had gained widespread acclaim throughout the AHS (of which Hospital ‘C’ was a member), having won the
2004 Leading Edge Award of the AHS, and for becoming a finalist in the NSW Health Baxter’s Award as shown in Appendix 14. In addition, the rotation of a few MOs from Hospital ‘B’ to Hospital ‘C’, as well as a few MRS staff from Hospital ‘C’ attending RAPs at Hospital ‘B’, also impacted on the findings at Hospital ‘C’. This no doubt had an impact on the possible reductions in the number of unnecessary examinations from both categories ‘A’ and ‘B’ at Hospital ‘C’, and as shown in Tables 5.4 and 5.6.

The other contributing factor was the installation of the new CT scanner at Hospital ‘C’ during the period when post intervention data were collected. The team determined that having the CT technology available would have created a positive impact through reducing some unnecessary requisitions. However, as shown in Table 5.4, the reduction was minimal and there were still a large number of unnecessary examinations requested. The rollout of the intervention to Hospital ‘D’ clearly validated the findings of the main CPI project. Overall, despite having a CT scanner at Hospital ‘D’ there were still 725 unnecessary examinations requested. That level was reduced to 97 examinations post the CPI intervention.

5.2.9 Conclusion Phase 2 Stage 4

There was a significant decrease in the number of unnecessary or selected examinations each time the RAP was delivered. A further reduction in the requisition of examinations was experienced after the CPI interventions at Stages 4 in Hospitals ‘B’ and ‘D’. At this point of time, the team agreed that the new Evidence Based practice was culturally imbedded throughout the ED. Evidence Based practice became the basis of the clinical management process. The total number of requested Skull, Ribs, Nasal and KUB Radiography examinations had reduced by 92.6%.
(p<0.0001), In addition, there was an overall decrease of 27.6% in referrals from the ED.

As for Stages 2 and 3, the hypothesis outlined in 1.3.1, (that radiation awareness has an immediate and measurable impact) had been proven. In addition, at this stage, the introduction of evidence based reference material and the accompanying website had resulted in a further reduction, in line with hypothesis 1.3.2. Finally, the hypothesis outlined in 1.3.3 that CPI is an efficient tool to deliver RAP and implement Evidence Based Clinical Management Strategies had been proven to deliver an immediate and measurable significant decrease in unnecessary imaging examinations requested on patients presenting to the ED (1.3.3.i). Furthermore, the sub-hypothesis 1.3.3.ii that the hypothesis in 1.3.3 can deliver immediate and measurable significant improvement efficiencies in cost to the imaging department was also proven.

Stage 4 through the rollout on the other hand confirmed that the CPI model methodology was adaptable and could be generalised to different sized hospitals.
Chapter 6

DISCUSSION, CONCLUSION & FUTURE SCOPE

"A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it.”

Max Planck

6.1 INTRODUCTION

This chapter provides a general discussion and conclusion of this study. The chapter outlines the outcomes of the study in the context of the accomplishment of the hypotheses. The various organisational, departmental, economic, patient care and profession-based implications of the findings are discussed. The adaptability and generalisability of the project to other organisations is also explored. The discussion concludes with some recommendations and potential opportunities for local and national application.

6.2 OUTCOMES OF THE STUDY

6.2.1 Over-utilisation

The preliminary study at stages 1 and 2 demonstrated similar results to the reported findings from other authors. Interestingly, this study identified the highest positive findings for ankle examinations. However, that does not indicate that those
examinations were actually necessary, nor contributed to changing the path of clinical management.

6.2.2 Hypothesis 1.3.1

There was an immediate and measurable, significant improvement in the use of appropriate imaging examination request for patients presenting to the ED as a function of the introduction of Radiation Awareness Programs for Medical Officers, Nurses and allied health professionals.

The results confirm our initial hypothesis; that promotion of general awareness of medical radiation would have an important role in reducing the over-utilisation of diagnostic imaging examinations. The study has shown that the number of selected examinations were reduced by 23.1% (p<0.01), while on the equivalent selected examinations at Hospital ‘C’ had in fact increased by 5.2% (p=0.44) for the same period.

To date, there have been few if any prospective controlled trials to assess the effect of RAP on reducing Radiographic over-utilisation. The extensive literature review of Chapter 2 showed that whilst there were a few studies using surveys of knowledge and awareness of medical radiation among health professionals and patients, no published reports were available regarding the topics of general awareness and the knowledge level of patients, radiologists, or requesting physicians. The present study may well be the first investigation to use CPI methodology, to reduce unnecessary x-ray examinations in the early management of patients presenting to the Emergency
Department (ED). This was achieved through raising the awareness of medical and allied health staff to medical radiation by means of clinical education and implementing evidence based diagnostic imaging requisition.

One of the beneficial effects of raising radiation awareness was that clinicians may have increased their concerns regarding associated cancer risks. The assumption was that raised awareness could result in clinicians becoming more committed in the requisition of appropriate examinations employing ionising radiation, and they may even become advocates of this approach.

Post Stage 2 intervention data from hospital ‘B’ shows an immediate reduction in the requisition of Radiographic examinations. However, data has also shown that the result was not sustainable if RAPs were not delivered to all new cohorts of medical officers. The study also showed that the level of knowledge of the presenter in radiobiology and physics plays an important role in maintaining the required level of consistency and quality to have a positive effect on attendees. Presenters were therefore trained and quality control measures applied. The study in fact showed that in the period where RAP was presented by a less experienced presenter to a new cohort of MOs, the reduction in requisition was reversed. In this situation, the mean frequency of referrals went up from 1.8 to 2.2 cases per one hundred ED presentations, and the reduction in number of imaging requisition compared to the pre-intervention period decreased from 36.9% to 23.6%. On the other hand and for
the same period, Hospital ‘C’ had experienced an increase in the total number of referrals.

6.2.3 Hypothesis 1.3.2

There was an immediate and measurable significant improvement in the use of appropriate imaging examination request for patients presenting to the ED. This was achieved as a function of the introduction of evidence-based appropriate imaging requisition method at Stage 3. The study has shown that the combination of RAP with the availability of Evidence Based educational references had reduced the number of imaging requisitions by 53.8% (p<0.01).

One of the main causes of the over-utilisation of imaging services has been attributed to the lack of available specific guidelines in emergency departments. These both govern and provide guidance in the requisition of x-ray examinations. Providing the appropriate tools to the medical team raised awareness of both the consequences of exposure to radiation and the impact of over-utilisation on the health care system. The resulting reduction in the number of requisitions was above expectations. In addition, this outcome promoted a sense of professional pride and value amongst the team members.

Previous efforts to reduce the over-utilisation of imaging examinations focused on implementing imaging guidelines and clinical decision rules based on clinical evidence. Some of these implementations such as the Ottawa Ankle Rules and the National Emergency X-Radiography Utilisation Study did indeed demonstrate
significant reduction in unnecessary or inappropriate uses of diagnostic imaging examinations. However, there remains a dilemma resulting from the substantial gaps between what is known to be achievable and what is achieved in practice; that is the failure to implement evidence-based medicine. This implies that the clinicians may to some extent act passively in failing to follow guidelines and rules. Furthermore, as since clinicians change employment as they progress through their career, they may practice at a new institution that does not utilise imaging guidelines. In this situation, they may simply revert to their previous practices.

6.2.4 Hypothesis 1.3.3

Clinical Practice Improvement “CPI” has been proven to be an efficient tool to deliver Radiation Awareness Programs and implement Evidence-Based Clinical Management strategies. Whilst this certainly proved to be the case in this research since appropriate imaging examinations were adopted as the standard, it was achieved as the result of the introduction of CPI intervention.

6.2.4.1 Sub-Hypothesis 1.3.3- i

i. There was an immediate and measurable significant decrease in unnecessary imaging examinations requested on patients presenting to the ED. This was a result of the introduction of CPI intervention.

The results have validated the hypothesis in that, promotion of pertinent radiological knowledge and awareness of medical radiation by CPI interventions does have an essential role in reducing the over-utilisation of diagnostic imaging examinations.
Data analysis from the CPI Stage indicates that the overall number of imaging examinations requested by hospital ‘B’ ED were reduced by 27%, Category ‘A’ requests were reduced by 92% (p < 0.0001), and Category ‘B’ reduced by 22% (p < 0.0001). Although the monthly data of Category ‘B’ varied far greater than those of Category ‘A’, the reduced number of referrals were consistently maintained.

However, for the control group Hospital ‘C’ during the same period, the number of referrals for Categories A and B were marginally decreased, but were found to be statistically not significant (p=0.0605 and p=0.1055 respectively). The team determined that the reduction at Hospital ‘C’ may be attributed to the introduction of a new Computed Tomography (CT) service in November 2003. However, it is to be noted that the overall reduction was minimal (23%) when compared to the 92% reduction at Hospital ‘B’. The number of requested unnecessary examinations at Hospital ‘C’ remained high and a CPI project was deemed necessary to achieve the desired outcomes.

It is noted that Categories ‘A’ and ‘B’ examinations comprise 17% of the total imaging examinations referred from ED. The great benefit of the investigation is the overall reduction of imaging examinations for all ED patients. As shown in Table 5.7, there was an overall reduction of 27% of all imaging requisitions per each 100 patients presenting to ED. The overall reduction in referrals is of a greater significance than the reduction of the target categories.
In addition, the outcomes from the rollout of the CPI intervention at Hospital ‘D’, supports and validates the data obtained at Hospital ‘B’.

The CPI project has positively contributed to the reduction of the most commonly referred examinations, chest, and abdomen Radiographs.

6.2.4.2 Sub-Hypothesis 1.3.3- ii

ii. There was an immediate and measurable significant improvement in efficiencies in cost to the Imaging Department, through the use of appropriate imaging examination requests for patients presenting to the ED as a function of the introduction of CPI intervention.

The study has shown that the reduction of inappropriate x-ray examination ordering contributed to a significant estimated annual saving in excess of $161,000 per annum to Hospital “B” ED radiology services. Overall, unnecessary examinations were reduced by 3,596 cases a year.

6.3 IMPLICATIONS

The visible and direct outcomes of the study were the immediate reduction in the number of imaging requisitions resulting in economic and efficiency gains for the hospital while sparing patients unnecessary exposure to ionizing radiation. The findings and the related benefits have significant local and national implications.
6.3.1 Organisational Wide and Departmental

This system could potentially be applied nationally to all Emergency departments and other health service organisations involved in requesting imaging examinations. The literature review in Chapter 2 reveals that over-utilisation of diagnostic imaging examinations is widespread across most clinical departments of public hospitals. A comprehensive analysis of Radiology data across regions, in a similar manner to that undertaken in the present study, would identify the frequency and extent of inappropriate requisition of imaging tests. Such an analysis would additionally provide an insight into the potential benefit that might be accrued from a revised system. A revised system would require a supporting education program for those staff requesting imaging examinations. In addition, staff responsible for implementing the CPI project would require appropriate training. The methodology used in the present study was subsequently implemented at a larger hospital within the same AHS and resulted in considerable success. CPI has been proposed at area health ‘ED Services’ meetings for adoption in all Emergency Departments of the AHS. The project attained a prominent position by reaching the finalist Stage in the 2004 NSW Health Baxter’s Award.

Preliminary observations also suggest that the present study has resulted in improved efficiency of both the Imaging and ED services at Hospital ‘B’. Although not measured in this current study, the efficiency of the imaging department has improved significantly, with patient waiting time reduced from an average of 15
hours wait to open access. These findings were acknowledged through the department being awarded the 2005 NSW Health Baxter’s Award in the Access Category.

The Emergency department at Hospital ‘B’ in turn has benefited from the benefits of improved and efficient imaging services. In addition, the success has seen CPI being entrenched within the day to day activities of both departments. This has resulted in the Hospital achieving the best ED access block in the AHS and the state.

6.3.2 Economic

The study has demonstrated significant opportunities for economic savings through the use of CPI and other related strategies within the ED and Imaging Departments. This was combined with staff education and a newly discovered “infectious” zeal for practice improvement which resulted in a significant decrease in the frequency of inappropriate x-ray examinations being ordered. The benefits of this are visible in terms of resource savings and “invisible” but just as real in the form of patients being spared from unnecessary x-ray exposure. It is clear from the findings that achievement of such a reduction in x-ray exposure, and resource wastage, throughout the public hospital system of Australia is desirable, and is achievable in practice.

Implementing the Imaging CPI model nationwide would have significant economic implications. The annual national costs of radiology and pathology testing is second only to the expenditure from pharmaceuticals (Hammett and Harris, 2002). Using Medicare data for 2005/2006 (Medicare Australia, 2007), the estimated potential
annual savings from the implementation nationally would be approximately $141 Million.

This data represents the transparent benefits to the health budget of cost savings. However, there would be other significant, though less visible benefits. Many patients could be spared from the radiation exposure, which resulted from 4,028,840 avoidable x-ray examinations. These avoidable examinations not only impact on the critical health service workforce shortage and on the health care budget, they also result in delayed services and reduced efficiencies.

6.3.3 The changed role of the MRS

One of the major aspects of the intervention that contributed significantly to the success of the CPI project was the new role of the MRS as the gatekeeper or the Arbiter of the requisition process.

This project in particular is centred around the knowledge of the MRS in radiobiology and research. This has allowed the MRS to take a prominent role in setting the path of the patient’s clinical management. The role of the MRS in this project was that of initiating and promoting the CPI program with the purpose of reducing unnecessary x-ray requisitions. This was to be achieved by increasing the awareness of medical radiation. The MRS was the arbiter, playing the ‘gatekeepers’ role in the ‘policing’ and monitoring of protocols. As a radiation licence holder, an MRS has the responsibility to conform with the ALARA (As Low as Reasonably Achievable) principle to protect patients from unnecessary exposure to radiation. It is well
founded in the literature that in addition to producing radiographs, the MRS is capable of assessing the need for an examination and suggesting the examination or modality of choice (Finch, 1997; CBRPA, 2007). Moreover, national and international reports have demonstrated that trained MRSs are capable of accurately reporting on plain radiographic images, mammography images, ultrasound images and even CT (Forrest, 1996) in clinical practice. They also assist referring medical practitioners in identifying abnormalities (Cook et al., 2004; Woodford, 2006; Smith and Baird, 2007). The above practices are particularly widespread in the United Kingdom (Brealey et al., 2003).

This project has emphasised the role of MRSs as health care professionals and redefined their duties and responsibilities. The project team assigned MRSs the ‘gatekeeper’s role’ to monitor adherence to the new protocols to prevent the unnecessary requisition of radiographic examinations. However, they were also the professionals researching and preparing imaging guidelines, supported by educational reference materials for all healthcare workers. During the evolution of the project, it was found that whilst this role required considerable attention to detail, it also required the interpersonal skills that support tactful diplomacy in dealing with the referring medical officers. The study during the CPI Stage dealt with complaints from MRS, as a result of requesting medical officers in many cases having antagonised the MRS. There was a general perception held that since medicals officers viewed MRSs as not as ‘qualified’ as themselves, they were not prepared to accept being over-ruled or contradicted in their decisions by them. This difficult issue was dealt with by the
CPI team leader (Clinical Director of ED) who was prepared to support the MRS in the pursuit of an improved process for x-ray requisitions. The commitment extended to the point of accepting ‘after hours’ calls from the MRS on duty, in order to intervene when the MO refused to yield over requests deemed unreasonable. During the project, the experienced senior MRSs, albeit with the assistance and support of the Clinical Director of ED and other senior medical officers, took on the role as gatekeepers. They played a vital role as the interface with the referring clinician, successfully preventing the requisition of the majority of Category ‘A’ examinations and thus assisted in reducing the number of unnecessary requisitions.

6.3.4 The critical role of Senior Medical Leadership

One of the main achievements of Stage 3 that lead to the success of the CPI stage was the recruitment of two important new members to the team, the clinical leader (the Clinical Director of ED), and a quality coordinator (QC) to assist in coordinating the project and ensure adherence to the CPI guidelines as set by the Easy Guide to CPI (2002).

As a clinical leader, the Clinical Director of ED had the authority to eliminate all Category ‘A’ examinations from all ED protocols. In addition, he was able to publish the new protocols and guidelines on the ED website, recommending the avoidance of certain imaging examinations without justification such as ankle, knee and cervical spine x-rays. This was achieved through implementation of clinical decision rules (decision algorithms) and was met with minimal resistance. Once the team had
decided on restricting available requests in the electronic requisition system, this was easily achieved since none of the requesting doctors was in a position to challenge his authority.

Without doubt, the appointment of the Clinical Director of ED as the CPI Team Leader was an important component in achieving success. As discussed earlier, many medical officers would not have readily accepted the new role established for the MRS. They would have been unlikely to have altered their practice. The appointment was essential in terms of leading and implementing the change management process. The project demonstrated that compliance and sustainment to new evidence-based requisition guidelines, was achievable when championed by a clinical leader with authority. This ensured the longevity and progress of the new approach.

6.4 STRENGTHS AND LIMITATIONS OF THE STUDY

The major strength of the study was the use of the quasi-experimental design. This scientific method included a parallel control group and an additional population group for further validation. The latter was in the form of the intervention being simultaneously rolled out using pre-test and post-test controlled conditions. The research design conformed to fundamental experimental theory by allowing adequate control over major threats to internal and external validity as noted earlier in 3.2.

A clear strength was the use of patient groups that comprised the total populations presenting to the ED of the hospitals. The issues often associated with sample size and random selections were therefore not present. In addition, the use of hospitals
within the same area health service allowed for the inclusion of populations with similar demographic and cultural profile and characteristics. Hospitals were able to be chosen that demonstrated similar levels of activity and service delivery, and under the same central area health administration.

One of the main weaknesses, however, was the potential for contamination of the control site, since the two hospitals operated under the one health service. Although each hospital provided their own local Emergency Department and Imaging services, there were occasions when one or two staff from the control group had attended RAPs presented at the other hospital. In addition, the routine rotation of junior medical staff within the health service resulted in a few medical staff working at the control site after a term at the other hospital. However, an analysis of the data over the full 37 months of the study clearly showed that such factors had little impact overall. With no formal CPI intervention strategies in place at the control group, the data derived over the entire period of the study confirms no significant impact on referral rates.

The use of qualitative research in addition to the quantitative methods employed, and the high response rates for surveys throughout the study were additional strengths. Whilst there is not always a hard and fast line drawn between qualitative and quantitative methods (Hayes 1977), the combined use provides definite strengths. In the current investigation, the surveys allowed the gathering of information from individuals of various professional groups. As some aspects of behaviour are not
simply derived from quantitative measures, the qualitative collection of data proved very important in terms of developing improvement strategies.

The design of the survey questions allowed the researcher to analyse the data with relative ease. However, the use of more open-ended questions may have provided greater insight into individual behaviour and experience. On the other hand, this additional information would have also been relatively difficult to assess and analyse.

An important strength was the formation, functioning and the commitment of the CPI team and its leadership. In particular, the leadership demonstrated by the CPI team leader was a key driving force for the improvement strategies that developed.

Another essential element and strength was the role of the Chief Investigator in coordinating the team. Although having a very limited clinical involvement in the day to day workload due to his managerial duties, the understanding of patient flow and the interdepartmental relationship between ED and Imaging played a major role in the application of the gate keeper’s role and in assessing the training requirements to boost the confidence of MRS staff and enhance their clinical knowledge. The minimum level of clinical involvement (only worked two shifts of the 142 shifts a month) ensured that there was no contamination of the results.

On reflection, one limitation was that the investigation lacked the presence of a Guidance Team. The study would have been enhanced through its inclusion at the intervention site. A guidance team that comprised senior managers not directly working on the project, but who could ensure high-level commitment to the research
implementation, including the provision of additional resources and the minimization of barriers.

6.5 ADAPTABILITY AND FLEXIBILITY OF THE CPI PROGRAM

As part of the CPI process, the implementation of the protocols in this study took considerable effort and diplomacy to achieve adoption at hospital ‘B’ and later at the larger sister Hospital ‘D’ within the AHS. As discussed in chapter 2.5 there are inherent cultural barriers amongst the different disciplines and professions within the health care system to resists any proposed change proposed by members of another profession. It is essential that the CPI team comprise stakeholders from all influencing disciplines involved in the requisition process for imaging examinations. It is also critical that each member is empowered to contribute and to have an equal voice in any relevant decision making.

Although the implementation of the project has proved successful at different size hospitals, the path to its universal roll out across the AHS, states and the nation is likely to be a challenging exercise. As a result of the experienced gained from this study, it is highly recommended that each organisation form its own CPI project team using this project as a guide. It would also be prudent to gain the commitment and involvement to the change process of the chief executive officer of the organisation.

Whilst this study demonstrated significant achievements, it does not necessarily guarantee the same degree of success if applied to settings such as public or private hospitals or community medical centres. Further investigation and work would be
required beyond this study in a variety of different settings in order to specifically test and develop appropriate models of CPI.

A CPI project must be implemented appropriately and each step should be followed to ensure that stakeholders are consulted with, and contribute to the process. As stated, it is also essential to obtain the endorsement and support of the management at each site.

The following factors have been identified in this study as exerting a major influence to the success of the investigation. It is provided to assist in the adoption and implementation of the model across organisations and health services to reduce unnecessary imaging requisitions:

- Within individual hospitals CEO and executive management endorsement and encouragement is essential.

- Area Health Service directives on cost reduction and service improvement should specify the use of such protocol-based programs and ensure the application of RAP throughout.

- The results of the project to be presented regularly at the ED AHS Network Meetings (or other Departments as appropriate) comparing requisition numbers at each site for key performance indicator examinations with alternatives.

- Radiation Awareness to be mandatory during all orientation programs, to
include medical officers, nurses, allied health and administration staff.

- Endorsement of the Radiation Awareness day as part of the Occupational Health and Safety committee’s yearly activities (as part of the numerical profile process at each site).

- An annual Radiation Awareness open-day inviting the community to be held as a mandatory event at each hospital.

- The AHS must assume the responsibility of disseminating RAP to the community in partnership with local government bodies, Schools and social organisations.

- Nurse initiated requisitions to be limited to only a few examinations. However, it should be mandatory for those nurses to pass a written radiation awareness test.

- Incorporation of protocols into the Electronic Requisition system throughout the AHS and the elimination of all batch or Blanket requisitions.

- An educational website and evidence based educational material should be readily available to all staff involved in the clinical management of patients.

### 6.6 CONCLUDING COMMENTS AND RECOMMENDATIONS

In conclusion, the findings of the study have confirmed the hypotheses that there is an immediate and measurable, significant improvement in the use of appropriate
imaging examination request for patients presenting to the ED as a function of the introduction of Radiation Awareness Programs for Medical Officers, Nurses and Allied health professionals; and the introduction of Evidence based appropriate imaging requisition method.

Clinical Practice Improvement (CPI) is the most efficient tool to deliver Radiation Awareness Programs and implement Evidence Based Clinical Management strategies. As a function of the introduction of CPI intervention, there is an immediate and measurable significant decrease in unnecessary imaging examinations requested on patients presenting to the ED; and there is an immediate and measurable significant improvement in efficiencies in cost to the Imaging Department, through the use of appropriate imaging examination requests for patients presenting to the ED.

The following recommendations arise from the study:

- Within individual hospitals CEO and executive management endorsement and encouragement is essential.
- Area Health Service directives on cost reduction and service improvement should specify the use of such protocol-based programs.
- The results of the project to be presented regularly at the ED Area Health Network Meetings (or other departments as appropriate) comparing requisition numbers at each site as a key performance indicator with
alternatives.

- Radiation Awareness to be mandatory during all orientation programs, to include medical officers, nurses, allied health and administration staff.

- Endorsement of the Radiation Awareness day as part of the Occupational Health and Safety committee’s yearly activities (as part of the numerical profile process at each site).

- An annual Radiation Awareness open-day inviting the community to be held as a mandatory event at each hospital.

- Nurse initiated requisitions to be limited to only a few examinations. However, it should be mandatory for those nurses to pass a radiation awareness written test.

- Incorporation of protocols into the Electronic Requisition system throughout the AHS.

- The educational website and evidence based educational material should be readily available to all staff involved in the clinical management of patients.

In addition, the study also makes the following recommendations:

- Medical course curriculum should include Radiation hygiene and the appropriate clinical application of Imaging as formal compulsory teaching.

- Education and certification should be made mandatory for clinicians involved
in requesting imaging examinations.

- Ongoing education for clinicians should be compulsory and include ‘refresher courses’, to assist in maintaining or improving standards.

- In addition, this work should become a component of clinical audit to ensure regular review of standards.

- Radiation dose and possible associated risks should be made available to the public.

  - The State Department of Health should make Radiation Awareness Programs as part of the accreditation process of Imaging Departments, and make them responsible for the education of the public to radiation hygiene by conducting Radiation Awareness days at health organisations and should contribute in delivering the RAP to high schools.

  - The Federal Ministry of Health should conduct Radiation Awareness campaigns using the media and the Internet.

  - The Federal Ministry of Health should promote and facilitate the acquisition and the use of non-ionising imaging modalities.

- Consideration needs to be given to introduce policy to inform patients, of all possible side effects of exposure to ionising radiation similar to the
prescription of medications or performing surgical procedures.

- Furthermore, this should be considered for legislation by Government at a Federal level.

- Establishing a national record of patients’ exposure to radiation should also be considered as a Federal Government requirement. Data should be incorporated in an electronic record such as Medicare. Referring physicians should then be required to formally acknowledge that this has been reviewed prior to any new referral.

- Similar protocols should be developed for the private sector.

- We believe that our system of controlling protocols should be trialled and then adopted throughout all public hospitals, with a parallel system of restraining protocols developed and implemented into the private medical sector, in order to gain the significant benefits that are potentially achievable.

The research has added significant new knowledge to the area of clinical diagnostic practice. The research further confirmed that the CPI methodology that had been used for the main intervention was adaptable to other organisations when it was found to have been successfully rolled out at another hospital. This confirmed that the main outcomes of the investigation could be generalised to other health facilities. There was an immediate reduction in the requisition of unnecessary examination similar to the results at the main intervention hospital.
The implementation and adoption of the CPI intervention across the health care system in general could significantly reduce unnecessary x-ray examinations, saving significant health care resources, and sparing patients from potential cancer risks associated with avoidable exposure to ionising medical radiation.
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Glossary of Terms.

Absorbed dose
The energy absorbed per unit mass by matter from ionizing radiation which impinges upon it. The unit of absorbed dose is joule per kilogram (J kg\(^{-1}\)), with the special name gray (Gy).

Activity
The measure of quantity of radioactive materials.

ALARA
Minimise the use of radiation ‘As Low As Reasonably Achievable’.

Alpha particle
A charged particle, consisting of two protons and two neutrons, emitted by the nucleus of a radionuclide during radioactive decay (\(\alpha\)-decay).

Avertable dose
The dose that may be prevented by the implementation of a protective action.

Beta particle
An electron or positron emitted by the nucleus of a radionuclide during radioactive decay (\(\beta\)-decay).
**Blanket Order**

Some major hospitals have protocols to automatically have a set order of imaging examinations, such as Chest, skull, Cervical Spine Ribs, pelvis and femurs taken.

**Clinical Practice Improvement (CPI)**

Clinical Practice Improvement (CPI) refers to a set of tools designed to improve patient care through process and systems redesign. In the present investigation, the CPI methodology follows the recommendations of the NSW Department of Health (Easy Guide to Clinical Practice Improvement NSW DOH, 2002). It is used as the main tool to implement intervention strategies that aim to introduce evidence based diagnostic imaging requisition.

**Committed effective dose**

The effective dose which a person is committed to receive from an intake of Radioactive material.

**Computed Tomography (CT)**

An imaging modality often referred to as a ‘CAT’, or **CT scanner**. Use powerful computers and a rotating x-ray/measurement system that is mounted within a gantry to acquire images in the form of slices as the patient is moved through on a couch. These cross sectional images provide much more information than conventional x-ray images and can be manipulated to produce 3D information.

**Continuous Quality Improvement (CQI)**

A concept that came out of the business sector. Rather than creating a culture of
blame, the focus is on a team approach to identifying problems. The solutions are found and implementing these results in an improvement. The process then continues by evaluation the improvement and moving onwards in identifying further or other problems.

**Controlled area**

An area to which access is subject to control and in which employees are required to follow specific procedures aimed at controlling exposure to radiation.

**Critical group**

A group of members of the public comprising individuals who are relatively homogeneous with regard to age, diet and those behavioural characteristics that affect the doses received and who receive the highest radiation doses from a particular practice.

**Current (mA)**

The current across an ‘X-ray tube’ during a radiographic exposure. Milliamps (mA): Together with time in seconds (mAs), it expresses the amount of radiation required for a radiographic exposure.

**Deterministic effect**

An effect, such as partial loss of function of an organ or tissue, caused by radiation and manifest only above some threshold of dose, the severity of the effect depending upon the dose received.
**Detriment**

A measure, or measures, of harm caused by exposure to radiation and usually taken to mean health detriment.

**Dose**

A ‘generic term’ which may mean absorbed dose, equivalent dose or effective dose.

**Effective dose**

A measure of dose which takes into account both the type of radiation involved and the radiological sensitivities of the organs and tissues irradiated.

Effective dose, E, is the sum of weighted equivalent doses in all organs and tissues of the body. The unit of effective dose is the same as for equivalent dose, J kg⁻¹; it is known as the sievert (Sv).

**Equivalent dose**

A measure of dose in organs and tissues which takes into account the type of radiation involved. Equivalent dose, H, is a weighted dose in an organ or tissue, with the radiation weighting factor(s) determined by the type and energy of the radiation to which the organ or tissue is exposed. The unit of equivalent dose is the same as for absorbed dose, is known as the sievert (Sv).

**Evidence Based Medicine (EBM)**

The evidence based notion started in the mid 19th century in Paris. Evidence based medicine is the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients. The practice of evidence based
medicine means integrating individual clinical expertise with the best available external clinical evidence from systematic research.

Exposure
The circumstance of being exposed to radiation, or a defined dosimetric quantity.

Fluoroscopy
An imaging modality often referred to as FLUORO. Fluoroscopy is an imaging technique commonly used by physicians to obtain real-time images of the internal structures of a patient through the use of a fluoroscope. In its simplest form, a fluoroscope consists of an x-ray source and fluorescent screen between which a patient is placed. However, modern fluoroscopes couple the screen to an x-ray image intensifier and CCD video camera allowing the images to be played and recorded on a monitor.

Gamma ray
Ionising electromagnetic radiation emitted by a radionuclide during radioactive decay or during a nuclear transition.

ICRP
The International Commission on Radiological Protection is an independent organisation that provides general guidance on radiation protection. The recommendations of the ICRP are not legally binding, but are generally followed by countries such as Australia in framing national regulatory requirements.
**Image intensifier**

Incorporates a device to intensify the x-ray image, to give high quality images at a lower patient dose. May be superseded, where appropriate, by a Caesium iodide or similar’ flat plate’ for direct image capture.

**Incident**

An event which causes, or has the potential to cause, abnormal exposure of employees or of members of the public and which requires investigation of its causes and consequences and may require corrective action.

**Intervention**

An action intended to reduce or avert exposure or the likelihood of exposure to radiation sources, which are not part of a controlled practice or which are out of control as a consequence of an accident or other event.

**Intervention level**

A reference level of an environmental or dosimetric quantity, such as absorbed dose rate; if measured values of that quantity are found to consistently exceed the intervention level, remedial action should be considered.

**Ionising radiation**

Electromagnetic or particulate radiation capable of producing ions directly or indirectly, but does not include electromagnetic radiation of a wavelength greater than 100 nanometres.
Junior Medical officer (JMO)
Junior qualified doctor in training, for example as a physician or surgeon.

Justification
The notion that human activities which lead to exposure to radiation should be justified, before they are permitted to take place, by showing that they are likely to do more good than harm.

Kilovoltage (kV)
Potential applied to an X-ray tube. For a given exposure, expressed as kilovoltage peak. The kV peak is primarily the factor affecting the contrast in the image. Generally, the higher the kV peak, the lower will be the contrast, but also the lower will be the patient dose.

Limitation
The requirement that radiation doses and risks should not exceed a certain value.

LOCUM Medical Officer
A casual Medical officer, who is not a permanent employee of an organisation. Will be called in to work on demand, and usually follow the protocols and guidelines of their permanent employment.

Magnetic Resonance Imaging (MRI)
An Imaging technique that provides similar cross sectional and 3D data sets to CT, but with far more contrast than any X-ray technique can provide, to allow
visualisation of the tissues and any pathology that may be present. Unlike CT, MR does not expose the patient to ionising radiation and is thus safe as ‘far as we know’. The strong magnetic field and RF employed do require special conditions to ensure safety, such as restricting patients with pacemakers or implanted devices that might be affected.

**Medical Radiation Scientist (MRS)**

Health professional qualified in the practice of imaging techniques such as Radiography or Computed tomography. Known also as Radiographer or X-ray / Radiologic Technologist. The Role of MRS has been discussed in chapter 2.

**Neutron**

An elementary particle of mass having some properties similar to the proton but carrying no charge; neutrons are constituents of all nuclei except for the stable isotope of hydrogen.

**Optimisation**

Process of maximising the net benefit arising from human activities which lead to exposure to radiation.

**Orthopantomography (OPG):**

The production of a radiograph of the entire upper and lower dental arches on one image. This tomographic procedure results in a film on which a layer of limited thickness is visible and all other tissues are rendered unsharp. This is achieved by controlled rotation of both the X-ray tube and the film around one or more axes within
the patient's head.

**PA: Postero-Anterior,**

Indicator of the anatomical relationship of the patient to the primary X-ray beam, i.e. the primary beam passes first through the rear aspect of the patient and emerges through the front aspect.

**Practice**

Human activity that introduces additional sources or exposure pathways or extends exposure to additional people or modifies the network of exposure pathways from existing sources, so as to increase the exposure or the likelihood of exposure of people or the number of people exposed to radiation.

**Public exposure**

Exposure of a person, or persons, to radiation which is neither occupational nor medical exposure.

**Pulsed tube output**

X-ray emission from the X-ray tube is controlled so that pulses of radiation are emitted at certain intervals to reduce dose, yet maintain clarity. Other techniques may use half the dose and integrate the data frame by frame, but suffer from blurring.

**Quality assurance**

The planned and systematic actions, necessary to provide adequate confidence that, system or component will perform to a required standard in service.
Radiography

Technique of producing, recording and optionally processing directly or after transfer, information contained in an X-ray image, may use film with intensifying screens, CR (Computed Radiography) or DR plates for direct image capture.

Radiology

The study and application of imaging modalities such as; X-ray and other ionising radiations, together with MRI, and US, in the diagnosis and treatment of disease. May also include Interventional, or minimal interventional techniques.

Radiologist

Medical Specialist qualified in the use and interpretation of imaging modalities. May also perform Interventional, or Minimal Interventional techniques.

Radiation

Electromagnetic waves or quanta, and atomic or sub-atomic particles, propagated through space or through a material medium.

Radiation weighting factor

Modifies absorbed dose in an organ or tissue to yield equivalent dose that is determined by the type and energy of the radiation to which the organ or tissue is exposed.

Radioactive decay

The spontaneous transformation of the nucleus of an atom into another state,
A CPI approach using Radiation Awareness and Evidence Based Medicine to Achieve Appropriate Use of Medical Imaging Examinations

Volume 2
Appendices

James E. Nol

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School of Biomedical and Health Sciences
University of Western Sydney
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Appendix 1

Radiation: From Atoms to Effects

“… then I laid the book and paper down, and put my eyes against the rays. All was blackness, and I neither saw nor felt anything. The discharge was in full force, and the rays were flying through my head, and, for all I knew, through the side of the box behind me. But they were invisible and impalpable. They gave no sensation whatever. Whatever the mysterious rays may be, they are not to be seen and are to be judged only by their works.”

An interview with Roentgen, discoverer of x-rays, reported in McClure’s Magazine, April 1896.
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1.1 BACKGROUND

The biological effects of low levels of radiation have been investigated and debated for more than a century. Ionisation caused by radiation can cause many changes in living cells through the dislocation of electrons at the molecular level. This can result in a change in the biological structure of organs, which can in turn affect function and thus the course of a variety of conditions. However, the risk of cancers induced by radiation is the primary consideration of the biological effects associated with diagnostic x-ray procedures. This is supported by the statistical data and epidemiological studies that are readily available.

It is universally accepted that there is no safe level of radiation. Even a single low dose exposure carries an associated risk and this risk increases with the dose received. It is also accepted that effects of radiation vary from one living structure to another, as is found with smoking, some individuals can be exposed to many episodes of exposure to radiation without noticeable effect, (That is not to say that damage has not occurred), whilst a very small dose may result in severe disease in others.

When a specific organ is exposed to radiation the manifestation of the effects begins at the cellular level. Different types of cells experience a variety of malfunctions leading to an affect on the function of other cells and thus leading to disruption of the whole organ.

For example, Carcinogenesis is a multi-stage process and for a cell to be affected a
series of events must occur in its lineage; it is the last event that renders it malignant, causing it to become the progenitor of the tumour and its metastases (Tubiana, 1990).

Due to the seriousness of the effects to exposure to radiation the International Commission of Radiological Protection recommends the occupational permissible dose should not exceed 20 mSv a year, and 50 mSv in 3 years (ICRP, 1991).

This chapter defines radiobiological theory. It is divided into three sections discussing the evidence for the dangers of radiation exposure provided by epidemiological studies, the Biological effects of Radiation from a Radiobiology perspective and basic radiation physics.
1.2 EPIDEMIOLOGICAL STUDIES

1.2.1 Introduction

Many somatic dangers of radiation became evident a few months following the discovery of x-rays. Pioneer workers in this field soon recognized the injurious potentiality of such radiation. Radiation is above the visible spectrum of the human eye, consequently many of the early radiologists and technologists carelessly exposed themselves to x-rays and radium, incurring serious local and general radiation injuries, often resulting in death.

The German physicist Wilhelm Konrad Roentgen announced his discovery in December of 1895. Within a few weeks after the discovery the first published reports of the health hazards of x-ray exposure began to appear (Roentgen, 1895). Not long after in 1896, 23 cases of radio-dermatitis were reported in the world literature.

The American physicist E. Thomson (1898) was the first to prove a direct relationship between x-ray exposure and some of the reported harmful effects. His left index finger was deliberately exposed to an x-ray beam for half an hour a day for several days. The resulting erythema, swelling and pain confirmed the relationship. Unequivocal proof of the hazards of x-ray exposure came with the report of W. Rollins (1901), who described the fatal results of prolonged x-ray exposure on guinea pigs.

Between 1911 and 1914, three review articles identified 54 cancer deaths and 198 cases of radiation induced malignancies.

The first American radiation fatality occurred in 1904 when Thomas Edison’s
assistant, Clarence M. Daily, died of cancer.

The death of several x-ray operators revealed the serious risk associated with x-ray exposure (Leonard, 1907). In the 1920s, Radiologist B. Ironside was the first death of a radiologist to be attributed to x-ray exposure (Thomas, 1995).

Marie Curie died of leukaemia as did her daughter. It was previously assumed that the extensive and prolonged exposure to radium caused the final illness of Marie Curie in 1934 (Eisenberg, 1992). However, in 1995, Marie Curie’s body was exhumed for reburial. It was found that the level of radium within the coffin was significantly lower than the maximum accepted safe level of public exposure (Butler, 1995). Given these low levels and the very long half-life of radium (1620 years), it was concluded that Marie Curie’s final illness and death were probably not caused by extended exposure to radium. More likely, it was the direct result of her exposure to x-rays during World War I, when she established mobile radiographic units (Coppes-Zantinga & Coppes, 1998).

A few farsighted individuals made strenuous demands for radiation controls; however their pleas were largely ignored. Finally, in 1921, the first official action was taken when the British X-Ray and Radium Protection Committee was founded to investigate methods for reducing exposure. The committee, however, did not complete this assignment until 1937.

The first dose-limiting recommendation was made by a group of American scientists; the Advisory Committee on X-ray and Radium Protection in 1931 (Curry et al., 1990).

In the intervening years, Radiation scientists have learned a great deal about radiation
hazards and their prevention. As a result, protective measures have become ever more stringent. This is not only due to the growing use of radionuclides in medicine and industry, but also with the high profile applications of atomic energy in civilian programs and the military. Due to the need to understand changes caused by radiation in biological materials, a new science emerged; Radiobiology.

1.2.2 Radiation Risks in Perspective

There are many circumstances that increase the risk of death, such as natural ‘unexplained’ causes, smoking, road traffic accidents, accidents at home and work, and exposure to radiation. Table 1.1 provides percentage risk of death from a variety of causes.

Table 1.2.1 The average annual risk of death from some common causes.

<table>
<thead>
<tr>
<th>Cause</th>
<th>Risk of death / year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smoking 10 cigarettes a day</td>
<td>1 in 200</td>
</tr>
<tr>
<td>Natural causes, 40 years old</td>
<td>1 in 700</td>
</tr>
<tr>
<td>Accidents on the road</td>
<td>1 in 10,000</td>
</tr>
<tr>
<td>Accidents in the home</td>
<td>1 in 10,000</td>
</tr>
<tr>
<td>Accident at work</td>
<td>1 in 50,000</td>
</tr>
<tr>
<td>Radiation exposure at rate of</td>
<td></td>
</tr>
<tr>
<td>1 mSv per year</td>
<td>1 in 20,000</td>
</tr>
<tr>
<td>20 mSv per year</td>
<td>1 in 1,000</td>
</tr>
</tbody>
</table>

Source: NRPB, 1990

The most information regarding the risk of cancer induced by radiation is based on the studies from atomic bomb survivors, patients irradiated for diagnostic and therapeutic purposes, and people working in radiation related professions and industries.
1.2.3 Atomic bomb survivors

The latest of the series of general reports on mortality in the cohort of atomic bomb survivors in Japan reported a 47-year follow-up (1950-1997) (Preston et al., 2003). This analysis includes a cohort of 86,572 people with individual dose estimates, 60% of whom have doses of at least 5 mSv. There have been 9,335 solid cancer deaths. It is estimated that there were 440 excess solid cancer deaths associated with the radiation exposure. The excess solid cancer risks appear to be linear in dose even for doses in the 0 to 150-mSv range. Although the atomic bomb survivor analyses have often been considered as high-dose studies, in fact, the mean dose in the cohort is only 200 mSv, with >50% of individuals in the cohort at doses <50 mSv. While excess rates for radiation-related cancers increase throughout the study period, a new finding is that relative risks decline with increasing age, as well as being highest for those exposed as children as noted previously. A useful representative value is that for those exposed at age 30 the solid cancer risk is elevated by 47% per Sievert at age 70.

Among these atomic bomb survivors, those exposed at age 50 had one-third of the lifetime risk per Sv for solid cancers as those exposed at age 30 (Pierce et al., 1996). Those exposed in childhood had 1-1.8 times the estimates for those aged 30. The excess lifetime risk of leukaemia for those exposed at age 50 was about two-thirds of the risk if exposed at an earlier age.

Both studies of children exposed to fallout from nuclear weapons testing with relatively lower radiation dose suggested increased incidence of leukaemia (Stevens et al., 1991, Darby et al., 1992). For children under age 5 years exposed to fallout in Nordic countries, the estimated fallout bone marrow dose was 1.5 mSv.
The incidence of leukaemia increased with RR = 1.11 with 95% CI = 1.00-1.24. In the study with case-control from fallout in south western Utah as a result of nuclear tests, a significant excess risk of acute leukaemia was seen in individuals who died at younger than 20 years of age (odds ratio = 5.8, 95% CI = 1.6-22). The received bone marrow doses ranged from 6 to 30 mGy.

