Received:
22 January 2013

Revised:
21 March 2013

Accepted:
10 April 2013

doi: 10.1259/bjr.20130053

Cite this article as:

Davis AT, Hopkins SA. Optimisation of patient dose for the horizontal beam technique in lateral lumbar spine radiographic examinations. *Br J Radiol* 2013;86:20130053.

SHORT COMMUNICATION

Optimisation of patient dose for the horizontal beam technique in lateral lumbar spine radiographic examinations

A T DAVIS, BSc, MIPeM and S A HOPKINS, BSc, MSc

Medical Physics Department, Portsmouth Hospitals NHS Trust, Queen Alexandra Hospital, Portsmouth, UK

Address correspondence to: Miss Anne Davis

E-mail: Anne.DavisMedPhysics@porthosp.nhs.uk

ABSTRACT

In the emergency department, patients undergoing lateral lumbar spine radiography examinations are positioned either lying on their side on an X-ray table with the X-ray beam vertical or lying supine on a trolley with the X-ray beam horizontal. The measured dose-area product (DAP) values were found to differ significantly, typically 1.3 Gy cm² for those patients examined on the X-ray table and 2.7 Gy cm² for those on a trolley. This work investigates the reason for higher DAP values with the horizontal beam technique. The UK's current recommended national diagnostic reference level (NDRL) for the lateral lumbar spine is 2.5 Gy cm². The measurements of body diameter on volunteers showed that rotating the patients from their side to their back resulted in an increase in tissue thickness of between 2 cm and 9 cm for the lumbar region. X-ray absorption increases exponentially with increasing tissue thickness. An increase of 5 cm in body diameter for a lateral lumbar spine at 93 kV will increase the DAP by more than two-fold. Mathematical modelling and measurements with polymethyl methacrylate provided data to predict the tube potential increase necessary to reduce the DAP. For the horizontal beam technique, the tube potential was increased from 93 kV to 102 kV and the average DAP reduced to 2.3 Gy cm². Radiographic technique should be understood when auditing the dose. Tube potential must be increased to optimise the horizontal beam technique. The 2.5-Gy cm² NDRL relates predominantly to the more common vertical beam technique. Separate local diagnostic reference levels for horizontal and vertical beam techniques are recommended.

It is a requirement under the Ionising Radiation (Medical Exposure) Regulations 2000 [IR(ME)R] [1] that hospitals in the UK monitor the dose levels for groups of standard-sized patients undergoing common radiographic examinations. A dose-area product (DAP) meter attached to the X-ray unit provides a quick and easy method to routinely monitor the dose. Guidance on the measurement of the patient dose [2,3] states that data should be collected for a minimum of 10 adult patients with a weight range of between 50 kg and 90 kg. The mean value of the dose from the sample should then be compared against a locally defined diagnostic reference level (DRL) [4]. Where local DRLs still have to be established, it is a common practice to adopt national diagnostic reference levels (NDRLs). The NDRLs are generally taken from the data published by the Health Protection Agency—Radiation Protection Division. Its national database contains dose data submitted from many hospitals across the UK, and summary reports are published every 5 years [5]. It is a requirement of IR(ME)R that, when the mean values of measured doses exceed the DRL, the cause is investigated and corrective action is taken appropriately.

METHODS

Patient dose audit

This study involved patients undergoing lateral lumbar spine radiographic examinations in the emergency department at the Queen Alexandra Hospital, Portsmouth, UK. The radiographic equipment used was an Axiom Aristos FX Plus FD imaging system (Siemens Healthcare, Erlangen, Germany). It had a Polydoros LX 50 Lite high-frequency generator (Siemens Healthcare) with a general radiographic X-ray tube Opti 150/30/50 HC (Siemens Healthcare) and an amorphous silicon Trixell 4600 digital detector (Trixell, Moirans, France). The target angle for the X-ray tube was 12°, and the measured ripple for tube potential was in the region of 1%. Total filtration for the X-ray system was measured as 2.7 mm of aluminum equivalent. A single automatic exposure control (AEC) system was available for use in the under-table or vertical position. The AEC system had been set to deliver a detector dose in the region of 1.8–2.2 µGy. The AEC detector dose was calculated using the detector system transfer properties and the dose vs the detector dose index (DDI) relationship. The AEC system had excellent consistency with the coefficient

