

# Dose reduction to radiosensitive tissues in CT. Do commercially available shields meet the users' needs?

D.J. McLaughlin<sup>a,\*</sup>, R.B. Mooney<sup>b</sup>

<sup>a</sup>Altnagelvin Area Hospital, Londonderry, and <sup>b</sup>Northern Ireland Regional Medical Physics Agency, Forster Green Hospital, Belfast, Northern Ireland, UK

Received 1 April 2003; received in revised form 13 October 2003; accepted 21 October 2003

## KEYWORDS

Dosimetry; Shielding; AttenuRad; Eye; Thyroid; Computed Tomography (CT)

**AIM:** To assess the effectiveness and economy of routinely using commercially available in-plane bismuth shielding during CT scanning of the chest and brain.

**METHODS AND MATERIALS:** Forty patients were scanned with thermoluminescent dosimeters (TLDs) in situ to measure the radiation dose to the thyroid and eye during CT scanning of the brain and chest. Half of the patients had the "AttenuRad" shield in place during scanning.

**RESULTS:** Use of the shielding reduced the mean dose to the eye from  $6.0 \pm 0.3$  mGy to  $4.9 \text{ mGy} \pm 0.2$  mGy and the thyroid dose from  $16.4 \text{ mGy} \pm 1.2$  mGy to  $7.1 \text{ mGy} \pm 0.5$  mGy.

**CONCLUSION:** Use of the thyroid shield is recommended for all CT scanning of the chest. The eye shield does not produce as marked a reduction in radiation dose to the lens of the eye, when an angled gantry is used, since the eyes are not in the primary beam. Use of the eyeshield is justifiable where irradiation of the orbit is unavoidable, although whether artifacts would be a problem if the shield was used in this way was not assessed.

© 2004 Published by Elsevier Ltd on behalf of The Royal College of Radiologists.

## Introduction

Computed tomography (CT) continues to contribute a significant portion, up to 50%, of the collective radiation dose from all radiographic examinations,<sup>1</sup> and this figure is likely to increase further with the advent of multislice CT. Advice has been issued by the International Commission on Radiological Protection<sup>2</sup> on how to minimize radiation dosage during CT examinations, and much of this advice is enshrined in legislation in the UK.<sup>3</sup> The radiation doses delivered to certain organs are significant enough to be a matter of concern. The thyroid and the lens of the eye are often included in the scan field, but are rarely the organs of interest. Given the radiosensitivity of these organs any easy-to-use, effective means of reducing the radiation dose is to be welcomed.

This paper examines the feasibility and effectiveness of commercially available shields designed to protect the lens of the eye and the thyroid<sup>4,5</sup> and to assess if the claims of 40 and 60% dose reductions, respectively, can be achieved in a busy acute general hospital without compromising image quality.

## Materials and methods

Approval was obtained from the hospital's medical ethics committee to proceed. Forty patients in total were included in the study, all of who were undergoing clinically indicated CT. Patients in the study were selected for inclusion if they could conform to the requirements for standard positioning and give informed consent. All patients were examined using a Toshiba GX Xpress CT machine (Toshiba Medical Systems, Tokyo, Japan), using parameters based on the European Guidelines.<sup>6</sup> These protocols were previously independently assessed by the Northern Ireland Regional Medical

\*Guarantor and correspondent: D.J. McLaughlin, Altnagelvin Area Hospital, Londonderry, Northern Ireland BT 47 6SB, UK. Tel.: +44-28-71-345171x3206.