1.2.4 Nuclear industry workers

Several researches have been conducted of nuclear industry workers. A study of over 95,000 people on the UK’s National Registry for Radiation Workers (NRRW) examined cancer mortality in relation to radiation dose (Kendall, 1992). The evidence revealed an association between radiation exposure and mortality from cancer, in particular leukaemia and multiple myeloma.


Trends of increasing mortality with cumulative exposure to whole body radiation were noted for all causes of death in both males and females. Statistically significant excess cancer incidence and mortality risks for solid cancers were found with a mean dose 6.5 mSv.

In contrast, in the USA, Gilbert et al. (1989) performed a joint analysis of data for about 36,000 workers at the Hanford site, Oak Ridge National Laboratory and Rocky Flats Nuclear Weapons Plant. These combined analyses provide no evidence of a correlation between radiation exposure and mortality from solid cancer or leukaemia. Of 11 other specific types of cancer analysed, multiple myeloma was the only cancer found to exhibit a statistically significant correlation with radiation exposure.
However, a combined study of the mortality 95,673 nuclear industry workers in the USA, the UK and Canada (Cardis et al., 1995) presented different results. These workers (85.4% men) were monitored for external exposure to ionizing radiation and employed for 6 months or longer in the nuclear industry of one of the three countries. These analyses were undertaken to obtain a more precise direct assessment of the carcinogenic effects of protracted low-level exposure to external radiation. The combined analyses covered a total of 2,124,526 person-years (PY) at risk and 15,825 deaths, 3,976 of which were due to cancer. As with NRRW, mortality from leukaemia, excluding CLL, was significantly associated with external radiation exposure. A significant association was also observed for multiple myeloma. There was no evidence of an association between radiation dose and mortality for other cancers.

In 1999 (Muirhead), NRRW published the largest epidemiological study of UK radiation workers with more precise information. This analysis was conducted using an enlarged cohort of 124,743 workers, updated dosimetry and personal data for some workers. In addition, the follow up period was longer. This report shows borderline evidence for an increased trend with dose in the risk of leukaemia. The central estimate of risk is similar to that estimated for the Japanese atomic bomb survivors at low doses. For all cancer other than leukaemia, the central estimate of the trend in risk with dose is closer to zero than in the first analysis, yet it is consistent with the findings for atomic bomb survivors.

1.2.5 Radiologists and Medical Radiation Scientists

Investigations of cancer risks among radiologists and radiation technologists have been carried out in several countries. Smith and Doll (1981) compared the mortality from cancer for radiologists who joined the British radiological society between 1897
and 1954 with that of male general medical practitioners. The mortality from cancer for radiologists who entered the profession before 1921 is 75% higher than that of other medical practitioners. There were 72 deaths from cancer among men who entered the study after 1920 whereas 68.6 deaths were expected, based upon rates among the other medical practitioners. There was some evidence showing that the ratio of observed to expected cancer increased with the duration of time that men were included in the study. Among those followed for more than 30 years there were 30 deaths against 22.1 expected. It is difficult to make a close estimate of the dose of radiation received prior to 1920. However, those who entered between 1920 and 1945 could have received an accumulated whole-body dose of the order of 1-5 Gy.

The possible mortality risk for all causes and cancers from diagnostic professional radiation exposure was evaluated among 143,517 American radiological technologists between 1926–1980 (Smith & Doll, 1981; Doody et al., 1998). In the cohort, 73% were female. Approximately 9% of the cohort had estimated cumulative exposure greater than 5 cGy. Significant risks for female breast cancer were correlated with employment before 1940 (standardised mortality ratios [SMRs] = 1.5, 95 percent confidence interval [CI] = 1.2-1.9), and among women certified for more than 30 years (SMR = 1.4, CI = 1.2-1.7) for whom the cumulative exposure was likely to be higher.

Yoshinaga et al. (1999) investigated excess cancer risks among 12,195 male radiological technologists in Japan from 1969 to 1993. Apparent high risks of lymphatic and haematopoietic cancers were observed. The SMR for leukaemia reached statistically significant level of 1.75 (95% CI: 1.07-2.71) when using whole professional and technical workers as a standard population. The results suggest that
chronic exposure to low-dose radiation might enhance the risk of lymphatic and haematopoietic cancers.

Relative risks (RR) of cancer incidence (1950-1995) among 27,011 Chinese medical diagnostic x-ray workers were studied by Wang et al. (2002). The standard comparison population is health workers working in the same hospitals. The average cumulative dose was 551 mGy for sub-cohort 1 (initially employed before 1970), and 82 mGy for sub-cohort 2 (initially employed between 1970 to 1980). The RRs of leukaemia and solid cancers were significantly higher for the sub-cohort 1, and were 2.4 and 1.2. For sub-cohort 2, the RRs were 1.7 for leukaemia and 1.1 for solid cancers, but not significant.

1.2.6 Patients irradiated for diagnostic and therapeutic purposes

Studies of irradiated patients for diagnosis and therapy produced informative results. These findings indicate the breast, thyroid gland, and bone marrow are among the most sensitive tissues to the carcinogenic force of medical radiation.

There was 14,106 patients with ankylosing spondylitis treated with a single course of x-rays from 1935 to 1954 in Britain were investigated (Darby et al., 1987). Up to 1 January 1983, the mortality from neoplastic disease other than leukaemia or colon was 28% greater than that of the general population. The proportional increase reached a maximum of 71% between 10.0 and 12.4 years after the treatment, and was only 7% at 25 years after the treatment. With respect to the mortality from leukaemia, there was a 300% increase. The relative risk was at its highest between 2.5 and 4.9 years after the treatment, and still nearly twice that of the control population even 25 years after the treatment.

Children are expected to have a higher risk to radiation. A scoliosis cohort of females
who had multiple diagnostic x-rays under age 20 years with a mean breast dose 108 mSv in 25 exposures in US was studied (Doody et al., 1998). The incidence of breast cancer significantly increased with RR = 1.6 with 95% CI = 1.1-1.6. Even the analysis was limited to the sub-cohort with breast doses between 10 and 90 mSv, the excess risk of breast cancer remained significant.

Land et al. (1980) analysed breast cancer incidence data of three cohorts exposed to ionising radiation, survivors of Japan atomic bomb, tuberculosis patients in Massachusetts having multiple chest fluoroscopy and patients treated with x-rays for acute postpartum mastitis in New York. Parallel analyses by radiation dose, age at exposure, and time after exposure demonstrated that risk of radiation-induced breast cancer increased approximately linearly with increasing dose and was heavily dependent on age at exposure. The risk was remarkably similar among the three cohorts. A longer follow-up study of the Massachusetts tuberculosis cohort was released by Boice (1991). This cohort consisted of 4,940 women suffering tuberculosis between 1925 and 1954. 2,573 women were followed for 30 years, having been examined by x-ray fluoroscopy an average of 88 times with a mean estimated radiation dose 79 cGy to the breast during lung collapse therapy. The observed/expected (O/E) incidence of breast cancer was 1.29 with 95% confidence interval CI = 1.1-1.5. No excess of breast cancer was seen among 2,367 women treated by other means. Increased rates for breast cancer were not apparent until about 10 to 15 years after the initial fluoroscopy examination. Young women were at highest risk, and those over age 40 were at lowest risk (RR = 1.06). There was strong evidence for a linear relationship between dose and breast cancer risk. Allowing for a 10-year minimum latent period, the RR at 1 Gy was estimated as 1.61.
Howe & McLaughlin’s study (1996) gave similar findings. 31,917 Canadian women with tuberculosis received multiple chest fluoroscopy from 1930 to 1952, and were followed up between 1950 and 1987. There was a strong linear trend of increasing risk with increasing dose (P < 0.0001). The excess relative risk per Sievert decreased with age at exposure (P = 0.0003). The excess relative risk was approximately constant between 5 and 39 years after exposure, with a suggestion of a decrease between 40 and 57 years after exposure, though this could be a chance effect (P = 0.22).

Ron et al. (1989) studied children who received irradiation of the scalp (five fractions, mean total thyroid dose 62 mSv with range 40-70 mSv). The RR of thyroid cancer increased significantly (RR = 3.3, 95% CI =1.6-1.7). If the age at exposure was limited to under 5 years, the RR reached to 5.0 with 95% CI = 2.7-10.3. Five cohort (approximately 58 000 exposed and 61 000 non-exposed subjects) studies of thyroid cancer after childhood exposure to external radiation were evaluated (Ron et al., 1995). The results showed clear evidence of an increased risk of thyroid cancer (RR = 2.5, 95% CI = 2-4) at a mean dose to thyroid of 50 mSv with range 10-90 mSv.

1.2.7 Irradiation in utero

It is generally accepted that radiation risks are higher for foetus because of the higher proportion of dividing cells and longer lifespan available for potential genetic effects to be expressed. Radiation risks for irradiation in utero have been extensively studied.

The relationship of radiation and severe mental retardation was well described in a study of about 1,600 Japanese children who survived into adolescence after being
exposed to radiation from the atomic bomb in utero. (UNSCER, 1993). About 25 of these children exposed between 8 and 15 weeks after conception developed severe mental retardation. The dose-response relationship is consistent with a frequency of 40% at 1 Gy, and about 5% at 0.05 Gy. The background frequency for comparison is 0.8%. A period of less vulnerability is observed between 16 and 25 weeks after conception.

The association between the low dose of ionizing radiation received by the foetus in utero from diagnostic radiography, and the subsequent risk of cancer in childhood provides direct evidence against the existence of a threshold dose below which no excess risk arises, and has led to changes in medical practice.

The Oxford Survey of Childhood Cancer (OSCC) provides detailed data of estimates of risk of cancer to age 15 years with estimates of dose to the foetus from obstetric x-rays (Mole, 1990; Muirhead et al., 1993). During 1958-1961 in Britain, the estimated mean foetal dose is 6 mSv from prenatal x-ray examination. This yields an estimated risk of leukaemia $2.5 \times 10^{-2}\text{Gy}^{-1}$ and of other cancers of $3.5 \times 10^{-2}\text{Gy}^{-1}$. There is no dependable evidence that radiosensitivity is greater in early pregnancy. A significantly raised cancer rate after diagnostic X-raying supports the hypothesis that carcinogenesis by ionising radiation has no threshold.

Doll & Wakeford (1997) analysed many studies of childhood cancer risks from diagnostic in utero exposures. It is concluded that a 10-mSv dose to the embryo and foetus does cause a significant and quantifiable increase in the risk of childhood cancer. The excess absolute risk coefficient at this level of exposure is approximately 6% per Gray, although the exact value of this risk coefficient remains uncertain.
1.2.8 Typical radiation doses from diagnostic x-ray examinations

Many medical diagnostic x-ray studies result in effective doses in the range 1-30 mSv, although chest x-rays are in the range of only 0.06 mSv.

Table 1.2 gives typical effective doses for some common medical x-ray procedures together with an indication of the range in values observed between hospitals in the UK in 1990s (Wall & Hart, 1997).
Table 1.2.2 Typical effective doses to standard adult patients in the UK in the 1990s

<table>
<thead>
<tr>
<th>Examination</th>
<th>Typical effective Dose (mSv)</th>
<th>Range 5th-95th percentile (mSv)</th>
<th>Ratio 95th/5th percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Single Radiographs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skull AP or PA</td>
<td>0.03</td>
<td>0.012-0.06</td>
<td>5.0</td>
</tr>
<tr>
<td>Skull LAT</td>
<td>0.01</td>
<td>0.005-0.02</td>
<td>4.0</td>
</tr>
<tr>
<td>Chest PA</td>
<td>0.02</td>
<td>0.008-0.037</td>
<td>4.6</td>
</tr>
<tr>
<td>Chest LAT</td>
<td>0.04</td>
<td>0.013-0.08</td>
<td>6.2</td>
</tr>
<tr>
<td>Thoracic spine AP</td>
<td>0.4</td>
<td>0.16-1.0</td>
<td>6.3</td>
</tr>
<tr>
<td>Thoracic spine LAT</td>
<td>0.3</td>
<td>0.06-0.7</td>
<td>12</td>
</tr>
<tr>
<td>Lumbar spine AP</td>
<td>0.7</td>
<td>0.25-1.6</td>
<td>6.4</td>
</tr>
<tr>
<td>Lumbar spine LAT</td>
<td>0.3</td>
<td>0.1-0.6</td>
<td>6.0</td>
</tr>
<tr>
<td>Lumbar spine LSJ</td>
<td>0.3</td>
<td>0.1-0.7</td>
<td>7.0</td>
</tr>
<tr>
<td>Abdomen AP</td>
<td>0.7</td>
<td>0.26-1.4</td>
<td>5.4</td>
</tr>
<tr>
<td>Pelvis AP</td>
<td>0.7</td>
<td>0.3-1.3</td>
<td>4.3</td>
</tr>
<tr>
<td><strong>Complete Examinations</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IVU (6 films)</td>
<td>2.5</td>
<td>0.8-5.6</td>
<td>7.0</td>
</tr>
<tr>
<td>Barium swallow (24 spot images, 106 s flouro.)</td>
<td>1.5</td>
<td>0.7-2.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Barium meal (11 spot images, 121 s flouro.)</td>
<td>3</td>
<td>0.9-4.3</td>
<td>4.8</td>
</tr>
<tr>
<td>Barium follow (4 spot images, 78 s flouro.)</td>
<td>3</td>
<td>1.1-6.5</td>
<td>5.9</td>
</tr>
<tr>
<td>Barium enema (10 spot images, 137 s flouro.)</td>
<td>7</td>
<td>2.6-15</td>
<td>5.8</td>
</tr>
<tr>
<td>CT head</td>
<td>2</td>
<td>0.9-3.0</td>
<td>3.3</td>
</tr>
<tr>
<td>CT chest</td>
<td>8</td>
<td>2.4-16</td>
<td>6.7</td>
</tr>
<tr>
<td>CT abdomen</td>
<td>10</td>
<td>4.0-18</td>
<td>4.5</td>
</tr>
<tr>
<td>Ct pelvis</td>
<td>10</td>
<td>4.0-18</td>
<td>4.5</td>
</tr>
</tbody>
</table>

**Source: Wall & Hart, 1997**

The other concern is organ-specific doses, which could vary with age. Table 1.3 contains some estimated organ-specific radiation doses from medical x-rays in the UK and Finland in the 1990s (Berrington de Gonzalez & Darby, 2004).
Table 1.2.3 Estimated organ-specific radiation doses (mGy) by type of diagnostic X-ray

<table>
<thead>
<tr>
<th>X-ray type</th>
<th>Bladder</th>
<th>Breast</th>
<th>Colon</th>
<th>Liver</th>
<th>Lang</th>
<th>Oesophagus</th>
<th>RBM</th>
<th>Stomach</th>
<th>Thyroid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdomen</td>
<td>1.14</td>
<td>0.05</td>
<td>1.63</td>
<td>1.10</td>
<td>0.27</td>
<td>0.03</td>
<td>0.37</td>
<td>1.64</td>
<td>0.03</td>
</tr>
<tr>
<td>Coronary angiography</td>
<td>0.23</td>
<td>0.42</td>
<td>0.51</td>
<td>1.54</td>
<td>37.69</td>
<td>13.79</td>
<td>7.39</td>
<td>0.67</td>
<td>1.08</td>
</tr>
<tr>
<td>Cerebral angiography</td>
<td>0.00</td>
<td>0.02</td>
<td>0.00</td>
<td>0.01</td>
<td>1.14</td>
<td>1.98</td>
<td>9.27</td>
<td>0.01</td>
<td>25.06</td>
</tr>
<tr>
<td>Barium meal</td>
<td>0.28</td>
<td>0.62</td>
<td>1.82</td>
<td>9.48</td>
<td>1.23</td>
<td>0.54</td>
<td>1.69</td>
<td>8.24</td>
<td>0.22</td>
</tr>
<tr>
<td>Barium enema</td>
<td>14.45</td>
<td>0.14</td>
<td>21.51</td>
<td>3.55</td>
<td>0.39</td>
<td>0.06</td>
<td>7.49</td>
<td>4.98</td>
<td>0.01</td>
</tr>
<tr>
<td>Cardiac catheterisation</td>
<td>0.23</td>
<td>0.42</td>
<td>0.51</td>
<td>1.54</td>
<td>37.69</td>
<td>13.79</td>
<td>7.39</td>
<td>0.67</td>
<td>1.08</td>
</tr>
<tr>
<td>Cervical spine</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.07</td>
<td>0.12</td>
<td>0.07</td>
<td>0.00</td>
<td>0.84</td>
</tr>
<tr>
<td>Chest</td>
<td>0.00</td>
<td>0.01</td>
<td>0.00</td>
<td>0.03</td>
<td>0.07</td>
<td>0.04</td>
<td>0.02</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>Hip</td>
<td>1.16</td>
<td>0.00</td>
<td>0.71</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.12</td>
<td>0.02</td>
<td>0.00</td>
</tr>
<tr>
<td>Hysterosalpingography</td>
<td>4.67</td>
<td>0.00</td>
<td>2.82</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.81</td>
<td>0.03</td>
<td>0.00</td>
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<tr>
<td>Intravenous urogram (IVU)</td>
<td>4.42</td>
<td>0.20</td>
<td>5.10</td>
<td>3.49</td>
<td>0.42</td>
<td>0.03</td>
<td>0.83</td>
<td>6.04</td>
<td>0.00</td>
</tr>
<tr>
<td>Lumbar myelography</td>
<td>7.90</td>
<td>0.01</td>
<td>10.85</td>
<td>1.20</td>
<td>0.04</td>
<td>0.01</td>
<td>4.06</td>
<td>1.62</td>
<td>0.00</td>
</tr>
<tr>
<td>Lumbar spine</td>
<td>2.49</td>
<td>0.03</td>
<td>2.40</td>
<td>2.16</td>
<td>0.15</td>
<td>0.02</td>
<td>0.68</td>
<td>1.51</td>
<td>0.00</td>
</tr>
<tr>
<td>Mammography (1-view screen)</td>
<td>0.00</td>
<td>2.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Pelvis</td>
<td>2.13</td>
<td>0.01</td>
<td>1.85</td>
<td>0.13</td>
<td>0.01</td>
<td>0.00</td>
<td>0.25</td>
<td>0.29</td>
<td>0.00</td>
</tr>
<tr>
<td>Skull</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
<td>0.02</td>
<td>0.12</td>
<td>0.00</td>
<td>0.14</td>
</tr>
<tr>
<td>Thoracic spine</td>
<td>0.00</td>
<td>0.47</td>
<td>0.00</td>
<td>0.57</td>
<td>2.25</td>
<td>1.15</td>
<td>0.55</td>
<td>0.25</td>
<td>2.97</td>
</tr>
<tr>
<td>CT: abdomen</td>
<td>5.07</td>
<td>0.72</td>
<td>6.60</td>
<td>0.05</td>
<td>2.70</td>
<td>0.56</td>
<td>5.58</td>
<td>22.20</td>
<td>0.05</td>
</tr>
<tr>
<td>CT: chest</td>
<td>0.02</td>
<td>21.40</td>
<td>0.07</td>
<td>5.64</td>
<td>22.40</td>
<td>28.30</td>
<td>5.94</td>
<td>4.06</td>
<td>2.25</td>
</tr>
<tr>
<td>CT: head</td>
<td>0.00</td>
<td>0.03</td>
<td>0.00</td>
<td>0.01</td>
<td>0.09</td>
<td>0.07</td>
<td>2.67</td>
<td>0.00</td>
<td>1.85</td>
</tr>
<tr>
<td>CT: internal auditory meatus</td>
<td>0.00</td>
<td>0.02</td>
<td>0.00</td>
<td>0.01</td>
<td>0.08</td>
<td>0.07</td>
<td>0.83</td>
<td>0.00</td>
<td>2.03</td>
</tr>
<tr>
<td>CT: orbits</td>
<td>0.00</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.04</td>
<td>0.03</td>
<td>1.05</td>
<td>0.00</td>
<td>0.87</td>
</tr>
<tr>
<td>CT: pituitary</td>
<td>0.00</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.04</td>
<td>0.03</td>
<td>0.96</td>
<td>0.00</td>
<td>0.77</td>
</tr>
<tr>
<td>CT: pelvis</td>
<td>23.20</td>
<td>0.03</td>
<td>15.10</td>
<td>0.68</td>
<td>0.05</td>
<td>0.01</td>
<td>5.62</td>
<td>1.06</td>
<td>0.00</td>
</tr>
<tr>
<td>CT: cervical spine</td>
<td>0.00</td>
<td>0.09</td>
<td>0.00</td>
<td>0.03</td>
<td>0.58</td>
<td>0.51</td>
<td>1.12</td>
<td>0.02</td>
<td>43.90</td>
</tr>
<tr>
<td>CT: thoracic spine</td>
<td>0.00</td>
<td>27.70</td>
<td>0.02</td>
<td>1.48</td>
<td>13.40</td>
<td>15.70</td>
<td>2.92</td>
<td>0.98</td>
<td>0.46</td>
</tr>
<tr>
<td>CT: lumbar spine</td>
<td>0.67</td>
<td>0.13</td>
<td>3.30</td>
<td>6.88</td>
<td>0.34</td>
<td>0.08</td>
<td>2.52</td>
<td>10.50</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Source: Berrington de Gonzalez & Darby, 2004

Organ-specific radiation doses could vary with age; with doses in paediatric radiology probably being lower than in adults for many common radiographic and...
fluoroscopic examinations, but possibly higher for CT scans (Mooney & Thomas, 1998). In a more recent study (Khursheed et al., 2002), a detailed calculation of age-specific adjustments estimated that dose to 0-1 year olds were at most 2.5 times higher than adult doses for CT, and for children aged 2-15 years were at most 1.8 times higher.

The total population dose of radiation from medical diagnostic procedures is increasing worldwide. In the USA, the rate of x-ray examinations increased from 670 to 962 per 1,000 population from 1970 to 1996 (Shapiro, 2002). In Japan, the rate has reached 1,477 in 1996 (Berrington de Gonzalez & Darby, 2004). In Australia, Medicare data indicate that Computed Tomography examinations alone increased 140% over the decade 1992-2002 (Dickie & Fichew, 2004).

1.2.9 Extrapolation of observed risks to lower doses

These epidemiological studies provide high quality evidence, showing an increase in risk of cancer at acute radiation dose > 50 mSv, and reasonable evidence for an increase of risk for some special type of cancers at doses above 5 mSv. Today, for many radiological examinations, a single procedure produces exposure in the range from 1 to 30 mSv.

Generally, protracted radiation exposures are associated with lower risks than those of acute exposures to the same total dose for cancer (NCRP, 1980; Brenner, 1999). These epidemiological studies also show that for radiation exposures over a prolonged period, there is no question that there is increased risk of cancer with a protracted dose greater than100 mSv, and little question for increased risk of cancers at protracted dose above 50 mSv.

For further lower dose exposure, it seems unlikely increased risks of cancers can be
estimated by epidemiological study. Compared with higher doses, the cancer risks associated with lower dose radiation are likely to be lower. An extraordinarily large sample population is required for lifetime follow-up to maintain statistical precision and power. It is almost practically impossible to conduct such a study. For example, if the excess cancer risk were proportional to the radiation dose, and if a sample size 500 persons were needed to quantify the effect of a 1,000 mSv dose, then a sample size 50,000 would be needed for 100 mSv dose, and about 5,000,000 for a 10 mSv dose (Pochin, 1976; Land, 1980).

There are different potential dose-response relations to extrapolate observed cancer risks associated with radiation exposure to lower doses, such as linear, downwardly curving, upwardly curving, threshold, and hormetic dose-response relationships as showed in figure 1. After reviewing available data from both epidemiological and laboratory studies, National Council on Radiation Protection and Measurements (NCRP, 2001) concluded that "Although other dose-response relationships for the mutagenic and carcinogenic effects of low-level radiation cannot be excluded, no alternative dose-response relationship appears to be more plausible than linear-non threshold model on the basis of present scientific knowledge."
Figure 1.2.1 Schematic representation of different possible extrapolation of measured radiation risks down to very low doses*.

*Curve a, linear extrapolation; curve b, downwardly curving; curve c, upwardly curving; curve d, threshold; curve e, hormetic.

Source: Brenner et al., 2003

In any case, at present it is not possible to be certain of the appropriate dose-response relation to use for risk estimation at very low doses. The linearly assumption is not necessarily the most conservative approach. It is possible that it could result in an underestimate of some radiation induced cancer risks and an overestimate of others. However, other alternative dose-response relationships are simply less credible than the linear model.

1.2.10 Cancer Risks

The most serious consequence of unnecessary radiological requisitions is the potential cancer risks associated with ionising medical radiation. As documented in
the literature review (2.3.1), the epidemiological studies suggest that for an acute exposure 10-50 mSv and for a protracted exposure 50 -100 mSv, evidence of increased cancer risk in humans is reliable. Many single diagnostic x-ray examinations produce doses in the range 1-30 mSv. These provide a reasonable basis to extrapolate possible cancer risks from even lower doses of radiation. Experimentally grounded and quantifiable biophysical arguments support that a linear extrapolation of cancer risk estimation appears to be the most reasonable methodology. A recent and more sophisticated study (Risk of cancer from diagnostic X-rays: estimates for the UK and 14 other countries, Berrington de González et al., 2004) demonstrated results for the USA suggesting that 0.9% of all cancers could be caused by diagnostic X-rays, almost double the 1981 estimate of 0.5% of cancer mortality. In the UK, they determined that about 0.6% of the cumulative risk of cancer to age 75 years could be attributable to diagnostic X-ray, equivalent to approximately 700 cases of cancer per year. Countries with higher estimated annual exposure fared less well, indeed, that study indicated that in Japan, with the ‘highest estimated annual exposure frequency’ this was more than 3%. Australia may not occupy the same position as Japan, which has the highest number of CT machines per capita (Nagel et al., 1999), however, it is essential to minimise annual exposure and maintain the ALARA principle. Raising awareness of the burden imposed by unnecessary exposures would assist in ensuring that Australia is as far removed from the situation in Japan as is achievable. Thus, it would assist in minimising annual exposure in Australia.

The cancer risk may be ‘relatively small’; however, in the UK, this represented approximately 700 people. For the individual at risk, unless there is sufficient justification for an examination, or an additional examination involving ionising
radiation, the examination should be contraindicated. If we can prevent causing cancer due to exposure to radiation, we will save the health care system the cost of treating those patients in the future. In chapter two, there was discussion regarding the notion that the potential outcome could be determined, in terms of excess cancer equivalents due to unnecessary exposure nationwide. Whilst, determining the cost of excess cancers resulting from over-utilising x-ray examinations and the best methods on how to achieve the desired outcomes, this lies outside the scope of this current work. The complexity required to undertake this work would require a separate dedicated study. It would however, be no mere academic exercise; the outcome would certainly support the underlying aims of this work and render it even more relevant. As to the complexities involved in determining the cost of such cancers, this would entail more than simply acquiring data on the frequency of examination and dose to organs. The risk models appropriate to this area would need to be applied. The work of Avritscher et al. (2001; 2006), proved that it is possible to determine the cost for a particular cancer, (bladder cancer). Furthermore, each cancer fatality that is prevented is estimated to save 17.5 years of life (ICRP, 1991), a cost may be attributed for this aspect of cancer.

1.2.10.1 Estimated cancer risks from diagnostic radiography

The cancer risks associated with medical x-ray examinations are estimated by extrapolation with the assumption that small doses of radiation can cause cancer, as experimental and epidemiological data do not suggest a threshold below which radiation does not cause cancer.

In 1981, Doll and Peto estimated that about 0.5% of the cancer deaths in the USA were attributable to diagnostic x-rays. Kaul et al. (1997) estimated that about 2% of
cancer deaths in Germany were attributable to diagnostic medical radiation.

The largest and most recent study was reported by Berrington de Gonzales and Darby (2004). From surveys of medical radiation use in 15 developed countries between 1991 and 1996, they obtained information on the average annual frequency of various x-ray procedures and estimated the doses to various organs from these procedures. Their results reveal that the diagnostic x-ray use in the UK accounts for 0.6% of the cumulative risk of cancer. Japan had the highest annual of diagnostic x-ray use and it also the highest attributable risks, with 3.2% of the cumulative risk of cancer attributable to diagnostic x-ray, equivalent to 7,587 cases of cancer per year. For Australia, the study suggests that about 431 cancers per year, 1.3% of all cancers, could be attributable to diagnostic x-ray.

Table 1.2.9 gives the details of the frequency of x-ray examinations per 1,000 population, percentage of cumulative cancer risk to age 75 years attributable to diagnostic x-rays, and radiation-induced cases of cancer per year for 15 countries.
Table 1.2.4 Frequency of x-ray examinations per 1000 population

<table>
<thead>
<tr>
<th>Country</th>
<th>Annual X-rays per 1000</th>
<th>Males</th>
<th>Females</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Attributable risk (%)</td>
<td>Cases cancer per year</td>
<td>Attributable risk (%)</td>
</tr>
<tr>
<td>Australia</td>
<td>565</td>
<td>1.2</td>
<td>204</td>
<td>1.5</td>
</tr>
<tr>
<td>Canada</td>
<td>892</td>
<td>1.1</td>
<td>406</td>
<td>1.0</td>
</tr>
<tr>
<td>Croatia</td>
<td>903</td>
<td>1.5</td>
<td>66</td>
<td>2.2</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>883</td>
<td>0.9</td>
<td>67</td>
<td>1.2</td>
</tr>
<tr>
<td>Finland</td>
<td>784</td>
<td>0.7</td>
<td>20</td>
<td>0.7</td>
</tr>
<tr>
<td>Germany</td>
<td>1254</td>
<td>1.3</td>
<td>963</td>
<td>1.7</td>
</tr>
<tr>
<td>Japan</td>
<td>1477</td>
<td>2.9</td>
<td>3724</td>
<td>3.8</td>
</tr>
<tr>
<td>Kuwait</td>
<td>896</td>
<td>0.7</td>
<td>25</td>
<td>0.6</td>
</tr>
<tr>
<td>Netherlands</td>
<td>600</td>
<td>0.7</td>
<td>100</td>
<td>0.7</td>
</tr>
<tr>
<td>Norway</td>
<td>708</td>
<td>1.3</td>
<td>28</td>
<td>1.1</td>
</tr>
<tr>
<td>Poland</td>
<td>641</td>
<td>0.5</td>
<td>99</td>
<td>0.7</td>
</tr>
<tr>
<td>Sweden</td>
<td>568</td>
<td>1.1</td>
<td>91</td>
<td>0.8</td>
</tr>
<tr>
<td>Switzerland</td>
<td>750</td>
<td>1.0</td>
<td>93</td>
<td>1.0</td>
</tr>
<tr>
<td>UK</td>
<td>489</td>
<td>0.6</td>
<td>341</td>
<td>0.6</td>
</tr>
<tr>
<td>USA</td>
<td>962</td>
<td>0.9</td>
<td>2573</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Taken from worldwide survey. Estimates assume annual frequency of CT examinations in Japan was equal to that for all health-care level 1 countries. However, number of CT scanners per million population in Japan is 3.7 times that for all health-care level 1 countries. If this number is reflected in annual frequency of CT examinations, then for Japan estimated annual number of X-rays per 1000 increases to 1573 and the attributable risk increases to 4.4 %, corresponding to 9905 cases of cancer per year.

**Frequency of diagnostic X-rays per 1000 population, percentage of cumulative cancer risk to age 75 attributable to diagnostic X-rays, and number of radiation-induced cases of cancer per year for 15 countries.**

**Source:** Berrington de Gonzalez & Darby, 2004

Children are more sensitive to radiation. The Oxford survey of Childhood Cancers estimated that the absolute risk of mortality from cancer following radiation exposure in utero is 1 in 20,000 per mSv (Mole, 1990).

Brenner et al. (2001) studied the risks of radiation induced fatal cancer from
paediatric CT in America. Estimated lifetime cancer mortality risks attributable to CT radiation in a 1-year-old are 0.18% for abdominal CT and 0.07% for head CT. Approximately 600,000 abdominal and head CT examinations are annually performed in children under the age of 15 years. It is estimated that 500 of these might ultimately die from cancers attributable to the radiation received from CT examinations.
1.3 RADIOBIOLOGY

Radiobiology is the study of the changes that are produced by radiation in biological material. Radiobiological changes may be gross or microscopic, lethal or non-lethal, immediate or delayed.

The science of radiation biology is dedicated to understanding the effects of radiation on living things. The effects of radiation on living organisms are considered paradoxical; radiation is known to cause cancer, yet administered in clinical radiotherapy, radiation represents the major anticancer modality in terms of successful tumour cure and patient survival. Studies on the physical, biological, and chemical changes, which follow the interaction of radiation with living matter, are of fundamental importance in understanding how radiation can be used to investigate cell function, normal and aberrant cell structure, also to diagnose and treat a variety of diseases, particularly cancer.

1.3.1 Biological Radiation Effects

During the simple interaction of ionizing radiation with an atom, tightly bound electrons can be moved from their orbits, causing the atom to become charged or ionized (Curry et al., 1990). The interaction of ionizing Radiation with biological systems results in some changes in the atomic and molecular structures in living beings. Changes due to radiobiological interaction may be grossly apparent, and become visible soon after exposure of the living organism. However, whilst changes might not appear on examination to have affected the organism at all, small changes can occur. These may be detected by careful chemical or microscopic study, or might be apparent only after many years, or in the offspring of the irradiated...
organism (Casarett, 1968).

**Radiation effects are classified under two categories, somatic and genetic.**

1.3.2 Somatic Effects

Somatic effects are lesions that become manifest in the exposed individual. These lesions occur when the exposed individual receives a dose of radiation above a certain threshold and their severity increases with the dose. At lower levels of exposure, which the population can normally expect to receive, the somatic effects are of most interest (Casarett, 1968), these are:

- cancer induction,
- production of developmental abnormalities in the foetus, and
- non-specific reduction in life span.

1.3.3 Genetic effects

Genetic effects are the result of lesions in germinal cells, or those lesions that affect the exposed individual’s descendants. The mutability of germinal cells differs between male and female individual (Tubiana et al., 1990).

The mutability of the germinal cells of the male is much greater than that of the female, by a factor of about 5. Gardner et al suggested in their case control study of leukaemia and lymphoma among young people (Gardner et al., 1990) that paternal irradiation may increase the incidence of leukaemia and non-Hodgkin’s lymphoma in children.

1.3.4 Stochastic effects

Stochastic effects are those resulting from alteration in normal cells caused by an
ionizing radiation event which is assumed to have a low probability of occurrence in cells at low doses. However, the severity of the effect does not depend on the magnitude of the absorbed dose. A stochastic effect is an ‘all-or-nothing’ phenomenon, and is assumed to have no dose threshold (Curry et al., 1990). There are two general types of stochastic effects. The first occurs in somatic cells and may result in the induction of cancer in the exposed individual, the second occurs in cells of germinal tissue and may result in hereditary disorders in the progeny of those irradiated (NHMRC, 1986).

1.3.5 Non-Stochastic effects

Non-stochastic effects are those in which the severity of the effect varies with the dose. They are usually degenerative effects, severe enough to be clinically significant, such as organ atrophy and fibrosis.

Non-stochastic effects are specific to particular tissues, for example, non-malignant damage to the skin, cataract of the lens of the eye, gonadal cell damage leading to impaired fertility. If an individual receives a dose greatly in excess of the threshold dose, the manifestation of the effect will occur in a relatively short period after irradiation. For example, the threshold for dry desquamation occurs after about 3 to 5 Gy, and symptoms appear after about 3 weeks. Moist desquamation occurs after 20 Gy, blistering occurs after 4 weeks. Cell death in the epidermal and dermal layers resulting in tissue necrosis occurs after a dose of about 50 Gy, this appears after about 3 weeks (ICRP, 60). However, if the dose is not in excess of the threshold dose, many of the resulting effects will be of a temporary nature and reversion to normal conditions is expected to occur (NHMRC, 1986).

Non-Stochastic effects in humans can result from general or localised tissue
irradiation causing an amount of cell destruction that cannot be compensated for by proliferation of viable cells. The resulting cell loss can cause severe with clinically detectable impairment of function in a tissue or organ.

It should be noted that the severity of the observed effect can be expected to depend on the dose.

For avoidance of non-stochastic effects, the recommended annual dose equivalent limits are:

15 rem (150 mSv) for the lens of the eye and

50 rem (500 mSv) for all other tissues or organs (Curry et al., 1990).

Those limits are easily exceeded during examinations when a series of examinations are requested and each examination usually requires more than one projection. Table 1.5 gives an estimate of the thresholds for some human tissues (ICRP, 60).

**Table 1.3.1** An estimate of the thresholds for some human tissues

<table>
<thead>
<tr>
<th>Tissue and Effect</th>
<th>Threshold dose Equivalent (Sv)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acute exposure</td>
</tr>
<tr>
<td><strong>Testes</strong></td>
<td></td>
</tr>
<tr>
<td>Temporary sterility</td>
<td>0.15</td>
</tr>
<tr>
<td>Permanent sterility</td>
<td>3.5-6.0</td>
</tr>
<tr>
<td><strong>Ovaries</strong></td>
<td>2.5-6.0</td>
</tr>
<tr>
<td><strong>Lens</strong></td>
<td></td>
</tr>
<tr>
<td>Detectable opacities</td>
<td>0.5 -2.0</td>
</tr>
<tr>
<td>Visual Impairment (cataracts)</td>
<td>5.0</td>
</tr>
<tr>
<td><strong>Bone marrow</strong></td>
<td></td>
</tr>
<tr>
<td>Depression of haematopoiesis</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**Source:** ICRP, 60

### 1.3.6 Weighting Factors

It is difficult to evaluate the risk of absorbed radiation in local regions of the body
such as skull, chest, or ankle radiographs, compared to radiation of the entire body from a source such as cosmic radiation. Therefore weighting factors are assigned to each type of radiation exposure in an attempt to express the risk involved from that exposure compared to the risk involved from total body radiation. This weighting is accomplished by the effective dose equivalent (HE). For example the HE resulting from a chest radiographic examination is .06 mSv (6 mrem). An HE of .06 mSv means that the risk involved from a chest examination is the same as the risk involved in exposing the entire body to an x-ray exposure of .06 mSv.

It is to be noted that HE does not measure exposure to the chest; HE does assign a risk value resulting from an exposure to the chest (Curry et al., 1990).

1.3.7 The Concept of Detriment

Apart from the fatal cancer risks, the International Commission for Radiation Protection “ICRP” uses the concept of detriment as a basis for expressing the expected harm in an exposed population. The general aim of detriment is to find a quantitative way of expressing a combination of the probability of an occurrence of a health effect and a judgement of the severity of that effect. The weighting factor for death of an individual or for severe hereditary effects in their descendants is taken to be 1. The weighting factor for non-fatal cancers would be much less than 1. The nominal probability coefficients for stochastic effect are given in table 1.3.7.1

<table>
<thead>
<tr>
<th>Detriment (10^-1 Sv^-1)</th>
<th>Exposed Population</th>
<th>Whole population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adult workers</td>
<td>4.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Whole population</td>
<td>0.8</td>
<td>1.0</td>
</tr>
<tr>
<td>Fatal cancer</td>
<td>0.8</td>
<td>1.3</td>
</tr>
<tr>
<td>Non-Fatal cancer</td>
<td>5.6</td>
<td>7.3</td>
</tr>
</tbody>
</table>

Table 1.3.2 The nominal probability coefficients for stochastic effect

Source: ICRP, 60
Different coefficients apply for adult workers and for general members of the public. The relative contributions of tissues to fatal cancer risk and the total detriment, form the basis of ICRP’s weighting factors. These weighting factors are given in Table 1.3.3 and can be used to calculate effective dose. This is useful in establishing the overall risk from partial body exposures. The simplified system of weighting factors has been chosen so that there is no more than a factor of 2 between the relative contributions. Table 1.3.3 gives the tissue weighting factors to calculate effective dose.

### Table 1.3.3 Tissue weighting Factors Used in Calculating Effective Dose

<table>
<thead>
<tr>
<th>Tissue</th>
<th>( W_t )</th>
<th>( W_t )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone surface, skin</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>Bladder, breast, liver, oesophagus, thyroid</td>
<td>0.05</td>
<td>0.30</td>
</tr>
<tr>
<td>Bone marrow, colon, lung, stomach</td>
<td>0.12</td>
<td>0.48</td>
</tr>
<tr>
<td>Gonads</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Source: ICRP, 60*

### 1.3.8 Dose-response Relationships

In radiotherapy, the severity of effects produced by radiation on human health is considered proportional to the dose of radiation received. Dealing with experimental animals or observations on humans has been devoted to describing the quantitative relationship between the radiation dose and biological effect. Such dose-response relationships have been described with great precision for the early effects of radiation following high doses. Most early effects, such as skin erythema, haematological depression, and lethality, exhibit a threshold type of dose-response relationship. Such a dose threshold indicates that there is a dose level below which no response will occur.
This is not true for the late effects of low-level radiation exposure. Late effects are considered to have no dose threshold and to be linear, where no radiation dose below which such an effect will occur (Ballinger, 1991). Figure 1.3.8 describes a dose-response relationship.

**Figure 1.3.1** Radiation dose-response relationships.

Dose-response relationships appear as either A, threshold, or B non-threshold in shape

**Source:** Ballinger, 1991

This type of dose-response relationship suggests that no radiation dose, regardless of how small, is considered safe. At zero dose a small but measurable response may be observed. This represents the natural incidence of effect under observation.

**1.3.9 Maximum permissible dose (MPD)**

What is the safe limit of exposure to radiation? It is doubtful whether any amount of radiation is ‘really’ safe. In attempt to regulate exposure to radiation especially to workers, the International Commission on Radiologic Units and Measurements (ICRU) recommended a maximum permissible dose equivalent (MPD). The MPD
may be defined as the maximum dose of ionizing radiation which an individual may accumulate over a long period of time, or in a single exposure, and which carries a negligible risk of significant bodily or genetic damage (Selman, 1980). It should be emphasized that the MPD is based on the balancing of risks versus benefits of radiation exposure.

As applied to scientists, radiologists, and other radiation workers, the lifetime accumulated occupational MPD from X, gamma, or beta radiation to the whole body and to certain radiosensitive organs, such as gonads, blood forming organs, lens of the eye, head, and trunk must not exceed

$$\text{MPD} = 20(N - 18) \text{ mSv}$$

where $N$ is the age in years and is greater than 18. For example, at age 32 the MPD is $20 (32 - 18) = 280 \text{ mSv}$. Thus, the average annual MPD is 20 mSv; and weekly, 0.4 mSv or 40 millirems. The hands and feet may receive as much as 750 mSv per year (see Figure 1.3). The above requirements apply only to radiation workers; mainly because of genetic effects. The radiation exposure received by personnel working in Radiology for their own diagnosis and therapy is not included in computing the MPD.