of variation for post-exposure mAs and DDI, both $<1\%$. The antiscatter grid was focused at 115 cm. The grid ratio was 15, and the number of strips per millimetre was 80. The integral DAP meter in use was a Scanditronix KERMAX-plus (Scanditronix Wellhofer, Uppsala, Sweden), which was calibrated annually and was accurate to within 2%.

Preliminary work had established that lateral lumbar spine examinations were carried out in two different ways depending on the clinical condition of the patient. Patients with good mobility were X-rayed lying on their side on the X-ray table with the X-ray beam vertically above them as shown in Figure 1a. Immobile patients were X-rayed lying supine on a trolley in front of a vertical bucky with the X-ray beam horizontal as shown in Figure 1b. Both techniques used AEC and a tube potential range of between 85 kV and 100 kV depending on the patient size. Average tube potential for both techniques was in the region of 93 kV.

Figure 1. Positioning of a patient for a lateral lumbar spine radiograph shown with the patient lying either (a) on their side on the X-ray table with the X-ray beam vertical or (b) on their back on a trolley with the X-ray beam horizontal.

(a)

(b)

With dose audit, there are difficulties in complying with the requirement to collect dose data for patients of a particular weight range (50–90 kg) within the busy environment of an emergency department. In this case, the decision was taken to increase the sample size to approximately 30 patients and to exclude those of very large or small build but not require the collection of patient weight information. Separate sets of DAP dose data were collected for each of the two radiographic techniques. Scrutiny of the DAP data showed that the dose values for the examinations carried out on the X-ray table with a vertical X-ray beam were significantly lower than for those examinations of patients on a trolley using a horizontal beam. For the vertical beam technique, the DAP ranged from 0.2 Gy cm^2 to 4.6 Gy cm^2 (average 1.3 Gy cm^2) and for the horizontal beam technique from 0.8 Gy cm^2 to 7.2 Gy cm^2 (average value 2.7 Gy cm^2). The horizontal beam technique produced an average DAP that exceeded the recommended NDRL of 2.5 Gy cm^2 . Investigations were carried out to look at the differences in the two techniques with a view to optimising exposure conditions.

Radiographic staff had suggested that rotating patients from lying on their side to their back would increase the tissue thickness in the lumbar region of the trunk. A group of volunteers were measured to establish the typical lateral thickness and the variation in thickness in this region for the two orientations. Only those weighing between 50 kg and 90 kg were included.

Simulation methods

Experimental work was carried out using polymethyl methacrylate (PMMA) of varying thickness to correspond with the two patient orientations. The 30-cm^2 slabs of PMMA were X-rayed using the AEC on the X-ray system. The slab size was chosen after observation of the volume of the tissue X-rayed. The aim was to ensure adequate coverage of the AEC chamber used and provision of realistic levels of an X-ray scatter. A 25-cm-thick block of PMMA was used to represent a “standard size” patient, and extra slabs were added to simulate the increasing thickness. A 25-cm PMMA block was judged to be equivalent to 26 cm of tissue for the tube potential range being investigated [6].

A field size of 15 cm by 35.5 cm was set at the bucky surface and remained unchanged throughout all variations in thickness. The field dimensions had been established by preliminary work with an experienced radiographer using an Alderson Rando phantom [7]. To match the typical clinical technique, 93 kV was selected for all PMMA thicknesses and exposures made using the central chamber of the AEC system. The post-exposure mAs values were recorded for each exposure. The DDI was also noted as a means of monitoring the dose at the detector. Post-exposure mAs values were normalised to a DDI of 400. Tube potential was then increased for various thicknesses to determine the tube potential setting that was needed to ensure no increase in post-exposure mAs for the horizontal beam projection.