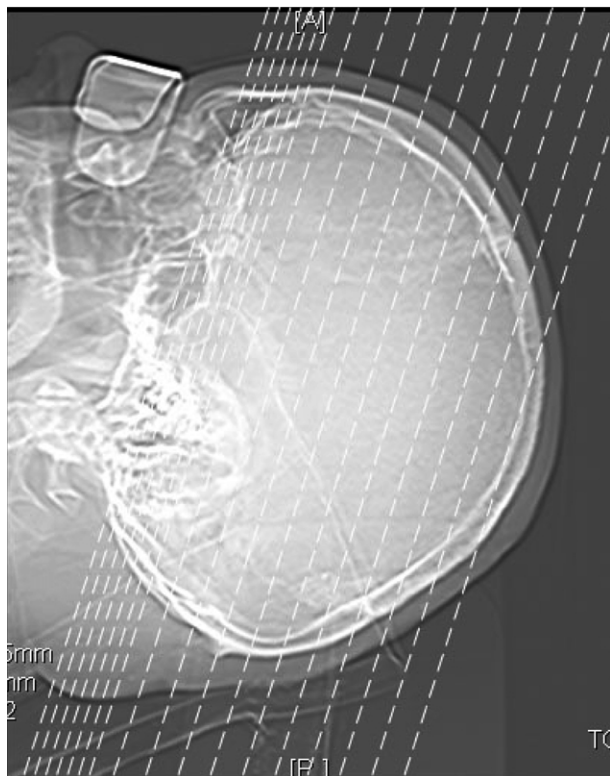


**Figure 1** AttenuRad eye shield in place.

Physics Agency (NIRMPA) and found to be satisfactory, within current UK guidelines. A single batch of thermo-luminescent dosimeters (TLDs) provided by NIRMPA was used to measure radiation dose to the target organ. The commercially available shields (AttenuRad Radioprotective Garments) were supplied by Lecks Medical Ltd, Dun Laoghaire, Co. Dublin, Ireland.

#### Measurement of dose to the lens of the eye during brain scanning ( $n = 20$ )

Ten patients were scanned as a control group without an eye shield and 10 with the AttenuRad eye shield in place following the manufacturer's



**Figure 2** Scanogram showing scan lines avoiding the orbits.

instructions (Fig. 1). The manufacturers have declared the eye shield a "single use" item due to the possibility of viral and bacterial contamination by teardrops.

A fresh TLD was taped to the closed right eyelid of each patient in each group during imaging, including the scanogram. If additional slices or a repeat examination after intravenous contrast administration was indicated the TLD was removed and the examination completed.

The recommended standard positioning of the head for CT is with the patient supine with the orbit-meatal baseline at  $90^\circ$  to the horizontal with the gantry angled to avoid irradiating the eyes. From the scanogram (scout film), the scan plane was adjusted to a line drawn joining the superior orbital margin to the base of the skull (Fig. 2). The angulation required varied between patients ( $0$  to  $17^\circ$  in the study group). All scans were performed at 120 kVp using the following protocol: a lateral scanogram from 1 cm below the occiput to the vertex (approx. 210 mA);  $6 \times 3$  mm slices at 400 mA from the base of the skull to show the posterior fossa;  $2 \times 5$  mm slices at 320 mA at the apex of the petrous bone; and  $10 \times 10$  mm slices at 320 mA to the vertex.

#### Measurement of dose to the thyroid during chest scanning ( $n = 20$ )

Again 10 patients were examined as a control group without a thyroid shield and 10 with the AttenuRad thyroid shield in place following the manufacturer's instructions (Fig. 3). A fresh TLD was placed over the thyroid gland, at a point mid way between the sternal notch and the cricoid cartilage in the midline before scanning. The recommended positioning for CT of the chest is with the patient supine and the arms extended and supported over the patient's head. Patients who could not comply with these positioning requirements were excluded from the study due to the possible attenuating effect of the arms. The protocol for CT of the chest varied slightly from patient to patient due to different patient habitus and also due to radiological preferences. This may have introduced some variation in the recorded doses. The examinations were performed at 120 kVp using the following parameters:

- An antero-posterior (AP) scanogram from the apices of the lung to below the kidneys
- A reference image (scan and view) at 50 mA
- Helical scan at 150 mA from the apices through the adrenal glands (pitch of 1.5) or
- Helical scan from the apices to the diaphragm at