The MPD for X and gamma radiation is stated in mSv because the equal absorbed doses of these types of radiation produces virtually the same effects in the tissues. However, to produce a given effect in tissues, a smaller absorbed dose (mSv) is required with heavy particles, such as alpha particles and neutrons, than with x-rays. Thus, one mSv of alpha particles & fast neutrons produces a greater tissue effect than one rad of x-rays, and it would therefore be incorrect to add the absorbed doses of such different kinds of radiation in arriving at the total MPD. To express on a common scale, for protection purposes only, the irradiation incurred by exposed
persons for all types of radiation, the ICRU has introduced the quantity dose equivalent (DE). By definition, the DE is the product of the absorbed dose and appropriate modifying factors that depend on the particular radiation hazard involved. Considering the quality factor (QF) only.

\[
\text{DE} = \text{absorbed dose} \times \text{QF}
\]

\[
\text{rems} = \text{mSv} \times \text{QF}
\]

By introducing the appropriate value of QF in the equation, we can convert rads to rems. The unit of DE is the rem, and the value of QF varies with the type of radiation. For x-rays of moderate energy (200 kV), beta particles, and gamma rays, QF has been arbitrarily assigned the value 1. Therefore:

\[
\text{DE} = \text{absorbed dose}
\]

\[
= 1 \text{ rad} \times 1 = 1 \text{ rem}
\]

or, 1 rad = 1 rem for x, beta, and gamma rays

On the other hand, the QF for fast neutrons is 10; for example, 1 rad of fast neutrons is ten times as effective as 1 rad of x-rays in producing cataracts (Selman, 1980). Conversely, it takes ten times more rads of x-rays than neutrons to produce the same effect. Therefore:

\[
\text{DE} = \text{absorbed dose} \times 10
\]

\[
1 \text{ rad} \times 10 = 10 \text{ rems}
\]

or, 1 rad = 10 rems for fast neutrons.

This means that with fast neutrons, 1 rad gives a DE of 10 rems insofar as cataract induction is concerned. The QF for alpha particles is 20, so that 1 rad of this radiation provides a DE of 20 rems. It must be emphasized that the rems of different kinds of radiation are equivalent (DE) and can be added. For example, if an individual was exposed to a mixture of radiations and received 1 rad from x-rays, 1
rad from fast neutrons, and 1 rad from alpha particles, the total absorbed dose would be 3 rads. However, this would seriously underestimate the radiation hazard. By converting these doses to dose equivalents, we would obtain:

- x-rays 1 rad \( \times 1 = 1 \text{ rem} \)
- fast neutrons 1 rad \( \times 10 = 10 \text{ rems} \)
- alpha particles 1 red \( \times 20 = 20 \text{ rems} \)

Therefore, the dose equivalent, in this case, 31 rems, provides a more realistic measure of the radiation hazard when the quality factor is different from 1. However, under ordinary conditions in the Radiology Department exposure is usually limited to radiation with a quality factor of 1 so that the MPD may be stated in rads, or even in roentgens because 1 R is numerically equal to about 1 rad.

The method of calculating MPD as described above is only a guide to be used for calculating yearly occupational permissible doses, but when considering accumulation of lifetime exposure the NCRP’s latest recommendation (Curry et al., 1990) can be defined as follows:

*An individual’s lifetime effective dose equivalent in rems should not exceed the value of his or her age in years.*

This will be achieved in using the formula Age in years \( \times 1 \text{ rem} \)

### 1.3.10 Public Exposure

Members of the public exposed to radiation are in a different situation as compared with radiation workers. Usually members of the general public have no knowledge of the risks of exposure to radiation and they do not receive compensation for the risk. Most importantly, they have no freedom to decide if they will accept the risk. For
example, when members of the general public visit an area where they are exposed, they become occasionally exposed individuals. The radiation exposure is ‘thrust’ on them, frequently without their knowledge. In addition, the population size of the occasionally exposed is not controlled, so large numbers of individuals could be involved, which would have a greater impact on the genetically significant dose (Curry et al., 1990).

Therefore the NCRP recommended the MPD for the general population to be 1/10 those exposed occupationally (e.g. 1/10 of 20 mSv = 2 mSv per year). That is 0.2 rem (2 mSv) annual effective dose equivalent limit for members of the public. This limit will maintain the annual dose equivalent to those organs and tissues, considered in the effective dose equivalent system, below levels of concern for non-stochastic effects. However, as some organs and tissues are not routinely included in the calculation of effective dose equivalent (such as extremities, skin, and lens of the eye), an annual dose equivalent of 5 rem (50 mSv) is recommended for these organs or tissues (Curry et al., 1990).

1.3.11 Patient Dose

Occupational health and safety issues are at the centre of today’s political agenda. As mentioned earlier in this chapter, the first dose limiting recommendation was introduced in 1931. Since then the MPD for occupational exposure has changed many times, in 1987 the NCRP recommended the replacement of the earlier MPD formula “(age — 18) x 15)” by a new formula “age in years x 1 rem”.

The right of the public in the workplace was also addressed. The main concern of this study being the cumulative dose received by patients from different medical examinations. To this day there are no regulations to control patient dose and an
MPD has not been recommended by any of the professional institutions nationally or internationally.

There are several techniques to measure patient dose; they are usually expressed in one of three ways:

- skin exposure,
- organ dose,
- foetal dose.

Each has a specific application in assessing the risk to the patient, but skin exposure is the easiest to estimate and obtain.

1.3.12 Skin exposure

Skin exposure is one of the most reliable methods to measure radiation doses especially when trying to make comparative assessments between different examinations and modalities. Skin exposure is the exposure to the entrance surface of the patient during any radiographic examination. It can be measured directly or estimated by measuring the output intensity following the Mathematical formula:

\[ \text{Output intensity} = k \times (\text{mAs}) \times (\text{kVp})^2 \]

where:

- \( k \) = empirically determined constant
- \( \text{mAs} \) = x-ray tube current multiplied the exposure time
- \( \text{kVp} \) = tube potential
- \( d \) = distance from the source to the entrance surface of the patient (SSD)

It should be noted that for a properly calibrated radiographic system the output intensity would vary directly with the milliampere seconds and the square of the kVp. It will also vary inversely as the square of the distance from the target.
Fluoroscopic units on the other hand, usually have beam intensities limited to 10 R/min (2.58 x 10^-2 C/kg-mm) at the tabletop. Experience has shown that, when operated with a technique of about 100 kVp/l mA, most fluoroscopes will produce an approximate tabletop exposure of 2 to 3 R/min (5 to 8 x 10^-4 C/kg-min) (Ballinger, 1991).

The best method of measuring skin exposure is to place a thermo-luminescent dosimeter (TLD) on the entrance surface of the patient, exposing the TLD during the clinical procedure. TLDs are very easy to use, their small size allows them to be easily positioned on the skin; and since they are almost tissue equivalent they will not result in an image artefact except at a very low kVp.

The use of TLDs takes preference above ion chambers or solid-state diodes because of their size, sensitivity and accuracy.

Ballinger (1991) stated that most current estimates of skin exposure are made with TLDs.

Therefore using TLDs to measure doses delivered to our patients would have the advantage of comparing the average dose per examination in our centre with the average dose used in other studies.

1.3.13 Organ dose

Radiation doses delivered to specific organs or tissues are of a primary importance. The range of effects varies among the different organs of the human body. For example, radiogenic cancers occur relatively frequent in the thyroid, the breast and the bone marrow; they are very rare in the prostate and testis (Tubiana et al., 1990). However, gonads are organs of primary concern in diagnostic radiology because of the possible genetic effects of ionizing radiation. Organ doses for the most part
cannot be measured directly so must be estimated.

1.3.14 Foetal dose

There are recommendations to limit exposure to the foetus of an occupationally exposed mother. However, because of the special sensitivity of the foetus consideration should be given in all situations, especially those involving medical exposures of the expectant mother. The NCRP’s recommendation is to limit the occupational total dose equivalent to the embryo-foetus to 0.5 mSv in any month during pregnancy (NCRP, 1987).

1.3.15 Hormesis

Radiation hormesis is based on the assumption that exposure to radiation in small doses might be beneficial. It is based on two theories:

- **The first is Evolutionary** where it is premised that radiation has been present on Earth since the beginning of life and it is conceivable that most organisms evolved in such a way that they are able to counteract the harmful influences, and use the energy supplied to their advantage. Photosynthesis and the formation of vitamin D are examples of this.

  The hormesis theory can only be credible when approached from exposure to low levels of natural radiation. For example mutation and recombination are two radiation inducible, evolutionary processes. These processes have been quite important in evolution and it appears that radiation may have played an important role in them. However, it is be arguable that these processes can not be classified as “hormetic” since they are not concerned with unknown mechanisms.
The second is based on the fact that many substances indispensable for proper body function are toxic above certain levels. However, the comparison with chemical agents overlooks the very fact that radiation interaction is quantal in nature and quite different from that of any pharmaceutical with the possible exception of radiomimetics. The basic response is therefore discontinuous. Lowering the dose does not mean “in the low dose region” that all cells receive less radiation but only fewer cells are killed. This is a fundamental difference, which cannot be circumvented.

Many studies researched the hormesis theory and their findings might be supportive of the theory. Table 1.3.4 is a list of few examples of “hormetic” effects, reported for micro-organisms, plants, animals and human beings.

Table 1.3.4 Examples of Radiation Hormesis.

<table>
<thead>
<tr>
<th>Organisms</th>
<th>Response</th>
<th>Dose-level</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human</td>
<td>cellular immunity</td>
<td>&lt;0.5 Gy</td>
<td>Bloom et al., 1987</td>
</tr>
<tr>
<td>Mice</td>
<td>immune reaction</td>
<td>0.025 - 0.1 Gy</td>
<td>Liu S et al., 1987</td>
</tr>
<tr>
<td>Human</td>
<td>cancer incidence</td>
<td>0.3 msv/year</td>
<td>Nambi &amp; Soman, 1987</td>
</tr>
<tr>
<td>Protozoa, bacteria</td>
<td>growth stimulation</td>
<td>&lt;50 mGy/year</td>
<td>Planet et al., 1987</td>
</tr>
<tr>
<td>Plant seeds</td>
<td>growth stimulation</td>
<td>Variable</td>
<td>Sheppard &amp; Regitnic, 1987</td>
</tr>
</tbody>
</table>

However nearly all hormesis authors mentioned in one way or another, that special conditions similar to low levels of natural radiation were necessary for the success of their experiments, and there is a general consensus that those conditions have a poor
chance of reproducibility.

Nevertheless, in certain instances stimulatory effects of low-level radiation are well documented. This is particularly so for early plant growth. Although the mechanism is not clear, this might not necessarily represent “hormesis” but may just be a change of regulation as a consequence of tissue damage. The same applies to findings about improved immune reactions in animals or humans. Another important observation is the reporting of lower cancer incidence in areas with higher natural radiation background. This has to be treated with some caution, due to the considerable statistical and epidemiological difficulties involved.

The most reliable researches would be those conducted on the survivors of the Hiroshima and Nagasaki nuclear bombs, it is to be noted that no beneficial effects of low radiation doses were encountered in any of those researches.

1.3.16 Chromosome Inversions, Translocations and Deficiencies

Exposure to radiation may cause inversions, translocations or deficiencies of the chromosomes of the exposed individual (Hall, 1994).

Figure 1.3.2 illustrates the two ways in which a radical can inflict damage – by a ‘direct hit’ on a point in the chromatid, or by hitting a water molecule thereby causing an outburst of secondary radiation, which strikes the chromatid.
In direct action, a secondary electron resulting from absorption of an x-ray photon interacts with the DNA to produce an effect. In indirect action, the secondary electron interacts with, for example, a water molecule to produce a hydroxyl radical (OH−), which in turn produces the damage to the DNA. The DNA helix has a diameter of about 20 Angström (2 nm). It is estimated that free radicals produced in a cylinder with a diameter double that of the DNA helix can affect the DNA. Indirect action is dominant for sparsely ionising radiation, such as x-rays (Hall, 1994).

Chromosome inversion is a region of the chromosome that has been reversed (Hall, 1994). For example if the normal order of genes is a b d e c f g, a chromosome with genes in the order a b e d c f g would contain an inversion. Inversion is caused by a double break of the chromosome, in this case between b and c and between e and f. Following this there is a rotation of the central section, c d e, through 180 degree and a subsequent fusion with the two ends of the chromosome. Inversions can reduce or
even prevent crossing over between genes in the inverted section of one chromosome and in the corresponding normal sequence of its homologue. In this particular inversion, the c inversion, crossing over is entirely prevented and the b genes will be inherited as a unit (Moore, 1963).

Translocation on the other hand is the attachment of piece of one chromosome to another where deficiencies are the elimination of a section of a chromosome.

The DNA damage most frequently deemed responsible for initiating the lethal effects of ionizing radiation is the double strand break (DSB). A DSB is created when a DNA lesion composed of 2 or more strand breaks effectively cuts a DNA molecule into smaller fragments. All other lesions composed of at least one strand break are called a single strand break (SSB). An idealized schematic contrasting a DSB with two SSBs is shown below in Figure 1.3.3.

**Figure 1.3.3 Strand Breaks.**

![An idealized schematic comparing two single strand breaks (top) and one double strand break (bottom).](Source: Hall 1994)

A double strand break is formed when two or more strand breaks are formed in opposite strands of DNA within about 10 to 20 base pairs of each other. The lines between strands of DNA represent hydrogen bonds between complementary base
pairs.

Because the initial number of double strand breaks created by ionizing radiation is 40 to 100 times higher than the frequency of lethal events, clearly not all double strand breaks are lethal. Additional evidence that double strand breaks are not always lethal includes the fact that cells are capable of rejoining double strand breaks by a process called recombination. Figure 1.3.4 illustrated the optional outcomes of genetic change – in this case, from a virus-induced chromosomal alteration.

**Figure 1.3.4** Outcome options in genetic change.

![Figure 1.3.4](image)


### 1.3.17 Mutations

It is commonly held view that radiation produces bizarre mutants and monsters. This view is ‘absolutely’ false. Radiation does not result in genetic effects that are new or unique but rather increases the frequencies of the same mutations that already occur spontaneously or naturally in that species (Hall, 1994). For example if the biological subject has built in disposition to acquire certain change in structure, exposure to radiation will increase the chances of that disposition to manifest.
1.3.18 Time of Manifestation

The initial Ionisation may take only $10^{15}$ second. The ion radicals have a lifetime of about $10^{10}$ second and the free radicals perhaps $10^{-5}$ second. The step between the breakage of chemical bonds and the expression of the biological effect may be hours, days, months, or years, depending on the consequences involved. If the Radiation damage is oncogenic, its expression as an overt cancer may be delayed 40 years. If it is a mutation, in a germ cell leading to heritable changes, it may not be expressed for many generations (Hall, 1994). It is to be noted that Mitosis might just take one hour where the S phase might be 8 hours.
1.4 RADIATION PHYSICS

1.4.1 Background: Atomic Structure, the Production of Radiation and its Effects

By the early 20th century the atom was pictured as in Image 1 – a nucleus orbited by electrons. Since each atom was electrically neutral, and the electrons were known to be negatively charged, it was deduced that the nucleus must be positively charged. Further, since the weight of the atom often exceeded the weight calculated from its atomic number (the number of electron and proton pairs), it was deduced that the nucleus must also contain additional mass, made up of neutrons, which were themselves composed of a combined electron and proton pair, and consequently neutral.

Figure 1.4.1 Early modern view of the atom

Mendeleev laid out his Table of the Elements based on the chemical properties of each element and similarities that recurred periodically through the list of elements. He predicted several undiscovered elements based on this periodicity, and this behaviour was later found to be dictated by the number of electrons in the atom’s
outer shell.

Through the first half of the 20th century researchers discovered far greater sophistication in atomic structure. Atoms of greater atomic number not only have extra electron-proton pairs, their electrons reside at different energy levels, and have different shaped ‘orbits’. Many further complexities are known, but for this study of radiation production, an awareness of the basics of energy levels and their properties will suffice.

Electrons circle the nucleus in fixed orbits, only with more complex properties than the planets of our solar system. An electron has a natural orbit that it occupies, but if you energize an atom, you can move its electrons to higher orbits, or energy levels. A photon of light is produced whenever an electron in a higher-than-normal orbit falls back to its normal orbit. During the fall from high-energy to normal-energy, the electron emits a photon - a packet of energy - with very specific characteristics. The photon has a frequency, or colour, that exactly matches the distance the electron falls. Different elements absorb only those photons that ‘fit’ the energy jump need of the eligible electron, and ignore photons that do not fit. Likewise, when the electron drops back to its original lower energy level, it emits a photon of that same ‘fit’, e.g. what is seen as the yellow characteristics of sodium light.

If the frequency or energy of an incoming light wave is much higher or much lower than the frequency needed to make the electrons in the material vibrate, then the electrons will not capture the energy of the light, and the wave will pass through the material unchanged. As a result, the material will be transparent to that frequency of light.

If the frequency of the incoming light wave is at or near the vibration frequency of the electrons in the material, it will be absorbed. The electrons take in the energy of the light wave and start to vibrate. What happens next depends upon how tightly the atoms hold on to their electrons. Absorption occurs when the electrons are held tightly, and they pass the vibrations along to the nuclei of the atoms. This makes the atoms speed up, collide with other atoms in the material, and then give up as heat the energy they acquired from the vibrations.

The atoms that make up body tissue absorb visible light photons very well. The
energy level of the photon fits with various energy differences between electron positions. Radio waves do not have enough energy to move electrons between orbits in larger atoms, so they pass through most materials. X-ray photons also pass through most things, but for the opposite reason: they have too much energy.

They can, however, knock an electron away from an atom altogether. Some of the energy from the X-ray photon works to separate the electron from the atom, and the rest sends the electron flying through space – the process of ionization. A larger atom is more likely to absorb an X-ray photon in this way, because larger atoms have greater energy differences between orbits - the energy level needed for the ‘jump’ more closely matches the energy of the photon. Smaller atoms, where the electron orbits are separated by relatively low jumps in energy, are less likely to absorb X-ray photons.

The soft body tissues are composed of smaller atoms, and so do not absorb X-ray photons particularly well. The calcium atoms that make up bones are much larger, so they are better at absorbing X-ray photons. This differential is what makes the traditional negative-image x-ray photograph.

All radioactive emissions are dangerous to living things. Alpha particles, beta particles, neutrons, gamma rays and cosmic rays are all known as ionizing radiation, meaning that when these rays interact with an atom they can ‘knock off’ an orbital electron. The loss of an electron can cause problems, including everything from cell death to genetic mutations (leading to cancer), in any living thing.

Because alpha particles are large, they cannot penetrate very far into matter. They cannot penetrate a sheet of paper, for example, so when they are outside the body they have no effect. Beta particles penetrate a more deeply, but again are only dangerous if eaten or inhaled; beta particles can be stopped by a sheet of aluminium foil or Plexiglas. Gamma rays, like X-rays, are stopped by lead.

Neutrons, because they lack charge, penetrate very deeply, and are best stopped by extremely thick layers of concrete or liquids like water or fuel oil. Gamma rays and neutrons, because they are so penetrating, can have severe effects on the cells of humans and other animals.
Reproduction of all living things depends on the ability to faithfully reproduce the genetic blueprint that is encoded in DNA strands. Just as computer information is digitized as strings of zeros and ones, genetic information is encoded in sets of three ‘bases’ each made up of various combinations of four amino acids. This encoding exists at a molecular level, and sometimes the molecular strands are damaged and break. Ionizing radiation can bring about this damage, amongst other causes.

When a strand breaks, either completely or partially, the cell applies its own mechanisms to repair it; sometimes it succeeds. If it does not succeed, and should the damage to the genetic message be lethal, the cell will not be able to reproduce. If the genetic message is changed so that reproduction produces a viable but somewhat modified life form, then that mutation is eligible to compete with its peers, either to prove itself more successful than they (evolution), or less successful, in which case the mutation most likely becomes extinct. This same evolutionary process applies at cellular level, at organ level, at individual level – and indeed at societal level.

In our human bodies, a mutated cell may become an improved feeder, or colonizer, in terms of its original form. It can propagate and grow faster and bigger than before; it can parasitise other organs, or infect them, or block blood flow to or from them. Unfortunately, our bodies usually cannot tolerate such radical changes in the status quo, and we suffer because of them. This is cancer.

1.4.2 Radiation Definition

Radiation is the movement, or propagation, of energy from one place to another. It is grouped into three general categories: electromagnetic, mechanical, and particle radiation.

1.4.2.1 Electromagnetic radiation is the transport of energy without the necessary intervention of a transporting medium. This may be accomplished either by electromagnetic waves or by particles, e.g. electrons, neutrons or ions. Sunlight and x-rays are the best known examples of electromagnetic radiation.

1.4.2.2 Particle radiation is the result of particle collision, fusion or of the natural
decomposition (fission) of a radioactive material such as plutonium. In such events, particles, something with a mass such as that of a helium nucleus (alpha ray) or an electron (beta ray) are physically projected from one place to another. Particle radiation is similar to EM radiation in that it can travel through a vacuum. This form of energy moves less freely through a physical medium; particles frequently collide with one another, often losing their energy in the process. This class of radiation is employed in Nuclear medicine.

1.4.2.3. **Mechanical radiation** requires a material medium to propagate energy from one place to another. For example, sound, produced by vibration, cannot travel through a vacuum but does travel freely through gases, liquids, or solids. Ultrasound and magnetic resonance imaging are examples of mechanical radiation (Taylor, 1994) Electromagnetic and Particle radiation are known as ionizing radiation whereas Mechanical radiation is known as non-ionizing radiation.

In our daily lives, we are continuously exposed to radiation from many sources, such as the sun’s rays, radio and TV transmissions etc. This paper is concerned with ionizing radiation, which can be harmful, and has multiple sources. The largest source is natural background radiation from external and internal sources over which we have no control.

1.4.3 **Natural External Sources**

1.4.3.1 **Cosmic Rays**

Primary cosmic rays, arising in the sun and other stars, consist mainly of high energy photons (more than 2.5 billion electron volts), but also include alpha particles, atomic nuclei and high energy electrons and photons.
Secondary cosmic rays are produced by interaction of primary cosmic rays with nuclei in the earth’s atmosphere and consist mainly of mesons (a type of nuclear particle), electrons, and gamma rays. Most cosmic rays observed in the laboratory are of the secondary type. They are so penetrating that they can pass through lead many meters thick.

1.4.3.2 Terrestrial Radiation

Terrestrial radiation includes that from naturally radioactive minerals in the earth itself. These occur in minute amounts almost everywhere in the earth’s crust, including building materials (bricks and concrete) and in larger amounts where the minerals of uranium, thorium, and actinium have been deposited. It must be emphasized that terrestrial background radiation varies from place to place; for example, in Kerala, India, it is about twenty times greater than that in most parts of the United States (Curry et al., 1990).

1.4.3.3 Natural Interaction

A third external source of natural radiation comprises radionuclides produced by interaction of cosmic rays with nuclides in the earth’s atmosphere. The main products are carbon 14 and hydrogen 3 (tritium) resulting from the capture of slow cosmic ray neutrons by stable atmospheric nitrogen; and krypton 81 from a similar reaction with stable krypton.

1.4.3.4 Internal Sources

Internal sources include naturally radioactive nuclides incorporated in the tissues of the body. There are two groups of these radionuclides; those that are ingested in food and water and those that are inhaled. The main naturally radioactive nuclides are potassium 40, carbon 14, and strontium 90. Among natural sources, inhaled radon
(with radon decay products) is the largest contributor to the average annual effective dose equivalent Internal Sources (Curry et al., 1990).

Table 1.4.1 The annual effective dose equivalent in the U.S. population.

<table>
<thead>
<tr>
<th>SOURCE OF RADIATION</th>
<th>ANNUAL DOSE (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Radiation</td>
<td></td>
</tr>
<tr>
<td>External</td>
<td></td>
</tr>
<tr>
<td>Cosmic</td>
<td>.26</td>
</tr>
<tr>
<td>Gamma</td>
<td>.28</td>
</tr>
<tr>
<td>Internal</td>
<td></td>
</tr>
<tr>
<td>In the body</td>
<td>.39</td>
</tr>
<tr>
<td>Inhaled</td>
<td>2.00</td>
</tr>
<tr>
<td>Medical Procedures</td>
<td>.53</td>
</tr>
</tbody>
</table>

1 mSv = 100 mrem

Source: Curry et al., 1990

1.4.4 Ionization – Excitation

Molecules are formed by Chemical Bond known as Ionic Bond or by covalent Bond. Disruption of the ionic structure by ionisation of any of the atoms forming the bond will change the nature of the molecule therefore affecting its role in the structure of an organ and its role in the human body.

Figure 1.4.2 Formation of water molecule

Source: Selman, 1980
Ionization is the process in which one or more electrons are added to or removed from atoms, creating ions.

**Figure 1.4.3 Dislocation of an electron by a Photon**

![Dislocation of an electron by a Photon](image)

Source: Selman, 1980

**Figure 1.4.4 Dislocation of an electron from the inner Shell by a Photon**

![Dislocation of an electron from the inner Shell by a Photon](image)

Source: Selman, 1980

In matter, electrons have regular places in the structure of atoms, molecules or ions. Supplying an atom with a quantity of energy greater than the energy of the intra-molecular binding will detach an electron and the atom will become positively charged, because one of its nuclear charges becomes unbalanced and the atom will
have an excess of positive electricity. That can be caused by a photon travelling at
light speed hitting an inner shell of an atom, dislocating an electron.

Meanwhile the removed electron may ionize other atoms, combine with neutral
atoms to produce negative ions, or recombine with positive ions to form neutral
atoms (Taylor, 1994). Not all electrons in an atom will dislocate and become
scattered. However, a scattered photon might still have the ability to dislocate
another electron within another atom.

**Figure 1.4.5** Dislocation of an electron by a scattered Photon

![Dislocation of an electron by a scattered Photon](source: Selman, 1980)

Excitation on the other hand occurs when an atom is supplied with a quantity of
energy lower than the energy of the intra-molecular binding; thus an electron can be
moved into a more external orbit. For example in an atom of hydrogen, the electron
can be carried from K shell into the L shell by providing it with an energy of 10.2eV.

“The ionizing or excitation of a cellular atom causes physical perturbations
leading to physico-chemical reactions, then chemical reactions and finally the
biological effects.” (Tubiana, 1990)

It must be emphasized that there are only two ways to produce ionizing radiations:
• **Acceleration** of charged particles, which may then react with suitable targets to yield secondary radiations. For example, x-rays in medical imaging.

• Use of *radioactive nuclei*. For example, radioactivity elements in nuclear medicine.

### 1.4.5 Transmutation reactions

Before the discovery of radioactivity, scientists thought that the atoms were indestructible, and although atoms might combine and recombine in endless chemical compounds, each atom always remained the same throughout all the changes. (Taylor, 1994)

After the discovery of radioactivity, researchers **proved that transmutation reactions can occur by the irradiation of stable elements**. For example, ordinary sulfur can be converted by neutron bombardment into radioactive phosphorus (Selman, 1980).

**Table 1.4.2** The conversion of ordinary sulfur to radioactive phosphorus

<table>
<thead>
<tr>
<th>Sulfur + neutron + phosphorus + hydrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>(stable)</td>
</tr>
<tr>
<td>---------------------------</td>
</tr>
<tr>
<td>32</td>
</tr>
<tr>
<td>32</td>
</tr>
<tr>
<td>S + n &gt; P + H</td>
</tr>
<tr>
<td>15</td>
</tr>
</tbody>
</table>

**Source: Selman, 1980**

In each term of the equation, the lower number or subscript represents the atomic
number, and the upper number or superscript represents the mass number. The sum on one side of the equation is equal to that on the other side. The same holds true for the subscripts. Knowing that the atomic number of phosphorus is always 15, we can represent radioactive phosphorus as \( ^{32}\text{P} \), since it has a specific number of protons (15) and neutrons (17) in its nucleus. It is an example of a radionuclide or radioactive nuclide. When \( ^{32}\text{P} \) is formed, its nucleus is unstable because of the extra neutron, (ordinary non-radioactive phosphorus is \( ^{31}\text{P} \)) and it therefore disintegrates into ordinary sulfur, emitting a beta particle (negative electron) in the process:

\[ ^{32}\text{P} \rightarrow ^{32}\text{S} + e^- + \nu \]

<table>
<thead>
<tr>
<th>32-Phosphorus</th>
<th>Sulfur</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>P .</td>
<td>S</td>
</tr>
<tr>
<td>15</td>
<td>16</td>
</tr>
</tbody>
</table>

beta particle    antineutrino

**Table 1.4.3** Inability to alter the type of radiation emitted by a given radionuclide, natural or artificial.

It is to be noted that at the present time, there is no way of altering the type of radiation emitted by a given radionuclide, natural or artificial (Selman, 1980).

### 1.4.6 Electromagnetic Radiation & Wavelength Frequencies

Atoms can absorb energy in many different forms from exterior sources; for example, heat and X-rays are both absorbed by matter. After absorbing such energy, the atom is in a state of excitation and may return to its normal state, by shedding the excess energy in a form similar to that absorbed. The energy absorbed by atoms and emitted in this way is called electromagnetic radiation. This term is used because the
energy which is radiated, in such forms as heat, light or X-rays, is always accompanied by electrical and magnetic fields, which have directions at right angles to the direction in which the radiation is travelling.

An x-ray beam consists of a group of rays, which are related to visible light, ultraviolet, infrared, and other similar types of radiant energy. They are all classified as electromagnetic radiation, wavelike fluctuations of electric and magnetic fields set up by oscillating (vibrating) electrons, similar to the waves on the surface of water produced by a stone dropped into the water.

Electric and magnetic fields fluctuate perpendicularly to their direction as well as to each other, as shown diagrammatically in Figure 1.4.6. Since they are identical in form, only one of them is usually depicted as in Figure 1.4.7.

All electromagnetic waves, including radio, heat, light, x-rays, gamma rays, and others, have the same general form and travel with the same constant speed as light (335,000 km / 186,000 miles per sec in a vacuum). However, they differ in wavelength, that is, the distance between two successive crests in the wave, such as A to B in Figure 1.4.7. The number of crests or cycles per second is the frequency of the wave, the unit of frequency being the hertz. One Hertz is equal to one cycle per sec.
Figure 1.4.6 The electrical and magnetic components of an electromagnetic wave.

Electromagnetic wave oscillate (vibrate) in mutually perpendicular planes.
Source: Selman, 1980.

Figure 1.4.7 Electromagnetic waves.

The upper and lower wave trains differ in wavelength, that is, the distance between two crests such as A to B and A’ to B’. The lower wave thus has a shorter wavelength and therefore more crests or cycles in a given period of time, than does the upper wave, because their speeds are identical. Thus, the wave with the shorter wavelength has frequency or number of cycles per sec hertz.
Source: Selman, 1980

By comparing the upper and lower waves in Figures 1.4.7, if the wavelength is deceased, the frequency must increase correspondingly.
The frequency is inversely proportional to the wavelength (Selman, 1980).

The wavelengths of x-rays are extremely short; for instance, in ordinary radiography, the useful range of x-ray wavelength is about 0.1 to 0.5 Å (Å being Angstrom units; 1Å equals 1cm x 10^-8 or one hundred millionth of a cm). Because of the extremely short wavelengths of x-rays, their frequencies are large 3 x 10^8 to 6 x 10^18 hertz (Hz).

The various types of electromagnetic waves, ranging from radio waves with wavelengths measured in several thousand meters, down to gamma rays with wavelengths in thousands of an Å, are shown with their wavelengths in Figure 1.4.8

**Figure 1.4.8:** The Electromagnetic spectrum.

![Electromagnetic spectrum diagram](image)

### 1.4.7 X-Radiation

Whenever a stream of fast moving electrons suddenly undergoes deceleration or electrons drop from an outer shell to a hole in an inner atomic shell, x-rays are produced. While these conditions may prevail in nature, they can be brought about artificially by means of an x-ray tube (Curry et al., 1990)

The x-ray tube is a device for obtaining free electrons, first speeding them up, and finally arresting them. The efficiency of ordinary radiographic equipment is such that
at 80 k V only about 0.6 percent of the energy produced is converted into x-rays while the remaining 99.4 percent appears as heat. The useful beam used for imaging purposes comprises only of those photons leaving the window of the x-ray tube, which is in fact about one part in a thousand of the kinetic energy of the electrons produced.

According to Max Planck in 1900 radiation waves are emitted intermittently in burst. Each discrete quantity of energy is called a quantum. Light, x-radiation and gamma radiations are regarded as streams of high-energy quanta or particles, rather than as waves. In radiation physics, quanta are called photons (Jaundrell-Thompson, 1970).

1.4.8 Scattered and Secondary Radiation

Scattered radiation refers to those x-ray photons that have undergone a change in direction after interacting with atoms. Secondary radiation is emitted by atoms after having absorbed x-rays.

It must be emphasized that many of the x-rays do not interact with atoms at all, but pass through the body unchanged (Selman, 1980). This results from two factors:

X-rays are electrical neutral so there is no electric force between them and orbital electrons,

Atoms contain mainly empty space.

1.4.9 Radiation Intensity

Intensity of radiation is defined as the quantity of energy flowing per unit time through unit area of a surface normal to the direction in which the energy is propagated. Intensity can therefore be measured either in ergs per square Centimetre per second, or in quanta of a given energy per centimetre per second.
(Erg is the work unit of the Centimetre-Gram-Second (CGS) system of units, and it is the work done by unit force (1 dyne) when it moves its point of application through unit distance (1 cm). 1 joule = 107 ergs.)
1.5 DOSE MEASUREMENT

Due to the exact relationship between energy and heat, the most direct way of measuring the intensity of radiation would be to measure the temperature rise in a suitable medium in which an exactly defined beam (known area) is completely absorbed. This would give the energy per unit area and would be called a calorimetric system of measurement. Calorimetry is not a very convenient method for routine clinical application, because the temperature rise produced by radiation intensities in common use is small. To accurately measure such small temperature rises requires the use of instruments with an inconvenient degree of sensitivity and complexity (Jaundrell-Thompson, 1970)

When a measurement of the intensity of radiation at a given point is required, a slightly less direct method, but one employing another of the effects of radiation, is usually preferred. Any effect could be chosen, but the three most commonly applied are the ionization of air, the photographic effect and the production of fluorescent light. The photographic and fluorescent effects are themselves fundamentally due to ionization.

There is a certain degree of discrepancy between true intensity and intensity as measured by the effects of radiation. The degree or amount of any such effect depends only on the amount of radiation absorbed and since, in most cases, not all the radiation arriving at a point is absorbed there, the true intensity may be greater than indicated by the resulting effect. The magnitude of effects such as the ionization of air or the blackening of photographic emulsions depends to a considerable extent on the absorption of energy from secondary sources, such as the electrons released in...
the ionization produced by photons of radiation. The energy absorbed also depends to some extent on the quality of radiation, and this may vary, even if the true intensity remains constant.

1.5.1 Dose Measurement in Clinical Practice

These sources of discrepancy are not necessarily a disadvantage in the radiation measurements required in clinical practice, as such measurements are in any case usually required in order to assess the effect, biological or photographic for example, possessed by radiation. It is therefore the absorbed energy, including that from secondary electrons that are of interest. Any difference between the energy absorption of the measuring system and that of the absorbing medium under consideration must be known and compensated for.

The measurement of radiation by one of the effects produced is therefore suitable for medical applications, such as x-ray or similar radiation. The magnitude of the effect chosen as a basis for a system of measurement must of course be known to be proportional to the absorbed energy. It is also desirable that the material in which the measured effect is produced (air for example), should absorb radiation in a manner close to, or similar to that, of the material to which the radiation is applied in practice, which is usually living cellular tissue.

In order to distinguish between true intensity, and intensity as indicated by measurement of absorption, the term dose-rate is used. If the dose-rate is constant, the product of this and the time provides the total amount of energy absorbed. This is called the absorbed dose (Tubiana, 1990), or simply ‘the dose’. Since in medical practice radiation is applied to volumes and not to planes, it is more realistic to consider the dose absorbed by unit mass rather than by unit area. Absorbed dose is
therefore defined as the energy imparted to matter per unit mass.

1.5.2 Radiation Dosimetry – Definitions

- **Air dose**
  Air dose is the dose measured at a specific point in air, in the absence of scattering from a denser medium.

- **Threshold dose**
  Threshold dose is the smallest dose that will produce a given effect.

- **Depth dose**
  Depth dose is the dose measured at a specified point below the irradiated surface.

- **Percentage depth dose**
  Depth expressed as a percentage of the field dose or skin dose.

- **Tumour dose**
  The dose delivered to the treated tumour.

- **Exit dose**
  Exit dose is the dose at the point where radiation emerges from the irradiated tissues.

- **Maximum permissible dose (MPD)**
  MPD is the maximum dose which an individual is permitted to receive in a specified period, and which is considered, so far as is known, to produce no harmful effect. It is applied particularly to persons ‘occupationally exposed’ to ionizing radiations for indefinitely long periods.

- **Integral dose**
  The amount of radiation energy absorbed by the body as a whole.
• **Isodose curves or charts**
  A series of lines on a chart, drawn through points in the tissues where the dose is the same.

• **Field dose**
  The dose of radiation given to a surface area, usually including radiation back-scattered to the surface from deeper tissues.

• **Skin dose**
  The dose received at a point on the skin, including back-scattered radiation.

• **Exposure dose**
  The dose at a specified point expressed as the ionization it produces per unit mass of air.

• **Effective dose equivalent (HE)**
  The purpose of the effective dose equivalent is to relate exposure to risk. Risk assessment is in some way related to the absorbed dose. This risk cannot be a simple linear function of just the absorbed dose, since irradiation from the external environment affects the entire body, whereas medical diagnostic procedures generally affect only selected areas of the body.

• **Genetically significant dose (GSD)**
  GSD is the dose that, if received by every member of the population, would be expected to produce the same total genetic injury as the actual doses received by the various individuals. For example, if the world population consisted of 1,000 individuals and each received a radiation dose of 0.1 rem, the genetic effect would be the same as if 10 individuals received 10 rem and the other 990 received nothing:

\[
1000 \times 0.1 = (10 \times 10) + (990 \times 0)
\]
The concept implies that the effect of large exposure to a few individuals is greatly diluted by the total population and thus has little overall genetic impact. Radiation workers may receive relatively large exposure without significantly changing the population’s genetically significant dose (Curry et al., 1990)

- **Relative biologic effectiveness (RBE)**

  The RBE is another expression used to compare the effectiveness of several types of radiation. It must be determined for each type of radiation and biologic system and, by convention, is reserved for laboratory investigation.

### 1.5.3 ALARA Principle

The International Commission on Radiological Protection (ICRP) recommends a system that includes three elements for limiting the dose received (Osborne, 2006).

- **Justification,**
- **Optimization,**
- **Dose limitation.**

With Justification, any activity that may cause exposure to persons should yield a benefit to society that justifies the risks incurred by the radiation exposure. Dose limitation sets upper limits on the dose that may be received by members of the public from all man-made exposures other than medical exposures. However, for optimization, the practice of ALARA (as low as reasonably achievable), radiation exposures must be reduced to the lowest level achievable, that is the test must be diagnostic and the dose applied should be as a low as possible in order to achieve this. Optimization, or ALARA, is required by many licensing agencies, for example the Nuclear Regulatory Commission. In the nuclear industry application of ALARA is more complex that in Medical Radiology. Optimization plays an
essential role in practice, and dose limits may actually play a ‘very’ secondary role, being used as guidance for setting action levels and other operating parameters.
1.6 RADIATION UNITS

1.6.1 Measurements by Air Ionization

The ionization of air is still the most widely applied method of measuring radiation dose and dose-rate. The method depends upon the collection of the electric charges, electrons or positive ions, due to the ionization of air by the photons of radiation and by the resulting secondary electrons or other ionizing particles. Exposure dose-rate (or alternatively exposure rate) is measured by instruments that register the electric current due to the continuous collection of the charges in the air between a pair of electrodes. Exposure dose (or alternatively exposure) is measured by instruments that register the loss of charge, or fall in potential of a capacitor using air as the dielectric medium.

The unit of exposure dose (or exposure) is the Roentgen. (Roentgen discovered x-rays). Since 1962, the symbol for the roentgen has been the letter R.

The roentgen is defined as that quantity of x or gamma radiation such that the associated corpuscular emission per 0.001293gm of air produces, in air, ions carrying one electrostatic unit of quantity of electricity of either sign (Juandrell & Thompson, 1970).

The following conditions are applicable to Roentgen’s definition:

The roentgen is a unit of quantity that measures exposure dose, or exposure dose-rate. Exposure dose-rate or exposure rate is measured in R per second (or per minute)

It applies specifically to X and gamma radiations, and not to other types of ionising radiation of particles.
‘Associated corpuscular emission’ means that the measuring instrument must collect and record from the stated mass of air, all the electric charge due to the absorption of energy from the radiation. It must therefore include the electrons or positive ions, which are due to the ionization by secondary electrons, ejected when photons of radiation are absorbed, and which in fact, contribute the largest fraction of the total charge registered.

0.001293gm of air is the mass of 1cc (unit volume) of dry air at 0°C and 760mm Hg barometric pressure. The amount of ionization produced in unit volume of air depends upon the number of gas molecules present. This number depends on the density of the air, and would for example, be smaller at higher temperature or lower pressure. Defined in a way the unit is therefore independent of atmospheric conditions.

The definition implies that the roentgen is a measurement of ionization in air, and in no other absorbing medium.

‘One electrostatic unit of quantity of electricity of either sign’ indicates that the measuring instrument can be designed to record the collection of either positive or negative electric charge. The most usual submultiples of the roentgen are the milliroentgen (=1/1,000 R or mR) and the microroentgen (1/1,000,000 R).

It is to be noted that:

The substitution of air, in place of tissue, as the medium in which exposure dose measurements are made in practice, and in terms in which the roentgen is defined, is justified because the roentgen is a measure of energy absorbed from radiation. In addition, the biological effect of radiation of a particular energy is closely related to
the energy absorbed by tissue (Juandrell & Thompson, 1970).

It is also essential to avoid confusion between exposure in the sense of exposure dose, and exposure in the sense of radiographic exposure factors. Exposure factors include the kVp and mA (or mAs) which are to be used for the generation of x-rays in the tube, the length of time for which they are to be applied, and the focus-film distance to be used (Juandrell & Thompson, 1970).

Furthermore, it does not follow that tissue cells, or any other medium, would absorb the same quantity of energy as that given by the exposure dose. Nor does it follow that the biological effect on the cells will be the same regardless of the type of energy to which they have been exposed. Other units of measurements are therefore desirable, and these are discussed in the following sections.

1.6.2 Other units of Radiation Measurement

1.6.2.1 The Rad

The Rad (radiation-absorbed dose) is defined as the absorbed dose of any radiation when the energy transferred to the irradiated material at the place of interest is 100 ergs per gram. The most frequently used submultiple is the millirad (1 mrad =1/1,000 rad). It should be noted that this unit is defined specifically in terms of fundamental units of energy (ergs) absorbed by material, usually tissue. It is therefore a true measure of absorbed energy. In addition, its definition does not restrict its use to any particular type or energy of radiation.

1.6.2.2 The Gray (Gy)

The Gray is the unit of choice of the International System of units (SI) for the absorbed dose. Named after Louis Harold Gray (1905-1965), the principle is now
known as the Bragg-Gray.

