# Patient dose audit for patients undergoing six common radiography examinations: Potential dose reference levels

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Abstract:  The purpose of this study was to determine radiation doses for patients undergoing six general radiography examinations at the main x-ray department of Charlotte Maxeke Johannesburg Academic Hospital (CMJAH). In addition, for the first time, a baseline for potential dose reference levels (DRLs) in South Africa was established for the selected examinations. Patient data and technical parameters related to the x-ray examinations were collected. The study involved the following examinations: chest posterior-anterior (PA), chest lateral (LAT), pelvis anterior-posterior (AP), abdomen AP, lumbar spine AP and thoracic spine AP. Entrance surface air kerma was calculated based on the x-ray tube output of the unit used and the exposure parameters used for the actual examination. Descriptive statistics were generated from the data using Microsoft Excel 2007. Diagnostic reference levels (DRLs) were established based on the third quartile of the entrance surface air kerma (ESAK) values. This study involved two x-ray rooms, 117 patients and a total of 166 ESAK calculations. Based on the mean ESAK values from the individual rooms, the following DRLs were established: 0.1 mGy for chest PA, 0.22 mGy for chest LAT, 2.98 mGy for pelvis AP, 4.19 mGy for abdomen AP, 5.30 mGy for lumbar spine AP and 3.28 mGy for thoracic spine AP. The established DRLs were compared with previously published DRLs from other countries. Since the data presented in this study is an initial attempt at establishing local DRL values, it provides a benchmark for the statutory authorities to establish dose reference levels for diagnostic radiology in South Africa.

Keywords:  entrance surface air kerma, dose optimization

## Introduction

Medical ionizing radiation sources give by far the largest contribution to the population dose from man-made sources and most of this contribution comes from diagnostic x-rays [1-3]. It is a generally accepted tenet that irradiation for medical purposes is associated with some hazard but in most cases the benefit to the patient outweighs any detrimental effects. However it is necessary to ensure that all doses are kept as low as compatible with good medical practice [4]. Surveys have shown wide variations in patient doses for patients undergoing the same x-ray examinations, at times by a factor of 100 [5]. This wide variation in patient doses proves that there is room to optimise the radiography process. There is also considerable evidence that substantial reductions in these medical exposures are possible without detriment to patient care [5]. The wide variation in doses led the Royal College of Radiologists (RCR) and the National Radiological Protection Board (NRPB) to recommend that regular patient dose monitoring should be an essential component of a quality assurance (QA) programme in diagnostic radiology [4].

In order to reduce the radiation dose there must be guidance on appropriate levels of patient exposure. The International Commission on Radiological Protection (ICRP) and the European Commission have recommended the use of diagnostic reference levels (DRLs) [6, 7]. DRLs are defined as dose levels in medical radio-diagnostic practices or, in the case of radiopharmaceuticals, levels of activity, for typical examinations, for groups of standard sized patients or standard phantoms and for broadly defined types of equipment [7]. The dose distribution in diagnostic radiology examinations is usually skewed with a long tail at the higher dose end of the scale. It has thus been recommended that the 75th percentile or third quartile of the dose distribution is an appropriate level for the DRL [8]. The DRL should fulfil the following criteria:

- Be clearly defined and easy to measure or calculate.
- Directly indicate the dose delivered to the patient.
- Allow easy correlations with the technical parameters of the medical examination.
- Be adapted to all types of radiological equipment.

DRLs provide an evaluation of the performance of the medical examination and thus could continuously improve the imaging procedure. The continual improvement of the medical procedure can be accomplished by monitoring the DRL in a given institution for a given medical device and subsequently make a comparison with other hospitals.

A DRL is not a dose limit and it does not apply to a single individual. These levels are expected not to be exceeded for standard procedures when good and normal practice regarding diagnostic and technical performance is applied. The purpose of DRLs, according to the Commission of the European Communities (CEC), is to encourage radiology departments to investigate their patient radiation dose levels and make historical, national or international comparisons [5]. In the event that the measured doses exceed the recommended DRL, then the radiology department should investigate the causative factors contributing to the high doses [5]. Consistently high departmental doses will result in either an acceptable justification for the dose, revisions in technique or equipment to bring radiation doses in line with other hospitals [5].