**Figure 3** AttenuRad thyroid shield in position.

150 mA (pitch of 1.5) plus helical scan from the diaphragm to below the kidneys at 200 mA (pitch of 1.5)

### Method of dose assessment

Skin dose was measured using LiF:Mg,Ti (TLD-100) TLDs from HarshawTLD (BicronNE, Solon, OH, USA), which were calibrated in terms of absorbed dose to air at diagnostic X-ray energies using a Keithley Model 35050A dosimeter (Keithley Instruments Inc., Cleveland, OH, USA), which had a calibration traceable to the Physikalisch-Technische Bundesanstalt (PTB) primary standard. As values of absorbed dose to tissue will vary by only a few percent depending on the exact composition of the medium taken to represent the tissue,<sup>7</sup> TL dosimeter readings were taken to represent absorbed dose to the underlying tissue. Overall uncertainty associated with dose measurement was estimated to be  $\pm 12\%$  (95% confidence level).

For each patient, a record was made of slice thickness, number of slices, pitch factor, X-ray tube voltage, tube mAs per slice and the anatomical start and finish position of the scan. Measurements of radiation output were made using a Radcal 1015C X-ray monitor with a 10 cm pencil ionisation chamber  $10 \times 5$ -10.3CT (Radcal Corporation, Monrovia, CA, USA) and a polymethylmethacrylate (PMMA) head (16 cm) and body (32 cm) phantom. Calibration of the radiation monitor and ionization chamber was traceable to the PTB primary standard. The method of dosimetry described by Imaging Performance Assessment of CT Scanners (ImPACT) group<sup>8</sup> was followed and measurements of the CT dose index in air ( $CTDI_{air}$ ) and weighted  $CTDI$  ( $CTDI_w$ ) were made.

Additionally, to provide an indication of the attenuating properties of the shields, measurements were also undertaken to determine the attenuation provided by the shields when irradiated

directly by the primary beam in scatter-free conditions. The measurements were made using a narrow beam of 120 kVp X-rays from a diagnostic X-ray tube and the Keithley dosimeter already mentioned.

### Results

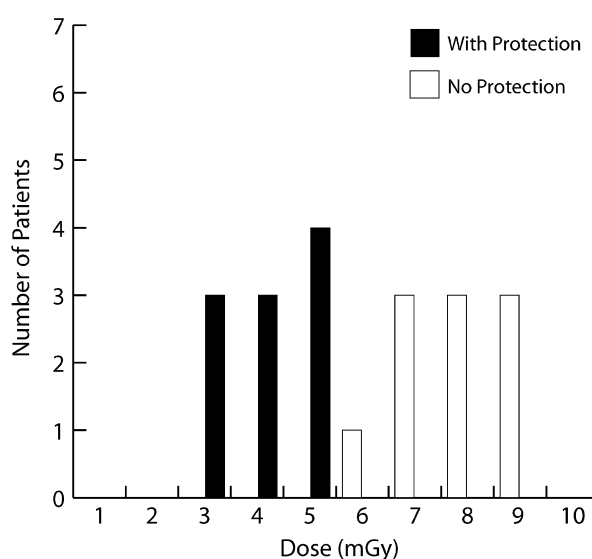
For both the thyroid and lens of the eye, a comparison of mean dose delivered to the organ during CT with and without shielding was made using Student's *t*-test. The introduction of shielding produced a statistically significant decrease in the mean thyroid dose (Fig. 4) from  $16.4 \pm 1.2$  mGy to  $7.1 \pm 0.5$  mGy ( $p < 0.0001$ ) and also a statistically significant decrease in the mean dose to the lens of the eye (Fig. 5) from  $6.0 \pm 0.3$  mGy to  $4.9 \pm 0.2$  mGy ( $p < 0.02$ ). These changes in dose equate to a 57% reduction in dose to the thyroid and an 18% reduction in dose to the lens of the eye.

