Radiography xxx (2017) 1–7

Contents lists available at ScienceDirect

Radiography

journal homepage: www.elsevier.com/locate/radi

Can placing lead-rubber inferolateral to the light beam diaphragm limit ionising radiation to multiple radiosensitive organs?

C. Hayre*, H. Bungay, C. Jeffery, C. Cobb, J. Atutornu

University of Suffolk, United Kingdom

ARTICLE INFO

Article history:
Received 3 February 2017
Received in revised form
6 September 2017
Accepted 7 September 2017
Available online xxx

Keywords:
X-ray experiment
Dose limitation
Light beam diaphragm
ALARP
General radiography

ABSTRACT

Introduction: This article investigates a practical method of reducing the impact of scattered radiation during a lateral radiographic projection of the elbow. The light beam diaphragm (LBD) is generally accepted to limit ionising radiation using horizontal and longitudinal lead shutters, yet this article evidences further dose limitation by placing lead-rubber inferolateral to the LBD device.

Methods: Using an anthropomorphic phantom and arm construction scattered radiation was recorded at multiple radiosensitive organs. A 15 cc ionisation chamber (model 10100 AT TRIAD) was placed on each radiosensitive organ (eye, thyroid, breast, testes, spleen and ovaries) measuring exposure rate (μGy/s). Dose readings were recorded before and after the placement of lead-rubber inferolateral to the LBD. A paired two sample *t*-test was undertaken affirming how likely dose limitation was attributable to chance ($p < 0.05$).

Results: Descriptive and inferential statistics demonstrate dose reduction to radiosensitive organs (right eye 53%, right breast 53%, left eye 39%, thyroid 13%, left ovary 9%, testes 6%, left breast 3% and spleen 2%) upon placement of the lead-rubber inferolateral to the LBD. The paired two sample *t*-test demonstrated statistically significant dose limitation ($t = 2.04$, df $= 7$, $p = 0.04$) thus significant for radiographic practice.

Conclusion: Placement of lead-rubber inferolateral to the LBD limits dose to multiple radiosensitive organs. Right (53%) and left (39%) eye lens, right breast (53%), thyroid (13%), left ovary (9%), testes (6%), left breast (3%) and spleen (2%) statistically demonstrate dose limiting opportunities to patients.

Introduction

The light beam diaphragm (LBD) is located beneath the X-ray tube housing and contains two sets of shutters enabling a radiographer to permit multiple square and rectangular field sizes.[1] Radiographers are required to keep the ‘field size’ to a minimum by adjusting two sets of shutters (longitudinal and horizontal) placed within the collimator housing. The primary function of the LBD is to limit the primary X-ray beam to an area of clinical interest and reduce unnecessary ionising radiation to patients undergoing radiographic procedures.[2] Whilst appropriate collimation is generally accepted to limit irradiated tissue, ionising radiation continues to reach other radiosensitive organs outside of the primary beam, a term known as ‘scattered radiation’.[2,3] Due to the known hazards associated with ionising radiation, studies continue to offer dose limiting strategies to patients and radiosensitive organs within the general radiographic environment.[4–8] The use of lead (Pb) is a common method of dose limitation due to its high atomic number ($Z = 82$) providing significant photoelectric absorption for energies used within diagnostic radiography and remains depicted in contemporary literature.[9] This has subsequently led to the manufacturing of lead-rubber devices, such as gonad shields, lead-rubber sheets, lead-aprons and lead-rubber gloves, limiting dose to both operators and patients.[4]

The International Atomic Energies Agency (IAEA)[2] affirm that shielding (where appropriate) should be used to protect a patient's radiosensitive organs, typically the breast, gonads, eyes and thyroid. The rationale for ensuring dose limitation is historical, but is maintained by contemporary guidance and evidence-based research.[4] Currently, legislation within the United Kingdom (UK) asserts that radiographers are expected to keep doses ‘as low as reasonably practicable’ (ALARP) to limit the hazardous affects

* Corresponding author.
E-mail address: c.hayre@uos.ac.uk (C. Hayre).

http://dx.doi.org/10.1016/j.radi.2017.09.002
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associated with ionising radiation.[10] This legislative practice derives from the theoretical linear non-threshold (LNT) dose response model proposed by the International Commission on Radiological Protection (ICRP)[11] assuming that all ionising radiation has the potential to induce malignant change, hence the rationale to minimise all radiation levels wherever possible.[10,11] Methods of dose limitation remain central to a radiographer's practice and remain evident within the current literature.[4–6] Contrary to this, few studies focus on dose limitation using lead-rubber in association with the LBD device. Whilst it is not within the scope of this paper to experiment with all radiography projections, the author(s) decided to select the lateral elbow examination due to the height of the table top (raised to the level of the lower boarder of the axilla and parallel to the image receptor), thus remaining in close proximity to radiosensitive organs identified by the IAEA. It is important to recognise that other radiosensitive organs exist when positioning for either anterior posterior and/or lateral elbow examinations, for example, a patient's head, neck and thorax remain in close proximity to the table top, yet this paper focuses on dose limitation the breast, gonads (male and female), eyes, thyroid and spleen.