## Aim

South African research in the field of patient dosimetry has been limited to fluoroscopy and interventional radiology [9-11]. This could be as a result of the generally high doses expected from these procedures. To the best of the authors' knowledge there is no South African published data on patient doses in general radiography, thus no suggested DRLs. Presumably this scenario leads to South African radiology departments having to rely on international DRLs. This is not advisable since DRLs are not universal in nature and radiography practice and technique vary from one country to another [5]. In addition, the ICRP encourages

authorized bodies to set up DRLs that are consistent for the regional, national or local area to which they apply [1]. The objectives of this study are as follows:

- Perform a radiation dose audit for a random sample of patients presenting for chest posterior-anterior (PA), chest lateral (LAT), pelvis anterior-posterior (AP), abdomen AP, lumbar spine AP and thoracic spine AP.
- Based on results of the patient dose audit establish DRLs for the above mentioned examinations.
- Compare the local DRLs with international DRLs.
- Propose changes to radiography practice with a view to lower patient doses.

## Materials and methods

For this study the methodology used was as per International Atomic Energy Agency (IAEA) protocol and guidelines on indirect patient dose measurements [1].

## Setting

The study was done at the main x-ray department of Charlotte Maxeke Johannesburg Academic Hospital (CMJAH). The main x-ray department has five x-ray rooms of which two were used for this study. Two Philips Medical Systems units, powered by Optimus 50 high frequency generators were used for this study. Each unit had an inherent filtration of 2.5 mm of aluminium (Al). However, added filtration could be activated by setting the built-in rotatable filter disk to one of the filter values indicated on the disk, namely, 0 mm Al, 1 mm Al, 2 mm Al and 1 mm plus 0.1 mm Cu. In addition the units had moving anti-scatter grids of grid ratio 12:1.

## Patients

This was a cross-sectional study in which patient doses were determined in terms of the entrance surface air kerma. For each participating patient, the following information was recorded: mass, height, exposure parameters (kVp, mAs), focus-film distance, use of grid and quality of the radiograph. A form was designed to allow for all the necessary information to be recorded. All this information was collected over a period of one week, during the times 09:30 to 14:30 hours. The body mass index (BMI) was calculated for each patient. Only adult patients undergoing the following examinations were eligible for the study: chest PA, chest LAT, pelvis AP, abdomen AP, lumbar spine AP and thoracic spine AP. Ethical clearance was issued by the University of the Witwatersrand, Human Research Clearance Committee. In addition informed consent was obtained from each study participant.

## Patient size

Instead of measuring the patient's thickness at the relevant anatomical site, the equivalent diameter (ED) in centimetres was calculated using the relationship from Reay et al (2003) [12].

$$ED = 2\sqrt{\frac{w}{\pi * h}} \quad (1)$$

where

- w is the patient's mass in grams
- h is the patient's height in cm

The above equation takes account of body shape by approximating the person to a cylinder with the same density as water.

## X-ray tube output

The x-ray tube output from the units was measured using a calibrated 1 cm³ PTW-Freiburg TM77334 ionization chamber connected to a PTW UNIDOS E electrometer. The air kerma K(d) from the x-ray unit for various exposure parameters (kVp and mAs) and at a distance d of 1 m from the source was calculated using equation 2:

$$K(d) = \bar{M} * N_{K,Q_o} * k_Q * k_{TP} \quad (2)$$

where

- $\bar{M}$ is the average of the readings from the ionization chamber at a distance $d_{FTD}$
- $N_{K,Q_o}$ is the ionization chamber calibration factor
- $k_Q$ corrects for the difference in ionization chamber response between the calibration beam quality Qo and the clinical beam quality Q.
- $k_{TP}$ is the temperature pressure correction factor.

From the measurement of K(d) the x-ray tube output, Y(d) in Gy per mAs was then calculated as the quotient of K (d) by $P_{It}$ where K(d) is the air kerma and $P_{It}$ is the tube loading during the exposure in mAs.

$$Y(d) = \frac{K(d)}{P_{It}} \quad (3)$$

## Entrance surface kerma

According to the IAEA Code of Practice whose methodology was adopted in this study, there are three principal dosimetric quantities to be measured in general radiography, namely, incident air kerma ($K_i$), the entrance surface air kerma (ESAK) and the air kerma-area product [1]. The incident air kerma is defined as the kerma to air from an incident x-ray beam measured on the central beam axis at the position of the patient or phantom surface, with the backscattered radiation excluded [1]. The incident air kerma is calculated using the following relationship.