One Gy is defined to be the radiation necessary to deposit energy of one joule in one kilogram of tissue (Gy = J/kg). The relationship between the Gy and the rad is:

\[ 1 \text{ Gy} = 100 \text{ rads} \]
\[ 1 \text{ rad} = 1 \text{ cGy (centigray)} \]

Values of absorbed dose are being increasingly reported in the literature in terms of the cGy, which in fact is the same as the rad.

The absorbed dose is independent of the compositions of the radiated material and energy of the beam. The number of rads (cGy) deposited per roentgen of exposure, however, varies both with energy of the beam and with the composition of the absorber (Table 1.10). The energy deposited in soft tissue per roentgen is approximately 95 erg/g in the diagnostic energy range. It may be five times as much in bone at low energies and actually a little less than 95 erg/g at 1 MeV. As a general rule, the absorbed dose is proportional to the degree of attenuation (Curry et al., 1990).

**Table 1.6.1 Approximate Absorbed Dose (RAD) per Roentgen Exposure.**

<table>
<thead>
<tr>
<th>Type of Tissue</th>
<th>50 kVp</th>
<th>1 MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft Tissue</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>Bone</td>
<td>5.0</td>
<td>0.90</td>
</tr>
</tbody>
</table>

**Source:** Curry et al., 1990.

The rad or cGy is a more satisfactory unit than the roentgen for use with high energy radiation, because the energy lost by such radiation within a specified region of an absorbing medium may not be equal to the total energy absorbed in that region. This may appear to be paradoxical, but it is due to energy being absorbed from secondary...
electrons which are ejected when photons of radiation interact with atoms of the absorber.

1.6.2.3 The rem
The rem is a unit of absorbed dose equivalent. It is used to measure the biologic effect of irradiation, and it is only used in radiation protection.

1.6.2.4 The Sievert (Sv)
The SI unit of absorbed dose equivalent is the Sievert (in honor of the Swedish scientist active in the ICRP for many years). The relationship between the sievert (Sv) and the rem is:

\[ 1 \text{ sievert (Sv)} = 100 \text{ rems} \]

The absorbed dose equivalent is equal to the absorbed dose multiplied by a quality factor (QF):

\[ \text{Rem} = \text{rads} \times \text{quality factor} \]

Some practical quality factors are shown in Table 1.11. These are only approximations; the actual numbers depend on the energy of the beam. Since the quality factor for x-rays is 1, the rad and rem are equal. In fact, at diagnostic energy levels the rad, rem, and roentgen may all be considered to be equal, because the energy deposited in soft tissues by 1 R of exposure is only 5% more than a rad:

\[ 1 \text{R} \sim 1 \text{rad} = \text{rem}. \]
Table 1.6.2 Recommended Quality Factor Values for Various Types of radiation.

<table>
<thead>
<tr>
<th>TYPE OF RADIATION</th>
<th>APPROXIMATE VALUE OF QUALITY FACTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-rays</td>
<td>1</td>
</tr>
<tr>
<td>Gamma Rays</td>
<td>1</td>
</tr>
<tr>
<td>Beta particles</td>
<td>1</td>
</tr>
<tr>
<td>Electrons</td>
<td>1</td>
</tr>
<tr>
<td>Thermal neutrons</td>
<td>5</td>
</tr>
<tr>
<td>Other neutrons*</td>
<td>20</td>
</tr>
<tr>
<td>Protons*</td>
<td>20</td>
</tr>
<tr>
<td>Alpha particles</td>
<td>20</td>
</tr>
</tbody>
</table>

Source: Curry et al., 1990.

*These are the worst-case (maximum) values. Since Q is a function of particle type and energy, Q values for a particular particle may be significantly lower.

1.6.3 Linear Energy Transfer (LET).

X-rays and beta particles have the same quality factor. That is because a beta particle is a moving electron and the ‘end’ product of x-ray attenuation is also a moving electron. They are used as the standard, and assigned a quality factor of 1. Larger particles deposit more energy per unit length of travel. The amount of energy deposited per unit length of travel, expressed in keV per micron, is called the linear energy transfer. If an electron and proton start with the same energy, the proton will be attenuated more quickly. Because of the proton’s large size, it encounters more “friction” as it passes between atoms. Having started with the same amount of energy as the electron, the proton deposits more energy per unit length of travel, so it is a higher LET radiation. The linear energy transfer of the radiation determines the amount of biologic damage. A tissue absorbing 100 rads of thermal neutron radiation sustains five times as much biologic damage as a tissue absorbing the same quantity.
of x-rays. Thus, thermal neutrons have a quality factor of 5. For radiation protection purposes the quality factor is multiplied by the absorbed dose in rads to determine the dose equivalent in rems.
1.7 BIOLOGICAL EFFECTS

Radiation is the longest known and best understood mutagenic agent present in the environment (Tubiana et al., 1990). The propensity of radiation to cause biological effects became known to scientists as early as the year 1927 (Moore, 1963). Muller (1927) in his experiment to test the effects of x-rays on the induction of mutation in Drosophila demonstrated that exposure to radiation could cause gene mutation as well as inducing lethal mutation in 1 per 1,000 of the exposed population. Muller’s experiment also proved that radiation would cause inversions, translocations or deficiencies in the genes of the exposed creature.

Muller’s experiment demonstrated that mutation could be produced artificially by exposing living creatures to radiation. As a result, the medical profession in general became careful about exposing patients and physicians to radiation and it became evident that guidelines were required to prevent the unskilled and untrained usage of radiation. The first radioprotection guidelines came into effect in 1937, and since then governments regulated the professions involved and precautionary measures became more stringent (EPA, 1993).

1.7.1 The Biological Effects at a cellular level

Radiation has different effects on cellular materials such as lipids, proteins and enzymes. Lipids for example are highly sensitive to radiation, especially those with unsaturated fatty acid components containing double bonds. Enzymes can be inactivated by exposure to radiation, whereas carbohydrates may suffer chain breaking or degradation.

Radiation would also affect energy metabolism causing the phosphorylation or
adenosine triphosphate production to be reduced in certain cells. Radiation might also cause the uncoupling of phosphorylation from oxidation, which has been considered by some investigators to be one of the primary effects of radiation that can result in the death of the cell (Casarett, 1968).

The main radiobiological concern is the sensitivity of genetic material to exposure to radiation. At specific DNA sites, involved in the initial events that result in malignant transformations, there is no threshold for the induction of the molecular changes, which can ultimately become cancerous (Casarett, 1968). In humans, the period between exposure to radiation and recognition of a cancer may take a number of years. This latency period may be about 8 years in the case of induced leukaemia and two or three times longer in the case of many induced solid tumours such as those of the breast or lung (Tubiana et al., 1990).

1.7.2 Chromosomal Aberrations

Irradiating germinal cells can cause mutations and chromosomal aberrations. From a biochemical point of view, structural changes in chromosomes can be induced at any stage of their mitotic cycle. They can easily be seen microscopically when cells are in metaphase or anaphase stages of division. Aberrations have been classified according to the portions of the chromosome, which appear to have been involved in the initial alterations. Thus, a Chromosome type aberration involves both chromatids of a chromosome at identical loci and acts as if it is the result of a single break in the chromosome, before it has replicated into chromatids. In this situation both chromatids of a chromosome are affected identically. A chromatid type aberration appears to be the result of a change in an individual chromatid after replication has taken place. These are produced by irradiation of chromosomes, which are either
visibly separated into chromatids or act as if they were separated. Subchromatid aberrations involve changes in only part of individual chromatids (Tubiana et al., 1990). These aberrations could be interpreted as chromosomal aberrations and should they occur, they will be significant if transmitted to become manifest as hereditary disorders in the descendants of the exposed individual.

Chromosomes are the primary information system of a cell. The sequence of bases on the DNA molecules constitutes the code for this information system, which directs the formation of all other cellular constituents.

If a portion of a chromosome is broken, inverted, or exchanged, the cell might still survive since it still has a full quantity of DNA. However, when the linear base sequence has been altered at a critical point, certain information will not be available to the cell. When the cell is unable to form certain structural elements or enzymes that are required, cell function might eventually be impaired. If division occurs in a cell which contains fragments or exchanges, some of the genetic information will not be transmitted to the daughter cells. This may be immediately lethal or may cause dysfunction or death at a later period.

Seriously harmful effects such as dominant mutations leading to genetic disease and chromosomal aberrations would predominantly occur in the first and second generations after exposure. Recessive mutations would contribute to the general pool of genetic damage in subsequent generations.

1.7.3 Biological Effects on DNA

The biologically important interaction of radiation with matter is ionization. The ionization process causes biological damage either by directly disrupting molecular bonds in sensitive cellular material such as deoxyribonucleic acid (DNA), cell
membranes or indirectly through the production of energetic molecular species, such as oxygen radicals, which disrupt molecular bonds. The following is a list of various kinds of damage that radiation may produce in DNA (Casarett, 1968).

Table 1.7.1: The different kinds of damage which radiation may produce in DNA.

<table>
<thead>
<tr>
<th>1. Change of a base (for example, deamination)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Loss of a base</td>
</tr>
<tr>
<td>3. Hydrogen bond breakage between chains</td>
</tr>
<tr>
<td>4. Single-strand fracture</td>
</tr>
<tr>
<td>5. Double-strand fracture (both chains simultaneously)</td>
</tr>
<tr>
<td>6. Crosslinking within the helix</td>
</tr>
<tr>
<td>7. Crosslinking to other DNA molecules</td>
</tr>
<tr>
<td>8. Crosslinking to protein</td>
</tr>
</tbody>
</table>


1.7.4 Cellular Damage Repair

Most radiation damage is thought to be repaired by cellular mechanisms or dealt with by inbuilt redundancies in the DNA. However, some cells die or loose the ability to replicate and very small fractions remain viable with altered function. The severity of the effect produced depends upon dose, dose rate, chemical environment, metabolic rate and other factors (Tubiana et al., 1990).

The magnitude of the effects of insults on tissues and organs from noxious agents is influenced by the particular tissue and its ability to compensate and repair damage. This ability is dependent upon age at exposure and the health status of the patient. The organs in the human body are more prone to be effected by the insults of radiation when the patient is sick (which unfortunately is when the patient receives necessary and unnecessary x-radiation), sex and genetic disposition of the individual.
Therefore, responses to these insults vary amongst individuals in a population exposed to pernicious environmental factors, especially radiation.

1.7.5 Biological Effects on Organs

Organs in which cells divide rapidly are generally more sensitive to radiation damage, for example, the epithelium of the intestine and bone marrow. In addition, cellular repair mechanisms are less effective during mitosis (Tubiana et al., 1990).

1.7.6 Biological Effects during pregnancy

The effects on the foetus of exposure to radiation depend on the time of the exposure relative to conception. Exposure to the embryo in the first 3 weeks following conception is not likely to result in deterministic or stochastic effects in the live born child, despite the fact that the central nervous system is beginning to develop in the third week. During the rest of the period of major organogenesis - from the start of the third week after conception - malformations may be caused in the organ under development at the time of the exposure. These effects are deterministic in character with a threshold, estimated from animal experiments, to be about 0.1 Gy. From three weeks after conception to term, it is likely that radiation exposure can cause stochastic effects in the live born. ICRP assumes that the nominal fatality probability coefficient is, at most, a few times that for the population as a whole.

For children exposed in utero at Hiroshima and Nagasaki there have been two principal quantitative findings. The first shows a reduction of about 30 intelligence points per Sv for exposures between 8 to 15 weeks after conception. A smaller reduction is detectable arising from exposure between 16 to 25 weeks, appearing to be a deterministic effect with a threshold determined by the minimum shift of intelligence that can be clinically recognised. The second finding is of a dose-related
increase in the frequency of children classified as 'severely retarded'. The number of cases is small, but the data indicates an excess probability of severe mental retardation of 0.4 at 1 Sv. All observations on intelligence and severe mental retardation relate to high dose and high dose rates, their direct use probably overestimates the risks (UNSCER, 1988).

1.7.7 Gonads

Table 1.7.2 indicates average gonad doses received during various procedures. The large difference between males and females results from the shielding of ovaries by overlying tissue. The weighted average gonad dose to the general population is used to estimate the GSD.

Table 1.7.2: Approximate Gonad Doses resulting from various Radiographic examinations.

<table>
<thead>
<tr>
<th>X-Ray Examination</th>
<th>Gonad dose (mrad)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
</tr>
<tr>
<td>Skull</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Cervical Spine</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Full-Mouth Dental</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Chest</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Stomach &amp; Upper Gastrointestinal</td>
<td>2</td>
</tr>
<tr>
<td>Gallbladder</td>
<td>1</td>
</tr>
<tr>
<td>Lumbar Spine</td>
<td>175</td>
</tr>
<tr>
<td>Intravenous Pyelography</td>
<td>150</td>
</tr>
<tr>
<td>Abdomen</td>
<td>100</td>
</tr>
<tr>
<td>Pelvis</td>
<td>300</td>
</tr>
<tr>
<td>Upper Extremity</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Lower Extremity</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

Source: Ballinger, 1990

1.7.8 Breast

The breast is another tissue of concern because of the relatively high dose of radiation received during mammography. Medical Radiation Scientists must apply
their utmost efforts to reduce radiation dose to the patient. It is to be noted that direct exposure examination (non-intensifying screen) is no longer used because of the high patient dose.

The glandular dose is that which is used to evaluate radiation carcinogenesis.

**Table 1.7.3**: shows the approximate skin exposures and glandular doses received by the breast as a function of the type of image receptor employed.

<table>
<thead>
<tr>
<th>Examination</th>
<th>Skin exposure per projection (mR)</th>
<th>Approximate glandular Dose per Projection (mrad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct exposure</td>
<td>6000-15,000</td>
<td>2500</td>
</tr>
<tr>
<td>Xeromammography</td>
<td>500-1500</td>
<td>400</td>
</tr>
<tr>
<td>Screen/film</td>
<td>200-1000</td>
<td>75</td>
</tr>
</tbody>
</table>

**Source**: Ballinger, 1990

**1.7.9 Bone Marrow**

Another organ of particular concern is the bone marrow. Bone marrow dose is used to estimate the population mean marrow dose (MMD) as an index of the somatic effect of radiation exposure. Table 1.7.4 relates some average bone marrow doses associated with various radiographic exposures (Ballinger, 1990). Each of these doses results from partial body exposure and is averaged over the entire body.
Table 1.7.4: Representative bone marrow doses for selected radiographic examinations

<table>
<thead>
<tr>
<th>X-ray examination</th>
<th>Mean marrow dose (mrads)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skull</td>
<td>50</td>
</tr>
<tr>
<td>Cervical Spine</td>
<td>20</td>
</tr>
<tr>
<td>Full-mouth dental</td>
<td>25</td>
</tr>
<tr>
<td>Chest</td>
<td>10</td>
</tr>
<tr>
<td>Stomach and upper gastrointestinal</td>
<td>400</td>
</tr>
<tr>
<td>Gallbladder</td>
<td>300</td>
</tr>
<tr>
<td>Lumbar spine</td>
<td>400</td>
</tr>
<tr>
<td>Intravenous urography</td>
<td>400</td>
</tr>
<tr>
<td>Abdomen</td>
<td>80</td>
</tr>
<tr>
<td>Pelvis</td>
<td>100</td>
</tr>
<tr>
<td>Extremity</td>
<td></td>
</tr>
</tbody>
</table>

Source: Ballinger, 1990

There are two risk projection models.

1.7.10 The multiplicative risk projection model assumes that the excess mortality from cancer after the minimum latency period has the same pattern in time as the natural mortality due to the same type of cancer.

1.7.11 The additive risk projection model postulates that the excess mortality would be broadly independent of the natural mortality.
1.8 DOSE IN COMPUTED TOMOGRAPHY (CT)

Historically, CT is regarded as a “high dose technique”. The work of ‘Shrimpton’ et al., (1998) in the UK showed that, though only approx 3% of medical exams involving ionising radiation were CT examinations, these contributed 30% to the overall dose. CT dose has increased as technology has improved allowing higher tube currents and longer ranges/ repeat ranges. (The Chest X-ray might account for 18% of all exams, however contributes to 5% of the dose) Ever since then CT has had ‘bad’ press with regard to dose. A chest X-Ray can be a relatively low dose, yet it can also be relatively insensitive in comparison to a CT, however, the extra projections and information come at a cost. As of December 2003, ARPANSA stated the dose of an adult CXR to be 0.04mSv. Other figures of 0.05mSv are quoted elsewhere. A low dose Chest MSCT at 0.2mSv for males and 0.3mSv for females will produce high noise yet diagnostic images that will result in a relatively sensitive examination and is hardly 1000 times the dose of a chest X-Ray. In comparison a ‘standard’ MSCT thorax, providing both thin slice high resolution for diffuse disease and data for focal disease, will give 3mSv (3.9 female).

A standard chest X-ray may be considered low dose, but a conventional Lumbar spine X-ray at 2.2 mSv is not necessarily low dose, a CT exam will give a further 4 mSv. Any procedure involving conventional X-ray fluoroscopy can result in relatively high doses, since the dose increases as the fluoroscopy time increases. So whilst CT is hailed as one of the most important developments in medicine and is recognized as the modality that is advancing more rapidly than any other, it also must be acknowledged as having a ‘dose’ stigma. Therefore, if CT is so useful, then dose
control is clearly the key. Both in the sense of scanning only as much as needed clinically and implementing automatic exposure control. Heggies (2005) study using Siemens CARE Dose on the Sensation 16 CT, demonstrated that dose with multislice could be brought back to the levels of single slice CT by employing dose modulation. New techniques such as ‘adaptive scanning’ reduce dose as they actively block the wasted radiation dose at the start and end of a multislice spiral. During the selection of new equipment, adjudicators should carefully evaluate the dose saving technology employed by vendors.

1.8.1 Special dose descriptors for CT

These special descriptors are required as CT involves;

- Irradiation by series of narrow x-ray beams
- Peak dose and shape of dose profile varies with scanner model
- Resultant dose from a series of slices also depends on the table increment/pitch.

1.8.2 Multiple Scan Average Dose (MSAD)

Average absorbed dose (mGy) to the irradiated area from a series of slices, MSAD is a measure of average absorbed dose (mGy) to the irradiated area from a series of slices. MSAD can either be measured directly or the measured CTDI can be corrected for Pitch or T/C.I. ratio

1.8.3 Effective dose

Effective dose indicates the radiation risk for the whole human body due to the CT exam performed. It can only be measured in whole body phantoms or calculated by sophisticated software. It depends on the absorbed energy (dose), gender, the type of
exposed organs and the volume (or, range) being covered. It is given in “Sv” or “mSv” (CT exam: typ. 0.5 to 10 mSv).

1.8.4 National Radiological Protection Board (NRPB) CT Organ Dose Datasets
NRPB used a hermaphrodite mathematical phantom. Simulating slice by slice irradiation using ‘Monte Carlo’ methods to generate organ dose data sets for each scanner model in study (Monte Carlo calculations: statistical calculation of x-ray interactions)

1.8.5 Computed Tomography Dose Index (CTDI)
Dose from CT scanners is commonly specified in terms of the CTDI, this is derived from measuring the dose from a single slice.

There are a number of CTDI standards in use, such as FDA and CDTI 100, comparisons are made below. CTDI 100 is generally fairly constant with slice width, whereas FDA decreases with decreasing slice width.

<table>
<thead>
<tr>
<th>Regulating body</th>
<th>CTDI FDA</th>
<th>CTDI 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>FDA</td>
<td>FDA</td>
<td>IEC</td>
</tr>
<tr>
<td>Integration distance</td>
<td>14 slices</td>
<td>100 mm</td>
</tr>
<tr>
<td>Measurement medium</td>
<td>Perspex</td>
<td>Perspex</td>
</tr>
<tr>
<td>Dose quoted to</td>
<td>Perspex</td>
<td>Air</td>
</tr>
</tbody>
</table>

1.8.6 CT Dose Index w (CTDIw)
Dose is always lower in the center and higher at the surface. A combination of the two gives an average dose in the scanned volume. If a whole organ is covered in the scanned volume, the organ dose equals the CTDIw. If however, half an organ is covered by the scan, the organ dose is 50% of the CTDIw. This CTDIw is displayed on the user interface of the CT system. The displayed dose is, or should be already pitch-corrected, (spiral and sequence) Pitch corrected CTDIw = CTDI vol
1.8.7 Guidelines.

European guidelines (ACR is working on similar recommendations) state the CTDIw should not be more than certain limits, e.g 35 mGy for abdomen CT scan in a standard patient (70 kg). They also state that dose applied to the individual has to be adjusted individually, especially in pediatric scans. Operators would do well to consider that age is not the only important factor in adjusting Pediatric dose, as even young patients present in a wide variety of shapes and sizes.

1.8.8 Multislice CT

The clinical benefits of MSCT are clear, however, it is also true that the resultant increase in patient dose must also be taken into account. When 4 slice CT was introduced the benefit from acquiring thin slices (4 x 1mm) was intended to be reserved for special applications and the belief was that the acquisition speed (4 x 5mm) would be the most common benefit (with fast rotation 8x as fast). It did not take long for Radiologists to realise the advantages of thin slices and for 4 x 2.5 and then 4 x 1mm to be employed routinely. The finer the collimation selected, the larger the contribution to patient dose from the ‘wasted’ dose that constitutes the penumbra in the z – axis. Dose can be reduced by increasing the number of thin slices acquired simultaneously, since the contribution to patient dose by the wasted or penumbra in the z-axis is reduced. This is due to the fact that penumbra is the same, but there are fewer rotations required to cover the anatomy (Flohr et al., 2002). Thus a 16 slice CT is more dose efficient than 4. Dose optimization using Automatic exposure control with dose modulation is available with most CT systems, a further advancement has been implemented with 4D dose modulation, this allows dose to be reduced by more than 66%.

So, an increase in dose relative to single slice CT is unavoidable due to the physical
principles and what is often referred to as “over beaming”. Technology improvements contribute to lowering dose back to the level of single slice CT and now with 4D dose modulation beyond this, so that CT is not always a high dose technique (Heggie, 2005).

Some authors may advocate use of high pitch indicating that reasonable image quality can still be achieved. However, caution must be used with this advice. This is true for single slice CT and most Multi-slice CT systems; however some are more sophisticated, linking tube current and pitch so that altering pitch alters tube current to maintain noise levels. It would be more effective for operator and Radiologist to determine acceptable Noise level in regard to dose and image quality for the examination in hand and employ a combined Dose modulation techniques (AEC), that operates ‘on the fly’ during rotation and in z-axis to reduce dose and maintain image quality. (Mannudeep, 2005)

1.8.9 CT Automatic Exposure Control

Whilst all vendors have a type of AEC, some are cruder than others are. "Combined Modulation techniques: combined modulation techniques such as Auto mA 3D, GE Medical Systems; CARE Dose 4D, Siemens Medical Solutions are available on some systems. The latter being more effective as it performs z-axis modulation based on attenuation data obtained from single localizer radiograph and then performs real-time, online, angular modulation for each tube rotation. Thus, attenuation profile (size, anatomic shape and attenuation at each position) along the patient’s long axis (z-axis) is measured in the direction of projection and estimated for the perpendicular direction with a mathematical algorithm. Based on these attenuation profiles, axial tube current values are calculated. An analytical function defines the
correlation between attenuation profile and tube current for slice position in the z-axis and adapts the tube current to the patient size and attenuation changes”. (Tejas, 2005)
1.9 CONCLUSION

Radiation and its effects on health have been studied by expert bodies for over half a century and more is known today about radiation risks than about those of practically any other physical or chemical agent in our environment.

Our main concern is the propensity of the available data as most of the research into radiation biology is focused upon exposure to large doses. The main sources of data are observations of humans exposed to the Hiroshima and Nagasaki nuclear bombs and lately from the Chernobyl disaster.

In the medical field most observations and studies are from patients exposed to large doses of x-ray for therapeutic purposes. Unfortunately little work has been carried out in the diagnostic field and most regulation and guidelines are based to some extent on speculation. Therefore radioprotection issues are plagued with controversial assumptions and there are no decisive sets of rules to protect the public from unnecessary exposure to relatively small doses of radiation, as delivered to patients for medical diagnostic purposes.

Exposure to radiation does not produce a unique set of health effects. The effects that can be attributed to low-level radiation are also known to be caused by a large number of other agents. Whilst not disregarding the risks of radiation, one must recognise that the health risks posed by some of these other agents might be greater and that many more are almost unknown.

The most important late effect of radiation is cancer, particularly fatal cancer. The fundamental process by which cancer is induced by radiation is not fully understood,
but a greater incidence of various malignant diseases has been observed in groups of humans who had been exposed to various high doses of radiation years previously. Whilst few individuals exposed actually go on to contract cancer, each has a probability of contracting it (Tubiana et al., 1990).

The situation is analogous to smoking, where those who smoke must run the highest risk of lung cancer, but by no means will all of them contract the disease. Cigarette smoke is claimed to be responsible for a third of all cancers in Australia today (NRPB, 1990).

The major technical difficulty in establishing an increased incidence of cancers for low-level exposures is caused by the fact that about 20% of the population will eventually die of cancer. Another important possible late effect is hereditary damage, the probability but not severity of which depends on dose. The damage arises through irradiation of the gonads (ovaries, testes). However, there is no direct evidence for hereditary defects, attributable to exposure either from natural or artificial radiation that has been found in human offspring. (The observed incidence of genetic abnormalities in the normal population is about 3%.)

The epidemiological studies suggest that for an acute exposure 10-50 mSv and for a protracted exposure 50-100 mSv, there is reliable evidence of increased cancer risk in human. Many single diagnostic x-ray examinations produce doses in the range 1-30 mVs. These provide a firm basis to extrapolate possible cancer risks from still lower dose radiation. Experimentally grounded and quantifiable biophysical arguments, support the concept that a linear extrapolation of cancer risk estimating appears to be the most appropriate methodology. It is generally accepted that there is no threshold of radiation dose for access cancer risk and even the smallest amount
increases the risk of cancer.

Radiation physics in turn explain the theories behind molecular genetic effects and Radiobiology, providing an explanation for the findings of the epidemiological studies.

In the final analysis, the purpose of this study is to provide a simple and easy to understand body of work for all radiation users; that is, requesting professionals such as general practitioners and surgeons, as well as Medical Radiation Scientists and Radiologists, plus of course the informed patient.
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Appendix 2

EVIDENCE-BASED versus CURRENT TRENDS IN IMAGING REQUISITIONS

“I will ensure patients receive the information and support they want to make decisions about disease prevention and improvement of their health. I will answer as truthfully as I can and respect patients’ decisions unless that puts others at risk of harm. If I cannot agree with their requests, I will explain why”.

From the BMA Hyppocratic Oath 1997
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2.1 BACKGROUND

A range of non-evidence based Radiographic examinations are frequently requested. It is not difficult to identify these, for example, unnecessary abdominal X-rays, especially erect Abdominal Radiographs. However, there is a wide range of examinations; Rib, Skull and Facial bones (including the nasal bones), Ankle and Knee x-rays, Kidney Ureter Bladder (KUB), Intravenous Pyelograms (IVP), and examinations of the Spine. The majority of these have a low sensitivity, yet yield a relatively high radiation dose as a result of the numbers of exposures required for the complete examination. The plain chest Radiograph is the most frequently requested examination (RIS, 2000 - 2003). However, the associated radiation dose is small when compared to all the other examinations. Table 2.1 illustrates the exposure from a range of examinations. It should be noted that a chest radiograph results in an exposure to the patient of 16 mR. However, when a radiographic examination of the thorax is performed for ribs, 400 mR are received. It will also be noted that an IVP examination exposes the patient to 3 times the radiation dose of the occupational permissible dose, as set by the international Commission of Radiation Protection (ICRP), and adopted by the Environmental Protection Authority (EPA) in New South Wales Australia.
Table 2.1 Comparative radiation exposure for x-rays of different sites:
(Note: a Chest X-ray = 12 mRads)

<table>
<thead>
<tr>
<th>Xray Site</th>
<th>Radiation exposure (in mRads)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dose per view</td>
</tr>
<tr>
<td><strong>Group A</strong></td>
<td></td>
</tr>
<tr>
<td>Skull (2 views)</td>
<td>300</td>
</tr>
<tr>
<td>Abdomen KUB (1 view) IVP (11 views)</td>
<td>600</td>
</tr>
<tr>
<td>Ribs (2 views)</td>
<td>400</td>
</tr>
<tr>
<td>Nasal Bones 2 views</td>
<td>150/300</td>
</tr>
<tr>
<td><strong>Group B</strong></td>
<td></td>
</tr>
<tr>
<td>Spine Cervical (3 views)</td>
<td>250</td>
</tr>
<tr>
<td>Spine Lumbar (4 views)</td>
<td>600/1000</td>
</tr>
<tr>
<td>Ankle (3 views)</td>
<td>150</td>
</tr>
<tr>
<td>Knee (3 views)</td>
<td>200</td>
</tr>
<tr>
<td><strong>Occupational Permissible Dose</strong></td>
<td></td>
</tr>
<tr>
<td>Measured as Skin Dose from Scattered Radiation</td>
<td></td>
</tr>
<tr>
<td>Within 1 year Staffs are not to exceed</td>
<td>2000</td>
</tr>
<tr>
<td>Within 3 years Staffs are not to exceed</td>
<td>5000</td>
</tr>
</tbody>
</table>

**Source: BMDH XR-ED**

This appendix is designed as reference material for clinicians, to assist them in selecting the correct examination for the most frequently requested imaging examinations. This educational paper will discuss the value of current historically based practice in comparison with published newer evidence-based trends.
2.2 DECISION MAKING PROCESS AND THE SEQUENTIAL FLOW OF THE CLINICAL MANAGEMENT PATH

2.2.1 Definitions

2.2.1.1 Ideal test
There are a wide range of medical imaging modalities and techniques available today in order to assist in identifying pathology. An Ideal test is the procedure of choice as such a test will reveal a specific pathology, being definitive, expedient and of course, cost effective.

For example, the ideal test for spinal cord compression due to metastases is Magnetic Resonance Imaging (MRI); MRI being the most definitive, expedient and cost effective. MR is able to display the spine in any desired plane, with the sagittal projection being ideal for this particular application, it can clearly depict the relevant anatomy and pathology, cerebro-spinal fluid, spinal cord, nerve roots, inter-vertebral discs, and bone marrow.

The location and extent of lesions and their relation to the spinal cord and dura are defined without the need for interventional Lumbar Puncture, intravenous or intrathecal contrast medium. MRI spares the patient unnecessary pain, risk and stress attributed to interventional procedures. MRI is the study of choice; indeed further studies will add little if any additional value.

2.2.1.2 False positive
This is a test that reveals a specific pathology, which then turns out to be a false prediction following a more specific test.
Example: Plain Radiograph in suspected aortic rupture often results in a false positive. In such a case when a plain chest radiograph is abnormal or suspicious, then a more specific test must be carried out (Angiography).

2.2.1.3 False negative

This is the case if the result of a test appears to be normal when in fact the patient really does have this pathology, another more specific test will reveal this pathology.

Example: When seeking a Renal Mass in the adult, the first test of choice is the intravenous urogram (IVU), it has a high accuracy with a high positive predictive value. However, a normal IVU does not exclude a mass and may turn out to be a false negative; hence, further studies are necessary in order to confirm the negative result. (CT and Sonogram)

2.2.1.4 Sensitivity

A test that has a very high accuracy of both negative and positive prediction has sensitivity.

Example: The sensitivity of meticulous real-time sonography for detecting stones in the gallbladder is very high and reported to be between 90 and 98%. (This only applies to meticulous real time sonography, as this technique can be highly operator dependent) However, if the screening sonogram is of good quality being normal or demonstrating calculi, the search for calculi or chronic cholecystitis almost always complete.

There are other examples that illustrate this, such as MRI in cranial imaging. This is very sensitive for small tumours and infiltrative processes. However, there are other examples where MRI is less sensitive. For example, Computed Tomography (CT) is
more sensitive in screening posttraumatic patients, for seizures, in cases where depressed fracture is a consideration.

2.2.1.5 Specificity

Specificity relates to when a procedure is configured especially to determine where a specific pathology is present.

Example: Nuclear Medicine scan (Tc-99m-pertechnetate) is sensitive and specific in establishing or excluding acute testicular torsion.

2.2.1.6 High accuracy of positive prediction

This is the case when a positive result from a test has the strength to complete the range of imaging investigations undertaken and render further studies unnecessary.

Example: In the case of suspected aortic rupture, the plain chest radiograph has a low accuracy of positive prediction. To avoid false positive prediction it is necessary to perform an Angiogram. In the case of an Angiogram being definitive, it has a high accuracy of positive prediction. A positive angiographic test demonstrating an aortic rupture completes the imaging work up, and Surgery can follow.

2.2.1.7 High accuracy of negative prediction

Relates to a negative result from a test that has the strength to complete the range of imaging investigations undertaken and render any further studies unnecessary.

Example: in the case of suspected aortic rupture, when an erect good quality PA radiograph excludes aortic rupture, this completes the imaging workup, as in this case the PA erect chest projection is reliable when there is negative result.

Another example is when there is a suspicion of a malignant pancreatic tumour; a
negative pancreatic CT will almost always complete the workup for pancreatic neoplasm in the absence of biliary obstruction.

2.2.2 GUIDELINES

2.2.2.1 Bayes’ Theorem

Baye’s theorem is useful in obtaining conditional probabilities. One application is determining the probability of disease given a symptom complex (or positive test) $P(D/S)$, which takes into account knowledge of the probability of the symptom complex (or positive test) given the disease $P(S/D)$. A simplified expression is:

$$P(D) \times P(S/D)$$

$$P(D/S) = \frac{[P(D) \times P(S/D)]}{[P(D) \times P(S/D)] + [P(D) \times P(S/D)]}$$

Example: If we suppose that, it is known that the prevalence of a particular disease in the general population is .002. If a person is selected at random and the question is posed, “What is the probability that he or she has the disease?” the answer would be .002. If, however, this individual is given a laboratory test specific for the disease and the results are positive, the estimate of the probability that they do indeed have the disease has to be modified. Let us assume that if a person has disease, this laboratory test is positive 80% of the time (true positive). If a person does not have the disease, it is positive 100% of the time (false positive). We can list all of these probabilities as
follows.

### 2.2.2.1.3 Let

P(D) = the probability that the disease is present for any random person (the prevalence ratio of the disease) = .002.

= the probability that the disease is not present for any random person = .998.

P(+/D) = the probability of a positive test given that the disease exist, i.e., sensitivity of the test = .80 (true positive)

P(+/D) = the probability of a positive test given that the disease does not exist = .10 (false positive)

P(D+/) = the probability of the disease given that the test is positive (i.e., the probability of interest)

Then according to Bayes’ Theorem the probability of the disease given the symptom complex or positive test is:

\[
P(D+) = \frac{P(D) \cdot P(+/D)}{[P(D) \cdot P(+/D) + P(D) \cdot P(+/D)]} = \frac{(.002) (.80)}{(.002) (.80) + (.998) (.10)} = .0158 \text{ or } 1.6%
\]

The Bayes’ Theorem probability for the individual having the disease is only 1.6%, but it may be sufficiently high to warrant the physician pursuing this diagnostic
avenue further. However, the physician will do so usually as an intuitive act, rather than as a deliberate following of Bayes’ rules.

2.2.2.2 Decision tree:

This is a graphical representation of decisions involved in the choice of statistical procedures. It can be depicted in terms of a series of choices made in alternating order by the decision maker and “chance”. Decision forks are represented by small squares, whereas no special designation will be used for chance forks. Forks may also be referred to as branching points or junctures.

Example: the first choice of the decision maker is at branching point 1. They can follow either branch A1 or branch A2. Assuming they follow path A1, they come to another juncture, which is a chance fork. Chance now determines the event which will occur; Θ1, Θ2, or Θ3. If chance takes the decision maker along the Θ path, the result or disease or whatever the decision making is regarding is of is I
The decision analysis process represented by Fig 2.2 is known as backward induction.

If we know that results IV, V and VI have a very low chance of occurring, A2 may be blocked as a non-optimal course of action. This is indicated on the diagram by the two vertical lines Fig 2.2.
Figure 2.2 Branching Points

High Chance of occurrence

Low chance of occurrence
2.3 KIDNEY, URETER, BLADDER X-RAY (KUB)

One of the most frequently requested non-evidence examinations is the kidney, ureter, and bladder (KUB) radiograph, which is usually followed by intravenous pyelography. Traditionally it was the first imaging modality requested for patients on their initial presentation of renal colic. A major disadvantage of KUB is its low sensitivity and specificity for the presence of calculi. The exact sensitivity for calculus detection is uncertain. A study by Smith et al. (1995) showed that 58% of calculi detected by CT were not depicted in a KUB. Another study by Levine et al. (1997) showed that KUB only had a sensitivity of 45% and a specificity of 77% for ureteral calculi.

If there is a high index of suspicion that the patient is presenting with renal colic, then whether the KUB is positive or negative, patients are referred for further examination by IVP or Ultrasound examination. Medical officers requesting IVP’s are unaware that this examination has a sensitivity of 59% for the detection of calculi (Anfossi et al. 2003). They are also unaware that an IVP will exposes their patient to a relatively high radiation dose and to the risks associated with the use of iodinated contrast media, for example anaphylaxis. In addition, the examination has a high cost in relation to materials and clinician time.

Imaging with CT is recommended as the first choice for these patients. By comparison, CT is more efficient, less invasive and less expensive, giving faster service and allowing identification of significant management altering diagnosis such as Abdominal Aortic Aneurysm, appendicitis, pancreatitis and colon perforation. CT is reported to have a sensitivity of 95-100% and a specificity of 93-98% (Olcott 1997;

In addition, CT may reveal other important secondary signs such as dilatation, rim sign and perinephric periureteral streaking, thus aiding in establishing diagnosis of renal colic. These secondary signs are frequently present even when a stone has been eliminated prior to examination (Sourtzis et al., 1999). Hammoud et al. (2001) reported that among patients with stone disease, 57% had associated pelvicalyceal dilatation, and 29.6% had perinephric streaking. In patients with ureteral and ureterovesical junction stones, 66.6% had ureteral dilatation, and 43.5% had periureteral streaking. In the patients with only ureteral stones, 43.3% had positive rim sign.

Post processing Techniques used with Multislice CT examinations, such as multiplanar reconstruction (MPR) can produce images similar in appearance to excretory urography. These may demonstrate the entire course of the ureter and any hydronephrosis, allowing identification of the exact location of calculi with 3-D measurements. This enables urologists to perform an evaluation similar to that obtained by urography, with a single examination.

Moreover, CT has the capacity to detect extraurinary pathologies in PPED with flank pain that mimic renal colic. According to the research by Eshed et al. (2002), at least 10% of patients undergoing CT when presenting with typical symptoms of renal colic had significant alternative pathologic findings to urinary stones, resulting in a change in clinical management. Additional pathologic findings not significant to the patient’s current complaint were also reported in another 22.3% of these patients.

If high pitch (1.5-2.5) and a thin collimation (3-mm thickness) are used, reasonably good image quality can still be achieved with radiation dose comparable to that of
normal urography (Diel et al., 2000; Liu W. et al., 2000).

However, caution must be used with this advice. This is true for single slice CT and most Multi-slice CT system; however, some systems are more sophisticated, linking tube current and pitch so that altering pitch alters tube current to maintain noise levels. It would be more effective for operator and Radiologist to determine acceptable Noise level with regard to dose and image quality for the examination in hand. Dose modulation techniques that operate ‘on the fly’ during rotation and in the z-axis can also reduce dose and maintain image quality.

Radiation dose to the patient should also play a major factor in deciding which examination is undertaken. The dose received by patients during an IVP can vary by up to a factor of 10 depending on the number of radiographs obtained; this is usually more than 10 exposures at 5 mSv each.

However, the dose from CT KUB has been estimated by some as comparable to urography, in one study this was 4.6 mGy for CT compared with 4.4 mGy for urography (Fielding et al., 1997). In the study by Mendelson et al. (2003), pitch of 2.5 was used with a total effective dose of 3.865 mSv for female and 2.806 mSv for males. The median total effective dose for urography examinations was 2.97 mSv.

Finally, the advantages of CT have resulted in reduced overall costs of management of patients with renal colic. This is highly relevant in the current medico-economic environment of fiscal responsibility and budgetary cuts. Patel et al. (2000) reported that with the implementation of a protocol of early CT for patients with suspected renal colic, in the Emergency Department (ED) of Royal North Shore Hospital, the time taken to reach a diagnosis was significantly shorter. Less time was spent in the ED resulting in remarkable cost savings. Radiological costs were reduced by 22%,
but the major cost saving was made by a reduction in the time spent in ED by 44%.

For centres without a CT service it is recommended that patients be transferred to one where CT is available, this will avoid the Radiation dose, high operational cost imaging with lower sensitivity, associated with IVP.

However, it should be acknowledged that KUB might still be helpful in some patients for follow up, as it may reveal precise stone location and radiolucency (Katz, 2003).

The following diagram is the recommendations from the Australian College of Radiologists.
Renal colic is a common reason for patients to present at the ED. An ideal imaging evaluation of patients with renal colic would provide relevant information to the clinical team in order to manager these patients. It would determine the presence or absence of ureteral obstruction. If ureteral obstruction is present, it would determine the cause. When a ureteral stone is present, it would determine the size and composition of the stone. If ureteral obstruction is absent, it would determine the presence or absence of other causes of renal colic.

Since it was first undertaken in 1923, IVP has been the imaging choice for investigating renal colic (Osborne et al., 1923). Using readily available equipment,
this examination provides structural and functional information, including site, degree and nature of obstruction, as well as the presence of congenital anomalies such as ectopia or duplication.

However, IVP has several disadvantages. It relies on plain radiography to identify stones and, therefore, may fail to determine the site and/or size of obstructing calculi, and, when negative, it cannot diagnose causes of renal colic unrelated to the urinary tract. Although IVP has reasonable specificity (92-95%), its sensitivity is only about 59-64% for detecting calculi (Niall et al., 1999; Anfossi et al., 2003).

IVP requires intravenous contrast material. In the general population, the incidence of contrast reaction is 5 to 10%, including mild reactions, such as vomiting and urticaria, as well as more serious reactions, such as bronchospasm and anaphylaxis (Witten et al., 1973; Shehadi et al., 1980; Hartman et al., 1982; Katayama et al. 1990). In the population with pre-existing renal failure and diabetes mellitus, the risk of contrast-induced nephrotoxicity is 25% (Barrett & Carlisle, 1993). Patients may require dehydrating bowel preparation, which is particularly relevant in those with pre-existing renal impairment or diabetes, as the risk of nephrotoxicity due to contrast material is significantly increased. Although the incidence of contrast reaction can be reduced with the use of low osmolar contrast agents, it cannot be entirely eliminated.

Examination Time is another disadvantage of IVP. The average time taken to perform an IVP examination is about 60 minutes (Niall et al., 1999). More than 2 hours may pass until the IVP is completed, particularly when delayed radiographs are required.

In the past 10 years, an increasing number of studies have demonstrated that UECT is a safe, rapid and highly accurate technique for evaluating renal colic (Smith et al., 1995; Sommer et al. 1995; Katz et al. 1996; Smith et al. 1996; Smith et al. 1996-2).
The examination takes approximately 5 minutes to perform.

