A Standardised Approach to Optimisation
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ABSTRACT

PURPOSE: Optimisation of radiographic images is said to have been obtained if the patient has achieved an acceptable level of dose and the image is of diagnostic value. In the near future, it will probably be recommended that radiographers measure patient doses and compare them to reference levels. The aim of this paper is to describe a standardised approach to optimisation of radiographic examinations in a diagnostic imaging department.

METHOD: A three-step approach is outlined with specific examples for some common examinations (chest, abdomen, pelvis and lumbar spine series). Step One: Patient doses are calculated. Step Two: Doses are compared to existing reference levels and the technique used compared to image quality criteria. Step Three: Appropriate action is taken if doses are above the reference level.

RESULTS: Average entrance surface doses for two rooms were as follows AP Abdomen (6.3mGy and 3.4mGy); AP Lumbar Spine (6.4mGy and 4.1mGy) for AP Pelvis (4.8mGy and 2.6mGy) and PA chest (0.19mGy and 0.20mGy). Comparison with the Commission of the European Communities (CEC) recommended techniques identified large differences in the applied potential. The kVp values in this study were significantly lower (by up to 10kVp) than the CEC recommendations.

DISCUSSION: The results of this study have indicated that there is a need to monitor radiation doses received by patients undergoing diagnostic radiography examinations. Not only has the assessment allowed valuable comparison with International Diagnostic Reference Levels and Radiography Good Practice but has demonstrated large variations in mean doses being delivered from different rooms of the same radiology department. Following the simple 3-step approach advocated in this paper should either provide evidence that department are practising the ALARA principle or assist in making suitable changes to current practice.

Keywords: Optimisation, radiation dose, chest, abdomen, pelvis, lumbar spine

INTRODUCTION

Diagnostic radiology accounts for about 14 per cent of the average annual effective dose from all sources including natural radiation, whilst providing over 90 per cent of that from all manmade exposures.\textsuperscript{1} According to Medicare data the number of diagnostic imaging examinations in Australia has increased from 8.2 million in 1991 to 11.3 million in 2000 representing an increase of nearly 40 per cent over the last decade.\textsuperscript{2}

However it is recognised that ionising radiation has the potential to induce cancer. The assumptions used by the International Commission on Radiological Protection (ICRP), as a basis for the dose response relationship for cancer induction is that it is linear down to zero (ie without threshold).\textsuperscript{3} This means that the medical use of ionising radiation can contribute to the induction of a small number of new cancers in the general population.

For this reason the medical use of ionising radiation can be perceived to be a public health issue and there is a need for close control of radiation exposure where the ultimate goal is to reduce the occurrence of stochastic effects.\textsuperscript{3} This leads to the need to consider radiation protection of staff, patients and the general public. For these groups the same general principles apply, and these are the justification, optimisation and individual limitation of dose.\textsuperscript{3} The justification of a practice states "No practice involving exposures to radiation should be adopted unless it produces sufficient benefit to the exposed individuals or to society to offset the radiation detriment it causes, in other words the benefit must exceed the harm".\textsuperscript{3} Even if a procedure is justified it should be optimised to minimise the risks due to ionising radiation; here the procedures should follow the ALARA (As Low As Reasonably Achievable) principle, with economic and social factors being taken into account.

The third principle of individual limitation of dose does not however apply to patients, as the assumption is that the benefit of any medical procedure will outweigh the risk from that procedure. In place of individual dose limits, the use of investigation levels (diagnostic reference levels, DRLs) has been recommended as a practical way of promoting the optimisation of protection.\textsuperscript{4,5}

It is important to look at the diagnostic objective of the exposure and use the lowest dose that is still consistent with the objective. We then consider those examinations that are unnecessary for effective clinical diagnosis; those examinations that are unlikely to modify patient management, repeats due to poor quality, repeats due to lost radiographs, and all those examinations where doses could reasonably have been reduced without loss of clinical efficacy by changes in technique or equipment.