$$K_i = Y(d) * P_{It} \left(\frac{d}{d_{FTD} - t_p}\right)^2 \quad (4)$$

where

- $Y(d)$ is the output (mGy(mAs)$^{-1}$) of the x-ray tube at particular exposure settings
- $d$ is the focus to chamber distance
- $P_{It}$ is the tube loading during the exposure of the patient
- $d_{FTD}$ is the focus to table distance
- $t_p$ is the patient thickness at the irradiation site

The entrance surface air kerma is defined as the kerma to air measured on the central beam axis at the position of the patient or phantom inclusive of the backscattered radiation. The ESAK can be calculated from incident air kerma by multiplying by an appropriate backscatter factor.

$$ESAK = K_i * BSF \quad (5)$$

where BSF is the backscatter factor as obtained from tabulated data [1].

The DRLs in this study were established from the calculated ESAK values, as advised in the IAEA Code of Practice [1]. Through the use of published conversion factors, ESAK values can be converted to risk related quantities, such as organ dose and effective dose [13, 14]. Entrance surface air kerma calculations were done only for exposures which resulted in films of diagnostic quality.

### Quality control tests
Quality control tests like reproducibility, linearity, and field light – radiation field congruence, and timer accuracy, were performed on the unit to establish compliance of the unit to the specifications of the Directorate: Radiation Control [15]. The department has an active film reject analysis program in place.

### Data analysis
Descriptive statistics were generated from the data using Microsoft Excel 2007.

### Results
Analysis was done on the patient attributes who presented at the two general x-ray rooms. The mean of patient mass, height and BMI are shown in Table I. Super HR – U30 orthochromatic x-ray films from FUJIFILM Corporation were used for all examinations. In addition only

Agfa Curix Ortho Regular screens were used. The x-ray units used have an automatic exposure control (AEC) facility. The AEC facility is not routinely used due to not being properly calibrated, thus the exposure parameters are set manually. Each room has a technique chart (exposure chart) displayed for a variety of examinations which can be performed on the x-ray unit. The descriptive statistics related to the patient attributes and exposure parameters are shown in Table I.

Patient mass varied from 41 kg to 127 kg; patient height fluctuated from a minimum of 1.42 m to a maximum of 1.92 m. In comparison to the mAs coefficient of variation the kVp coefficient of variation is narrower. The wide variation in mAs used for the examinations subsequently leads to wide variations in patient ESAK. Consistent with good radiographic practice a high kVp technique is being used for chest examinations.

The x-ray tube output across the clinically used kVp range was calculated from the measured air kerma using equation 3. The x-ray tube output at 125 kVp was calculated as 0.0991 mGy/mAs and 0.0997 mGy/mAs for the two x-ray units respectively. The x-ray tube output was measured at 1 metre (100cms) from the x-ray source and for an added filtration of 1 mm Al.

A total of 166 ESAK calculations were done based on the exposure parameters used for the particular examination and on the measured x-ray tube output. The descriptive statistics (mean, minimum, maximum,

*Table I. Summary of the patient attributes and typical exposure parameters used.*