Un-enhanced spiral CT (UECT) avoids the need for iodinated contrast medium or physician supervision and provides prompt results. It demonstrates superior sensitivity and equal specificity to IVP in detecting renal tract calculi with 95 -100% sensitivity, 98% specificity and 97% accuracy (Olcott 1997; Miller et al., 1998; Sheley 1999; Sheafor et al., 2000; Abramson et al., 2000; Ryu et al., 2001; Mendelson et al. 2003). UECT has equivalent sensitivity of IVP for detecting obstruction. The degree of obstruction can be assessed by the severity of hydronephrosis (Figure 2.3) and perinephric fluid indicating forniceal rupture.

**Figure 2.4** An axial CT of 35-year-old woman with right flank pain and hematuria, shows right hydronephrosis (arrow) and hydrourerter (curved arrow). B, 4 mm. obstructing calcium oxalate stone at right ureterovesical junction (arrow).

**Source: Fielding 1996**

Multiplanar reconstruction (MPR) of multi-slice CT data can produce images similar in appearance to IVP, demonstrating the entire ureter course and hydronephrosis; in addition, this may identify the exact site of calculi, allowing 3-D measurements to be performed. This enables urologists to make an evaluation similar to that obtained by
IVP with a single examination.

**Figure 2.5** CT data of a 71-year-old man experiencing right flank pain reconstructed as a curved reformatted image in coronal plane (same projection as plain radiograph). Reconstruction was performed after review of un-enhanced CT axial images (not shown) revealed stone in distal right Ureter. Dilated right Ureter (small arrows) was revealed to level of obstructing calculus (large arrow).

Source: Dalrymple et al. 1998

Moreover, CT images can show the secondary CT signs of obstruction such as renal sinus fat blurring, perinephric or periureteral stranding (Figure 2.4), dilatation of the intrarenal collecting system (Figure 2.5) and increased renal cortical thickness are frequently present even when the stone is eliminated before image investigation is performed (Sourtzis et al., 1999) (Figure 2.6). In the study of Smith (1996-2), the sensitivity of each secondary sign was ureteral dilatation, 90%; perinephric stranding, 82%; collecting system dilatation, 83%; and renal enlargement,
**Figure 2.6** CT of 28-year-old man with right flank pain who reported relief of symptoms during scan. A, axial image reveals right ureteral dilatation (arrow). B, recently passed stone within bladder.

*Source: Mendelson et al. 2003*
Figure 2.7 CT of 43-year-old man with right flank pain demonstrates severe perinephric stranding surrounding lower pole of right kidney. A small fluid collection is seen adjacent to kidney (arrow), and there is thickening of bridging septae (arrowhead) and Gerota's fascia (open arrow). Stone was present in distal right ureter (not shown).

Source: Dalrymple et al. 1998
Figure 2.8 CT of 35-year-old man with left flank pain reveals dilatation of proximal left ureter (straight arrow) and moderate perinephric stranding around left kidney (open arrow). Right ureter (arrowhead) is not dilated. Compared to right side intrarenal collecting system of left kidney is dilated (curved arrow)

Source: Fielding et al. 1997

71%. The specificity of each secondary sign was ureteral dilatation, 93%; perinephric stranding, 93%; collecting system dilatation, 94%; and renal enlargement, 89%. Ureteral dilatation and perinephric stranding were either both present, or both absent in 181 of the 220 patients with a confirmed diagnosis. In this subgroup, this combination of signs had a positive predictive value of 99% and a negative predictive value of 95%. Hammoud et al. (2001) reported that among these patients with stone disease, 57% had associated pelvicalyceal dilatation, and 29.6% had perinephric streaking. In patients with ureteral and ureterovesical junction stones, 66.6% had
ureteral dilatation, and 43.5% had periureteral streaking. In the patients with only ureteral stones, 43.3% had positive rim sign.

The ability to diagnose a wide range of disease entities that mimic renal colic remains a distinct advantage of UECT (Figure 2.8). Organs beyond the genitourinary tract can be evaluated, allowing rapid triage of the patient to the appropriate medical or surgical service (Figure 2.8). From the research by Eshed et al. (2002), at least 10% of the patients present with typical symptoms of renal colic undergoing UECT had significantly alternative pathologic findings to urinary stones, which altered patients’ clinical management. Additional pathologic findings not significant to the patient’s current complaint were also reported in another 22.3% of these patients.
Figure 2.9 Showing an example of a left haemorrhagic ovarian cyst presenting as left flank pain. Had an IVP, been performed, this would not have demonstrated these alternative diagnoses and most would have required further imaging (e.g. ultrasound, CT or chest radiograph) for confirmation.

Source: Thompson et al. 2001
**Figure 2.10** CT pelvis of 47-year-old woman with bilateral groin pain shows fat containing mass in right adnexa diagnostic of dermoid (arrow). No obstructing ureteral stones were identified.

Source: Fielding et al. 1997

Fielding et al. (1998) studied whether UECT alone could be used for diagnosis and treatment planning of patients with obstructing ureteral stones. They found IVP added no additional information for patients that had had UECT, and UECT could be used in place of IVP to plan treatment of patients with flank pain caused by obstructing ureteral stones.

Finally, all these advantages of UECT have reduced the overall costs of managing patients with renal colic. This is important in the current medico-economic environment of fiscal responsibility and budgetary cuts. Patel et al. (2000) reported that in a retrospective study comparing NECT with an historical IVP control group,
NECT reduced overall costs of management of patients with renal colic in an Australian teaching hospital RNSH. The time taken to diagnosis was significantly shorter and resulted in a less time spent in ED. Radiological costs were reduced by 22% because of the avoidance of additional diagnostic imaging tests. However, the major cost saving was made by a reduction in the time spent in ED by 44%.

It is important not to promote the indiscriminate use of CT for all patients with renal colic. The clinical presentation should determine the choice of investigation. For example, if a patient presents with postprandial right flank and upper quadrant pain without microscopic haematuria, ultrasound is the more appropriate initial diagnostic examination. On the other hand, if a patient with a history of radio-opaque stones presents with classic renal colic and a new calcification on plain radiography of the kidneys, ureters and bladder (KUB) in the expected course of the ureter, information provided by CT would add little to short-term management.

NECT does have limitations. It does not provide a functional study of the renal tracts or an evaluation of the urothelium. Problems can occur in differentiating distal ureteral calculi and phleboliths, though this can be overcome to a large extent by selected a collimation of 5 mm or less, since this eliminates volume averaging errors. With increasing experience overlapping CT images can be reconstructed from volume data allowing the evaluation of suspicious high attenuation focus without having to acquire more data. Difficulty may be encountered following the ureter along its entire length, especially in thin subjects with little intra-abdominal fat, nevertheless, suspicious calcification can usually be observed and then evaluated as necessary.

The tissue rim sign is a useful observation that helps differentiate distal a calculus from a phlebolith (Smith et al. 1996; Kawashima et al., 1997; Niall et al. 1999). The
tissue rim sign is a rim or halo of soft-tissue attenuation seen around the circumference of an intraureteral calculus due to tissue around an obstructing ureteral calculus becoming oedematous, thus may also be possibly due to ureteral spasm at the site (Figure 2.10, 2.11). The odds ratio for the frequency of the tissue-rim sign with stones versus tissue-rim with phleboliths was 71:1 (Smith et al., 1996-2). Another factor that may distinguish a calculus is the presence of a dilated ureter superior to the opacity.

**Figure 2.11** A, non-contrast CT shows bilateral calcific densities in region of distal ureters. Tissue rim sign is clearly seen on left side (straight arrow) where there is cuff of tissue. Surrounding opacity, which correlates with ureteral calculus, compared to phlebolith on right side (curved arrow) with no tissue rim sign. B, magnified view of tissue rim sign (arrow).

*Source: Niall et al 1990*
Figure 2.12 CT of 58-year-old man with left flank pain demonstrates small stone in distal left ureter (arrow). Rim of soft tissue thought to represent urethral wall oedema surrounds stone.

Source: Thompson et al. 2001

Radiation dose is a major factor in the argument for replacing IVP with UECT for renal colic imaging. The dose of a CT KUB has been estimated by some authorities as comparable to IVP - 4.6 mGy for CT compared with 4.4 rads for IVP in one study (Fielding JR et al., 1997-2). When a pitch 2 and a 7 mm collimation was used, reasonable good image quality with a sensitivity of 97%, specificity of 96%, and accuracy of 97% for stone detection still were achieved, with radiation dose 2.8 mSv for UECT (Liu et al., 2000). In the study by Mendelson et al. (2003), pitch of 2.5 was used. The total effective dose was 3.865 mSv for female and 2.806 mSv for male from UECT. The median total effective dose for IVP examinations could be lowered from 2.97 to 1.5 mSv if only 3 radiographs were taken (Meagher et al., 2001). Nevertheless, in practice 7 to 10 radiographs are usually produced for an IVP
examination. Again, patients with renal colic having IVP alone are more likely have additional diagnostic imaging tests to make a satisfactory diagnosis. These will result in additional radiation dose (Thompson et al., 2001).

Although IVP has the advantage of being a functional study, there are many advantages of UECT over IVP in image evaluation of renal colic. In the current health care environment it is important to take advantage of the benefits of new technology in ways that optimize patient treatment while minimizing morbidity and maintaining cost-effectiveness. UECT is an accurate, safe, rapid technique to assess renal colic, and the evaluation of choice for patients who would otherwise require IVP for diagnosis. UECT provides sufficient information for the clinician, so that if intervention is necessary it can be performed without further imaging. It seems reasonable that CT should replace IVP in the evaluation of renal colic. Once a stone is detected on CT, KUB should be routinely performed to facilitate patient follow-up care.
2.5 CRANIAL IMAGING

There are numerous studies recommending that routine skull Radiographs following head trauma are not justified for clinical management, yet this examination remains a frequent request. This is especially the case in public hospitals where a staff specialist is unavailable on site and clinical management decisions are made by locum, or junior medical officers and registrars. Skull radiography may demonstrate fractures; however, it does not display either brain or blood, it is unable to demonstrate an intracranial injury. Due to its limited capability, negative skull Radiography does not exclude intracranial complication; it even may miss some minor skull fractures (Pasman et al., 1995; Zee et al., 2002; Lewis, 1993; Lloyd et al., 1997). Furthermore, negative findings may provide false reassurance. Toupin et al. (1996) reported that up to 60 per cent of the children with extradural haematoma, 85 per cent of children with subdural haematoma and 35 per cent of children with brain damage did not have any associated skull fracture.

In the initial evaluation of minor head injured patients, skull radiographs are unnecessary for the decision process because management decisions are based on a careful neurological examination. A clinical neurological abnormality is a more reliable predictor of intracranial injury. Lloyd et al. (1997) reported that for prediction of intracranial injury, the sensitivity of skull radiography was 65% and the sensitivity of neurological abnormalities was 91%. The negative predictive values were 83% for skull radiography and 97% for neurological abnormalities. If imaging is required, it should be by computed tomography (CT) and not skull radiography.

Where CT is available, it has become the first modality of choice for imaging patients
with acute head trauma. It is rapid and easily performed even with plethora of monitoring equipment that is used to support many trauma patients. Both soft tissue lesions and bone injury can be assessed precisely. Magnetic resonance imaging (MRI) is more cumbersome and expensive than CT, but it may give additional information especially in subacute and chronic posttraumatic conditions. It is more sensitive to parenchymal changes such as the location and extent of cerebral oedema (Bruce, 2000).

In an effort to reduce over utilisation of skull radiography, different criteria and imaging guidelines have been developed to identify those likely to need or not need imaging. All have been shown to be very effective and reduce requests for skull radiography by between 21.3% to 72.9%, without any apparent adverse effect on patients (MacEwan, 1984; Baker, 1985; Clarke, 1990). Savings made by decreased skull radiography match the related costs of CT but with an improved patient care when head CT is readily available.

Stiell et al. (2001) prospectively studied 3,121 adults with minor head injury using a Glasgow Coma Scale (GCS) score of 13-15 in the EDs of ten large Canadian hospitals. In the Canadian CT head rule for patients with minor head injury, there are five high risk factors. These make a CT examination a necessity due to the high likelihood of neurological intervention being required; they includes failure to reach GCS 15 within 3 hrs, suspected open skull fracture, signs of basal skull fracture, more than one episode of vomiting, patient of the 65 years of age or greater. There are also two medium risk factors; an amnesia longer than 30 minutes prior to injury, and dangerous mechanism of injury. The management of both risks recommend a CT scan or close observation. The results showed that the high risk factors were 100%
sensitive for predicting need for neurological intervention, and only 32% patients would have CT. Medium risk factors were, 98.4% sensitive and 49.6% specific for predicting brain injury clinically, and would require 54% of patients to undergo CT. Patients without these factors would not need skull radiography or CT scan.

In fact, most of latest imaging text books (Grainger & Allison, 2001; Johnson, 2001), have plain radiography assuming a historical role, since neuro-radiological examinations now consist of cross-sectional imaging with computed tomography (CT) and magnetic resonance imaging (MRI).

**Figure 2.13** Protocol of imaging guidelines for head injury from the Royal Australian and New Zealand College of Radiologists. No skull radiography is included.

![Flowchart of imaging guidelines for head injury](image)

**Source: RANZCR**

Updated imaging guidelines for head injury by radiologists exclude skull radiography (Chisholm, 1991; RANZCR, 2001). Figure 2.10 is the protocol of imaging guidelines.
for head injury from the Royal Australian and New Zealand College of Radiologists.

No skull radiography is included in this.
2.6 ANKLE AND KNEE RADIOGRAPHY

Acute ankle trauma is one of the most common presenting injuries seen in EDs. Patients with ankle injury constitute approximately 5% of all patients, and up to 12% of adult patients who visit EDs (Heyworth 2003; Cockshott et al. 1983).

Medical Officers usually refer most patients with this problem to have a radiographic examination in order to exclude fracture, although such fractures are typically present in less than 15% of cases (Dunlop et al., 1986; Stiell et al., 1993; Clarke et al. 1983). Most of these patients will have sustained simple injury to ligamentous soft tissue or a small avulsion fracture of no clinical significance. It is estimated that more than 5 million ankle radiographic examinations are performed annually in Canada and USA (Cockshott et al., 1983).

Requesting ankle radiographs is usually dictated by the nature of ED practice (Lloyd et al., 1986). Usually patients suffering pain and anxiety have brief encounters with busy doctors whom they have not seen before, and who will not be following their care. Doctors frequently believe that patients expect radiography and are concerned about the medico-legal consequences of missing a fracture (Long et al., 1985; Svenson, 1988; Matthews, 1986). Such an unselective policy has resulted in inestimable numbers of unnecessary exposures to radiation for little diagnostic yield. In addition to being poor medicine, such profligacy is a luxury that is no longer acceptable in any health system.

There has been considerable interest in developing clinical prediction or decision rules, which attempt to reduce unnecessary ankle radiography and increase the yield of ankle x-ray examinations in EDs. In 1993, Stiell and colleagues developed the
concept of a clinical decision rule to guide the assessment of ankle injuries in particular, to determine the indications for radiography for adult patients older than 18 years presenting acute ankle injury Stiell et al., 1993). Their objective was to produce reliable and reproducible guidance based on objective criteria and thus reduce the subjective component of assessment. This became known as the Ottawa Ankle Rules (OAR).

Ottawa Ankle Rules (OAR): An ankle radiographic series is only necessary if the patient has pain near the malleoli and one or more of these findings: age 55 years or greater, inability to bear weight immediately after the injury and for four steps in the ED, or bone tenderness at the posterior edge or tip of either malleolus. The definition of weight bearing in the ED is the ability to transfer weight twice onto each leg (a total four steps). The likelihood of causing a fracture to displace by this assessment is extremely remote as unstable fractures are usually grossly apparent with obvious bone tenderness. The OAR allows clinicians to accurately assess patients for clinical significant fractures, defined as a bony fragment greater than 3 mm in diameter.
The first validation report of applying OAR clinically was published by Stiell et al. in 1993. 1032 of 1130 eligible patients in the first stage using the original OAR and 453 of 530 eligible patients in the second stage using the refined OAR took part in the study carried out in the ED of two Canadian university hospitals. In the first stage, the original decision rules were found to have sensitivities of 1.0 (95% confidence interval (CI), 0.97 to 1.0) for detecting 121 ankle fractures. Kappa value was 0.56. In the second stage, the sensitivities was 1.0 (95% CI, 0.93 to 1.0) for 50 ankle fractures. The potential reduction in radiography was estimated to be 34%. The probability of fracture, if the corresponding decision rule were "negative," was estimated to be 0% (95% CI, 0% to 0.8%).

Although the demonstrated sensitivity of OAR for fracture is 100%, the CI (95% confidence interval (CI), 0.97 to 1.0) and common sense suggest that a fracture may
occasionally be missed. Nevertheless, such a missed fracture would be relatively small and be relatively insignificant, with the likelihood of morbidity for the patient being very small.

During the subsequent decade, OAR proved to be a safe, cost effective, and reliable approach to assessing injured ankles with impressive consistency when applied by senior emergency doctors, junior doctors in training, and nurse practitioners (Mann et al., 1998; Salt & Clancy, 1997), in hospital and community settings, in different countries.

The OAR has been validated in patient populations and medical systems outside Canada in independent studies conducted in different countries such as the USA, France and the Netherlands (Pigman et al., 1994; Solomito et al., 1994; Auleley et al., 1998; Pijnenberg et al. 2002). Bachmann (Bachmann et al. 2003) systematically reviewed 27 studies evaluating the implementation of the OAR involving 15581 patients. They concluded that a sensitivity of almost 100% was confirmed, with a possible overall reduction in the number of radiographs performed of 30-40%.

The rapid application of a few simple clinical variables indicates those patients that are at negligible risk for a fracture and therefore need not undergo radiography. Based on the findings of several thousand cases, both physicians and patients can be reassured that the probability of a fracture among such low-risk patients is extremely small. The money saved by forgoing hundreds of thousands of ankle radiographs may be better used elsewhere in the health care system.

Bloomberg and Stuart (2003) carried out a study of prospective validation of the OAR in Australia following appropriate education in use of the rules involving ankle 366 injuries. Sensitivity was 100% for ankle (95% confidence interval (CI): 92–100)
with specificity 15.8% (95% CI: 11–21) when used by both junior and senior doctors. They conclude that when taught and accurately applied, the OAR is a valid tool for clinical decision-making when used by both junior and senior physicians in the ED of an Australian teaching hospital.

However, the transportability of decision rules between countries and among related populations has been questioned by the studies conducted in USA, New Zealand, Scotland and Singapore due to a high false-negative rate (Kerr et al., 1994; Lucchesi et al., 1995; Perry et al., 1999; Tay et al. 1999). These studies have been criticised for their design and for not having trained physicians in the correct application and interpretation of the OAR, leaving their conclusions open to question (Stiell et al., 1996).

In the US study, the investigators assessed 30 clinical variables for ankle injury that included the decision rules of the OAR; clinicians did not have a pictorial representation of the OAR. The Scottish study did not use the refined rules, none of the physicians were taught to use or apply the OAR correctly, and 12 parameters, which included but were not limited to the OAR, were recorded. In fact, apart from the authors, none of the physicians working the ED was aware that a study was in progress. Furthermore, 216 of the 800 patients analysed did not have radiographs taken, making an accurate determination of sensitivity and specificity impossible. The study from Singapore also did not indicate that physicians were trained in the correct application and interpretation of the rules. They included patients aged 12–18 years, a group for which the refined OAR were never designed or validated. Of the seven clinically significant fractures missed, one was the base of the first metatarsal, which is not included in the ankle of the OAR. For the six other fractures, all patients

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were unable to recall whether they were able to weight-bear immediately after the
injury, making the application of the OAR in these six patients unreliable. Critical to
the validation is an initial education program.

The applicability of any ankle decision rule in paediatrics is influenced by significant
developmental and physiologic differences between adults and children. These
differences include age-related variations in fracture epidemiology, the potential for
physeal growth plate injuries, and the inability of young children to localize pain. In
addition, because of the increased potential for complications in healing during
growth, the definition of a clinically significant fracture may differ between the
paediatric and adult population.

A few of prospective studies have assessed the utility of the OAR in children.
Chande (1995) reported on the application of the OAR prospectively in 71 children
with acute ankle injuries, and Plint et al. reported on 670 children. In both studies,
sensitivity of the OAR in predicting clinically significant fractures was reported to
be 100%. However, Clark’s study (2003) showed that the sensitivity of OAR was
83%, and suggested that the OAR cannot be applied to children with the same
sensitivity as with adults. One hundred and ninety five patients with ankle injuries
were evaluated in this study. The mean age of patients was 12.6 years.

Compliance with the OAR would lead to an average 30-40% reduction of x-ray
examination in patients with acute ankle injuries, avoiding unnecessary radiation
exposure. One attendant clinical benefit would be decreased waiting times for patients
discharged without radiography and possibly for patients who could be sent directly
to the radiology department by triage nurses trained to use the rules. The other benefit
would be cost savings to the health care system. For example, the total professional
and technical cost of performing 5 million ankle radiographs annually in North America can be estimated at $500 million (Stiell et al., 1993).

Allerston and Justham (2000) did a case-control study to assess influence of using the OAR by nurse practitioners on the transit time for patients with ankle injury in ED. This study included 354 consecutive attendances with ankle injuries. Those patients assessed by a nurse practitioner who had been both trained and had authority to use OAR, were referred for radiographs from triage assessment. The control group (initially 120) consisted of those patients who were assessed by nurses untrained as nurse practitioners and not empowered to use the OAR, but were sent for radiographs when assessed at the treatment stage. Significant reductions in transit time were demonstrated for those patients required to have an X-ray to confirm a diagnosis if this was requested at the time of the triage assessment by nurse practitioners.

However, Cameron and Naylor’s study (1999) found that although clinicians widely recognized the test as a decision tool, its use and the change of clinical behaviour was limited. Clinicians aim to minimize the number of missed fractures and would therefore maximize sensitivity at all costs. Fear of a bad professional reputation or litigation might explain this. The transient nature of the relationship between a doctor in the ED and a patient makes it more likely that a patient will bring a complaint or malpractice suit against a doctor he or she does not know. These transient physician-patient relationships and the lack of follow-up by the ED doctors are major factors in the high use of radiographic assessment in the ED (Lloyd, 1986). In contrast, a health insurer and government would be interested in the optimal balance between sensitivity and specificity of the instrument.
8.7 CERVICAL SPINE RADIOGRAPHY (CSR)

Conservative estimates indicate that more than 1,000,000 blunt trauma patients who have the potential for sustaining a cervical spine injury are seen in EDs in the United States each year. About 800,000 CSR examinations are performed annually. Virtually, all patients with trauma to the neck are requested for imaging by emergency doctors (Vandemark, 1990). Among those patients presenting with intact neurological status (arriving either walking or by ambulance), the incidence of acute fracture or spinal injury is less than 1% (McCaig, 1992). The estimated annual cost to American society is about $3.4 billion in 1993 (Berkowitz, 1993).

Stiell et al. (1997) assessed the variation of CSR requisition in the EDs in 6 teaching and 2 community hospitals in Canada for alert, stable adult trauma patients. There was considerable practice variation among well-trained emergency physicians, with radiography rates ranging as much as 6-fold, from a low of 15.6% to a high of 91.5%. None of the institutions with low requisition rates missed any patients with cervical spine injury.

In recent years, there have been dramatic changes in the approach to imaging of patients with suspected cervical spine injuries. Indeed, imaging of cervical spine trauma is one of the most controversial topics in radiology today. There have been a large number of reports in the medical literature dealing with this problem. The controversy is based around several questions.

2.7.1 Importance of cervical spine radiography

This controversy focuses on the cervical imaging indications, depending on the factors that determine whether trauma patients are at high or low risk for cervical
injury. The extent of imaging to be performed mainly depends on the high accuracy of diagnosis, time requirements for study, and cost of the study. Concern for cost containment and radiation exposure has led to developing and establishing study methods of improving selection of patients who truly are at risk and need imaging.

Some of the earliest attempts to address this problem began more than a decade ago (Mirvis, 1989, Vandemark, 1990). A list of clinical history-based indicators was established for patients at high risk for C-spine injury.

These early efforts were followed by the formation of the National Emergency X-Radiography Utilization Study (NEXUS), which was the first large-scale attempt to formulate a decision instrument to identify patients with an extremely low probability of spinal injury.

The NEXUS suggests that a set of clinical criteria can identify patients who have an extremely low probability of injury and who consequently have no need for imaging studies. The decision instrument requires patients to meet five criteria in order to be classified as having a low probability of injury: no midline cervical tenderness, no focal neurological deficit, normal alertness, no intoxication, and no painful distracting injury. The report of a prospective, observational study applying the criteria at 21 centres across the United States involving 34,069 patients with blunt cervical spine trauma was published in 2000 by Hoffman et al. The criteria identified all but 8 of the 818 patients who had cervical-spine injury (sensitivity, 99.0% [95% CI, 98.0 to 99.6%]). The negative predictive value was 99.8% (95% CI, 99.6 to 100%), the specificity was 12.9%, and the positive predictive value was 2.7%. Only two of the patients classified as unlikely to have an injury according to the criteria met the preset definition of a clinically significant injury (sensitivity, 99.6% [95% CI, 98.6 to...
100%; negative predictive value, 99.9% [95% CI, 99.8 to 100%]; specificity, 12.9%; positive predictive value, 1.9%), and only one of these two patients received surgical treatment. According to the results of assessment with the criteria, radiographic imaging could have been avoided in the cases of 4309 (12.6%) of the 34,069 evaluated patients.

In 2002, Touger et al. published their validation study of the NEXUS criteria to reduce CSR in elderly patients at least 65 years of age with blunt trauma. The sensitivity of the NEXUS criteria for clinically significant injury in the geriatric group was therefore 100% (95% CI, 97.1 to 100%).

Dickinson et al. (2004) evaluated the accuracy, reliability, and potential impact of NEXUS low-risk criteria for CSR, applied in Canadian EDs among 8,924 patients. 151 (1.7%) patients had an important cervical spine injury. The combined NEXUS criteria identified important cervical spine injury with a sensitivity of 92.7% (95% CI 87% to 96%) and a specificity of 37.8% (95% CI 37% to 39%). Application of the NEXUS criteria would have potentially reduced CSR rates by 6.1% from the actual rate of 68.9% to 62.8%. They stated that the NEXUS low-risk criteria to be less sensitive than previously reported in their retrospective validation study.

Stiell and his colleagues, who formulated the "Ottawa Rules" as discussed earlier in this chapter under Ankle injuries, continued their crusade and developed the "Canadian C-spine Rule". This rule consists of 3 major questions:

1) Are there any high-risk factors that mandate radiography?

2) Are there any low-risk factors that would allow a safe assessment of a range of motion? and
3) Is the patient able to actively rotate the neck 45° to the left and to the right? High-risk factors include age 65 years or older; a "dangerous mechanism of injury" (e.g., a fall from a height of more than 1 m; an axial loading injury [e.g., diving injury]; high-speed [>100 km/h] motor vehicle crash, rollover, or ejection; motorized recreational vehicle or bicycle collision), or the presence of paresthesias in the extremities. Low-risk factors include simple rear-end motor vehicle crashes ("fender benders"), patient able to sit up in the ED, patient ambulatory at any time, delayed onset of neck pain, or the absence of midline cervical tenderness.

In 2001, Stiell et al. published their validation study involving 8924 adults who presented to the ED with blunt trauma to the head/neck, stable vital signs, and a Glasgow Coma Scale score of 15 at 10 large Canadian EDs.

Among the study sample, 151 (1.7%) had important C-spine injury. By cross validation analysis, this rule had 100% sensitivity (95% CI, 98%-100%) and 42.5% specificity (95% CI, 40%-44%) for identifying the 151 clinically important C-spine injuries. The rule also would have identified 27 of 28 patients (0.7%) who had "clinically unimportant" cervical injuries, primarily avulsion fractures, defined as those that do not require stabilizing treatment or specialized follow-up. The potential radiography requisition rate would be 58.2%. Stiell et al. (2001) estimate that their rule could reduce the use of C-spine radiographs requested for alert trauma patients by an absolute rate of 10.7% or a relative rate of 15.5%. The Canadian C-Spine Rule appears comparable to the NEXUS study in being able to identify patients who need radiography, but appears more effective in determining which patients can be managed without radiography.
In the study by Kerr et al. (2005), implementation of the Canadian C-spine Rule reduced x-ray requisition by 25%.

How many views in a CSR study are needed is another controversy. The standard series of screening CSR for blunt trauma patients consists of lateral, AP, and odontoid peg views. Some practices use 4, 6, and even 7 view series. In addition, a large number of radiographically inadequate views are often repeated.

Holliman et al. (1991) evaluated the usefulness of AP view in initial trauma screening. They found that there were no cases of cervical spine injury evident on the AP view without an obvious corresponding abnormality on the lateral or open-mouth view. Only an adequate lateral view and open-mouth peg view would then be necessary to evaluate the cervical spine in the trauma patient, and decisions to obtain further studies could be based safely on only the lateral and peg views.

2.7.2 Patients without trauma history

Heller et al. (1983) studied the value of x-ray examinations in their district general hospital for patients with neck pain without trauma. It was estimated that such examinations occupied one radiographer and one room for four hours a week. Eighty-five percent of the patients aged 60 or more x-rayed for cervical spine in one year were reported as having cervical spondylosis. No unexpected findings of infection or malignancy were found. The Radiographs of control patients who had originally attended for barium studies were compared. There was no significant difference in the prevalence of cervical spondylosis between the two groups. There were also no consistent relations between symptoms and changes found from the radiographs. It was suggested that patients with chronic neck pain after a trauma, should only be referred for radiographic examination when there is a clinical suspicion of
malignancy or infection, when surgery might be indicated. There is little point in taking radiographs of the neck to diagnose cervical spondylosis.

2.7.3 Examination of Choice?

The low sensitivity of CSR to reliably identify or exclude fractures after blunt trauma is well known. On the other hand, there has been a significant body of evidence within the radiologic literature supporting a more prominent role for CT instead of plain radiography as a screening tool for patients with suspected spine injury. This has led to CSR taking on a secondary role for imaging not only for patients suspected of cervical spine injury but also those with injuries of the thoracic and lumbar spine. Some authors even recommend that the three-view radiographic study be performed only when CT is not available.

As early as in 1993, Woodring & Lee retrospectively reviewed CSR films and CT scans of 216 consecutive patients with blunt trauma. The CSR series included an AP, horizontal lateral, and an open-mouth odontoid view. Compared with CT, the lateral view alone, detected only 33% of the fractures and 55% of the subluxations and dislocations. Although the 3 view series improved the sensitivity, still only 39% of the fractures and 64% of the subluxations and dislocations were detected. Nunez (1996) reported cervical spine evaluation in another 88 patients with cervical fracture and found that 42% of blunt cervical spine fractures were missed by CSR.

Schenarts et al. (2001) evaluated the use of CT in the upper cervical spine in 1,356 patients with altered mental status, 70 of which had 95 injuries to the upper cervical spine (occiput to C3). Forty five percent of these fractures were not demonstrated on CSR.

In a few studies, higher sensitivities for CSR were reported. In a study of 1,199
patients (Griffen, 2003), fractures were identified in 116 patients by CT. 75 of 116 (64.7%) fractures were seen on CSR. Mower et al. (2001) reported their data of the radiographic findings of the NEXUS study group with 34,069 patients. Although, the authors stated that, ‘standard three-view imaging provides reliable screening for most patients with blunt trauma, the sensitivity of CSR was only 60.9%. For the 818 patients who had 1,496 injuries identified, in 320 patients (39.1%), 564 (37.7%) separate cervical spine injuries were missed by plain CSR. These sensitivities of CSR to detect such clinically important injuries are unacceptable. In another study by Nguyen & Clark (2005), an even higher sensitivity of 93.3% with specificity of 95% for CSR was reported in their high-risk group patients with blunt trauma. However, there were only 15 spinal injuries in this study.

Recent studies evaluated the values of CSR and CT for screening blunt trauma patients. In 2003, Diaz et al. reported their study of 1,006 patients with an average Glasgow Coma Scale score of 12. 172 distinct cervical spine injuries were identified by CT. The sensitivity and specificity of five-view plain CSR was 44% and 100%, respectively. Widder et al. (2004) published a prospective study of 102 patients with Glasgow Coma Scale scores less than 9. CT identified 18 fractures, of which only 7 were seen on the three-view CSR. Sensitivity and specificity for plain CSR were 39% and 98%, respectively. Again, Gale et al. (2005) studied the efficiency and specificity of plain radiography to evaluate the cervical spine after blunt trauma. Compared with CT, the sensitivity and specificity of CSR to detect fractures was 31.6 and 99.2%, respectively. It was suggested that CSR should not be requested for these patients.

Plain radiographs are often technically inadequate, requiring repeated examinations. Using CT as the initial imaging modality may allow a more rapid radiological
exclusion of cervical spine fracture than performing CSRE. A long time advocate of the six-view series of cervical spine injury found that averaged time for a six-view series was 22 minutes and 79% of patients required repeat of one or more of the views. The most commonly repeated view was the open-mouth atlanto-axial view. In the other study for cervical spine CT, the average examination time was found to be only 12 minutes, clearly a significant time interval in the trauma setting. In 2000, Daffner (2000) also compared CSR with CT for examining cervical spine trauma. Radiographic examination times ranged from 5 to 46 min, with an average of 32 min. CT examination times ranged from 3 to 30 minutes, with an average of 12 minutes. Forty-five percent of patients required one or more repeated radiographs in order to provide a satisfactory examination.

As more evidence has been emerging in favour of CT instead of CSR for a screening imaging modality after blunt trauma, the cost-effectiveness issue has been addressed. In 1999, Blackmore et al. studied the cost-effectiveness from a societal perspective. They analysed these published sensitivities for fracture identification by plain CSR and CT, and grouped these patients for cervical injuries into three separate groups: low-, moderate-, and high-risk. The authors concluded that CT is the preferred cervical screening modality in trauma patients at high and moderate risk for cervical spine fracture. Tan et al. (1999) studied the cost-effectiveness of CT for the inadequately visualized C7-T1 level on CSR in a retrospective cohort study. In 360 patients without evidence of lower cervical spine injury requiring CT of C7 to T1 as this level was not adequately visualized on CSR, 11 fractures were identified. The authors determined that the cost-effectiveness of CT for averting potential sequelae was $9,192 for each fracture identified, $16,852 identified for each potentially or definitely unstable fracture identified, and $50,557 for each definitely unstable
Grogan et al. (2005) evaluated the institutional costs associated with missed injuries when settlement costs were taken into account. They found that the institutional cost for CT was $554 compared with $2,142 for plain CSR. The authors even calculated out that the cost benefit of CT was maintained for plain CSR sensitivities up to 90%.

Although CSR has been known for being of little or no value for patients with blunt trauma, a routine single lateral cervical spine radiograph (LCSR) is still being advocated. In the standard trauma resuscitation protocols of many trauma centres and EDs, a single lateral CSR is routinely requested in the evaluation of alert and high-risk trauma patients to screen for possible cervical spine injury even when spiral or multi-slice CT is performed (ACR, 2006; ACS, 1993).

Rybicki et al. (2000) considered that, notwithstanding the value of CT, the lateral radiograph remains an essential and fundamental part of cervical spine imaging because of its value for assessing the pre-vertebral soft tissues and vertebral alignment. It is also employed for evaluating foreign bodies. They also pointed out that the lateral view can reveal subtle end-plate fractures and distraction injuries that can be elusive on CT. However, Zabel et al. (1997) examined the adequacy and accuracy of lateral cervical spine radiographs in the initial evaluation of alert, high-risk trauma patients evaluated at a level I trauma centre. The sensitivity, specificity, and negative predictive probability for LCSR were 67, 58, and 1.4%, respectively. Apart from the increased imaging cost, such a practice would slow down the transition from the primary to the secondary survey in these potentially critically injured patients and give unnecessary radiation exposure. Lawrason et al. (2001) looked into the question of whether lateral screening radiography of the cervical spine
adds any useful data to what can be discovered by CT, they concluded that lateral CSR does not add any diagnostic value to the process of clinical management.

However, it is to be acknowledged that CT, similar to CSR, would have some limitations in assessing incidence of ligamentous injury, with MRI always as the final arbitrator. It is important to note that this does not change the fact that CT remains the best modality to demonstrate the bony anatomy of the spine.

It should also be acknowledged that there are many reports regarding the major downside to the indiscriminate use of CT; increased radiation dose to the patient. Rybicki et al. (2002) measured radiation dose, finding the mean skin dose for CT of the cervical spine to be 27.2 mGy, in distinction to the mean skin dose 2.89 mGy for radiography. According to their calculations, the radiation dose to the thyroid gland from CT of the entire cervical spine was 14 times greater than that delivered to the thyroid by CSR. Unfortunately, the researchers failed to acknowledge that in majority of cases, the spine X-ray is of no value, and symptomatic patients will still proceed to CT.
Figure 2.15 Cervical Spine Imaging Protocols

Source: Blacktown Mt Druitt Imaging protocol
Low back pain (LBP) is the second most common complaint among patients presenting to primary care physicians, and 4 of every 5 people experience low back pain at some point in their lives in the USA (Brant-Zawadzki et al., 2000). 7% of the adult population consults for this condition each year in United Kingdom (RCGP, 1995).

In the United Kingdom, some 5% (£81.6 million) of the direct health care cost of back pain is spent on radiology and imaging (Maniadakis & Gray, 2000).

Vader et al. (2004) studied the use of and irradiation from plain lumbar spine radiography in Switzerland. They estimated the use of LSRE to be 39 requisitions per 1000 inhabitants per year in Switzerland.

8.8.1 Effectiveness

Radiography of the lumbar spine in LBP patient seldom reveals lesions of therapeutic importance. Whilst there is little or no evidence that associates the examination to improved clinical outcomes, it may be associated with greater patient satisfaction.

In 1978, Rockey et al. published their study on the relationship between LSRE and outcome from 440 patients with LBP. As a part of their care, 106 patients (24 percent) had ‘back x-ray’ examinations. They found that the contribution of LSRE to diagnosis was minimal, and had little effect on therapeutic decisions, although the patients with LSRE were more likely to be satisfied with their care than these without LSRE. For patients under 50, ‘back x-ray’ examinations had negligible diagnostic
value and their use could be reduced without decreasing the quality of medical care.

Witt et al. (1984) compared the radiographs of the lumbar spine from 238 patients with LBP with sciatica with films from 66 patients without LBP. No difference between the two groups could be demonstrated concerning the incidence of spondylosis and disc degeneration.

Padley et al. (1990) compared a single lateral view with the standard 3 view series LSRE in LBP. The results showed that a single lateral radiograph was diagnostically satisfactory and would have the added advantages of reducing patient radiation dose and radiographic workload. Khoo et al. (2003) evaluated the diagnostic contribution of the AP lumbar spine radiograph in community referred low back pain (a prospective study of 1030 patients).

In the 90.5% of cases, the AP view was non-contributory. In 4.2% the diagnosis was strengthened and it was altered in 4.6%. However, in the latter group, only 1.3% of the total findings were considered significant such as possible pars defects and sacroiliitis. Specific important conditions such as infection, malignancy and benign tumours were not missed on the lateral view alone. The radiation burden was reduced by 75% by omitting the AP view.

Recently, Miller et al. (2002) assessed the cost-effectiveness of LSRE in primary care patients with LBP in 52 practices in the East Midlands, United Kingdom. The major finding from this study is that LSRE is associated with increased patient satisfaction but not with improvement in other clinical outcomes. Strategies for increasing patient satisfaction that do not involve radiography need to be developed and tested in primary care. Van Den Bosch et al. (2004) reviewed abnormalities reported on 2007 LSRE of patients referred with low back pain by general practitioners. The reports
were classified into different diagnostic groups and subsequently stratified according to age. The prevalence of reported lumbar spine degeneration increased with age to 71% in patients aged 65-74 years. The overall prevalence of fracture, possible infection, and possible tumour was 4, 0.8 and 0.7%, respectively. Possible tumour was only reported in patients older than 55 years of age. They concluded that although the prevalence of degenerative changes was high in older patients, the therapeutic consequences of diagnosing this abnormality are minor. The prevalence of possible serious conditions was very low in all age categories.

2.8.2 Risk

LSRE has a very high negative consequence due to the high density of bone marrow in the spine. According to anatomy books, 60% of the blood is generated in the spine. It does not seem reasonable to expose the most active blood forming cells in the body to ionising radiation.

In Switzerland (Vader et al., 2004), the collective dose to the population due to LSRE was 1130 Sv (0.16 mSv per person per year). LSRE is the third most frequent radiographic procedure performed and delivers the highest population dose of ionising radiation of any radio diagnostic procedure.

2.8.3 Evidence Base Requesting

The vast majority of patients with back pain will have resolution of symptoms without treatment; imaging is generally not indicated at initial presentation. Even in patients with radioculopathy, the high prevalence of imaging abnormalities, such as disc protrusions, in an asymptomatic population further complicates the issue. A certain percentage of findings in symptomatic patients will merely be coincidental findings, unrelated to symptomatology. For patients with persistent symptoms,
constitutional symptoms, or suspicious of tumour, infection or fracture, imaging is indicated more promptly. However, that does not mean that LSRE is the imaging method of choice. CT and MRI have dramatically changed the imaging of LBP. MRI presents superior soft tissue resolution for detecting abnormalities of the disc, thecal sac contents, bone marrow, and paraspinous tissues. On the other side, CT best visualises bony structures for fracture, osteophyte, and other osseous changes. Plain x-ray has become a useless, costly and dangerous initial screening study. Should pathology be detected, imaging usually shifts from a screening study to further investigating or diagnostic imaging evaluation.

2.8.4 What is current reality?

Increasing demands for cost effective in health services and concern for the risks associated with ionising radiation have accelerated the process of establishing image guidelines for LSRE. The main purpose of plain radiographs for back pain is to exclude the possibility of infectious, neoplastic, or inflammatory disease, which may affect treatment. Although imaging guidelines aiming to reduce unnecessary LSRE have been set up, in reality, guidelines have not been adhered to for referring patients with LBP for imaging. Hollingworth (2002) studied the utilization of these imaging guidelines in two large hospitals in the UK from 1994 to 1999. There was no evidence that primary care referrals for LSRE for patients with LBP had decreased between 1994 and 1999 at either hospital.