This paper concentrates on the latter issue dealing with the ways that doses can be minimised by optimising the radiographic technique. A simple three-step system, which allows radiographers to use their expertise, is outlined. These steps will ensure that the ALARA principle is being adhered to. They will be discussed in particular reference to dose measurements performed.
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at the Mater Misericordiae Hospital, Newcastle for a number of common diagnostic radiography examinations (chest, abdomen, pelvis & lumbar spine series).

METHOD

Method Step One – Assessment of Patient Dose

The choice of dose quantity used depends on the type of examination performed. The measurement to be undertaken should be easy to understand, easy to measure, reflect radiological practice and obviously allow assessment on patients.6

One dose quantity meeting these criteria for plain and simple single X-ray examinations is the entrance surface dose (ESD). ESD is defined as the absorbed dose to air at the point of intersection of the X-ray beam axis with the entrance surface of the patient, including backscatter.9 ESD can be assessed directly by measurement with TLD’s or calculated from standard data with knowledge of the exposure factors applied in clinical practice.

The dosimetric mode chosen for this study was ESD by calculation, where measurements made in air with a calibrated ionisation chamber are corrected using appropriate backscatter factors and radiographic techniques to estimate the entrance surface dose. The patient PA and LAT distances were measured to allow accurate focus-skint distances. It is acknowledged that the TLD is the gold standard instrument for the assessment for ESD; however the use of dose calculations and comparison with TLD measurement is a recognised method.7

The goal of the study was to assess the radiation doses for 10 patients per tube.8 The datasheet used for monitoring purposes requested information on patient anatomical thickness, gender and technical factors. The technical factors included applied potential (kVp), current-time product (mAs), focus to film distance (FFD), and the use of grid and AEC.

The datasheet was located near the console of each room and was completed when a patient entered requiring one of the specified examinations. Only patients over the age of 18 were included in the study. Opportunity sampling was used for patient selection; that is, the first 10 patients presenting for the examination and matching the criteria (age, habitus) were recruited.

Dose assessment was done in two stages, firstly quality control testing was performed on each tube and secondly exposure factors were recorded for each patient. Tube output and filtration was assessed with a Rad-check plus exposure meter (model 06-526, S/N C993136100) and high purity aluminium filters and kVp calibration was measured with a kVp III Digital kVp meter (model 07-494, S/N 141 168000). Tube output and the exposure values were input into an excel spreadsheet to allow the calculation of the entrance surface dose (ESD) values for each patient to be automated. The backscatter factors for the examinations were taken from the data contained in a National Radiological Protection Board Report.9

It is recommended that dose measurements be made for those examinations that make a significant contribution to the collective population dose. The chest, abdomen, pelvis and lumbar spine examinations were chosen for this study as they are common examinations in most departments and reference levels are readily available for comparison.

Method Step Two – Comparison with Reference Levels and Image Quality Guidelines

The concept of diagnostic reference doses, established in the UK in 1990, is now recognised internationally as a useful and practical tool for facilitating optimisation of patient protection.8 Diagnostic reference levels are ideal for radiology departments as they allow for easy comparison of dose levels with accepted levels and they are recommended as a practical way of promoting the optimisation of protection.

Diagnostic reference levels are based on the third quartile (75th percentile) for the distributions of mean ESD measured in a number of radiology sites.8 This approach was simply proposed to help identify those 25 per cent of hospitals with the highest doses; it is assumed that if 75 per cent of departments obtain mean doses lower than the DRL then the other 25 per cent should be capable of changing their practice to reduce their doses. Thus DRLs can be used as levels to trigger a local review by an X-ray department when their mean ESD exceeds the DRL. This could be by either justifying the use of relatively high doses, or to improve practice through changes in technique or equipment.9

A UK dosimetry protocol established in 1992 enabled a database to be set-up for the collation of National survey data; this is known as the National Patient Dose Database (NPDD). The results from these collated surveys have allowed a review of the doses in 1995 and 2000.10,11 A comparison of the initial survey (1992) and the values obtained in the 1995 and 2000 review are given in Table 1. Due to the increases in film-screen speeds and general increases in kVp over the years, there has been a significant reduction in ESDs recorded in the UK.