| Examination | Chest PA | Chest LAT | Pelvis AP | Abdomen AP | Lumbar spine AP | Thoracic spine AP |
|---|---|---|---|---|---|---|
| **Room A1** | | | | | | |
| Number of patients | 27 | 27 | 5 | 19 | 10 | ***** |
| Mean mass (kg) | 75.0 | 75.0 | 63.2 | 75.8 | 66.9 | ***** |
| Mean height (m) | 1.70 | 1.70 | 1.57 | 1.70 | 1.63 | ***** |
| Mean BMI (kg/m²) | 25.7 | 25.7 | 25.6 | 26.5 | 25.3 | ***** |
| kVp | 125 (109-125) [3%] | 125 (117-125) [2%] | 63 (60-64) [4%] | 60 (60-66) [3%] | 66 (60-77) [9%] | ***** |
| mAs | 1 (1.0-3.2) [48%] | 3 (2.0-6.3) [38%] | 40 (50-63) [15%] | 40 (32-100) [47%] | 40 (40-100) [52%] | ***** |
| Screen film speed | 400 | 400 | 400 | 400 | 400 | ***** |
| Film size | 35cm x 43cm | 35cm x 43cm | 24cm x 30cm | 24cm x 30cm | 18cm x 43cm | ***** |
| FFD (cm) | 180 | 180 | 100 | 100 | 100 | ***** |
| **Room A2** | | | | | | |
| Number of patients | 22 | 22 | 8 | 7 | 8 | 11 |
| Mean mass (kg) | 68.1 | 68.1 | 68.1 | 67.4 | 56.9 | 65.8 |
| Mean height (m) | 1.68 | 1.68 | 1.76 | 1.60 | 1.70 | 1.68 |
| Mean BMI (kg/m²) | 24.1 | 24.1 | 22.1 | 26.5 | 19.7 | 23.2 |
| kVp * † | 125 (109-125) [5%] | 125 (109-125) [3%] | 63 (57-66) [5%] | 60 (60-81) [11%] | 66 (60-90) [15%] | 60 (55-66) [8%] |
| mAs * † | 1 (1.0-2.25) [39%] | 3 (1.6-4.0) [19%] | 40 (22-40) [17%] | 40 (40-100) [56%] | 40 (32-80) [52%] | 40 (40-100) [62%] |
| Screen film speed | 400 | 400 | 400 | 400 | 400 | 400 |
| Film size | 35cm x 43cm | 35cm x 43cm | 24cm x 30cm | 24cm x 30cm | 18cm x 43cm | 18cm x 43cm |
| FFD (cm) | 180 | 180 | 100 | 100 | 100 | 100 |

*****  Data not available
* Ranges are shown in parentheses ( )
† Coefficients of variation are shown in brackets [ ]

median, etc.) of the ESAK values from the two x-ray rooms are given in Table II. The relative expanded uncertainty in the ESAK determination was ±6%. In comparison with other published studies, the ratio of the maximum ESAK to minimum ESAK ratio varies moderately, having a maximum of 1:5.8 for the patient examinations studied. Despite the two rooms having x-ray units of the same make and same technique chart, there was a significant variation in the mean ESAK particularly for pelvis AP and abdomen AP examinations.

From these ESAK values the 75th percentile or third quartile was established based on the mean ESAK values per examination from each room, and this corresponds to the DRL for the respective examination. These preliminary DRLs were subsequently compared with DRLs from international studies as shown in Table III [16 - 20].

## Discussion

The DRLs from this study are comparatively lower than those set up by most countries. This could be a result of the fact that the DRLs from international studies are established from several x-ray rooms in different hospitals and therefore radiography practice and technique varied widely. In addition in some cases, authors setting up DRLs do not report on the patient dose influencing factors like added filtration, screen-film speed, generator type, use of AEC or manual method, and image receptor technology. For instance, the DRLs from this study are based on a screen-film speed of 400 compared to 200 used in the IAEA study [19]. As hospitals migrate to digital technology, patient dose audits must be carried out and DRLs representative of this technology established.

In this study the authors were actively responsible for the data collection as the radiographers felt it would be an extra work load to them, being short-staffed. From our experience, this indirect method of assessing patient doses introduces minimal inconvenience to the running of an x-ray department. However, for large scale studies it would be much easier and less disruptive for the radiographers working on the x-ray units to collect the data required for ESAK calculation. In addition, direct involvement of radiographers in the measurement process would improve their awareness of patient doses and the effectiveness of radiation protection measures.

It is recommended that at least 10 patients per x-ray room be used in the establishment of DRLs [4]. In this study this was not always possible. However, since the data collection was spread over a week it can be argued that a true reflection of radiographic practice and technique was captured.

Since all the dose influencing parameters are to be recorded when setting up DRLs, it makes it easier to pinpoint parameters leading to higher doses and thereafter optimise the process. Although DRLs are not applicable to individual patients, their establishment is based on knowledge of the x-ray tube output, which means queries from patients regarding their personal doses can be answered with confidence.