Attempts to understand the induction of stochastic cancers within diagnostic radiography have been debated for decades. Yet, within the current radiobiological paradigm it is generally accepted that a safe radiation exposure (however small), does not exist.[11] In response the authors offer an alternate approach to dose limitation by applying lead-rubber inferolateral to the LBD device during a lateral projection of the elbow. It is hypothesised that by placing lead-rubber inferolateral to the LBD device it may limit ionising radiation to multiple radiosensitive organs during a single X-ray exposure. The objectives of this study were to, 1) design a phantom resembling the positioning of a lateral radiographic examination; 2) implement an original method of dose limitation to the side of the LBD device and 3) record exposure rates of scatter ionising radiation to radiosensitive organs and undertake statistical analysis to enhance the reliability and validity of the methodological approach and empirical findings.

Methods and materials

The experiment was undertaken in a controlled X-ray laboratory environment at the investigating academic institution. The list of equipment used during the experiment is detailed below:

- Siemens Multix Pro with Optilix HC100 X-ray tube anode angle 12°
- Polydoros ITS 35 generator
- Female anthropomorphic phantom
- Fuji EC-A cassette and Agfa Curix C1 screens
- Cardinal Health 10100A triad field service kit
- 15 cc Ionization chamber model no. 96035b and electrometer model no. 35050A.

Anthropomorphic phantom and elbow construction

The X-ray experiment used a female anthropomorphic phantom to simulate a patient and relative radiosensitive organs. The anthropomorphic phantom (Rando Alderson Research Laboratory, Stamford, Connecticut, USA) was designed such that any ionising radiation absorption would mimic an adult patient.[12] The phantom material contains a density of 0.99 g/cm^3, an effective atomic number of 7.3.[12] The arm was constructed using real bone(s) to make the elbow joint, consisting of the humerus, radius and ulna (density 1.75 g/cm^3). Water (density 1.00 g/cm^3) was injected into a saline bag (density 1.11 g/cm^3) to simulate human soft tissue. This was used because it contains similar densities associated with human muscle (1.06 g/cm^3) and fat (0.91 g/cm^3). A plastic mesh (1.15 g/cm^3) was created encapsulating the materials, simulating anatomical shape and radiographic positioning of a patient attending for a lateral radiographic examination of the elbow. Whilst this method has been found methodologically useful in previous studies,[13,14] it is important to recognise that the X-ray beam will undergo different absorption and scattering effects on the materials selected for this experiment and thus impacting scattered radiation. This remains a limitation of this methodology. The lead-rubber device had a thickness of 0.3 cm (density 11.36 g/cm^3) and dimensions of 37 × 20 cm^2. It was attached to the inferolateral board of the LBD device using sellotape. The lead-rubber device extended approximately 20 cm inferolaterally to the LBD device. Fig. 1 demonstrates the anthropomorphic phantom (images 1 and 2), elbow construction (images 3 and 4) and application of lead-rubber inferolateral to the LBD (Image 1).

Radiographic positioning mimicked a female patient attending for a left lateral radiographic examination of the elbow. In accordance with radiography positioning literature the phantom and arm construction were positioned with the patients' arm and forearm placed in the lateral position with the elbow joint flexed at 90° with the hand rotated externally into the true lateral position.[9]

Radiographic parameters and recording of dose

A 15 cc ionisation chamber was used to record exposure rates (μGy/s) to each radiosensitive organ. The 15 cc ionisation chamber (model 10100 AT TRIAD) is a technologically advanced, microprocessor-controlled ionisation chamber and is depicted in Fig. 2.

Fig. 3 illustrates the placement of the dosimeter for each radiosensitive organ during the experiment, enhancing internal validity. Further, it is important to discuss the accuracy and precision of the ionisation chamber. The exposure accuracy of the device is ±1% of reading ±2 range resolution steps over a range of 18°–28 °C and ±2% of reading ±2 range resolution steps over the full operating temperature range of 0°–50 °C. Exposure time accuracy is ±0.1% of reading ±0.2 ms. Maximum exposure time is 6.5 s and measurement resolution is 0.2 ms. Due to the effective range of the ionisation chamber (1–20 μGy/s), levels of ionising radiation remained undetected using a clinically relevant mAs (3.20 mAs). The inability for the ionization chamber to record exposure rates to radiosensitive organs representative of 3.20 mAs required the author(s) to increase the mAs value (63 mAs, 320 mAs and 560 mAs) to record exposure rates. This will now be discussed.

Upon deciding to increase the mA values this altered the number of electrons flowing across the X-ray tube (with other independent variables remaining unchanged). In short, this altered the intensity of the X-ray beam per unit time thus directly proportional to the mA through the tube. This is represented by equation (1).[3]

$$I \propto \mathrm{mA} \tag{1}$$

Increasing the mA value had a direct relationship on the X-ray quantity and intensity, which allowed the researcher(s) to record an exposure rate from the ionisation chamber. This is important to recognise methodologically because whilst the intensity of the X-ray beam reduces as energy is either absorbed or scattered in matter, a quantifiable reading had been received and thus useful for data collection and analysis. The X-ray spectral intensities for mAs values 63, 360 and 560 are shown in Graphs 1–3 respectively. These demonstrate that at the maximum keV an increase in mA resulted in a significant increase in both quantity and intensity of

Please cite this article in press as: Hayre C, et al., Can placing lead-rubber inferolateral to the light beam diaphragm limit ionising radiation to multiple radiosensitive organs?, Radiography (2017), http://dx.doi.org/10.1016/j.radi.2017.09.002