The Commission of the European Communities (CEC) established a Quality Criteria for Diagnostic Images,12 The aim being to characterise an acceptable level for radiographic image quality obtained with acceptable levels of patient dose. The CEC criteria presents the technical information for the radiographic techniques, which if followed will produce a good image of standard quality. Diagnostic reference levels produced by the NRPB in 1992 accompany this technical information. The guidelines can be used to achieve a good standard of practice in any radiology department, while producing ESDs lower than the DRLs. The recommended technique (shaded rows) for three of the examinations in this study is given in Table 2. There is no

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Table 1: Entrance Surface Doses for Common X-Ray Examinations as published by the National Radiological Protection Board (NRPB). The NRPB mid 1980’s values are the first values published and involved 10 hospitals. Five yearly updated 3rd quartile levels from a National Database are given in the columns NRPB1995 (current DRLs) and NRPB2000.
available data for the abdomen examination at this time.

**Method Step Three – Take Action**

The first two steps will allow the comparison of dose for a range of different examinations. If dose levels are high, then the CEC criteria can help assess some key areas for change with regards to radiographic technique. This can be as simple and inexpensive as increasing kVp levels. At the lower kVp values there is a higher probability of photoelectric absorption within the patient, and the mAs will need to be increased to ensure sufficient transmission of radiation and optimal optical density of the radiograph. This results in higher patient dose.

Alternatively, a film-screen system of higher speed or a lower ratio grid may be acquired at some cost. In addition to these changes, we must not forget the effect of the film processor on radiation dose. Using a film-screen system with a reported speed of 400, does not guarantee a combined actual speed of 400. One study found that actual film-screen speeds could be significantly lower than the reported manufacturer values due to incompatible film chemicals and low developer temperatures.1,5

Following changes in technique or equipment (or both), then the cycle starts again, with the assessment of radiation dose. These three steps should be incorporated into the routine quality control of the department.

**RESULTS**

**Results Step One – Patient Dose**

The results from the quality control measurements are given in Table 3. Both units have kVp calibration (accuracy) within five per cent and the co-efficient of variation in radiation output is well within the required limits of 0.05. There are however differences in radiation output and filtration between the units. The radiation output is approximately five per cent lower in the X-ray tube in room 2, which may be due (in part) to the difference in half value layer of the units.

A summary of the mean technique factors, patient thickness and entrance surface dose (ESD) for the 4 examinations in the study is given in Table 4. A histogram of all patient PA chest ESDs obtained in this study is given in Figure 1. It contains the range of doses for 28 patients in two rooms and demonstrates that DRL’s should not be used for individual patients, where doses may vary significantly owing to differences in patient size. The PA chest ESDs ranged from 0.1 to 0.82mGy with mean values of 0.19mGy for room 1 and 0.20mGy from room 2. The lateral

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Table 2: Comparison of radiographic technique used at the Newcastle Mater Hospital compared with the recommended technique of the CEC (shaded rows) for examination of the Chest (PA and LAT), Pelvis (AP) and the Lumbar Spine (LAT).

Table 3: Summary results from the quality control measurements taken at the start of the study. The results demonstrate slight differences in radiation output and HVL values.

Table 4: Mean values for patient thickness, technical factors and entrance surface dose (ESD) for the 4 examinations in the study.
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Results Step Two – Comparison with Diagnostic Reference Levels and CEC Guidelines

It is recommended that departmental mean ESDs are compared with the DRLs. It is clarified that the DRLs were derived from mean room values from hospitals included in the NRPB study; though they were set to target those 25 per cent of rooms (departments) who produced the highest ESDs. All the mean doses at the Mater produce levels lower than the DRLs (Figure 2 and Tables 1 & 4). One thing that was obvious is the difference in mean dose between the two rooms; with room 2 producing doses much lower than room 1. The exception was the doses for the chest examination. The full reason for the dose differences between the two rooms is part of an ongoing study, though some of the reasons will be discussed later.