Espeland et al. (1999) evaluated how referrals from Norwegian general practitioners for LSRE conform to the Norwegian image guidelines. Of the 323 referrals, 24% conformed to the Norwegian guide, 34% did not conform, and 42% were considered uncertain, mainly because of lack of pertinent information in the referral letters.
There does appear to be some effective implementation. Tracey et al. (1994) found that the referring of LSRE for patients with LBP was reduced from 48.4% to 27.2% following introduction of the guidelines in their large teaching hospital.
**Red Flags for Back pain**

**Differential diagnosis of back pain**
- intra-abdominal and pelvic disease
- Abdominal aortic aneurysm
- kidney, pancreas,
- gallbladder, duodenal
- ulcer, diverticulitis,
- endometriosis

**Pathology of back pain**
1. Compression fracture
2. Spondylolisthesis
3. Ankylosing spondylitis
4. Osteoarthritis
5. Osteochondritis
6. Epidural abscess
7. Osteomyelitis
8. Disc prolapse
9. Neoplasm
10. Rheumatoid arthritis

**Investigations for neoplasm or infection**
- MRI
- Perform FBC, urine analysis, sedimentation rate, plain x-ray
- Bone Scan may be useful

**Investigations for ankylosing spondylitis**
Obtain x-rays of the sacroiliac joints

---

**RED FLAGS for Neoplasm**
- Age greater than 50
- Previous history of cancer
- Pain greater than one month
- Failure to improve with conservative treatment
- Nocturnal pain,
- Pain which awakens the patient from sleep,
- and
- Pain not relieved by bed rest are suggestive of a neoplasm

**RED FLAGS for vertebral osteomyelitis/epidural abscess**
- Skin infection-Staph aureus
- *H. influenzae* illness in children
- Tuberculosis
- Gram Neg infection
- Indwelling urinary catheter
- IV drug use: *Pseudomonas* and *Serratia marcescens*

**RED FLAGS for compression fracture**
- history of trauma
corticosteroid use
- age > 70y.o.

**RED FLAGS for ankylosing spondylitis**
- morning stiffness
improvement after exercise
onset before age 40
- insidious pain >3 months

**Investigations for compression fracture**
- Plain X-ray of lumbar spine
- Note that oblique views are NOT necessary (they add significant radiation exposure and cost but do not add much information)
- Consider a bone scan if the index of suspicion for fracture is high and x-rays are negative.

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Royal Australian New Zealand College of Radiologist Lumbar Spine – RANZCR
Rib fracture is the most common thoracic injury (Rasmussen et al., 1986). The severity of the pain associated with this injury motivates patients to demand that their clinician perform diagnostic tests in order to determine the cause and receive the proper treatment. Unfortunately, neither clinical examination nor plain radiography is ideal for the diagnosis of rib fractures (ACR). Radiographs are specific but not very sensitive (for un-displaced fractures), and clinical examination is sensitive but not specific (Griffith et al., 1999). A Comparison of different imaging modalities showed that all have low sensitivity to detect rib fractures. Griffith et al. (1999) compared sonography and plain film radiography (chest x-ray plus one oblique rib x-ray) in 50 patients and found that plain radiographs detected only 8 of 83 (10%) of sonographically detected rib fractures and were positive in only 6 of the 39 patients who had demonstrated fractures.

Most clinicians are aware that imaging has low sensitivity to detect rib fractures. A study conducted by Dubinsky and Low (1997) of 69 patients with non threatening trauma (stable vital signs with no evidence of cardiac injury, solid or hollow viscous rupture, or fractures associated with significant blood loss), concluded that neither rib studies nor even chest radiographs were of clinical benefit.

However the examination is still been requested, since there is a belief that the referred case might be one of the few where fracture can be shown. Consulting the guidelines of the Australian College of radiologist would also recommend the referral for radiographs of the rib.

The simple question is what will be achieved by discovering a fracture? There is no
evidence that the presence, absence, or number of fractures directly influences the diagnostic approach and treatment (ACR). In the early days, one of the main treatments was to bandage the chest. Due to respiratory motion of the chest, that approach has been proven invalid for rib fracture treatment. The current clinical management for un-displaced rib fracture is to administer analgesics and wait for the body to heal itself. So if the treatment is to alleviate pain and wait regardless of the findings then why request an imaging examination?

There is a vast difference in radiation dose between Rib and chest radiographs. A rib examination exposes the patient up to 10mSV, whereas chest radiograph will be 0.20mSV. If the reason behind the requestion were to rule out displaced fractures, pneumothorax or hemothorax, then chest X-ray would be more than adequate to serve the purpose. The same theory applies to the ruling out of various organ injuries. For example, with trauma to the thoracic cage, there is increased likelihood for injury to the adjacent subclavian and innominate vessels with displaced first and second rib fractures, but this injury is usually suspected based upon the clinical situation or from the findings on plain chest films (Poole, 1989). Lower rib fractures on the other hand are frequently associated with upper abdominal organ injury (Campbell, 1992; Schurink et al., 1997; Thompson et al., 1986). In those cases, a proper physical examination by expert clinicians is the best diagnostic approach, abdominal CT can be requested for verification. Schurink et al. (1997) reported that the negative predictive value for abdominal organ injury with lower rib fractures due to low energy impact was 100%; with lower rib fractures in the setting of a reliable negative physical examination, negative predictive value was 97%.

Lee et al. (1997) reported that fractures of the clavicle, sternum, scapula, and thoracic
spine have no positive predictive value for aortic injury, and that rib fractures had a very weak positive predictive value. Thoracic spine fractures actually had a negative predictive value for aortic injury (ACR).

The diagnosis of a flail chest can usually be made at physical examination. It is conceivable that in a heavy patient, a flail chest could be missed by clinical examination. However, a plain chest x-ray usually shows the displaced fragments (Campbell, 1992).

Discovering Rib fractures might carry some prognostic significance, for example the finding of multiple fractures in the elderly may warrant the transfer of a patient with this finding from a community hospital to a tertiary care centre (Lee et al., 1990; Svennevig et al., 1986). Children younger than 14 years of age have more compliant rib cages than adults do. The presence of rib fracture(s) therefore indicates that the child’s chest has sustained significant trauma (Garcia et al., 1990; Kleinman et al., 1988; Ng et al., 1998).

Such fractures frequently occur at the costovertebral and costochondral junctions and may be difficult to identify on standard chest and rib r-rays (Kleinman et al., 1988; Ng et al., 1998). Garcia et al. (1990) reported 14 deaths in 33 children with more than one rib fracture. Although thoracic injury accounted for only 1.6% of the total cases of 2,080 injuries, it led to 25% of the deaths. In addition, a large percentage of those the children younger than three years of age had been abused (ACR).

In summary, it is usually unnecessary to perform dedicated rib films (in addition to the plain chest film) in adults, because CT is usually used to evaluate potential organ injury in patients with significant chest and upper abdominal trauma (ACR).
Although multiple fractures have prognostic implications, there is no evidence that performing rib studies is beneficial (as opposed to performing other, diagnostic procedures to evaluate the presence or absence of more important internal organ injuries). An exception is the evaluation of a child in whom abuse is suspected; extended examination is warranted because of the high association of certain rib fractures with abuse and the difficulty of identifying such fractures with standard chest films. Another possible exception is to establish the presence of multiple fractures in the elderly if such information is to be used clinically to determine the need for tertiary or intensive care. A recent study suggests that sonography is much more sensitive than radiography for situations in which identification of rib fractures is clinically important (Griffith et al., 1999).
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### PRELIMINARY ANALYSIS STAGE 1 HOSPITAL ‘A’

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Total number with normal reports 162 79.02
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Total Number **Ankle Examinations** 381 %
Total number with normal reports 300 78.74
Total number with findings 81 21.26

**PRELIMINARY ANALYSIS STAGE 2 HOSPITAL ‘B’**

Total Number of examinations 11463
Total Number of skull x-Rays 300
Total Number of Rib Examinations 163
Total Number of Cervical Spine Examinations 302
Total Number of Lumbar Spine examinations 203
Total Number of Pelvis Examinations 163

Total Number **Skull Examinations** 145 46.33333 % Analysed
Total number with normal reports 139 95.86
Total number with findings 6 4.14
Total number of Fractures 2 1.44

Total Number **Rib Examinations** 90 55.21472 % Analysed
Total number with normal reports 80 88.89
Total number with findings 10 11.11

Total Number **Cervical Spine Examinations** 162 53.64238 % Analysed
Total number with normal reports 149 91.98
Total number with findings 13 8.02
Total number of Suggestive Fractures 2 1.34

Total Number **Lumbar Spine Examinations** 106 52.21675 % Analysed
Total number with normal reports 100 94.34
Total number with findings 5 4.72
Total number of Fractures 1 1.00

Total Number **Pelvis Examinations** 76 46.62577 % Analysed
Total number with normal reports 68 89.47
Total number with findings 8 10.53
Appendix 4

RADIOLOGY INFORMATION SYSTEM DATA

HOSPITAL ‘B’, ‘C’ & ‘D’

Referrals from ED, Selected Examinations. Pre & Post RAP/CPI interventions

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Appendix 5

MEDICAL RADIATION SCIENTIST SURVEY

1. Do you believe medical officers request unnecessary examinations? (see results in table below)

Yes ☐ No ☐

2. If the answer is yes to what percentage you believe they overuse imaging services? (see results in table below)

1. 25%
2. 50%
3. 75%
4. 90%
5. 100%

3. Do you question referring Medical Officers when you see an unjustified requisition? (see results in table below)

Yes ☐ No ☐

4. In your opinion what are the reasons behind the unjustified requisitions?
Appendix 6

MEDICAL OFFICERS SURVEY

1. Radiation Safety. Was it included in the formal medical training course?
   Yes ☐ No ☐

2. Have you been introduced to the occupational permissible radiation doses?
   Yes ☐ No ☐

3. Do you have an idea of the approximate Radiation doses of the different Medical Imaging Examinations?
   Yes ☐ No ☐

4. Do you think you have enough knowledge about radiation safety and radiation doses?
   Yes ☐ No ☐

5. After today’s Introduction to the Radiation Awareness presentation/talk, do you think you need further training on radiation safety or radiation doses?
   Yes ☐ No ☐

6. Have you been considering the radiation dose to the patient before requesting an imaging examination?
   Yes ☐ No ☐

7. May you please name your last clinical placement before (Hospital ‘B’)?

8. Are there differences in protocols and guidelines of requesting imaging examinations amongst the different hospitals where you have done your clinical placements? If yes, can you name some of the differences?
   Yes ☐ No ☐
   Comments:

9. Do you agree with the use of set ordering protocols such the “trauma series? Why? Why not?
   Yes ☐ No ☐
   Comments:
10. Do you find it difficult to request high end modality examinations such as CT/US or MRI in comparison with general X-ray?
   
   Yes □       No □
   
   Comments:

11. Do you always request the examinations for your patients, if not please specify?
   
   Yes □       No □
   
   Comments:

12. Have you been faced with situations where you had to request an examination for non-clinical purposes?
   
   Yes □       No □
   
   Comments:

Thank you for answering the questions. This will help us in providing you with a better service.
Appendix 7

UNCOVERING THE CAUSES OF REPEATED MEDICAL IMAGING EXAMINATIONS, OR PART OF, IN TWO HOSPITAL DEPARTMENTS.

Published in the Radiographer;
The official Journal of the Australian Institute of Radiography.
Uncovering the causes of unnecessary repeated medical imaging examinations, or part of, in two hospital departments

James Noi, Godfrey Isouard and Jerzy Mirecki

Abstract A study was undertaken to identify the causes of unnecessary repeated medical imaging examinations. The repeat analysis study investigated repeated medical imaging examinations at two medium sized hospitals in Sydney, Australia. The study was conducted jointly by a radiologist and a radiographer. Overall, there were 9.3% and 7.2% of total films repeated respectively at the two hospital sites. Unnecessary repeats were found to have been caused by numerous factors including: poor technical judgement, the adoption of unconventional techniques, non availability of radiologist for advice, patient movement or motion, equipment mishandling, disorganised practice and poor supervision of students. At both the sites, senior radiographers were associated with 70.2% and 84.5% respectively of dark and light film errors, and 50.7% and 85.5% respectively of the repeated cases had students' involvement. On the other hand, junior radiographers were involved with 70.3% and 86.1% respectively of positioning errors.

It was recommended that major changes be introduced to radiographer practice including, quality control, radiological techniques, training, supervision and continuing professional development. It was also recommended that the radiologist takes a more active role in future guidance and training of radiographers.

Key words: image analysis, equipment use, education, repeat analysis, exposure selection, positioning and techniques

Introduction

Repeating imaging examinations impacts significantly on imaging services by adding additional cost due to wastage of resources and reduced radiographer time. Repeating examinations also affect patients by exposing them to additional radiation and causing them discomfort.

Evaluation through periodic repeat analysis studies has been an essential component of quality assessment in the provision of radiology services to control and minimise repeated examinations for more than four decades. The tool has been used to identify the cause of errors in medical imaging examinations and assist in identifying areas of improvement in the continuing development and practice of the radiographer. The analytical study is also a valuable tool for health services as a quality indicator, and a tool to monitor and measure efficiency.

An appropriate quality assurance program will assist the development and maintenance of an efficient radiology service. Several factors may contribute to errors resulting in repeat medical imaging examinations being taken. These factors include the knowledge and training of the radiographer (such as positioning errors, and dark and light films), the patient (preparation and motion), the organisation of the practice, and equipment failure.

The role, knowledge and ongoing performance of the radiographer is critical to ensuring that all procedures are undertaken within the quality criteria and standards required. With the introduction and application of clinical governance to all clinical areas, the onus is now on healthcare professionals including radiographers to evaluate performance, develop departmental audits and ensure effective and safe practice while minimising the associated risk. In addition, the recent move for future role expansion of radiographers in radiographic image interpretation, the administration of intravenous injections and in nuclear medicine therefore demands that radiographers need to ensure that their professional and legal obligations are met in daily quality assurance activities and clinical practice.

Patients having medical imaging examinations are exposed to harmful radiation that has detrimental biological effects. Non-stochastic effects are also a concern, and according to Singh et al. cancer could be triggered at a very low radiation dose. It is the responsibility of the radiographers who are using radiation for medical purposes to ensure that their patients are not receiving any unnecessary doses of radiation and that the benefits of the repeated examinations outweigh the harmful effects.

The aim of this study was to identify any common factors across imaging departments that contributed to repeating examinations, to determine the likely causes of repeated examinations, and to make recommendations for improvement. The study used the repeat analysis study protocol as described by Gray et al. focusing on repeated films at two hospital medical imaging departments.

Methods and patients

Setting and patient groups

A repeat analysis study was conducted at two medium size hospitals, each approximately 200-beds and located in two
different area health services within the Sydney metropolitan area in Australia. The first hospital, designated Site 1 in the study, is located in the south western region of Sydney. The second hospital, designated Site 2, is located in the western region of Sydney. The study included all inpatients and outpatients referred to each hospital over a four-week period for general radiological examination using a conventional film system.

Ultrasound examinations and all films taken by radiologists during special procedures such as barium studies and venograms were excluded from the study.

**Repeat analysis method**

In accordance with the method of Gray et al., reject films in the present study were defined as all repeat films including green films, black films, clean-up films, and patient films. Repeat films were limited to those radiographs that were not accepted and required an additional exposure to the patient.

All reject films were, in the first instance, collected in a box dedicated to reject films. Two independent senior radiographers monitored reject film collection at each hospital as part of the regular reject analysis study.

At the end of the collection period, all request forms for that month were forwarded to the chief radiographer's office. A copy of the electronic statistical data was also produced. Special electronic templates were produced to identify the examinations and the radiographer performing the examination. The chief radiographer took responsibility for the gathering of the data, sorting films and preliminary film analysis. A second and final round of film analysis was then performed conjointly with the reporting radiologist and the chief radiographer.

At first instance, films were sorted into four categories: Dark, Light, Positioning Error, and Miscellaneous. On completion of the reject film collection, the radiologist and the chief radiographer assessed the films and the results were tabulated on a worksheet. Structured face-to-face interviews were then held with each of the radiographers to establish the causes of the repeat films. Radiographers were specifically asked to comment on their films and identify the reason behind each film.

**Identification of radiographers**

Each radiographer involved in the study used markers bearing their initials on the film which identified the radiographer who had performed the examination and repeated the view. The identification of the radiographer was then confirmed using further information obtained from the radiographer's initials on the request form, the electronic data record and from the staff roster.

Radiographers were classified in the study as 'senior' or 'junior', depending on their employment classification.

The senior radiographer category included the chief radiographer and level 3 medical radiation scientists. Junior radiographers included level 1 and level 2 medical radiation scientists.

At the end of data compilation, radiographers were interviewed to discuss their cases and to understand the reason behind the repetition of some examinations. In order to determine the causes of repeated examinations, investigators spent time observing radiographers performing the examination and discussed the technique with staff at clinical meetings. Observations, justifications and causes of such repeat films were analysed and are listed in Table 9.

**Error classification**

This category is to sort films according to the error; e.g. dark, light, positioning, good film, motion error, equipment mishandling, clear and black films.

- Dark and light films were sorted into three different levels according to the severity of the error as follows:
  - 1.1 slightly light
  - 1.2 light
  - 1.3 too light

- 1.1 slightly dark
- 1.2 dark
- 1.3 too dark

Level 1 cases were those that were slightly light or dark. Errors at this level might be cases where the patient was properly measured and an exposure chart consulted, but the image was too light or dark either due to pathology or patient structure. Level 2 cases were cases where the exposure measurement was poor or the exposure was too high or too low. Level 3 cases were those where exposure selection had been inappropriate; as an example, selecting .2 instead of .02. All three level errors might also have had different causes than the examples given above.

- Positioning errors were classified as P1, P2 and P3 according to the level of adjustment required in positioning. For example P3 is the level where the positioning is severely rotated or off centre. Positioning errors includes:
  - (1) wrong positioning;
  - (2) cut-off or over-coned;
  - (3) off-centre;
  - (4) marker obstructing site in question and;
  - (5) anatomy in question not shown.

- Good films are images that would have been accepted by radiologists and should not have been rejected.

- Other errors have been classified as M for miscellaneous. This category includes:
  - (1) patient preparation (jewellery or other metallic substances not removed);
  - (2) double exposure;
  - (3) patient motion;
  - (4) equipment fault (processor).

**Results**

**Films and examinations**

As shown in Table 1, over 1500 examinations were undertaken at each site, with 3089 films used at Site 1 and 3610 films used at Site 2. At Site 1 there were 327 rejected films, of which 256 were repeats. At Site 2 there were 361 rejected films, of which 233 were repeats. Overall this resulted in a repeat rate of 9.3% at Site 1 and 7.2% at Site 2.

<table>
<thead>
<tr>
<th>Hospital</th>
<th>No. reject films</th>
<th>No. repeat films</th>
<th>% repeat</th>
<th>No. examinations</th>
<th>No. accepted films</th>
<th>Total films</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>327</td>
<td>256</td>
<td>9.3</td>
<td>1503</td>
<td>2762</td>
<td>3089</td>
</tr>
<tr>
<td>Site 2</td>
<td>361</td>
<td>233</td>
<td>1.2</td>
<td>1535</td>
<td>3249</td>
<td>3610</td>
</tr>
</tbody>
</table>

Table 1 Number of repeat and accepted films.
Table 2 lists the various examinations at each site. Table 3 lists details of the rejected films at each site.

**Exposure error dark and light films:**

As shown in Table 4, approximately 47% of the repeated films at both sites were dark and light films. The alarming result was that senior radiographers were responsible for more than 70% of the re-peats in this category at each of the sites (Table 5). The majority of dark and light repeats were of level 2 and level 3 error types, which needed more than a minor adjustment in exposure setting (Table 4).

**Good films**

As shown in Table 5, the reject rate of good films at Site 1 was less than 7%, with the majority of these related to junior radiographers. However at Site 2 the reject rate was over 22% of the total repeats, with senior radiographers being involved in more than 62% of these cases.

**Positioning**

As shown in Table 4, positioning errors constituted a large proportion of the total errors in the study. Site 1 had 42% of the total repeats and Site 2 had less than 28%. Table 5 lists the various positioning errors through spinal examination. The junior radiographers contributed to the largest proportion of positioning errors with 86% and 70% of errors at Sites 1 and 2 respectively.

**Miscellaneous errors**

As shown in Table 5 the percentage of error in this category was 4.3% at Site 1 and 2.6% at Site 2, of the total repeat rate.

**Students**

As shown in Table 8, student supervision still resulted in a large proportion of repeated films carrying students’ markers. The majority of repeated films were attributed to supervision provided by senior radiographers, with 59.7% and 85.5% of films repeated by students being attributed to senior supervision at Sites 1 and 2 respectively.

**Green, black and clear films**

As per Gray et al., all green, black and clear films were considered as rejects and not as repeats.

Green films were fresh films disposed for recycling without going through the processor. Black films were usually films exposed to light. Clear films were films usually used as a cleaner for the processor. They were placed in the processor without exposure to light.

As shown in Table 1, this group constituted 21.7% of the total reject films at Site 1 and 35.4% at Site 2.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Examinations undertaken with the repeated films</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Examination</strong></td>
<td><strong>Site 1</strong></td>
</tr>
<tr>
<td>Chest</td>
<td>24</td>
</tr>
<tr>
<td>Extremities</td>
<td>29</td>
</tr>
<tr>
<td>Abdomen</td>
<td>21</td>
</tr>
<tr>
<td>Head</td>
<td>29</td>
</tr>
<tr>
<td>Pelvic girdle</td>
<td>21</td>
</tr>
<tr>
<td>Shoulder girdle</td>
<td>29</td>
</tr>
<tr>
<td>Spine</td>
<td>21</td>
</tr>
<tr>
<td>Dorsal</td>
<td>29</td>
</tr>
<tr>
<td>Thorax</td>
<td>21</td>
</tr>
<tr>
<td>Total</td>
<td>256</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3</th>
<th>The rejected films</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hospital</strong></td>
<td><strong>No. green films</strong></td>
</tr>
<tr>
<td>Site 1</td>
<td>6</td>
</tr>
<tr>
<td>Site 2</td>
<td>38</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Types and degree of errors in films</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Error Site 1</strong></td>
<td><strong>Level 1</strong></td>
</tr>
<tr>
<td>Dark</td>
<td>16</td>
</tr>
<tr>
<td>Light</td>
<td>21</td>
</tr>
<tr>
<td>Positioning</td>
<td>20</td>
</tr>
<tr>
<td>Good</td>
<td>16</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>11</td>
</tr>
<tr>
<td><strong>Error Site 2</strong></td>
<td><strong>Level 1</strong></td>
</tr>
<tr>
<td>Dark</td>
<td>16</td>
</tr>
<tr>
<td>Light</td>
<td>13</td>
</tr>
<tr>
<td>Positioning</td>
<td>14</td>
</tr>
<tr>
<td>Good</td>
<td>22</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 5</th>
<th>Radiographer involvement in repeated films</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Radiographer</strong></td>
<td><strong>Exam by student</strong></td>
</tr>
<tr>
<td>Total SR1</td>
<td>77</td>
</tr>
<tr>
<td>Total JR1</td>
<td>73</td>
</tr>
<tr>
<td>Total SR2</td>
<td>1503</td>
</tr>
<tr>
<td>Total JR2</td>
<td>907</td>
</tr>
<tr>
<td>Total J2</td>
<td>8</td>
</tr>
<tr>
<td>Total Site 2</td>
<td>1535</td>
</tr>
<tr>
<td>% SR2</td>
<td>65.0</td>
</tr>
<tr>
<td>% JR2</td>
<td>35.0</td>
</tr>
</tbody>
</table>

*exams, examinations; SR1, senior radiographers at Site 1; SR2, senior radiographers at Site 2; JR1, junior radiographers at Site 1; JR2, junior radiographers at Site 2.*
Table 6 Positioning errors in relation to body region

<table>
<thead>
<tr>
<th>Examination</th>
<th>Site 1</th>
<th>Site 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest</td>
<td>36</td>
<td>21</td>
</tr>
<tr>
<td>Extremity</td>
<td>14</td>
<td>11</td>
</tr>
<tr>
<td>Abdomen</td>
<td>16</td>
<td>6</td>
</tr>
<tr>
<td>Head</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>Pelvic girdle</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>Shoulder girdle</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Spine</td>
<td>23</td>
<td>13</td>
</tr>
<tr>
<td>Breast</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>109</td>
<td>64</td>
</tr>
</tbody>
</table>

Table 7 Positioning errors in relation to the spine

<table>
<thead>
<tr>
<th>Examination</th>
<th>Site 1</th>
<th>Site 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cervical</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Odentorad</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Thoracic</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Lumbar</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Sacrum</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
<td>12</td>
</tr>
</tbody>
</table>

Table 8 Supervised student involvement in repeated films

<table>
<thead>
<tr>
<th>Supervising radiographer</th>
<th>No. repeated films</th>
<th>% of total repeats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total SR1</td>
<td>42 (69.7%)</td>
<td>10.3%</td>
</tr>
<tr>
<td>Total JR1</td>
<td>29 (46.5%)</td>
<td>11.5%</td>
</tr>
<tr>
<td>Total site 1</td>
<td>79 (100%)</td>
<td>28.1%</td>
</tr>
<tr>
<td>Total site 2</td>
<td>47 (65.5%)</td>
<td>28.1%</td>
</tr>
<tr>
<td>Total site 2</td>
<td>8 (11.5%)</td>
<td>3.4%</td>
</tr>
<tr>
<td>Total site 2</td>
<td>53 (100%)</td>
<td>23.5%</td>
</tr>
</tbody>
</table>

Suspected causes

Table 9 lists the various causes that contributed to the unnecessary repeated medical imaging examinations as identified through structured interviews.

Discussion

This study has revealed that a considerable number of medical imaging examinations are unnecessarily repeated within hospital departments. On close investigation, it was found that these repeats were caused by a variety of factors including poor technical judgement, non-availability of radiologists for advice, patient movement or motion, equipment mishandling, disorganised practice, and poor supervision of students.

Exposure errors were found to be an issue that requires special attention. Despite the general perception that repeat films are attributable to inexperienced junior radiographers, it was found that most repeats related to exposure factors were linked to senior radiographers. They were found to rarely consult an exposure chart and never to measure patient size.

Investigators' attention was particularly drawn to the peculiar methods used by a number of radiographers in selecting exposure. Some had their original course study notes in their pockets with exposure sheets written from their training days. Despite having newer methods and techniques available (such as high kVp techniques) they relied greatly on the methods originally taught to them and used these whenever supervising current students. Another traditional method was the notion of 'small equals pelvis equals half a knee and so on'. Although this method has no scientific evidence, advocates believe that it works. Unfortunately, patients do not present with the same size of pelvis or abdomen and the proportional relationship between body parts differs between patients.

To overcome exposure errors it is recommended that medical imaging departments undertake a yearly exposure chart review with radiographers taking a lead role in the process. Strict methods should be employed to ensure that follow up monitoring is undertaken to prevent further unnecessary examinations.

The investigation also revealed that a large proportion of all repeat examinations were attributed to poor positioning technique. In x-ray rooms where there is automatic exposure selectors, the positioning techniques used were causing improper body part alignment with the photo-timer. That was found to be largely due to a poor understanding of the design of the bucky stand.

Through a process of observing radiographers at both sites it was noticed that improper detection of the right density of body part in question is caused by failing to follow manufacturer's recommended positioning technique, especially for chest x-rays. The present investigation shows that more than 30% of the

Repeats are for chest x-rays.

Most bucky stands are designed with the chin rest positioned on the upper side of the Stand-Bucky. Radiographers automatically assume that when positioning a patient for chest x-ray, the patient's chin should be resting on the chin rest. This would be ideal for most tall to average size males (Figure 1). However for most female patients a smaller size cassette, that of a 35 x 35 cm size, is used to reduce unnecessary space on the film. Most radiographers compensate the difference in the size of the cassette by raising the cassette inside the bucky holder so that the patient
can still rest the chin on the chin rest. Raising the cassette and positioning the chest to the cassette places the ion chambers in a position to detect the density of the hilum and not the density of the lung fields (Figure 2) producing darker images.

To correct this problem, some radiographers try to adjust the sensitivity of the photo-chamber, which usually results in having light films. The same problem applies to large size male patients when the 43 x 35 cassette is used crosswise.

The investigation found that positioning errors were largely associated with junior radiographers. This was an indication that the problem may be due to lack of experience, training and improper supervision. The errors were found to be mainly due to the rotation of the body part in question or poor alignment with the cassette.

Cervical spine examination and in particular performing odontoid views, attracted the attention of the investigation team. In two cases the radiographer repeated the odontoid process view three times without achieving a successful result. When the radiographer was interviewed, it was ascertained that this view was being performed by majority of radiographers in the erect position. According to the Merrill’s Atlas of Radiographic Positions, this view should, preferably, be performed with the patient in the supine position. While observing junior and senior radiographers performing the examination, it was noticed that as the lateral cervical spine view is performed in the erect position, radiographers go ahead and complete the remainder of the procedure in the erect position instead of laying the patient down for the AP and odontoid view. In the erect position, the orchestration of the trapezius muscle, socalloped and sternocostoid differs from that found when the patient is supine. Therefore, it is much more difficult to get the odontoid in the right position and this leads to a large number of repeats. Reviewing the accepted images submitted for reporting, the radiologist determined that the images were still not of a good quality. To reduce the number of repeated odontoid views in the department it is recommended to have proper in-house training and staff need to be encouraged to follow appropriate techniques. It was also identified that radiographers need to be reminded that supine position means having the patient lying down with the face upward.

The large number of good films that were subsequently repeated at Site 2 were closely investigated. The investigators were unable to understand why many of those images were rejected and in many cases the radiographers were unable to explain their reasons for the repeat examination. It was found that the radiographer usually experienced difficulties in determining the quality of the image in order to make a proper assessment. As an example, some images were slightly over or underexposed and determined as unacceptable by the radiographer. However, the radiologist in such cases was satisfied with the image. A similar situation arose when, for example, some images were repeated because the body part in question was rotated or some of it was cut-off. In many of these cases the radiologist was satisfied that the information seen in the film was sufficient for diagnostic purposes.

One important observation was the significant difference in the number of good films that were rejected at Site 1 where the radiologist was present at most times and personally taking part in supervising the work and commenting on the quality of work as produced. Radiographers took special interest in consulting with the radiologist before a decision was made on whether to perform a repeat examination.

### Table 9 Suspected causes of unnecessary repeated medical imaging examinations or part of in two hospital departments

<table>
<thead>
<tr>
<th>Type of error</th>
<th>Suspected causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure</td>
<td>In X-ray rooms where only manual exposure selection is available; the error is largely attributable to the selection of incorrect exposure factors, mainly due to the incorrect estimation of the patient’s size. In X-ray rooms equipped with automatic exposure selection, the error is largely attributable to the incorrect positioning of the body part in question in relation to the ion chambers. Radiographers found not to usually consult an exposure chart or measure patient size.</td>
</tr>
<tr>
<td>Positioning</td>
<td>Not following the correct positioning technique as recommended by the manufacturer, and especially when taking chest X-rays (more than 30% of repeats are for chest X-rays). Not following the correct positioning technique as recommended by educational references such as the Merrill’s Atlas, especially when taking odontoid views. Junior radiographers largely attributed, and possibly due to lack of experience, training and improper supervision. Errors mainly due to the rotation of the body part in question or poor alignment with the cassette.</td>
</tr>
<tr>
<td>Good films</td>
<td>Availability of radiologist at the site for consultation and advice reduced the number of rejected good films.</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>(1) Patient movement or motion Errors due to patient movement or difficulty in holding breath. Error rate increased with severity of illness. (2) Equipment mishandling and off-centre images Errors found to be due to a number of causes, including the bucky being off centre (bucky not pushed in correctly), the tube being off centre (tube not aligned with bucky centre), tomography not correctly set up, or films placed the wrong way (cassette placed crossways for an A/F skill). (3) Double exposure Error due to disorganised practice and loss of concentration by Radiographer. 4 Over-collimation and over-lapped images Errors due to the radiographer for example, trying to fit a number of images on the one film, or another example may be poor patient presentation resulting in jewellery remaining in the way or equipment fault (for example, the lead shutters in the light beam diaphragm may need adjustment).</td>
</tr>
<tr>
<td>Supervised students</td>
<td>Close observation of the supervisory process showed that supervision from senior staff was rarely undertaken appropriately. In many cases the radiographer would start the case with the student but would not maintain the supervision throughout.</td>
</tr>
<tr>
<td>Green, black</td>
<td>Several cases were noted including, a faulty automatic cassette holder at Site 2, and clear films mishandling of films in the darkroom, and organised imaging practices.</td>
</tr>
</tbody>
</table>

On the other hand, at Site 2, the same radiologist was also the reporting radiologist; however, he spent a very limited time at the site and therefore radiographers had to rely on their own judgment for such decisions. In the absence of a radiologist, radiographers tended to be extra cautious and not risk accepting an image that could potentially be problematic. It was clear to the investigators that radiologist’s involvement in supervising work production had a significant impact on the number of repeated examinations, 22%
of the total repeats at Site 2 compared to 6.5% at Site 1. It was also noted that the confidence of radiographers and their ability to assess image quality was higher due to their close relationship with the radiologist.

To reduce the number of unnecessary repeat examinations especially images of an acceptable diagnostic value, it is highly recommended to get the radiologist involved with the close supervision and training of radiographers.

Few rejected films were in the miscellaneous category, ranging from 2 to 4% of the total rejects at each site. Investigators found several factors for the cause of these errors such as poor technical judgement, patient movement or motion, equipment mishandling, and disorganised practice.

The contribution of students to the number of repeats was also apparent. According to the protocols for student supervision at each site, student-assisted cases are under the full control and supervision of the senior radiographer. However, the investigation team observed that in practice this was not always followed appropriately. In many instances the senior radiographer would commence the case with the student and would not maintain supervision throughout. In some instances it was noted that students were allowing other students, a practice that should be avoided.

There were also a large number of green, black and unclear films at both sites, and in particular at Site 2. The investigation found a number of likely causes that contributed to this which included a faulty automatic cassette holder at Site 2, mishandling of films in the darkroom and disorganised imaging practices. The radiographers provided a variety of reasons for this when interviewed by the investigation team. In some instances radiographers realise that they have selected the wrong exposure and open the cassette to overwrite the latent image, keeping the film to be used as a processor cleaner. Another explanation was that in some cases radiographers left unused cassettes in the room and that these cassettes may end up not being used. When the following shift starts, the next radiographers do not take the risk of using misplaced cassettes and therefore change the film before reuse.

One recommended solution is for medical imaging departments to provide a special carriage box on wheels made from two compartments; one side to be labelled 'clear' and the other 'exposed'. This would help in sorting films as well as providing an excellent manual-handling tool that can prevent back injuries from carrying too many cassettes.
Appendix 8

DIGITAL REPEAT ANALYSIS; SETUP AND OPERATION

Published in the Journal of Digital Radiography
Digital Repeat Analysis; Setup and Operation


Since the emergence of digital imaging, there have been questions about the necessity of continuing reject analysis programs in imaging departments to evaluate performance and quality. As a marketing strategy, most suppliers of digital technology focus on the supremacy of the technology and its ability to reduce the number of repeats, resulting in less radiation doses given to patients and increased productivity in the department. On the other hand, quality assurance radiographers and radiologists believe that repeats are mainly related to positioning skills, and repeat analysis is the main tool to plan training needs for up-skilling radiographers. A comparative study between conventional and digital imaging was undertaken to compare outcomes and evaluate the need for reject analysis. However, digital technology still being at its early development stages, setting a credible reject analysis program became the major task of the study. It took the department, with the help of the suppliers of the computed radiography reader and the archive and communication systems, over 2 years of software enhancement to build a reliable digital repeat analysis system. The results were supportive of both philosophies; the number of repeats as a result of exposure factors was reduced dramatically; however, the percentage of repeats as a result of positioning skills was slightly on the increase for the simple reason that some rejects in the conventional system qualifying for both exposure and positioning errors were classified as exposure error. The ability of digitally adjusting dark or light images reclassified some of those images as positioning errors.

KEY WORDS: PACS, CR, digital reject analysis, equipment use, education, repeat analysis, exposure selection, positioning and techniques

INTRODUCTION

Reject analysis (RA) has been one of the key quality control tools in conventional medical imaging departments using film processing technology for as long as many of us can remember. The Quality Control in Diagnostic Imaging3 has been used as the bible of reject analysis in most Australian imaging departments. We also acknowledge that some departments in Australia and other countries refer to Peer et al.2 Results of RA are used to plan for training needs and prepare clinical presentation targeting staff weaknesses. Reject films also provide a valuable tool in calculating radiation dosage delivered to patients for radiobiology purposes; for example, when a patient is found to be pregnant after being x-rayed, physicists require to know the number of exposures taken to assess the situation and put their recommendations. With the change to computed radiography (CR) and picture archiving and communication systems (PACS), film RA was replaced with digital reject analysis (DRA) because of the physical elimination of film.

The original aim of our study was to conduct a comparative study between film and image RA to compare the outcomes between conventional film processing and CR technology and assess the need of DRA program in digital environments. The collection of data for the conventional RA was simply reliant on manually collecting rejected films in an assigned box.
For PACS, our provider has a built-in electronic folder where radiographers have the choice of sending an unwanted image to the reject folder. Records are available to system administrators, and images cannot be deleted even if it has been rejected by the operator. However, our CR provider was not well equipped for DRA, and there were few problems to be solved to maintain a credible system; in fact, engineering and marketing key personnel were encouraging users to delete unwanted images immediately to clear memory space. Reviewing other publications, it was obvious that being at the early stages of the digital era, RA has been overlooked, and not much thought has been given to it. Because of the complexity of collecting data for the DRA, the main aim of our project drifted toward a lengthy process to set a credible DRA system.

**Setting and Patient Groups**

In a major project to change over from conventional film processing system to a computed radiography system in a large metropolitan hospital made up from two campuses in Western Sydney, a reject analysis study was conducted to compare between conventional RA and DRA outcomes.

The study was conducted at the smaller campus of the hospital that has over 20,000 examinations a year. The project was submitted to the ethics committee, and clearance was granted. Two months prior to the switch over to the new system, the collection of reject films took place based on the recommendations set by Gray et al. to include all reject films belonging to inpatients and outpatients referred to the hospital over a 4-week period for general radiological examinations. The second part of data collection started 2 months after the starting date of the PACS system, comprising the same category patients and examinations collected for the conventional system. Ultrasound examinations and all films or images taken by radiologists during special procedures such as barium studies, Venograms, etc., were excluded from the study.

**MATERIALS AND METHODS**

The first part of the study of conventional RA was based on universal guidelines as set by Gray et al. Reject films were defined as all scrap films including green films, black films, and cleanup films. Repeat films were limited to those radiographs that were not accepted and required an additional exposure to the patient. Reject films were collected and controlled by the senior radiographer in charge of conducting the periodic reject analysis study. At the end of the collection period and after performing the initial sorting and analysis, the collected batch went through another sorting process by the researching team. Films were sorted into four categories: exposure, positioning, good, and miscellaneous errors. Clear, black, and fresh films were included as part of the reject analysis and not of the repeat analysis.

For the purpose of this study, exposure errors were sorted into three levels depending on the severity of being over- or underexposed. A third-level error required modification by more than 15 kV. A second-level error required modification by an average of 8–10 kV. A first-level error required a minor change up to 6 kV. In addition, for the purpose of this study, an additional category (digitally fixable) was created where level 1 and 2 exposure errors from the conventional batch were scanned and reassessed by the radiologist. The second part of the study took place 8 weeks after the change over to CR technology. Proper collection failed because of a conflict of philosophy between the PACS provider and the CR provider. The PACS system was properly set up to have a reject analysis folder available in the main quality assurance folder. However, the CR system did not have the capability to comply with DRA requirements. In response to an enhancement request, the CR provider modified and upgraded the software to rectify the problem (refer to CR system settings). Before starting data count and analysis, we had to make sure that all images residing in the CR recycle bin have been sent to PACS. Similar to the conventional batch, image analysis was conducted by the research team comprising of a radiologist and a senior radiographer. Films were analyzed using image viewing light boxes. PACS images were viewed using a radiologist PACS workstation.

Statistical data related to the number of patients and examinations were collected from the radiology information system (RIS) for a whole month for both batches. To assess the number of films and exposures taken in the conventional batch, a film stock take was carried out at the beginning and at the end of the collection process. For PACS, the task was much easier because figures were provided electronically by the PACS engineer. All data were entered in an Excel worksheet.

**CR System Settings (Sequence of Events)**

Conventional RA studies relied on manual collection of films. It was up to the integrity of radiographers to keep rejects in the dedicated bin. With PACS, however, there are many complexi-
ties mainly because PACS and CR are usually given by different providers. CR is the first point of capturing digital images, where PACS has the role of modifying and archiving the image. At the time of purchasing the PACS system, prospects of continuing repeat analysis were promising. Ability to maintain a proper record of all rejected images was part of the specifications of the new PACS. It was expected that reject images are readily available whenever they are needed by administrative radiographers. It was further promised that the PACS engineer would automatically provide the department with monthly reports of the reject folder based on modality.

After 1-month operation, the first reject analysis report was received from the PACS engineer. The number of the rejected images was below of what was expected. Analyzing the available images in the reject folder, we only found images of good diagnostic quality. Rejected images comprised identical images saved in the patients’ folder that has been modified, with the addition of digital shutters (apparently any image that had digital shutters applied is saved as a new image, and the old one is automatically sent to the reject folder; this rule does not apply to other digital modifications); the remaining rejects were duplicates of existing images resent to PACS because of interface failure between two or more systems, such as RIS, hospital information system, and PACS. Identifying the nature of the images in the reject folder raised a suspicion. Is it possible that we have no repeated images?

Troubleshooting the problem with the PACS engineer, it was discovered that the CR system has the ability of sending images to PACS either manually or automatically. Radiographers had the ability to switch autoselect on and off. To hide mistakes, bad images were never sent to PACS. It was also found that radiographers had the ability to delete images permanently from the CR system. As a result, there were no records of any repeated images in the system. Contacting the CR provider, we discovered that there was no functionality to stop deleting images or switching autoselect off. The inability of the CR to maintain a proper reject analysis record has been identified by other users.

To overcome the inadequacy of CR/PACS relationship, some users decided to use the CR as the means of archiving rejected images. We were not able to do the same because CR has a very limited archiving space, and it is not used as the long-term archiving tool. To comply with the equipment registration guidelines imposed by the New South Wales Environmental Protection Authority to allow retrospective dose assessment if required (e.g., if a patient is found to be pregnant after being exposed to x-rays), we are required to archive all acquired images. After all, it is a moral and professional obligation to comply with the ALARA principle, and quality assurance (QA) is an essential tool to assess training needs and to keep exposure to radiation as low as possible.

With PACS being the long-term archiving tool, it would be expected that all images including the repeated ones are sent from CR to PACS for future reference. The solution for the problem was to prevent users from switching autoselect off. Raising an enhancement request to the manufacturer to upgrade the software was our only available action. It took the CR provider a year to come up with an enhancement patch to the current software, where the ability of nonadministrative users to switch autoselect off and on was removed. Radiographers found another way of stopping images from going to PACS. They realized that if they were quick enough to double click the image after acquisition (before the image is sent to PACS), they can stop it from being transferred to PACS and then delete it.

The only solution was to raise another request for enhancement to disable manual deletion from the CR system. It was almost a year when the new software was released, and the radiographers’ ability of deleting images was replaced with the ability of sending images to the recycle bin, and only a system administrator can empty the recycle bin. However, the problem of stopping images from going to PACS was not fixed. The reason was that some users, especially in other countries, were not happy in sending bad images to PACS.

Another request for software enhancement was placed to the manufacturer, but as an interim measure, we adopted a new policy where the QA radiographer tags all images from the CR recycle bin and send them to PACS as a batch. Unfortunately, that causes lots of complications, the main problem being the creation of a new folder for every single image sent to PACS as unspecified, and the system administrator has to sort them in their proper folders one by one. Radiographers were informed of the new policy and were in-
constructed not to try to stop images from going to PACS, and they were also informed that images in the PACS reject folder will be dealt on an anonymous level. On the other hand, images in the CR recycle bin will be examined closely and discuss every single case with the staff in question.