The use of PMMA as a tissue equivalent material was validated using an X-ray spectrum analysis program [8]. This enabled theoretical prediction of the level of absorption in soft tissue and

the required increase in mAs as tissue thickness increased. The results obtained were used to provide advice on how to modify clinical tube potential for the lateral lumbar spine horizontal beam technique so as to reduce the dose. Effective dose values were calculated for each tube potential setting. This was done using a personal computer-based Monte Carlo program for calculating patient doses in medical radiographic examinations (PCXMC20; STUK Radiation and Nuclear Safety Authority, Helsinki, Finland). A repeat audit of the patient DAP values at the higher tube potential setting was then carried out.

RESULTS AND DISCUSSION

For the group of volunteers where lateral tissue thickness was measured, 20 volunteers were within the 50–90 kg weight range. The key parameters for this group are shown in Table 1.

These data demonstrate an increase in the body diameter for people lying on their back compared with those lying on their side. The data, however, are insufficient to draw any firm conclusions as to the quantity of increase for a particular weight and body mass index. Further work would be required to provide a more robust correlation.

For the measurements made using PMMA, Table 2 shows the level of increase in post-exposure mAs, and hence the dose, as 1-cm slabs were added to a 25-cm-thick PMMA block, 25 cm had been used to represent a standard size patient.

Estimated error in the data given in Table 2 was 2%. Results showed that the experimental values obtained using PMMA were similar to the theoretical results for soft tissue. This indicated that the experimental results would be representative of the conditions under which clinical radiographs are taken.

The results from the work to determine the effect of the increasing tube potential for the horizontal beam technique compared with the vertical beam technique are shown in Table 3. The data show that the tube potential needed to be increased from 93 kV to between 113 kV and 117 kV to compensate for the increase in lateral body thickness to match the delivered mAs.

Radiographers chose to increase the tube potential for horizontal beam lateral lumbar spine projections to 102 kV. This was

Table 2. Multiplication factor for post-exposure mAs when thickness is increased relative to 25 cm (at 93 kV)

Amount of absorber (cm) added to 25 cm	mAs multiplication factor relative to 25 cm of PMMA (at 93 kV)	Multiplication factor for soft tissue based on X-ray spectral analysis program
1	1.2	1.2
3	1.8	1.9
5	2.6	3.0
7	4.0	4.6

PMMA, polymethyl methacrylate.

a conservative choice of the tube potential to ensure that the radiographic contrast remained satisfactory. For the re-audit of DAP following the tube potential increase, 30 sets of dose data were collected. The DAP ranged from 0.8 Gy cm² to 8 Gy cm² (average 2.3 Gy cm²), showing a reduction of 15% for the average DAP compared with the lower tube potential technique. 102 kV was used for all sizes of patients in the sample. The new average DAP value was below the NDRL of 2.5 Gy cm². A review of image quality by a senior radiographer determined that there was no detrimental effect on the image contrast owing to the tube potential increase.

CONCLUSIONS

Patients who require lateral lumbar spine examinations while lying supine will receive a higher exposure, under AEC and without tube potential change, than if they had been lying on their side. This is because of the increased tissue thickness in the X-ray beam path. The measured DAP values will increase by a factor of at least two for an average size patient unless the tube potential is increased. The results of this work highlight the importance of fully understanding the detail of the radiographic technique in use when a patient dosimetry audit is carried out.

Radiographic staff should be aware of the impact that the use of a horizontal beam may have on the patient dose. Radiographers should routinely increase the tube potential for larger patients. Additionally, when horizontal beam technique is used for lateral lumbar spine radiographs, a further increase in tube potential is required. In this case, the vertical beam technique typically used 93 kV, and for the horizontal beam technique this was increased to 102 kV. The tube potential increase partially compensated for the increase in lateral thickness that occurs when the patient is in the supine position for the horizontal beam technique. Radiographic contrast was maintained to a satisfactory level and a further tube potential increase could be considered. As with all dose optimisation work, a change in the exposure technique must be accompanied by a thorough review of image quality.