For those departments obtaining ESDs above the reference levels, comparisons with accepted guidelines on technique and equipment can be helpful in identifying ways to reduce dose. While the ESDs calculated at the Mater are lower than the current DRLs, comparison with the 1995-2000 NRPB review doses, indicate that there is much room for improvement. In comparing the techniques used at the hospital with those recommended in the CEC criteria (Table 2), the applied potentials (the kilovoltage selected by the radiographer) for the pelvis and lumbar spine are lower than recommended by the CEC [10]. For the AP pelvis, the CEC recommends voltage settings of between 75 and 90 kVp, while the value in this study was only 65 kVp. Similarly, for the lateral lumbar spine examination, the values used at the Mater Hospital (70 - 73 kVp) were significantly lower than those in the recommended range of 90 - 100 kVp. Another difference is the grid ratios used; the Mater uses 12:1 grid-ratios and not 10:1 as recommended by the CEC, which will result in higher doses. It is expected to observe higher grid ratio's being used at higher kVp values due to the increase in forward scatter produced, and not at the lower kVp's used at the Mater.

For the chest examination, the kilovoltage selected at the Mater Hospital corresponded with the recommended range of 125 kVp, and the doses measured were much closer for both rooms to the NRPB 1995-2000 review values.

Results Step Three – Take Action

Investigating the data given in Table 1 highlights the potential for dose reduction that can be achieved if this simple three-step approach is followed. The rounded third quartile ESD values in the UK have been reduced by approximately 50 per cent over the last decade.

This study has highlighted the discrepancy in the doses between...
two rooms in the same department. The same value of applied potential is used, and the same film-screen system and processor as would be expected for the same department. Investigating the results of the QC measurements (Table 3) shows room 1 has a lower HVL and a slightly higher (~5 per cent) radiation output than room 2. However, these small differences are not fully responsible for the differences.

As stated in the methods, the PA and Lateral thicknesses of the patients were measured to allow for the calculation of the ESDs. The mean patient thickness for each examination type and room are given in Table 3. The values for the abdomen and the chest examinations were similar for each room, but differences were noted for the lumbar spine and the pelvis, with room 1 examining larger patients. The larger patient size will explain the larger mAs values used in room 1, but again to the extent that has been calculated and not for the Abdomen examination.

A discrepancy in doses between the rooms might also be attributed to the way in which the entrance surface dose values were obtained. One error that can arise in calculation is variation between actual and reported values of technical factors. For example, incorrect reporting of the Focal Film Distances used. That is the radiographers think that they are using a FFD of 200cm, and this is what is being reported, but in fact the distance actually used may be different. A 10 per cent increase in FFD (200cm to 220cm) would result in a 20 per cent decrease in calculated ESD, while a 10 per cent decrease in FFD (200cm to 180cm) would result in a 27 per cent increase in calculated dose. These changes will then result in corresponding (inverse) changes in mAs values to ensure that the optical density remains constant. This may explain the higher mAs values used in room 1 for all examinations using 100cm and 120cm FFD.

There is an obvious need to have a more thorough investigation into the operation of both tubes and this is underway with the use of the Pehamed Alpha Test Tool (Intellicorp Australia). This will allow an assessment of the AEC set-up and resultant optical density. The comparison of techniques between the Mater and those recommended by the CEC has started an investigation with a larger study population into the use of higher kVp’s and their effect on entrance surface dose measured with TLDs.

**CONCLUSION**

Dosimetry is an essential element for the overall management of the patient undergoing X-ray examination. Periodic monitoring of patient dose should be routinely performed in all X-ray departments as it can help identify any problems or discrepancies. This was particularly demonstrated in this study by differences approaching 50 per cent for the mean doses between two rooms in the same hospital. The use of diagnostic reference levels and good technique guidelines can then be implemented to ensure that the diagnostic imaging department is following the ALARA principle.

**REFERENCES**


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