Final Setting of the Digital Reject Folder

The final product of the CR/PACS setup is to automatically send all images from the CR reader to the PACS-ISU immediately when the image is captured in the reader. Images failing to go to PACS as mentioned above are sent manually on a regular basis by the system administrator especially before starting the periodic DRA. When an image hits PACS, radiographers are then required to either reject, QA, or accept an image. After finishing the examination, the radiographer will sign off the image by completing the examination in the RIS system. That will verify the examination moving it to the undated folder for the radiologist to report.

The PACS workstation has the same QA capability as the CR; however, users have the option of switching the viewing of annotated text off or on. For the untrained user in the hospital wards, that might be a problem, and if annotation is switched off, remarks added to the image can be missed. The CR QA station, on the other hand, has the capability to permanently burn the text into an image such as markers to identify the side in question, identify AP from PA, etc. Therefore, radiographers prefer to use the functionality to eliminate questions raised by users. The CR QA station is also used to change image algorithm using the raw data. For example, an abdominal image can be reoutput with a chest algorithm to assess the bases of the lungs, or chest images can be reoutput with abdomen algorithm to locate nasogastric tubes.

It is important to note that, to save short-term archiving space, PACS was set to automatically remove images from the reject folder after 7 days. After much negotiation, the period was increased to 90 days. However, from the text data, images can still be accessed at any time by the system administrator for as long as the long-term archive media is available on the premises. Another request for an enhancement has also been put to the PACS provider to store the reject folder on a CD on a monthly basis.

ERROR CLASSIFICATION

In the process of sorting images to identify the causes of repeats, we realized that some users came up with a larger number of categories than the conventional method. Some went to an extreme, having 38 categories. After careful analysis, our team decided to stick to the original categories set for the conventional RA program, with the addition of a new category related to the digital environment. Repeated films and images were sorted as exposure, positioning, good film/image, and miscellaneous errors. Exposure errors included all repeated images for being dark or light films/images. Positioning errors were included, with wrong positioning as set by Merrill's Atlas. Cutoff or overconed, off center, marker obstructing the site in question and the part in question was not shown.

Good films/images category consists of those images where radiographers decided to repeat the image because they thought they can obtain a better image, wherein the radiologist would be happy to accept that film or image (mainly those cases where images can be digitally adjusted to an acceptable window and level). For the purpose of this study, the research team decided to review the conventional batch, add a subcategory tagging films as fixable digitally, and scan images that can be adjusted.

The miscellaneous category included improper patient preparation (jewelry or other metallic elements not removed), double-exposed film/image plates, patient motion, and equipment fault (processor, dirty films or image plates).

Clear, black, and fresh films as well as re-processed images were included as part of the reject analysis and not of the repeat analysis. As recommended by Gray et al., green and QC films were categorized as reject but were not included in the conventional RA. Reprocessed images included all images that have been resent to PACS after QA, such as applying shutters, reoutput images from the CR, or images sent originally to the wrong patient or folder.

RESULTS

As shown in Table 1, the total number of examinations for the 4 weeks of the conventional batch was 1680 examinations. According to the
imaging protocol of that department, the number of films taken and forwarded to radiologist for reporting should be 2780 films. The number of films in the reject bin was 407 films, bringing the total number of used films to 3187. The usage of films accounting to film stock record was 3200 films. The number of repeated views was 325 films, which makes 10.5% of the total views taken.

In the digital batch, the number of examinations was 1615 examinations, and according to PACS records, the number of images forwarded for reporting was 3063 images. The number of images in the reject folder was 189 images, bringing the total number of stored images to 3252. The number of repeated views was 152 images, which makes 4.7% of the total views taken (Tables 2-4).

The results of the repeats are as follows:

- **Exposure errors:** in the conventional batch, 5.2% of the repeats were of this category. In the digital batch, exposure errors made 0.87% of the repeats.

- **Positioning errors:** 3.05% of the repeated films in the conventional environment were because of positioning error. In digital batch, 3.2% fell in this category.

- **Good films:** 1.3% of the repeated films in the conventional batch were good films, whereas in the digital batch, they were 0.2%.

### Table 1. Number of repeat and accepted films/images

<table>
<thead>
<tr>
<th>Hospital</th>
<th>No. of reject films</th>
<th>No. of reject films/improved images</th>
<th>No. of repeat</th>
<th>Percent repeat</th>
<th>No. of examinations</th>
<th>No. of accepted films/images</th>
<th>Total films/images</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>407</td>
<td>80</td>
<td>327</td>
<td>10.5</td>
<td>1680</td>
<td>2780</td>
<td>3187</td>
</tr>
<tr>
<td>Digital</td>
<td>189</td>
<td>37</td>
<td>152</td>
<td>4.7</td>
<td>1615</td>
<td>3063</td>
<td>3252</td>
</tr>
</tbody>
</table>

### Table 2. Examinations undertaken with the repeated films/images

<table>
<thead>
<tr>
<th>Examination</th>
<th>Conventional</th>
<th>Digital</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest</td>
<td>162</td>
<td>50</td>
</tr>
<tr>
<td>Extremities</td>
<td>37</td>
<td>18</td>
</tr>
<tr>
<td>Abdomen</td>
<td>32</td>
<td>30</td>
</tr>
<tr>
<td>Head</td>
<td>19</td>
<td>16</td>
</tr>
<tr>
<td>Pelvic girdle</td>
<td>26</td>
<td>15</td>
</tr>
<tr>
<td>Shoulder girdle</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>Spine</td>
<td>38</td>
<td>18</td>
</tr>
<tr>
<td>Thorax</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Unknown</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>327</td>
<td>152</td>
</tr>
</tbody>
</table>

### Table 3. Causes of errors

<table>
<thead>
<tr>
<th>Technology</th>
<th>Positioning</th>
<th>Exposure</th>
<th>Good</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>95</td>
<td>163</td>
<td>40</td>
<td>29</td>
</tr>
<tr>
<td>Digital</td>
<td>103</td>
<td>28</td>
<td>7</td>
<td>14</td>
</tr>
</tbody>
</table>

#### DISCUSSION

As a marketing strategy, most CR and PACS providers are promoting digital imaging as the answer to reducing repeated exposure, which is based on early reports when digital radiography...
Table 4. Suspected causes of unnecessary repeated medical imaging examinations

<table>
<thead>
<tr>
<th>Type of Error</th>
<th>Suspected Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure</td>
<td>In x-ray rooms where only manual exposure selection is available, the error is largely attributable to the selection of incorrect exposure factors, mainly because of the incorrect estimation of the patient's size. In x-ray rooms equipped with automatic exposure selection, the error is largely attributable to the incorrect positioning of the body part in question in relation to the ion chambers. Radiographers found not to usually consult an exposure chart or measure patient size.</td>
</tr>
<tr>
<td>Positioning</td>
<td>Not following the correct positioning technique as recommended by educational references such as The Merrill's Atlas.</td>
</tr>
<tr>
<td>Good films</td>
<td>Availability of radiologist at the site for consultation and advice reduces the number of rejected good films.</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>1. Patient movement or motion. Errors as a result of patient movement or difficulty in holding breath. Error rate increased with severity of illness.</td>
</tr>
<tr>
<td></td>
<td>2. Equipment mishandling and off centered images. Errors found to be a result of a number of causes, including the Bucky being off center (Bucky not pushed in correctly), the tube being off center (tube not aligned with Bucky center), tomography not correctly set up, or films placed the wrong way (cassette placed crossways for an An² skull).</td>
</tr>
<tr>
<td></td>
<td>3. Double exposure error because of disorganized practice and loss of concentration by radiographer.</td>
</tr>
<tr>
<td></td>
<td>4. Overexposure and overlapped images. Errors because of the radiographer (e.g., trying to fit a number of images on one film or may be poor patient preparation resulting in jewelry remaining in the way) or equipment fault (e.g., the lead shutters in the light beam diaphragm may need adjustment).</td>
</tr>
<tr>
<td>Scrap/blank</td>
<td>Several causes were noted such as faulty automatic cassette holder, mishandling of films in the darkroom, and disorganized imaging practices.</td>
</tr>
<tr>
<td>Reprocessed</td>
<td>Reprocessed images to ad formats and apply shutters.</td>
</tr>
</tbody>
</table>

emerged as a new technology, some latest publications also had comments unsupported by proper analysis. Unfortunately, advocates of discarding reject analysis programs and encouraging the deletion of unwanted images failed to understand that it is a moral and legal requirement to keep all patients' records and doses in case we need to determine the radiation dose delivered to the patient. They also failed to realize that conventional systems used to have an average of 7–14% reject rate. The national reject rate in the UK was 10%. If 45% of that percentage were caused by “over- or underexposure,” that leaves 55% that cannot be improved digitally, and different approaches are required to improve the rate. In a digital department with 60,000 examinations and 100,000 images a year, more than 2700 unnecessary exposures are still delivered to patients, and that is something that cannot be neglected.

The percentage of repeating films in the conventional batch was 10.5%, which is well above the recommended volume by Gray et al. that is 5%. On the other hand, digital technology being at its early stages and staff still being at the learning stage, the reject folder contained 152 images, which is comparatively less than half of that of the conventional batch, constituting less than 5% of the total number of exposed images; however, that would be considered well above the recommended rate when deducting the percentage allocated for exposure errors from the 5%.

Positioning Errors

The results of the digital batch were slightly higher than those of the conventional batch. In the conventional batch, positioning errors made up 3% of the total reprints, and it was 3.2% for the digital batch. That can be a result of previously categorizing some images as exposure errors. Digitally fixing the window and level highlights the bad positioning side of it; therefore, it gets classified as positioning error. That indicates that technology has no influence on the radiographer's skills, and DRA is still the best method to assess and tailor training needs.

In the original planning for acquiring digital technology, it was speculated that because of the readily available images, radiologists would have a greater involvement in checking unverified images from their own workstations to help radiographers in improving and embellishing their skills to reduce the number of the unnecessary views taken. Instead, it seems the gap in the communication between radiologists and radiographers got a bit larger with radiologists getting locked up in their offices staring at monitors, whereas radiographers
got busy in insuring proper data transfer between RIS and PACS. This problem qualifies to have a separate study conducted on its own.

The major reduction in the number of errors reducing unnecessary examinations to the patient was in the exposure factors category. Dark and light errors went down from being almost 5.2% of the errors in the conventional batch to 0.9% in the digital batch.

**Good Films**

These films made up 1.3% of repeated films in the conventional batch. According to quality assurance seniors in the department, the main reason behind this category is the absence or the lack of communication between radiographers and radiologists. Using digital technology, images that could have been missed by some radiographers and repeated by others based on their experience with different radiologists, where some would accept a one- or two-star dark image while others would not, were eliminated by digitally adjusting the brightness and contrast of the image. That reduced the unnecessary repetition of good images from 40 to 7 images.

**Miscellaneous Errors**

These errors were reduced by half in the digital batch. The main reduction in this category was equipment error, mainly processor errors. With digital technology, errors such as scratch films, poorly developed or fixed, were completely eliminated. Obviously, that has a positive implication on the department where the staff does not have to worry about equipment errors and to waste time to monitor processor performance.

**Green, Black, and Clear Films**

These films made up 20% of the rejects in the conventional batch. A good number of those images could be exposed images that radiographers decided not to process. With digital technology, this specific problem will not be eliminated because radiographers have the option of running primary exposure on a digital plate without processing the image. However, digital radiography eliminated few problems such as static marks and film wastage as a result of exposure to daylight or humidity.

**Fixable Digitally**

In the conventional environment, the department had a special method of classifying rejected films; same categorization was applied to the digital batch. However, as stated earlier, exposure-related repeats were decreased by 83%. Comparatively with the conventional batch, exposure errors in the digital batch were mainly of the highest level.

When the radiologist was trying to sort the repeated images in the conventional batch, 124 were classified as fixable digitally. Images were of first- and second-level exposure errors. Preventing those repeats would have reduced the repeat rate from 10.5 to 6.5%.

The digital batch had eight images that the radiologist would have accepted if they were properly reprocessed using different algorithm.

**Reprocessed Images**

Surprisingly, only 26 images were reprocessed by adding shutters to the image. Adding digital shutters to an image enhances image quality by obstructing the glare from the large white border of an image. That will give the image a professional look and will make it user-friendly to radiologists. We would have expected the number to be much higher, but it seems that auto-shuttering prior sending to PACS is taking care most of the cases. A request for software enhancement has been placed for PACS to recognize shuttered images as a replacement image and not as a new image.

**CONCLUSION**

Repeat image analysis is one of the major quality improvement tools used in imaging departments, regardless of the technology. The main challenge is to set a credible system and to work around the deficiencies of the products available in the market. Raising software enhancement requests to the manufacturer is the best approach to tailor newly setup digital systems based on the relationship of PACS, RIS, and CR systems in place.
It is unfortunate that companies involved in providing the CR/PACS setup did not give a proper consideration for the setting of a repeat analysis system to cater for the Australian market. This study has become a learning curve for radiographers and the two major companies involved with the installation of the CR/PACS equipment. A prototype has been developed; however, it is at its early stages and, still, more detailing is required.

The results of the study showed a great advantage of the digital system over the conventional system. A serious reduction in the number of unnecessary exposures has been recorded because of the ability of manipulating the brightness and contrast of an image. The number of repeating good films was also reduced mainly because of the speed of passing images to radiologists for comments. However, the digital system has not been used to its full capacity; therefore, it did not have the expected impact on improving the number of positioning errors. It was expected that radiologists would do random checks on unverified images from their own stations to insure the production of high-quality images. Unfortunately, things went the other way around, and radiologists got locked up in their offices and, in most cases, do their own QA adjustments, and communication between radiologists and radiographers got worse. It was up to radiographers to ask for radiologist’s comment on an image; that helped in reducing the number of repeating good images but had no positive effect on reducing positioning errors.

Radiographers need to be cautious not to develop a complacent attitude and become overconfident because of having advanced technology. In conventional setups, radiographers used to relate 50% of the repeats to film processing and wrong exposure factors. The DRA in the digital system showed that the reject rate for positioning errors was slightly on the rise, and the number of rejections did not go down as much as it was expected. Actually, the total reject for chest examinations went down from 40 to 26% instead of 20%. Abdomen and cranial examinations increased almost twice, which shows a serious need for in-house training and clinical meetings. However, it has been noted that some of the films rejected in the conventional batch, classified as exposure error, would also qualify as a positioning error. That justifies the slight increase in positioning errors in the digital environment. It is also recommended that radiologists take a more proactive approach in commenting on the quality of images, and it will be beneficial to all parties if they take part in the training program.

ACKNOWLEDGMENTS

Special thanks are due to Ms. Susan Fisher, Mr. Matthew Lam, and Mr. Mario Carpini for their help with the study.

REFERENCES

4. PathSpeed Workstation 8.1, Operating Instructions. GE Medical Systems P.O. Box 414, Milwaukee, WI 53201, USA, 5/4, 6/14, 2000
Appendix 9_1

RADIATION AWARENESS PROGRAM STAGE 2

Content and Discussion

Slide 1 – Introduction to the presentation
The purpose of the Radiation Awareness program to make the public aware of Radiation Hazards, and how to approach Radiation in our daily life.

Slide 2 – Definition of radiation
Source of Radiation
All sorts of wavelength Frequencies.

Slide 3 – Types of Radiation
We have 2 sorts of Radiation
Natural & Artificial
Example of Natural Radiation
Ultraviolet Rays from the sun.

Slide 4 – Types of Radiation Examples
Medical X-rays is the best example of Artificial Radiation.
In our natural environment we are exposed on daily basis to different sort of Radiation ie.
Ultra Violet
Cosmic Rays
Slide 5 – Doses from Natural Radiation and benefits

A regular member of the public is exposed approximately to 20 milliSievert of Radiation a year from Cosmic rays.

That mainly contributes toward the natural mutation which helps to develop our body’s adaptability to the natural environment and the evolution of life forms.

Slide 6 – Natural Radiation negative impact

Unfortunately Natural Radiation is also responsible for development of some diseases, especially when exposed to high doses.

Artificial Radiation

Slide 7 – Types of Artificial Radiation

Microwave radiation

for example units used for domestic purposes (cooking) and diathermy units.

Slide 8 – Microwave ovens

All microwave units manufactured after 1989 comply with the relevant Australian Standard.

But it is still recommended that units are checked every five years.

As some of you may noticed that in the last few years, microwave testing equipment became available in mail ordering catalogues, but unfortunately because of lost interest from the public, they have been withdrawn again.

Slide 9 – Microwave oven, Hazards

Hazards of High level Exposure to Microwave Radiation

Burns mainly the Skin
Ocular effects Lens opacities
Effects on the gonads Temporary or even permanent sterility
Teratogenic effects Abnormalities in offspring have been reported in several animal species.
Slide 10 – Microwave ovens, Safety

Safety Precautions
Place Microwaves at an adequate level, so as not to be at the level of children’s eyes or your Thyroids.
The alarm bell must go off before you open the microwave oven Door.
Professionals using Diathermy Units must follow the code of practice imposed by NHMRC.

Slide 11 – Radiation at Schools
Radiation in our Schools
If you are involved with schools you have to make sure that teachers are properly trained to perform their experiments.
Shielding is the most important safety factor

Slide 12 – Shielding
Shielding Requirements:
If the teacher is using:
Beta Particles
few millimetres of aluminium or 1-2 centimetres of plastic.
X-rays 2-3 mm of lead or 10-15 cm of concrete
Gamma rays 5 cm of lead or 1 metre of concrete
Alpha particles can be stopped by a sheet of paper.
Students not to exceed 5 mSv in a year

Slide 13 – TV and Monitors
TV sets and computer screens.
Distance is the main preventative method
Cover the computer monitor with a shielding screen.
Slide 14 – Laser Lights

Laser lights

Make youngsters aware that long exposure to concert lights can damage their eyes.

If the concert is local and the function is not monitored by the EPA, think of the consequences of unsafe practices.

Slide 15 – Introduction to Radiation in Health

RADIATION & HEALTH

Slide 16 – Occupational Dose

We would like to constantly remind HEALTH WORKERS that the Recommendations of the International Commission of Radiation Protection is not to exceed

20 millisevert (2000 mR) per year

or 50 mSv (5000 mR) per 3 years.

Slide 17 – Characteristics of exposure to Radiation

RADIATION DOSES ARE CUMULATIVE

The simple concept is

Damaged or mutated cells produce more damaged cells carrying the mutated genes.

Slide 18 – Detrimental Effects

Detrimental effects of radiation can be classified as:

SOMATIC if they become manifest in the exposed individual

GENETIC if they affect the exposed individuals descendants
Slide 19 – Probable Effects

STOCHASTIC effects are those for which the probability of an effect occurring rather than its severity. The effects often follow a linear dose response and include such effects as the induction of LEUKEMIA, other CANCERS, as well as GENETIC EFFECTS.

Slide 20 – Evident Effect

NON-STOCHASTIC When SEVERITY of the effect varies with the DOSE, effects such as CATARACT and RADIATION SICKNESS are recorded to produce NON-STOCHASTIC EFFECTS. DOSES ARE GREATER THAN A FEW HUNDRED rem.

Slide 21 – Radiation effects to low doses

Lately there has been a change in the understanding to non-stochastic effects. Many Research Studies in Eastern European Countries proved that low doses of Radiation can manifest cell damage, especially in children. The Health industry in most Western countries deliberately ignores the effects of Medical Radiation to protect their interest.
Slide 22- Radiation doses measured (Skull)

SKULL
Lateral Skull 265 mR
AP Skull 295 mR
AP Towne 315 mR

---------
Total of one SXR 875 mR
CT Skull # 500 mR
U/S (Paediatric) 000 mR

Slide 23- Radiation doses measured (Lumbar)

Lumbar Spine
AP 500 mR
Lat 1000 mR
R Oblique 550 mR
L Oblique 550 mR
Spot Lateral 1100 mR

---------
Total 3700 mR
CT Lumbar Spine 2000 mR

Slide 24- Radiation doses measured (Other regions)

Cervical Spine AP 180 mR
Thoracic spine AP 460 mR
Chest PA 12 mR
Abdomen 500 mR
IVP 500 mR x 11
CT of Abdomen 900 mR
U/S 000mR
MRI 000 mR
Slide 25 - Non Ionising Radiation
US and MRI do not use Ionising Radiation
However side effects are still unknown
(lately a research conducted in western Australia showed that U/S examination effects the unborn babies).

Slide 26 - Safety
Proper precautions are always to be taken
Safety comes first
But unfortunately Radical changes to the culture and the understanding of Radiation is required

Slide 27 – Guidelines 1
1- Under no circumstances should it be necessary
for unshielded parts of the body, ie
a HAND to intercept
the PRIMARY BEAM

Slide 28 – Guidelines 2
2- LEAD APRONS are to protect persons staying in the room during the procedure from Scattered Radiation
not from Primary beam

Slide 29 – Guidelines 3
3- persons not required to assist during the actual exposure of X-rays should move
TWO METRES FROM THE REGION OF THE PATIENT BEING EXAMINED
AND WELL OUT OF THE PRIMARY BEAM
Slide 30 – Guidelines 4
4- Pregnant Ladies are encouraged to stay in the room during the examination to assist their children, as long as they are properly protected.
Why?
To reduce the number of unnecessary repetition of exposure to children.

Slide 31 – Guidelines 5
5- The proper use of shielding techniques.
Professionals and the public should be aware that sometimes shielding might do more harm than good.

Slide 32 – Guidelines to MRS
Radiographers **MUST** do their best to reduce radiation doses to their patients,
That is by using special techniques, such as
- High KV
- Collimation
- Tube Distance
- Filter Wedges
- Regular QA testing
- Selection of proper exposure

Slide 33 – Introduction to NHMRC Guidelines
**NATIONAL HEALTH AND MEDICAL RESEARCH COUNCIL**
AUSTRALIAN GOVERNMENT - CANBERRA 1986
Recommendations for Minimising Radiological Hazards to Patients
Slide 34 – NHMRC Guidelines C12

clause 12
Radiological procedures should not be performed as an alternative to taking a thorough history and physical examination or in order to protect the referring clinician from possible Medico-legal action.

Slide 35 – NHMRC Guidelines C16

clause 16
It is suggested that where no medical consideration exist to justify radiological procedures, then no legal considerations exist. A Practitioner cannot be held to be negligent if there is no evidence of any breach of standard practice in either diagnosis or treatment.

Slide 36 – NHMRC Guidelines C19

clause 19
Radiography of the SKULL and RIBS following trauma should not be automatic BECAUSE there has been trauma. It was found in one study that only approximately 1% of cases of trauma to the skull have revealed a fracture.

If there will be no change in the medical treatment of the patient following Radiography as is frequently the case with skull and rib injuries then it must be considered that the Radiography is UNNECESSARY.

Slide 37 – NHMRC Guidelines C23

clause 23
It is recommended that junior hospital MEDICAL STAFF and referring clinicians Consult with medical imaging staff where is doubt as to the correct INVESTIGATION.
Slide 38 – NHMRC Guidelines C24
clause 24

Alternative imaging procedures such as

ULTRASOUND
COMPUTED TOMOGRAPHY
NUCLEAR MEDICINE

should be used in preference to other diagnostic X-RAY procedures, Especially
when the other procedure is going to be required after all.

Slide 39– Recommendation

IF THE PATIENT HAS BEEN X-RAYED BEFORE COMING TO THE
HOSPITAL IT IS WORTH OBTAINING THEM EVEN IF THAT MEANS
SENDING RELATIVES BACK HOME TO FIND THEM

Slide 40– Questions?
Appendix 9_2

RADIATION AWARENESS PROGRAM STAGE 3

Content and Discussion

Slide 1 – Introduction to the presentation

OH&S SAFETY AT WORK AND HOME
The purpose of the Radiation Awareness program to make the public aware of Radiation Hazards, and how to approach Radiation in our daily life.

Slide 2 – Definition of radiation

Source of Radiation
All sorts of wavelength Frequencies.

Slide 3 –
Slide 4 – Types of Radiation

We have 2 sorts of Radiation
Natural & Artificial
Example of Natural Radiation
Ultraviolet Rays from the sun.

Slide 5 – Natural Radiation has a role in the development of all creatures
Unfortunately Natural Radiation might also be responsible for the development of some diseases, especially when exposed to high doses.
For Example frequent exposure to Cosmic Rays during Air Travel

Slide 6

A regular member of the public is exposed approximately to 20 milliSievert of Radiation a year from Cosmic rays.
That mainly contributes toward the natural mutation which helps to develop our body’s adaptability to the natural environment and the evolution of life forms.
Slide 7

Formation of Molecules

2 HYDROGEN ATOMS + 1 OXYGEN ATOM → 1 WATER MOLECULE

valence +1 valence -2

Slide 8

Formation of Characteristic X-Ray
Biological Change

**Slide 10 - RADIATION DOSES ARE CUMULATIVE**
The simple concept is damaged or mutated cells produce identical damaged cells carrying the mutated genes.

**Slide 11 – Hazards of High level Exposure to Microwave Radiation**

- **Burns**
  - mainly the Skin
- **Ocular effects**
  - Lens opacities
- **Effects on the gonads**
  - Temporary or even permanent sterility
- **Teratogenic effects**
  - Abnormalities in offspring have been reported in several animal species.
Slide 12 – Occupational Dose

We would like to constantly remind HEALTH WORKERS that the Recommendations of the International Commission of Radiation Protection is for staff not to exceed 20 millisevert (2000 mR) per year or 50 mSv (5000 mR) per 3 years.

Slide 13- Radiation doses measured (Skull)

SKULL

<table>
<thead>
<tr>
<th>View</th>
<th>Dose (mR)</th>
<th>Dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral Skull</td>
<td>265</td>
<td>2.65</td>
</tr>
<tr>
<td>AP Skull</td>
<td>295</td>
<td>2.95</td>
</tr>
<tr>
<td>AP Towne</td>
<td>315</td>
<td>3.15</td>
</tr>
</tbody>
</table>

---------

Total of one SXR | 875 | 8.75 |

CT Skull | 400 | 4 |

MRI | 000 | 0 |

U/S (Paediatric) | 000 | 0 |

Slide 14- Radiation doses measured (Lumbar)

Lumbar Spine

<table>
<thead>
<tr>
<th>View</th>
<th>Dose (mR)</th>
<th>Dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP</td>
<td>500</td>
<td>5</td>
</tr>
<tr>
<td>Lat</td>
<td>1000</td>
<td>10</td>
</tr>
<tr>
<td>R Oblique</td>
<td>550</td>
<td>5.5</td>
</tr>
<tr>
<td>L Oblique</td>
<td>550</td>
<td>5.5</td>
</tr>
<tr>
<td>Spot Lateral</td>
<td>1100</td>
<td>11</td>
</tr>
</tbody>
</table>

---------

Total | 3700 | 37 |

CT Lumbar Spine | 600 | 6 |
Slide 15- Radiation doses measured (Other regions)

- Cervical Spine AP: 180 mR, 1.8 mSv
- Thoracic spine AP: 460 mR, 4.6 mSv
- Chest PA: 12 mR, .12 mSv
- Abdomen: 500 mR, 5 mSv
- IVP: 500 mR x 11
- CT of Abdomen: 600 mR, 6 mSv
- U/S: 000 mR
- MRI: 000 mR

Slide 16- The side effects of U/S and MRI are still unknown (lately a research conducted in western Australia showed that U/S examination effects the unborn babies).

Slide 17 – Occupational Guidelines 1

1- Under no circumstances should it be necessary for unshielded parts of the body, ie
   - a HAND to intercept
   - the PRIMARY BEAM

Slide 18 - Occupational Guidelines 2

2- LEAD APRONS are to protect persons staying in the room during the procedure from
   **Scattered Radiation**
   not from
   **Primary beam**
   by wearing a LEAD APRON
Slide 19 – Guidelines 3
3- persons not required to assist during the actual exposure of X-rays should move TWO METRES FROM THE REGION OF THE PATIENT BEING EXAMINED AND WELL OUT OF THE PRIMARY BEAM

Slide 20

Slide 21 – Guidelines 4
4- Pregnant Ladies are encouraged to stay in the room during the examination to assist their children, as long as they are properly protected. Why? To reduce the number of unnecessary repetition of exposure to children
Slide 22 – Guidelines 5

5- The proper use of shielding techniques.

Professionals and the public should be aware that sometimes shielding might do more harm than good.

Slide 23

Cultural Practices

Slide 24 – Guidelines to MRS

Radiographers MUST do their best to reduce radiation doses to their patients,

That is by using special techniques, such as

- High KV
- Collimation
- Tube Distance
- Filter Wedges
- Regular QA testing
- Selection of proper exposure
Slide 25 – Introduction to NHMRC Guidelines

NATIONAL HEALTH AND MEDICAL RESEARCH COUNCIL
AUSTRALIAN GOVERNMENT - CANBERRA 1986
Recommendations for Minimising Radiological Hazards to Patients

Slide 26 – NHMRC Guidelines C12
clause 12
Radiological procedures should not be performed as an alternative to
taking a thorough history and
physical examination
or in order to protect the referring clinician from possible
Medico-legal action

Slide 27 – NHMRC Guidelines C16
clause 16
It is suggested that where no medical consideration exist to justify
radiological procedures, then no legal considerations exist.
A Practitioner cannot be held to be negligent if there is no evidence of any
breach of standard practice in either diagnosis or treatment.

Slide 28 – NHMRC Guidelines C19
clause 19
Radiography of the SKULL and RIBS following trauma should not be
automatic
BECAUSE there has been trauma. It was found in one study that only
approximately 1% of cases of trauma to the skull have revealed a fracture

If there will be no change in the medical treatment of the patient following
Radiography as is frequently the case with skull and rib injuries then it must
be considered that the Radiography is UNNECESSARY
Slide 29 – NHMRC Guidelines C23

clause 23

It is recommended that junior hospital **MEDICAL STAFF**
and referring clinicians Consult with **medical imaging staff**
where is doubt as to the correct INVESTIGATION

Slide 30 – NHMRC Guidelines C24

clause 24

Alternative imaging procedures such as

**ULTRASOUND**

**COMPUTED TOMOGRAPHY**

**NUCLEAR MEDICINE**

should be used in preference to other diagnostic X-RAY procedures,

Especially when the other procedure is going to be required after all.

Slide 31 – Recommendation

**IF THE PATIENT HAS BEEN X-RAYED BEFORE COMING TO THE**
**HOSPITAL IT IS WORTH OBTAINING THEM EVEN IF THAT MEANS**
**SENDING RELATIVES BACK HOME TO FIND THEM**

Slide 32 – Microwave ovens

All microwave units manufactured after 1989 comply with the relevant
Australian Standard.

But we recommend units to be checked every five years.
Slide 33 – Microwave ovens, Safety

Place Microwaves at an adequate level, so as not to be at the level of children’s eyes or your Thyroid.
The alarm bell must go off before you open the microwave oven Door.
If in doubt you can buy a leakage detector from Electronic stores

Slide 34 – Radiation at Schools

Radiation in our Schools
If you are involved with schools you have to make sure that teachers are properly trained to perform their experiments.
Shielding is the most important safety factor

Slide 35 – TV and Monitors

distance is the main preventative method
Cover the computer monitor with a shielding screen.
LCD Monitors do not emit Radiation

Slide 36 – Mobile Phones

There are many contradicting researches depending on whose side is the researcher.
Do I think we should use Mobile Phone?
The answer is I am using one but trying to apply common sense

Slide 37 – Mobile Phones Safety Precautions

Use SMS when ever you can
Avoid holding the phone close to your head use a head set.
Place the mobile on the thickest and most solid part of your body “Usually your waist”.
Put your Mobile on message bank if you are not expecting an important call.
Return the call using a landline

540
Slide 38 – Laser Lights

Laser lights

Make youngsters aware that long exposure to concert lights can damage their eyes.

If the concert is local and the function is not monitored by the EPA, think of the consequences of unsafe practices.

Slide 39

Source: Tubiana et al. 1999.

Slide 40 – Questions
Appendix 10

RAP MARKETING

MEDIA COVERAGE
All about radiation

Students learned about the double-edged sword of radiation in Blacktown last Thursday.

They found out it could be used constructively, like in X-rays, and destructively, like in an atomic bomb.

Blacktown-Mount Druitt Health chief radiographer James Nol spoke on the subject when the students visited the hospital's imaging department.

The visit coincided with Radiation Safety and Awareness Day.

Mr Nol said that since the discovery of radiation, scientists had harnessed the deadly energy to save lives.

He said staff and patients could protect themselves by wearing a lead apron or keeping at least two metres from the machine.

The imaging department recently opened its doors.

GPs can now send their patients to be scanned by its computed tomography (CT) machine.
Heart & Soul

Showcasing our staff, volunteers and supporters

BMDH Radiation Safety forum

On Tuesday, 24th May
Blacktown Mt Druitt Hospital
(BMDH) Medical Imaging
Dept held a public forum
about radiation safety.

Over 100 year 11 and 12
students from Chifley College
Mt Druitt and Loyola Senior
High School Mt Druitt
attended, where they were
encouraged to choose a career
in radiography.

The students and members
of the public were treated to
morning tea as well as a variety
of visual displays.

There were presentations from
James Nol Chief Radiation
Scientist BMDH, Brad Astill
General Manager Imaging
SWAHS, Paul Potts Director
Corporate Services BMDH, Dr
Michael Hesson Director Emergency
Services BMDH.

This was the
second program to
be held at
Blacktown Mt Druitt
Hospitals. James
Nol said, "Two
years ago, Mt Druitt
Hospital reduced unnecessary
radiation examinations by using
the right x-ray to the right
person”.

Dr Michael Hesson then
outlined that this clinical
practice quality project was a
finalist the 2004 NSW Health
Baxter Awards.

Pictured above (L-R): Dr Michael
Hesson Director Emergency
Services BMDH, Brad Astill
General Manager Imaging SWAHS,
James Nol Chief Radiation
Scientist BMDH, Brian Beaty
Human Resources Manager BMDH,
Paul Potts Director Corporate
Services BMDH, and Matthew
Kwong Chief Radiographer Auburn
Hospital.

There were Hovermat
demonstrations, before a
discussion about the dangers
of radiation from laser lights
and mobile phones, and what
happens to your body when hit
with radiation.
SAFER CHOICE: The Chief Radiation Scientist at Blacktown Mt Druitt Hospital, James Nol (right), says the hospital had reduced the number of unnecessary radiation examinations by 65 per cent.

Healthy reduction

EMILY SMITH

DOCTORS referring patients to Mt Druitt Hospital have helped reduce the number of unnecessary and potentially dangerous radiation examinations.

The Chief Radiation Scientist at Blacktown Mt Druitt Hospital, James Nol, said Mt Druitt Hospital had reduced the number of unnecessary radiation examinations by 65 per cent.

Mr Nol hosted a radiation safety day for school students and the public at the hospital last Tuesday.

He displayed equipment that emitted radiation and spoke about how people can reduce the amounts of radiation they receive from appliances.

Together with the director of emergency services at Blacktown Mt Druitt Hospitals, Dr Michael Hession, Mr Nol has conducted the campaign over two years.

Unnecessary examinations include skull X-rays for patients presenting with head trauma.

Previously, doctors were requesting a skull X-ray to check for fractures and a CT scan to check for brain injury.

Mr Nol spoke about alternative procedures that do the same job in scanning the body but do not emit ionising radiation.

Mr Nol also spoke about how people can reduce the amounts of radiation they receive. Standing at least three metres from a microwave, or a metre from a TV, and using an earpiece when speaking on a mobile phone are ways to reduce the level of radiation exposure.

He said doctors were pleased about the reduction in procedures and were also referring more ultrasound examinations to the hospital.

Ultrasound examinations require lower doses of radiation and were found by chest X-rays which require radiation to penetrate through fat and muscle tissue.

"Any way in which we can ensure the patient receives a lower dose of radiation is good," Mr Nol said.

He said doctors were pleased about the reduction in procedures and were also referring more ultrasound examinations to the hospital.

"The number of ultrasound examinations referred from Mt Druitt has doubled in the past year," Mr Nol said.

"The number of ultrasound examinations referred from Mt Druitt has doubled in the past year," Mr Nol said. "Where possible we have switched from chest X-rays to ultrasound examinations with safer outcomes."
Healthy reduction

EMILY SMITH

DOCTORS referring patients to Mt Druitt Hospital have helped reduce the number of unnecessary and potentially dangerous radiography examinations.

The Chief Radiation Scientist at Blacktown Mt Druitt Hospital, James Nol, said Mt Druitt Hospital had reduced the number of unnecessary radiation examinations by 85 per cent.

Mr Nol hosted a radiation safety day for school students and the public at the hospital last Tuesday.

He displayed equipment that emitted radiation and spoke about how people can reduce the amounts of radiation they receive from appliances.

Together with the director of emergency services at Blacktown Mt Druitt Hospitals, Dr Michael Hesston, Mr Nol has conducted the campaign over two years.

Unnecessary examinations include skull X-rays for patients presenting with head trauma. Previously, doctors were requesting a skull X-ray to check for fractures and a CT scan to check for brain injury.

"The X-ray is unnecessary ... the CT scan shows both the brain and the damage to the skull," Mr Nol said.

Ribs X-rays have been replaced by chest X-rays which require 30 times less radiation to penetrate through fat and muscle tissue.

"Any way in which we can ensure the patient receives a lower dose of radiation is good," Mr Nol said.

He said doctors were pleased about the reduction in procedures and were also referring more ultrasounds to the hospital.

Ultrasounds do not emit the ionising radiation emitted in X-rays and CT scans that can cause cells to mutate and become cancerous, Mr Nol said.

"The number of ultrasound examinations referred from GPs have doubled in the past year," Dr Nol said. "Where possible we are trying to replace the radiation examinations with safer procedures."
Radiation terror

MILY SMITH

OCTORS could be putting patients at risk by overprescribing potentially dangerous radiation procedures, a Mt Druitt radiation expert has warned.

James Nol, chief medical radiation scientist at Mt Druitt Hospital, said so many patients were ordered to undergo radiation procedures that were not necessary.

"People shouldn't have X-rays or CT scans unless they really need them," Mr Nol said.

Blacktown Mt Druitt Hospital conducted 65,000 X-ray or CT scans a year, up 44,000 on Mt Druitt Hospital's 2003 figures. In 1998, there were just 15,000 procedures carried out at Mt Druitt.

Mt Druitt's emergency department has the lowest rate of procedures in NSW after Mr Nol's campaign to reduce scans by 66 per cent.

"Around 90 per cent of X-ray examinations give normal results," Mr Nol said.

"We suggest doctors not order X-rays for skull injuries if they are going to order a CT scan to check for brain damage. A CT scan can do both jobs and the patient isn't exposed to as much radiation."

Mr Nol said general practitioners, including those in Mt Druitt, also referred too many patients for unnecessary scans.

Mt Druitt Medical Practitioners' Association secretary Reun Song Lim said the rise in scan numbers was due to the threat of litigation, repeated procedures and patient expectations, rather than a lack of care.

"There is a problem with continuity of care - patients may see different doctors for the same problem, meaning the same procedure is re-ordered," Dr Song Lim said.

Patients also expect to walk away with a referral for a procedure. And with increasing litigation, doctors are investigating more aggressively."

Mr Nol will hold an information session about radiation exposure in relation to medicine.

The session will be at Mt Druitt Hospital from 6pm-8pm on Tuesday, March 22.

EMILY SMITH

THE effects of excessive radiation can be both biological and hereditary, according to James Nol, chief medical radiation scientist at Mt Druitt Hospital.

While biological effects such as cancer effect a person during their lifetime, hereditary effects are more insidious, offsetting a person's bloodline.

"The radiation effect is cumulative, the damage to DNA never goes away," Mr Nol said.

Children are particularly vulnerable to radiation effects.

Radiation changes the structure of a cell's DNA - when the cell divides, it creates more "mutated" cells.

Because children have longer life expectancies, there is a higher risk of the mutated cells becoming cancers.

Mr Nol said modern society was exposed to radiation from its technological lifestyle.

Computers, televisions, microwaves and mobile phones all emit radiation.

"Children sit one metre away from the television and develop eye problems," Mr Nol said.

"If safety precautions are taken, we can overcome this.

The radiation levels of household appliances are minimal compared to those of an X-ray, CT scan or mammogram.

There are no state or federal guidelines for safe dosages of radiation exposure for patients in Australia, although there is a limit for those working with radiation.

Mr Nol believes Australian doctors and hospitals need to keep accessible public records of the amount of radiation a patient was exposed to.

"In Europe, people are more aware of radiation," he said.

"In Germany, people are issued with radiation passports so doctors can see how much radiation a patient has been exposed to in their lives.

"We are not trying to scare people," Mr Nol said.

"We are just helping people make educated decisions and guide them."
Appendix 11

CLINICAL MANAGEMENT GUIDELINES PUBLISHED ON THE EMERGENCY DEPARTMENT WEBSITE

11.1 INTRODUCTION

To facilitate the implementation of the new protocols a website was developed for the Emergency Department (ED) displaying all the recommended protocols as discussed in appendix 2.

An X-Ray ordering Guide was developed and placed on the ED website for an easy reference to referring Medical officers.

A Radiation Dose Guide was placed on the website to make Medical Officers aware of the levels of Radiation given to patients in comparison with the Occupational yearly permissible dose.

11.2 GUIDES FOR X-RAY REQUISITION

Examinations under review were divided into two Categories and clinical decision tree and management guidelines were placed on ED website and printed copies were placed on the clinical management Medical Officers desk as follows:

11.2.1 Category ‘A’

- Skull x-ray - for head injury
- Abdomen-KUB (Kidney, Ureter, Bladder) - for Renal Colic
- Chest Rib views - for rib fracture
- Nasal Bone x-rays - for fracture
There should be no x-ray orders for this category since there is no evidence that x-ray of these sites contributes to the diagnosis and management of patients.

**Figure 11.1.1** Guidelines for Category ‘A’ Imaging examinations

---

**No XRay orders for these groups**

**Head Injury**
- No skull XRay - not in diagnostic algorithm (RANZCR)
- Canadian Head CT rules minor head injury

**Renal Colic**

Multiple studies show that the KUB has low sensitivity and specificity for the presence of urolithiasis and adds nothing to the emergent clinical impression.

- Plain KUB are not in the diagnostic algorithm (RANZCR)
- Comments (<www.emedicine.com/emerg>)

**Chest rib views**

- Are unhelpful to management (most patients should be admitted with clinical rib fractures)
  - Make a clinical diagnosis or use ultrasound and exclude complications on CXR.
  - American College of Radiology Appropriateness

**Nasal bone X Rays**

- Are unhelpful to management. Make a clinical diagnosis and refer to Plastic Surgeon.

References

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Blacktown Mt Druitt hospital. Sydney West Area Health Services, NSW Australia
**Figure 11.1.2** Warning Poster to stop requesting Category ‘A’ examinations

![Poster](image)

---

Blacktown Mt Druitt hospital. Sydney West Area Health Services, NSW Australia

The above have also been linked to educational aid decision tree Flow Charts, shown in figures below.