The UK's current recommended NDRL of 2.5 Gy cm² for the lateral lumbar spine was derived from data where the distinction was not made between the horizontal and vertical beam techniques. This work identified that, because of increased tissue

Table 1. Measured lateral thickness across the lumbar region of volunteers lying on their back and on their side

Measured parameter	Range	Mean	Standard deviation
Weight (kg)	54–88	67	10.7
Body mass index	19–34	25	3.9
Lateral thickness when lying on back (cm)	26–38	32	3.4
Lateral thickness when lying on side (cm)	24–31	26	2.6
Thickness difference for the two orientations (cm)	2–9	5	2.2

Table 3. Effect of increasing tube potential to compensate for the 5-cm increase in lateral thickness typically associated with the lateral lumbar spine horizontal beam technique

Thickness of PMMA absorber (cm)	mSv		DAP ($\mu\text{Gy m}^2$)	DDI	Effective dose (mSv)
	kV	mAs			
25	93	53.7	105	400	0.04
30	93	146.3	283	410	0.12
30	96	120.7	246	387	0.11
30	100	101.4	222	385	0.11
30	102	94.6	214	390	0.11
30	105	85.4	203	394	0.10
30	113	58.3	156	353	0.09
30	117	52.3	147	358	0.09

DAP, dose-area product; DDI, detector dose index; PMMA, polymethyl methacrylate.

volume, DAP values from the horizontal beam technique will be higher than those from the vertical beam technique. The extent of this difference will depend on the tube potential chosen for the horizontal beam technique. In this study, the average DAP values were 2.3 Gy cm^2 for horizontal beam and 1.3 Gy cm^2 for vertical beam techniques. It is therefore recommended that separate local DRLs are set for the two techniques.

ACKNOWLEDGMENTS

The authors wish to thank Morag Baldwin, Janine Hatch and the radiographic staff in the Emergency Department at Queen Alexandra Hospital, Portsmouth, UK, who were involved in the collection and review of data used. We also thank Donna Stretton of the Medical Physics Department who contributed to data collection.

REFERENCES

1. Ionising Radiation (Medical Exposure) Regulations 2000 SI 2000/1059. London, UK: HMSO; 2000.
2. Dosimetry Working Party of the Institute of Physical Sciences in Medicine. National protocol for patient dose measurements in diagnostic radiology. Didcot, UK: National Radiological Protection Board; 1992.
3. Department of Health. Guidance on the establishment and use of "diagnostic reference levels" (DRLs) as the term is applied in the Ionising Radiation (Medical Exposure) Regulations 2000. London, UK: DH; 2007.
4. Institute of Physics and Engineering in Medicine, Joint Working Party. Guidance on the establishment and use of diagnostic reference Levels for medical X-ray examinations. IPEM Report 88. York, UK: IPEM; 2004.
5. Hart D, Hillier MC, Shrimpton PC. Doses to patients from radiographic and fluoroscopic X-ray imaging procedures in the UK: 2010 review. HPA-CRCE-034. Didcot, UK: HPA; 2012.
6. Martin CJ, Sutton DG, Workman A, Shaw AJ, Temperton D. Protocol for measurement of patient entrance surface dose rates for fluoroscopic X-ray equipment. Br J Radiol 1998;71:1283–7.
7. Alderson SW, Lanzl LH, Rollins M, Spira J. An instrumented phantom system for analog computation of treatment plans. Am J Roentgenol Radium Ther Nucl Med 1962;87: 185–95.
8. Reilly AJ, Sutton D. Catalogue of diagnostic X-ray spectra and other data. IPEM Report 78. York, UK: IPEM; 1997.