In compliance with the Directorate: Radiation Control in South Africa quality control and quality assurance requirements it is assumed that most suites know the x-ray tube output from their units [15]. It is possible that most radiology centres have been indeed conducting patient dose audits in an effort to optimise their examinations. Should this be the case then it is suggested that a national database be established in the mould of the National Patient Dose Database (NPDD) of the United Kingdom (UK), in which measurements of radiation doses to patients are collated [21]. Trends could then be monitored and

Table II. Distribution of ESAK values in milligrays for the different examinations.

| Examination | Chest PA | Chest LAT | Pelvis AP | Abdomen AP | Lumbar spine AP | Thoracic spine AP |
|---|---|---|---|---|---|---|
| ESAK | | | | | | |
| **Room A1** | | | | | | |
| Minimum | 0.05 | 0.12 | 2.87 | 1.58 | 2.20 | ***** |
| Mean | 0.10 | 0.23 | 3.41 | 2.98 | 5.63 | ***** |
| Median | 0.08 | 0.20 | 3.21 | 2.72 | 4.78 | ***** |
| Maximum | 0.20 | 0.44 | 4.77 | 5.43 | 11.22 | ***** |
| Max/Min ratio | 4 | 3.7 | 1.7 | 3.4 | 5.1 | ***** |
| | | | | | | |
| **Room A2** | | | | | | |
| Minimum | 0.05 | 0.07 | 1.14 | 2.36 | 1.75 | 2.33 |
| Mean | 0.09 | 0.19 | 1.68 | 4.59 | 4.32 | 3.28 |
| Median | 0.08 | 0.20 | 1.75 | 3.14 | 4.16 | 2.99 |
| Maximum | 0.15 | 0.26 | 2.31 | 13.78 | 8.31 | 4.91 |
| Max/ Min ratio | 3.0 | 3.7 | 2.0 | 5.8 | 4.7 | 2.1 |
| | | | | | | |
| Mean Room A1 ESAK / Mean Room A2 ESAK | 1.11 | 1.21 | 2.03 | 0.65 | 1.30 | |
| ***** Data not available | | | | | | |

Table III. Established DRLs from this study compared with DRLs from national and international recommendations. Quoted DRLs are in milligrays.

| Examination | This study | Brazil [16] | UK [17] | Iran [18] | IAEA [19][1] | IAEA [20] |
|---|---|---|---|---|---|---|
| Date of setting DRLs | | 2009 | 2005 | 2008 | 2004 | 2008 |
| Chest PA | 0.10 | 0.35 | 0.15 | 0.41 | 0.40 | 0.33 |
| Chest LAT | 0.22 | 0.96 | 0.60 | 2.07 | 1.50 | *** |
| Pelvis AP | 2.98 | *** | 4.00 | 3.18 | 10.00 | 3.68 |
| Abdomen AP | 4.19 | *** | 4.00 | 4.06 | 10.00 | 3.64 |
| Lumbar spine AP | 5.30 | 6.60 | 5.00 | 3.43 | 10.00 | 4.07 |
| Thoracic spine AP | 3.28 | *** | 4.00 | 2.72 | 7.00 | *** |

[1] DRLs based on a screen film relative speed of 200. To compare with this study, values should be reduced by a factor of 2.

reliable national DRLs could be developed and refined. The Directorate: Radiation Control (South Africa) are best suited to set-up such a database given that annual quality control returns from all licensed radiation users in the country are collated by them.

The variation in mean ESAK values between the two examination rooms shows that there is room to further optimise the radiography process at CMJAH. Possibly use of well calibrated AEC chambers could reduce the variation in patient doses between imaging rooms. Currently the two units are always used with an added filtration of 1 mm Al. Use of other available filter thicknesses could lead to dose reduction. Furthermore, adoption of the radiography techniques suggested in the document *European Guidelines on Quality Criteria for Diagnostic Radiographic Images* for instance could further decrease patient doses while maintaining good image quality [22].

## Conclusion

It has been demonstrated how a patient dose audit could be performed in a large teaching hospital with minimal interference to practice. To the best of the authors' knowledge this is the first time patient doses for general radiography examinations have been audited and published in South Africa. The data presented in this study is an initial attempt at establishing local DRL values. The following local dose reference levels were established: 0.1 mGy for chest PA, 0.22 mGy for chest LAT, 2.98 mGy for pelvis AP, 4.19 mGy for abdomen AP, 5.30 mGy for lumbar spine AP and 3.28 mGy for thoracic spine AP. This study has an educational function to the radiology community and furthermore provides a benchmark to assist any statutory organization to establish DRLs for diagnostic radiology in South Africa.

## Acknowledgements

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