The following is related to Head injury protocols as a link on the website when head trauma is selected.
Figure 11.2 Implemented Algorithms and Protocols for Head Injury

![Flowchart](image)

*Note: there is no skull X-ray in this protocol*

11.2.1.1 Educational publications were also added to the website linked to Head injuries

Figure 11.3  The Canadian CT Head Rule

<table>
<thead>
<tr>
<th>The Canadian CT Head Rule for patients with minor head injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use this decision rule for use of CT scan if any one of these factors is present in a patient presenting with MINOR head injury:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CT scan is mandatory:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High risk Factors</strong></td>
</tr>
<tr>
<td>Any of these indicates high likelihood of need for neurological intervention</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Recommend CT scan OR close observation:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Medium risk Factors</strong></td>
</tr>
<tr>
<td>Either of these indicates high likelihood of clinically important brain injury, but NOT need for neurological intervention</td>
</tr>
</tbody>
</table>

- Failure to reach GCS of <15 within 2 hrs
- Amnesia >30 min before impact
- Suspected open skull fracture
- Dangerous mechanism of injury
- Any sign of basal skull fracture
- Vomiting: more than 1 episode
- Age: 65 years or greater

Source: The Canadian CT Head Rule for patients with minor head injury. THE LANCET • Vol 357 • May 5, 2001 1391, Ian G Stiell et al
Summary to the Canadian CT Head Rule for patients with minor head injury

**Background** There is much controversy about the use of computed tomography (CT) for patients with minor head injury. We aimed to develop a highly sensitive clinical decision rule for use of CT in patients with minor head injuries.

**Methods** We carried out this prospective cohort study in the ED of ten large Canadian hospitals and included consecutive adults who presented with a Glasgow Coma Scale (GCS) score of 13–15 after head injury. We did standardised clinical assessments before the CT scan. The main outcome measures were need for neurological intervention and clinically important brain injury on CT.

**Findings** The 3121 patients had the following characteristics: mean age 38.7 years; GCS scores of 13 (3.5%), 14 (16.7%), 15 (79.8%); 8% had clinically important brain injury; and 1% required neurological intervention.

We derived a CT head rule, which consists of **five high-risk factors and two additional medium-risk factors**. The high-risk factors were 100% sensitive (95% CI 92–100%) for predicting need for neurological intervention, and would require only 32% of patients to undergo CT. The medium-risk factors were 98.4% sensitive (95% CI 96–99%) and 49.6% specific for predicting clinically important brain injury, and would require only 54% of patients to undergo CT.

**Interpretation** We have developed the Canadian CT Head Rule, a highly sensitive decision rule for use of CT. This rule has the potential to significantly standardise and improve the emergency management of patients with minor head injury.

Source: The Canadian CT Head Rule for patients with minor head injury. THE LANCET • Vol 357 • May 5, 2001 1391, Ian G Stiell et al
Other examples from other hospitals were also been inserted to the Head Trauma protocols, the following is the Melbourne Children’s Hospital Protocol for Head injuries.

**Figure 11.5 Indications for SXR**

- Skull X-ray (SXR) is a poor indicator of intracranial injury and with few exceptions has little to offer in the management of head injury in infants and children. Children with clinical findings of only mild head trauma do not have a statistically increased risk of intracranial injury.

  - Indications for SXR
    - Non accidental injury (more sensitive than Bone Scan)
    - Depressed fractures
    - Penetrating injury
    - Large boggy vault hematoma

The Melbourne Children’s Hospital Victoria, Australia
Figure 11.6 Recommendations to reduce the number of requested skull x-rays

Retrospective chart analysis Royal Berkshire Hospital with a head injury from 1-30 September 1999

50% (193/385) of all patients had skull X-rays.

one fracture found

If the guidelines from The Royal College of Surgeons of England Working Party for the use of skull X-rays in institutions which possess a CT scanner were applied, the number of skull X-rays performed would reduce from 193 to 14 without detriment to any patient.

11.2.1.2 Renal Colic cases as a link on the website when Kidney or renal colic is selected.

**Figure 11.7** Decision Tree for Renal Colic

11.2.2 Category B

- Ankle x-ray - for ankle injury
- Knee x-ray - for Knee injury
- Spine x-ray - for trauma, low back pain & radiculopathy

When considering ordering x-rays of these sites, clinical assessment and decision algorithms should be applied to determine whether an x-ray would assist diagnosis and management of the condition.

The following Summaries are embedded in the ED Website as educational aid.

11.2.2.1 Ottawa Ankle Rule

Clinical indications for ankle x-ray are:

- Pain in the malleolar zone, AND
- Bone tenderness at posterior edge of distal 6cm or tip of medial or lateral malleolus, OR
- Unable both to weight bear immediately after injury and walk four steps in ED

Figure 11.8 Refined Ottawa Ankle Rules

Figure 11.9 Ottawa ankle decision rules

- Bone tenderness at posterior edge of distal 6 cm or tip of medial or lateral malleolus
- Unable both to weight bear immediately after injury and walk four steps in A&E department


Figure 11.10 Ottawa ankle decision rules

- Bone tenderness at base of 5 th metatarsal
- Bone tenderness over navicular
- Unable both to weight bear immediately after injury and walk four steps in ED

**Figure 11.11** Meta-analysis of Ottawa ankle/foot rules.

- 32 studies were found some looking at the ankle rules some at the foot rules some at both and while most were in adults some were in children.
- Of 15581 patients 27 (0.3%) had a false negative result where the Ottawa test was negative but where they actually had a fracture.
- Saved 1713 patients from having an X-ray.
- Saved 36 patient-days waiting in a hospital emergency room.
- Saved $154,000

G Wells, A Laupacis et al. Multicentre trial to introduce the Ottawa ankle rules for use of radiography in acute ankle injuries.

**Source:** British Medical Journal 1995 311: 594-7.

### 11.2.2.2 Ottawa Knee Rule

A knee x-ray examination is only required for acute knee injury in patients with one or more of the following findings

- Age over 55, OR
- Tender on patella, OR
- Tender on fibular head, OR
- Unable to flex knee more than 90 degrees, OR
- Unable to weight bear both immediately after injury and in the ED (transfer weight twice onto each lower limb, regardless of the presence of limping)
"Physicians can, however, be assured that they are unlikely to miss a clinically important knee fracture if they apply the radiography decision rule accurately.

Patients aged 55 years or older are at significantly increased risk for fracture, possibly due to osteoporosis.

Specific areas of bone tenderness, either at the patella or the head of the fibula, are high risk features. The specificity of the patellar finding is increased by ordering radiography for patients whose bone tenderness is isolated to the patella only.

Patients are also at higher risk for fracture if function is compromised, that is, if they are unable to flex their knee to 90 degrees or to bear weight both immediately and in the ED.

Patients are judged to be able to bear weight if they can transfer weight twice onto each lower limb, regardless of the presence of limping.

This clinical finding has proven to be reliable with good kappa scores for this decision rule and for the Ottawa ankle rules"

Source: Stiell, Ian G et al  Prospective Validation of a Decision Rule for the Use of Radiography in Acute Knee Injuries. JAMA Volume 275(8) 28 February 1996 pp 611-615
Figure 11.12 Decision rule for ordering knee x-rays in adults after acute trauma.

- Tender on patella
- Tender on fibular head?
- Age over 55?
- Unable to flex more than 90 degrees?


11.2.2.3 Cervical spine radiography - NEXUS* Low-Risk Criteria

Cervical spine radiography IS NOT necessary for trauma patients who satisfy all of the following criteria:

- No tenderness at posterior midline of cervical spine
- No focal neurological deficit
- Normal level of alertness
- No evidence of intoxication
- No clinically apparent painful injury that might distract the patient from the pain of a cervical spine injury

Patients with blunt trauma have low probability of clinically significant injury to the cervical spine if they meet all the above criteria.

*These criteria were used in the National Emergency Utilisation Study of 34,069 patients receiving spine x-ray at 21 centres across USA (Nexus Trial)

Figure 11.13 BMDH Cervical Spine flow chart

Blacktown Mt Druitt hospital. Sydney West Area Health Services, NSW Australia
Figure 11.14 Spine indications

- >50 y.o.
- Fall, pedestrian, bicycle, car >50km/hr
- LOC, GCS <12
- Focal deficit
- CT intracranial, brain contusion, skull fracture

Royal Australian New Zealand College of Radiologist Cervical spine – RANZCR C

11.2.2.4 NEXUS  Cervical Spine

- prospective observational study
- 21 EDs
- all patients with blunt trauma for whom cervical spine radiographs were ordered.
  - sensitivity, 99.0 percent [95 percent confidence interval, 98.0 to 99.6 percent])
  - negative predictive value was 99.8 percent (95 percent confidence interval, 99.6 to 100 percent)
  - specificity was 12.9 percent
  - positive predictive value was 2.7
- identified all but 8 of the 818 (2 clinically signif, 1 surgery)
- radiographic imaging could have been avoided in the cases of 4309 (12.6 percent) of the 34,069 (Hoffman et al 2000)
Figure 11.15 Cervical Spine Nexus Trial

Criteria used in the NEXUS trial, reprinted courtesy of Dr. Jerome Hoffman


According to the **NEXUS Low-Risk Criteria**, cervical spine radiography is indicated for trauma patients unless they exhibit **ALL** of the following criteria:

1. No posterior midline cervical spine tenderness
   and
2. No evidence of intoxication
   and
3. Normal level of alertness
   and
4. No focal neurological deficit
   and
5. No painful distracting injuries

**Red Flags for Back pain Back X-rays**

**Differential diagnosis of back pain**
- intra-abdominal and pelvic disease
- Abdominal aortic aneurysm
- kidney, pancreas,
- gallbladder, duodenal
- ulcer, diverticulitis,
- endometriosis

**Pathology of back pain**
1. Compression fracture
2. Spondylolisthesis
3. Ankylosing spondylitis
4. Osteoarthritis
5. Osteochondritis
6. Epidural abscess
7. Osteomyelitis
8. Disc prolapse
9. Neoplasm
10. Rheumatoid arthritis

**Investigations for neoplasm or infection**
- MRI
- Perform FBC, urine analysis, sedimentation rate, plain x-ray
- Bone Scan may be useful

**Investigations for ankylosing spondylitis**
Obtain x-rays of the sacroiliac joints

**RED FLAGS for Neoplasm**
- Age greater than 50
- Previous history of cancer
- Pain greater than one month
- Failure to improve with conservative treatment
- Nocturnal pain,
- Pain which awakens the patient from sleep, and
- Pain not relieved by bed rest are suggestive of a neoplasm

**RED FLAGS for vertebral osteomyelitis/epidural abscess**
- Skin infection-Staph aureus
- *H. influenzae* illness in children
- Tuberculosis
- Gram Neg infection
- Indwelling urinary catheter
- IV drug use: *Pseudomonas* and *Serratia marcescens*

**RED FLAGS for compression fracture**
- history of trauma
- corticosteroid use
- age > 70y.o.

**RED FLAGS for ankylosing spondylitis**
- morning stiffness
- improvement after exercise
- onset before age 40
- insidious pain >3 months

**Investigations for compression fracture**
- Plain X-ray of lumbar spine
- Note that oblique views are NOT necessary *(they add significant radiation exposure and cost but do not add much information)*
- Consider a bone scan if the index of suspicion for fracture is high and x-rays are negative.
Figure 11.17 Spine Decision Tree

Royal Australian New Zealand College of Radiologist Lumbar Spine – RANZCR L
Figure 11.18 Spine Decision Tree with RED FLAGS

RANZCR Guide for spine X-Ray

Low back pain and radiculopathy

Clinical assessment

Uncomplicated acute low back pain

Low back pain and radiculopathy

Red flags:

- Over 70 yrs? Osteoporosis?
  - Consider: Crural compression
  - Order: Plain XRay (or MRI)

- Indwelling catheter? I-V drug user?
  - Risk of bacterial seeding
  - Order: CT or MRI

- Existing primary neoplasm?
  - Neoplasm?
  - Order: MRI

- Morning stiffness? Age <40 yrs?
  - Ankylosing spondylitis?
  - Order: Plain XRay

Imaging IS NOT indicated

Royal Australian New Zealand College of Radiologist Lumbar Spine – RANZCR L
11.2.2.5 Radiation Doses published on the ED Website

The team suggested in the meeting to have a table on the website displaying the different radiation doses and the yearly occupational dose as a control measure. It was believed that this will attract the attention of the reader and raise their awareness.

Table 11.18 Comparative radiation exposure for x-rays of different body parts and permissible occupational dose.

(Note: a Chest X-ray = 12 mRads)

<table>
<thead>
<tr>
<th>Xray Site</th>
<th>Radiation exposure (in mRads)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dose per view</td>
</tr>
<tr>
<td><strong>Category A</strong></td>
<td></td>
</tr>
<tr>
<td>Skull (2 views)</td>
<td>300</td>
</tr>
<tr>
<td>Abdomen KUB (1 view) IVP (11 views)</td>
<td>600</td>
</tr>
<tr>
<td>Ribs (2 views)</td>
<td>400</td>
</tr>
<tr>
<td>Nasal Bones 2 views</td>
<td>150/300</td>
</tr>
<tr>
<td><strong>Category B</strong></td>
<td></td>
</tr>
<tr>
<td>Spine Cervical (3 views)</td>
<td>250</td>
</tr>
<tr>
<td>Spine Lumbar (4 views)</td>
<td>600/1000</td>
</tr>
<tr>
<td>Ankle (3 views)</td>
<td>150</td>
</tr>
<tr>
<td>Knee (3 views)</td>
<td>200</td>
</tr>
<tr>
<td><strong>Occupational Permissible Dose</strong></td>
<td></td>
</tr>
<tr>
<td>Within 1 year Staffs are not to exceed</td>
<td>2000</td>
</tr>
<tr>
<td>Within 3 years staffs are not to exceed</td>
<td>5000</td>
</tr>
</tbody>
</table>

Blacktown Mt Druitt hospital. Sydney West Area Health Services, NSW Australia
Appendix 12

CPI TABLES AND TOOLS

As presented to team members during meetings

12.1 Setting the Goals

Table 12.1 - Setting the Goals of the CPI

<table>
<thead>
<tr>
<th>Site of X-Ray</th>
<th>Total</th>
<th>General Area</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdomen KUB</td>
<td>278</td>
<td>Ankle</td>
<td>631</td>
</tr>
<tr>
<td>Nasal Bones</td>
<td>88</td>
<td>Knee</td>
<td>493</td>
</tr>
<tr>
<td>Ribs</td>
<td>269</td>
<td>Spine</td>
<td>748</td>
</tr>
<tr>
<td>Skull</td>
<td>312</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Category ‘A’  | 947   | Total Category ‘B’ | 1872 |

Set Goal for Project: Total Category ‘A’ + Category ‘B’ x-rays = 2819

Aim: Reduce ED Total x-rays by N = 1132

Reduce by 80%: 757 less | Reduce by 20%: 374 less (~7% of total)
<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Registrars busy, Mo or nurse make a decision to speed up the process</td>
<td>Electronic requisition is complicated, choose a drop down for a series is easy</td>
<td>Lack of senior’s opinion (more x-rays requested by junior drs)</td>
</tr>
<tr>
<td>6</td>
<td>the quicker the request is placed speeds up the process because patients will be waiting for transfer to x-ray</td>
<td>Automatically write an x-ray form for specific cases to speed up process</td>
<td>Patient too aggressive. Acquiring physical exam not possible</td>
</tr>
<tr>
<td>7</td>
<td>Nurses busy to arrange transfer to X-ray, the sooner the request is placed will speed up the process</td>
<td>Electronic Requestion, by MO based on own judgement not registrar</td>
<td>Equivocal Clinical findings</td>
</tr>
<tr>
<td>8</td>
<td>MO not experienced</td>
<td>Request the x-ray before physical examination,</td>
<td>Inadequate clinical assessment</td>
</tr>
<tr>
<td>9</td>
<td>unsure of the proper process</td>
<td>exams requested before MO exam</td>
<td>Not sure of diagnosis from physical examination</td>
</tr>
<tr>
<td>10</td>
<td>X-rays are free</td>
<td>Blanket’ views requested, where specifics are required</td>
<td>Patients complain of many problems and severe pain</td>
</tr>
<tr>
<td>11</td>
<td>Nurses will automatically fill the form based on the triage process</td>
<td>Fear of possible medicolegal issues</td>
<td>Imaging provides a more reliable assessment than clinical</td>
</tr>
<tr>
<td>12</td>
<td>X-rays are requested by nurses, without knowing if its necessary</td>
<td></td>
<td>Imaging reduces the unknown and reduce the clinical assessment process</td>
</tr>
<tr>
<td>13</td>
<td>no harm in requesting x-rays</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Nurse initiated X-Ray, but x-ray not really needed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>blanket requests cover everything</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>No sense of cost to patient in terms of rads</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>X-rays are free in public hospitals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Never thought Radiation can be dangerous</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>X-rays don’t cost money in the hospital, so why no use it</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>not always sure which part to request</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Unclear of the real symptoms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>X-rays are the best tool to help diagnosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Radiation dangers are exaggerated</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Trauma series is the protocol in large hospitals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>any trauma case requires x-ray</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Nurses blame you if you don’t request x-ray</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rank</td>
<td>Reason</td>
<td>hoops Required</td>
<td>Clinical Findings</td>
</tr>
<tr>
<td>------</td>
<td>------------------------------------------------------------------------</td>
<td>----------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>2</td>
<td>Wrong protocol for x-ray requirement</td>
<td>Reassurance for MO</td>
<td>Inadequate Clinical Assessment</td>
</tr>
<tr>
<td>3</td>
<td>X-rays are free</td>
<td>Fear of trusting Clinical Findings</td>
<td>Blanket’ views requested, where specifics are required</td>
</tr>
<tr>
<td>4</td>
<td>Inadequate Instructions</td>
<td>Fear of medico legal issues</td>
<td>Pressure from Patient</td>
</tr>
<tr>
<td>5</td>
<td>No sense of cost to patient in terms of rads</td>
<td>Senior Mo's not present</td>
<td>Pressure from relatives</td>
</tr>
</tbody>
</table>

**24 Sep, 2003: From these, select the top six reasons that you think lead to unnecessary Xray requests =**

Each Team member has 6 weighted votes. The issue believed to be the strongest contributor to the delays is given 5 points, the next strongest contributor to delays is given 5 points, and so on down to 1 point for the sixth vote.
<table>
<thead>
<tr>
<th></th>
<th>MO</th>
<th>Clinical Assessment</th>
<th>Patient that something has been done</th>
<th>'teams' on in-patients</th>
<th>Nurse in XRay</th>
<th>Everyone is busy no one to ask</th>
<th>Fear of trusting Clinical Findings</th>
<th>Blanket views requests</th>
<th>Reassurance for patient</th>
<th>GP referral</th>
<th>Rush Radiology close down</th>
<th>To speed up workflow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inadequate Instructions</td>
<td>Fear of medico legal issues</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>GP referral</td>
<td>Rush Radiology close down</td>
<td>To speed up workflow</td>
</tr>
<tr>
<td>Poor knowledge of Radiation doses</td>
<td>no Senior Mo</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>GP referral</td>
<td>Rush Radiology close down</td>
<td>To speed up workflow</td>
</tr>
<tr>
<td>Category</td>
<td>Description</td>
<td>Votes</td>
<td>1%</td>
<td>2%</td>
<td>3%</td>
<td>4%</td>
<td>5%</td>
<td>6%</td>
<td>7%</td>
<td>8%</td>
<td>Total Votes</td>
<td></td>
</tr>
<tr>
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<td>------------------------------------------------------------------------------</td>
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<td>----</td>
<td>----</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>B2</td>
<td>Reassurance for MO</td>
<td>17</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.00%</td>
<td></td>
</tr>
<tr>
<td>B6</td>
<td>Lack of trust in clinical findings</td>
<td>8</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.00%</td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>Lack of senior's opinion (more x-rays requested by junior drs)</td>
<td>8</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.00%</td>
<td></td>
</tr>
<tr>
<td>D1</td>
<td>Equivocal Clinical findings</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>100.00%</td>
<td></td>
</tr>
<tr>
<td>D5</td>
<td>Can't rule out clinically</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>100.00%</td>
<td></td>
</tr>
<tr>
<td>D6</td>
<td>Inadequate clinical assessment</td>
<td>18</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td>100.00%</td>
<td></td>
</tr>
<tr>
<td>D7</td>
<td>Blanket' views requested, where specifics are required</td>
<td>17</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td>100.00%</td>
<td></td>
</tr>
<tr>
<td>E5</td>
<td>Requested by 'teams' on in-patients</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td>100.00%</td>
<td></td>
</tr>
<tr>
<td>E6</td>
<td>Advised by specialty registrars</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td>6</td>
<td>100.00%</td>
<td></td>
</tr>
<tr>
<td>F1</td>
<td>Want to get the x-ray done before Radiology closes</td>
<td>20</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>100.00%</td>
<td></td>
</tr>
<tr>
<td>G1</td>
<td>Pressure from relative</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0%</td>
<td>100.00%</td>
<td></td>
</tr>
<tr>
<td>G10</td>
<td>Keeps the patient busy until doctor is available to see patient</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.00%</td>
<td></td>
</tr>
<tr>
<td>G4</td>
<td>Reassurance for patient</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0%</td>
<td>100.00%</td>
<td></td>
</tr>
<tr>
<td>G8</td>
<td>To show the patient that something has been done</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.00%</td>
<td></td>
</tr>
<tr>
<td>H3</td>
<td>Fear of possible medico-legal issues</td>
<td>23</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td>100.00%</td>
<td></td>
</tr>
<tr>
<td>I1</td>
<td>No sense of cost to patient in terms of rads</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.00%</td>
<td></td>
</tr>
<tr>
<td>I2</td>
<td>X-rays are free in public hospitals</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td>100.00%</td>
<td></td>
</tr>
<tr>
<td>J1</td>
<td>To speed up work flow</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.00%</td>
<td></td>
</tr>
</tbody>
</table>

Total Votes: 214
<table>
<thead>
<tr>
<th></th>
<th>Reason</th>
<th>Votes</th>
<th>%</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>D6</td>
<td>Inadequate clinical assessment</td>
<td>18</td>
<td>8%</td>
<td>40%</td>
</tr>
<tr>
<td>B2</td>
<td>Reassurance for MO</td>
<td>17</td>
<td>8%</td>
<td>48%</td>
</tr>
<tr>
<td>D7</td>
<td>Blanket’ views requested, where specifics are required</td>
<td>17</td>
<td>8%</td>
<td>56%</td>
</tr>
<tr>
<td>A8</td>
<td>Wrong protocol for x-ray requirement</td>
<td>12</td>
<td>6%</td>
<td>62%</td>
</tr>
<tr>
<td>E6</td>
<td>Advised by specialty registrars</td>
<td>12</td>
<td>6%</td>
<td>67%</td>
</tr>
<tr>
<td>B1</td>
<td>You don't get into trouble for requesting an examination- only for not requesting one.</td>
<td>11</td>
<td>5%</td>
<td>72%</td>
</tr>
<tr>
<td>A7</td>
<td>Nurse initiated X-Ray, but x-ray not really needed</td>
<td>10</td>
<td>5%</td>
<td>77%</td>
</tr>
<tr>
<td>B6</td>
<td>Lack of trust in clinical findings</td>
<td>8</td>
<td>4%</td>
<td>81%</td>
</tr>
<tr>
<td>C1</td>
<td>Lack of senior's opinion (more x-rays requested by junior drs)</td>
<td>8</td>
<td>4%</td>
<td>85%</td>
</tr>
<tr>
<td>J1</td>
<td>To speed up work flow</td>
<td>7</td>
<td>3%</td>
<td>88%</td>
</tr>
<tr>
<td>G10</td>
<td>Keeps the patient busy until doctor is available to see patient</td>
<td>5</td>
<td>2%</td>
<td>90%</td>
</tr>
<tr>
<td>D1</td>
<td>Equivocal Clinical findings</td>
<td>4</td>
<td>2%</td>
<td>92%</td>
</tr>
<tr>
<td>D5</td>
<td>Cant be ruled out by clinical assessment</td>
<td>4</td>
<td>2%</td>
<td>94%</td>
</tr>
<tr>
<td>G8</td>
<td>To show the patient that something has been done</td>
<td>4</td>
<td>2%</td>
<td>96%</td>
</tr>
<tr>
<td>I2</td>
<td>X-rays are free in public hospitals</td>
<td>4</td>
<td>2%</td>
<td>98%</td>
</tr>
<tr>
<td>E5</td>
<td>Requested by 'teams' on in-patients</td>
<td>2</td>
<td>1%</td>
<td>99%</td>
</tr>
<tr>
<td>G1</td>
<td>Pressure from relative</td>
<td>1</td>
<td>0%</td>
<td>99%</td>
</tr>
<tr>
<td>G4</td>
<td>Reassurance for patient</td>
<td>1</td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td>I1</td>
<td>No sense of cost to patient in terms of rads</td>
<td>1</td>
<td>1%</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Total Votes</strong></td>
<td><strong>214</strong></td>
<td></td>
<td><strong>100%</strong></td>
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</tr>
<tr>
<td>Code</td>
<td>Description</td>
<td>Votes</td>
<td>% Against</td>
<td>% In Favour</td>
</tr>
<tr>
<td>------</td>
<td>------------------------------------------------------------------------------</td>
<td>-------</td>
<td>-----------</td>
<td>-------------</td>
</tr>
<tr>
<td>B2</td>
<td>Reassurance for MO</td>
<td>17</td>
<td>8%</td>
<td>48%</td>
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<tr>
<td>D7</td>
<td>Blanket’ views requested, where specifics are required</td>
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<td>8%</td>
<td>56%</td>
</tr>
<tr>
<td>A8</td>
<td>Wrong protocol for x-ray requirement</td>
<td>12</td>
<td>6%</td>
<td>62%</td>
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<tr>
<td>E6</td>
<td>Advised by specialty registrars</td>
<td>12</td>
<td>6%</td>
<td>67%</td>
</tr>
<tr>
<td>B1</td>
<td>You don't get into trouble for requesting an examination- only for not requesting one.</td>
<td>11</td>
<td>5%</td>
<td>72%</td>
</tr>
<tr>
<td>A7</td>
<td>Nurse initiated X-Ray, but x-ray not really needed</td>
<td>10</td>
<td>5%</td>
<td>77%</td>
</tr>
<tr>
<td>B6</td>
<td>Lack of trust in clinical findings</td>
<td>8</td>
<td>4%</td>
<td>81%</td>
</tr>
<tr>
<td>C1</td>
<td>Lack of senior's opinion (more x-rays requested by junior drs)</td>
<td>8</td>
<td>4%</td>
<td>85%</td>
</tr>
<tr>
<td>J1</td>
<td>To speed up work flow</td>
<td>7</td>
<td>3%</td>
<td>88%</td>
</tr>
<tr>
<td>G10</td>
<td>Keeps the patient busy until doctor is available to see patient</td>
<td>5</td>
<td>2%</td>
<td>90%</td>
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<tr>
<td>D1</td>
<td>Equivocal Clinical findings</td>
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<td>D5</td>
<td>Cant be ruled out by clinical assessment</td>
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<td>2%</td>
<td>94%</td>
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<tr>
<td>G8</td>
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<td>4</td>
<td>2%</td>
<td>96%</td>
</tr>
<tr>
<td>I2</td>
<td>X-rays are free in public hospitals</td>
<td>4</td>
<td>2%</td>
<td>98%</td>
</tr>
<tr>
<td>E5</td>
<td>Requested by 'teams' on in-patients</td>
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<td>99%</td>
</tr>
<tr>
<td>G4</td>
<td>Reassurance for patient</td>
<td>1</td>
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<td>99%</td>
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<tr>
<td>G1</td>
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<td>100%</td>
</tr>
<tr>
<td>H1</td>
<td>No sense of cost to patient in terms of rads</td>
<td>1</td>
<td>1%</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td><strong>Total Votes</strong></td>
<td><strong>214</strong></td>
<td><strong>100%</strong></td>
<td></td>
</tr>
</tbody>
</table>
Main menus and sub-headings for Investigations Pre Intervention

Figure 12.10 - Electronic Requisition Imaging Requisition Menu Post CPI Intervention

New main headings and sub-headings for Investigations at Hospital B Post Intervention

Screen shots of the requisition menus as Ed staff see them. Note the restricted choice of examinations available in...
Appendix 13

BAXTER 2005

NSW HEALTH AWARD

OPEN ACCESS
Baxter 2005 NSW Health Awards

Name of Project/Entry: Open Access to Blacktown Mt Druitt Imaging Department
Category of Entry: Access to services
Name of team: Blacktown-Mt Druitt Imaging Setting the Benchmark

Contact Details:
Name: James Noll
Position: Chief Medical Radiation Scientist
Stream / Directorate: Imaging, Central Cluster
Phone (w): 98818373
Mobile: 0410 973 959
Facsimile: 98816028
Email: James_Noll@wsahs.nsw.gov.au

Work Location:
Blacktown Hospital, Imaging Department
The Imaging Model of the Millennium
Postal Address:
PO Box 6105 Blacktown rd
Blacktown NSW 2148

<table>
<thead>
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<th>Name of File (MS Word document)</th>
<th>WSAHS_Open_Access to BMDH Imaging.doc</th>
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</thead>
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</tr>
<tr>
<td>Number of pages (maximum 5, excl. references):</td>
<td></td>
</tr>
<tr>
<td>Tables and figures included after text?:</td>
<td></td>
</tr>
<tr>
<td>Tables and figures referenced in body of the text?:</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WSAHS_Open_Access to BMDH Imaging. Photo</th>
<th>Photo 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>WSAHS_Open_Access to BMDH Imaging. Photo</td>
<td>Photo 1</td>
</tr>
</tbody>
</table>
Open Access to Blacktown Mt Druitt Imaging Department

1. ABSTRACT

The high number of cancelled imaging request forms and the numerous complaints from medical and surgical wards regarding delayed patient discharge from the hospital due to the long waiting time for patients to have access to imaging examinations triggered the launch of a revolutionary approach to solving the most endemic problem in imaging departments of medium and large size public hospitals around the world, switching from a well organised and highly sophisticated booking system to a very simple and unsophisticated method and that is “Open Access”.

The CPI project went through 2 consecutive interventions over one year.

The end results as per May 2005 are:

- Average General X-ray examination time “from time of request to time of image availability in the wards” changed from 15 hours to 1 hour.
- Average General X-ray examination time “from time of request to time of image availability in the Emergency Department” changed from 3 hours to 30 minutes.
- Average CT examinations from 2 days to 4 hours.
- Average report availability from 2 days to 4 hours.
- From an average of 80 cancelled general x-ray examination a month to Zero cancelled examinations.
- Compliance with the College of Radiologists KPI requirement, reports of urgent cases available to clinicians within 24 hours, from 42% to 98%.

2. AIM

- To eliminate cancelled inpatient imaging requests
- Make X-rays available upon request without booking and ensure that 70% of X-Ray orders are completed within 3 hours of order time
- To therefore increase department productivity and access in general.

3. BACKGROUND

Similar to any other imaging department in a NSW public hospital, Wards where complaining of the delays caused by imaging, affecting patient management, and patient discharge which in turn reducing the hospitals bed availability.

- Ward doctors expressed concerns regarding an increasing number of inpatient being discharged without having their pre discharge x-ray examination
- Ward Nursing Unit Managers forwarded a major complaint that they usually have approximately 3 to 6 patients at any time waiting to be discharged based on the results of the x-ray examination.
- 236 x-ray request forms being cancelled within 3 months prior to imaging examinations being performed.
4. METHODOLOGY

a. Pre first intervention
   - A multi-disciplinary team was formed under the leadership of the chief Radiographer, sponsored and supported by the General Manager of the Area Health service Imaging stream.
   - Identify the main aim of the project and set a goal.
   - A workflow map was developed (Figure 1), this tool mapped out the processing of requests and patients from entry into the department, until completion of report.
   - Identify the main causes of the problem and set the priorities.
   - Brainstorming to eliminate unnecessary points from the existing patient flow chart.
   - Not having Electronic ordering system, additional data were added to the request form to include time of writing the form. Nurses from Imaging made frequent trips to the wards to ensure compliance.

b. Pre second Intervention
   - Expanded the Team to involve other wards, a quality coordinator, the director of Emergency and a patient who has spent a considerable time in the Hospital. The project got a wider scope of sponsorship including the Medical Admin, Director of Nursing and the Director of Corporate Services.
   - Repeated the above process.

5. FINDINGS
   - The main problem was found to be often delays in the distribution of the request forms to relevant Imaging sections. Not having the forms early enough was causing delays in the morning, and snowballing the number of requests towards the afternoon.
   - The delivery and handling of the request form occupied 80% of the flow chart.
   - Radiologists hardly had any new requests to report in the morning, always clearing yesterday’s backlogs. Current day’s requests usually given to radiologists in the late afternoon and due to time restriction the reporting process was postponed to the next day.
   - Because the majority of examinations being delayed till the afternoon, Patient Transport staff experienced overwhelming demand upon their services. This resulted in increasing complaints from individual sections of the Imaging department not receiving their patients, and complaints from the PSA about their workload.

5. IMPLEMENTATION

a. FIRST INTERVENTION
   - A new flow chart was developed cutting the sporadically engineered and highly sophisticated system to a very simple method, called open Access.
   - Radiographers undergoing training in special modalities such CT and US where placed on standby to move in to the General rooms if required to clear any patient overflow.
   - Wards became responsible of contacting patient transport when the patient and an escort if required are available.

b. SECOND INTERVENTION
   - Immediate access to all patients for General X-Rays
   - No request form to be accepted in the department prior to patient’s arrival
   - Nurse or “Escort” to page Patient Transport located in Imaging
• Hospital Based PSA to be moved to imaging. Both PSA’s to work as a team and transport patients for all modalities.
• CT & US Appointments Booked Directly By M-R-S
• CT & US Trainees to intervene when General Radiographers are occupied
• Use the outpatient General rooms when the Trauma rooms are occupied
• If all rooms are occupied patient to go to Nursing Recovery Area.

6. OUTCOME & EVALUATION

After the system was trialled for 3 months, the results were reviewed and demonstrated a definite positive change to the flow and efficiency of patient completion times for examinations. These facts were evidenced by:

• The Key performance indicators illustrate booking to completion time decreased.
  Average X-Ray to completion time reduced from 3.73 hours to 76 hours, a reduction of 76.26% (Graph 1)
  Average Completion and Typing time reduced from 15.5 hours to 13.16 hour, a difference of 14%. (Graph 2)

• Cancelled exams have been eradicated.

• Ward Junior Medical Officers and Registrars were invited for comments. There was a unanimous response that the system is too efficient. Being originally trained in other hospitals where a decision based on imaging isn’t done before 2 or 3 days after requesting the examination, they are finding it difficult to cope with their workload where patient management decision is to be made one to two hours after writing the request form.

• Medical Admin to start a new CPI project to improve patient management process to take maximum advantage of imaging availability upon request.

• Department productivity and access experienced an overall increase in all sections as demonstrated by the above statistics.

• As a result of the new work practices, a reduction in complaints from ward doctors was noted, as well as the PSA expressing satisfaction with workload.

OUTCOMES FOR THE HOSPITAL

• No more delayed discharge due to delays in imaging

• Increased bed availability

• Better Patient Management

• Staff resources used more effectively throughout the hospital
7. **FUTURE SCOPE**

- At the final meeting it was decided that Patient Transport staff to be a communication device called Vocera where staff can talk to them directly instead of paging.

- Continuously monitor outcomes.

- Carry the project to the larger size Hospital within SWAHS project started 26 June 2005.

---

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BAXTER 2004

NSW HEALTH AWARD

EVIDENCE-BASED X-RAY ORDERING
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We apologise for the quality of some of the images used in this publication. In the interests of efficiency, the images sent to the Department of Health in the original entries have been used. Further information including entry contacts is available via the Health Awards website at: http://internal.health.nsw.gov.au/quality/healthawards2004/
Message from the Director-General

The Baxter 2004 NSW Health Awards are fast becoming a tradition in showcasing the great work of health professionals across NSW.

This year a record 275 projects were entered and the calibre of projects continues to impress me. I congratulate everyone, including those who entered their projects yet did not make this year’s group of finalists.

In a continuously busy world and workplace, finding the time and energy to formulate new processes and ideas can is an enormous challenge. It’s inspiring to see that there are so many dedicated individuals in our health system prepared to take the time and make the effort required to develop and trial new and innovative ideas.

I am honoured to be part of this celebration and proud to showcase the amazing projects from across the health system.

[Signature]

Robyn Kruk
Director-General
NSW Department of Health
Evidence-based x-ray ordering
Western Sydney Area Health Service

Abstract
We aimed to incorporate evidence-based protocols into clinical practice.

A review of data 2002/03 showed patterns of requests for x-rays from the Mt Drurt Emergency Department (ED) that were not evidence-based. In response, the multidisciplinary team developed a range of strategies to reduce inappropriate ordering of x-rays. These included the education of medical and nursing staff, the redesign of the ordering process; and communication with a wide range of stakeholders. Subsequent monthly data shows that inappropriate x-ray ordering in the Mt Drurt ED has decreased. This has reduced unnecessary radiation exposure for patients, and has lessened the use of staff time and equipment in the Radiology Department. In addition, the new system to improve the appropriateness of x-ray orders, is saving $29,000 per annum for Western Sydney Area Health Service (WSAHS).

Aim
By 14 December 2003, to reduce unnecessary x-rays ordered from the Mt Drurt Hospital Emergency Department:

- Group A x-rays by 80%
- Group B x-rays by 20%
- overall monthly rate of x-ray orders by over 7%.

Method
Planning
The project commenced in July 2003 with a meeting between senior staff specialists from ED and radiology to discuss the findings. This group gave their support for actions to reduce unnecessary x-ray ordering. A multidisciplinary team was formed, representing senior and junior medical staff, radiology staff, nursing staff, the ED data manager and a quality manager. The team investigated the problem using the following methods:

- reviewed the data that demonstrated current x-ray ordering practices were not evidence-based (Table 1)
- developed an aim statement based on the data and agreed on a workable timeline

<table>
<thead>
<tr>
<th>Group A</th>
<th>Group B</th>
<th>Set goal for project:</th>
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<tbody>
<tr>
<td>Site of X-Ray</td>
<td>Total</td>
<td>Total</td>
</tr>
<tr>
<td>Abdomen KUB</td>
<td>209</td>
<td>486</td>
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<tr>
<td>Nasal bones</td>
<td>64</td>
<td>281</td>
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<tr>
<td>Fibs</td>
<td>174</td>
<td>517</td>
</tr>
<tr>
<td>Skull</td>
<td>209</td>
<td>723 less</td>
</tr>
<tr>
<td>Total Group A</td>
<td>838</td>
<td>Total Group B = 1364</td>
</tr>
<tr>
<td>Reduce by 80%</td>
<td>510 less</td>
<td>Reduce by 70%</td>
</tr>
</tbody>
</table>

Table 1: Background information — Analysis of x-ray orders from Mt Drurt ED July 2002—June 2003

2000, Steel 1996a, 1996b, Waddell 1996) that have reduced x-rays of Group B sites by about 20%.

At Mt Drurt ED, the ED is responsible for ordering half of all the x-rays performed in the hospital. Our analyses for July 2002—June 2003 identified that each month, ED ordered 30–70 x-rays that provided no benefit (Group A sites). In addition, we identified approximately 120 x-ray orders per month for which a decision algorithm should be applied (Group B sites).
mapped patient flow through ED and identified where decision is taken to order an x-ray
• brainstormed the reasons why x-rays are ordered unnecessarily at Mt Druitt ED
• prioritised the reasons that they believed contributed most significantly to the problem
• developed a list of 14 interventions to trial, based on the shortlist of reasons
• enlisted a consumer into the team, as consumer attitudes were raised as an important contributor to unnecessary orders.

**Implementation**

The range of actions implemented by the team included:

• Cycle 1 – protocols and decision aids were established on the emergency website; medical officer meetings; education; reviewed x-ray ordering data and results; the director provided assurance to medical staff that using evidence-based practice would not leave them vulnerable to litigation. Senior radiographers endorsed acting as ‘gatekeepers’.
• Cycle 2 – the system for ordering tests in ED was changed to an online, clinical problem-based system to guide clinicians and to direct test ordering. The prompts and links in this system made it more difficult for clinicians to go outside the guidelines. Paper order forms were removed from ED workstations, enabling computer-generated requests, only. Radiology department introduced a policy for radiographers to query orders for x-rays from Group A sites.
• Cycle 3 – the project was promoted to nursing staff. Registrars presented evidence for and against inappropriate orders at medical officer meetings, and reviewed patient records to identify whether the x-rays assisted the course of patient management. Consumer input provided helpful insight to medical and nursing staff about consumer expectations. This led to the development of a patient brochure that explains the x-ray ordering policy at Mt Druitt ED.

**Outcomes and evaluation**

By 14 December 2003, the total number of x-rays ordered by Mt Druitt ED per month had reduced by 20%, and the improved results were maintained:

• Group A orders were reduced by 90% (from 53 to 3 x-rays/month) (Figure 1)
• Group B orders, those requiring decision algorithms, were reduced by 75% in Nov 2003 (from 114 to 25 x-rays/month). These monthly figures are more variable than Group A (Figure 2)
• overall reduction of 11% (from 53 to 42 x-rays per 100 presentations to ED by Dec, 2003) (Figure 3).

The graphs show that the change to computer-aided decision making for test ordering (Cycle 2) made the most impact on results, particularly for these sites that should not be x-rayed at all. The gatekeeper role of radiologists has also played a strong part and the other actions have increased acceptance of the new system.
Cost-weights in terms of dollars saved and avoidance of radiation exposure have been applied to our results. This models an annual saving of $39,000 to WSAHS radiology services and avoidance of between 350mRad to 2,000mRad exposure in 944 cases per annum at Mt Druitt ED (Table 2). Run-charts of X-ray request patterns at all WSAHS emergency departments showed that those sites with the new system have changed outcomes significantly, whereas those without the revised system continue to order approximately 30-40 x-rays per month that provide no benefit to patient care (Figure 4).

<table>
<thead>
<tr>
<th>X-ray Site</th>
<th>Annual Total 2002/3</th>
<th>Nov 2003 x12</th>
<th>Projected Annual Reduction</th>
<th>Cost per x-ray ($)</th>
<th>Projected annual savings ($)</th>
<th>Radiation exposure (mRad)</th>
<th>Projected annual savings (mRad)</th>
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<td>$2944.50</td>
<td>2000</td>
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Total: $39,079.30

Note the comparison: radiation exposure from a chest x-ray is ~ 10mRad.

Table 2: Cost-benefit analysis from reduction in x-rays.

Future scope

The computer-based ordering system was developed by the data manager and the director ofMt Druitt ED, in collaboration with medical officers. This system can be applied in all emergency departments across NSW that use HASS EDIS (Hospital Administration Software Solutions Emergency Department Information System) or Point-of-Care Clinical System: electronic ordering. Analysis of Radiology data set wide would identify the frequency of inappropriate x-ray ordering and potential for benefit from the revised system. Any such revised system would require a supporting education program for staff ordering x-rays.

The system was subsequently implemented at Blacktown Hospital Emergency Department with considerable success, and has been proposed at an Emergency Services Stream meeting for adoption in all emergency departments in WSAHS.
References


ALL BEGINNINGS HAVE AN END,
WHAT COUNTS IN LIFE
ARE THE ENDS, THAT START NEW BEGINNINGS.

James E. Nol