### Discussion

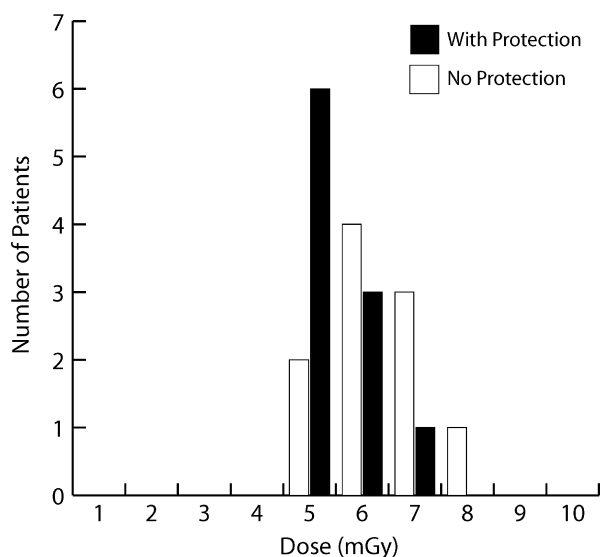
CT images were independently assessed by two radiologists in terms of image quality. The artefact produced by the thyroid shield was found to be slightly distracting, but did not interfere with the interpretation of the image (Fig. 6). As the eyes and thus the eye shield are routinely excluded from the imaging field its presence is inconsequential in terms of image quality.

### Comparison of attenuating properties with expected patient dose reduction

Our measurements of the attenuation of a 120 kVp



**Figure 4** Distribution of radiation dose to the thyroid for CT scan of the chest.



**Figure 5** Distribution of radiation dose to the lens of the eye for CT scan of the brain.

primary beam provided by the shields showed that the thyroid shield and eye shield attenuated the primary beam by  $72 \pm 4\%$  and  $65 \pm 4\%$ , respectively. The difference between this attenuation and the dose reduction claimed by the manufacturer (60 and 40%, respectively) is due to the conditions of irradiation during CT scanning. As the CT tube rotates around the patient, the reduction in dose to the eye or thyroid caused by each shield is due to the shield attenuating the primary beam before it enters the patient. The shield will not, however, reduce the dose from

the primary beam when the shield intercepts the beam as it exits the patient. Additionally, a significant amount of scatter radiation is generated within the patient, which the shield is unable to reduce as the shield lies on the surface of the patient. As a result, the organ will receive a dose from scattered radiation even when it is some distance from the imaged slice that is irradiated by the primary beam.

### Suitability of the thyroid shield for routine use

The detriment to a patient from irradiation of the lens of the eye during CT of the brain is solely due to deterministic effects such as lens opacities, whereas the detriment arising from irradiation of the thyroid during CT of the chest, such as cancer induction, is stochastic in nature. The stochastic risk arising from irradiation of the thyroid contributes to the overall stochastic risk to the patient from the CT chest examination and any reduction in dose to the thyroid will tend to reduce the effective dose delivered to the patient. Conversion coefficients for deriving effective dose from measurements of scanner radiation output and CT scanning technique have been developed by the National Radiological Protection Board (NRPB)<sup>9</sup> and adapted by the ImpACT group.<sup>10</sup> Results of the dosimetry measurements on the scanner and the records of radiographic technique used for each patient examination were used to calculate the mean effective dose for the patients scanned during the survey. The mean effective dose to patients undergoing a chest CT examination was 6.8 mSv. As the mean reduction in thyroid dose with the use of the AttenuRad shielding is known, the mean reduction in the effective dose to the patient can be calculated with the use of the ICRP tissue weighting factor for the thyroid ( $w_T = 0.05$ ).<sup>11</sup> The mean effective dose fell from 6.8 to 6.3 mSv, with the use of the thyroid shield, a reduction of 0.5 mSv (7%). The significant reduction in thyroid dose and the consequent reduction in effective dose warrant the routine use of the AttenuRad thyroid shield.

### Suitability of the eye shield for routine use

In this centre, the gantry is angled to avoid irradiating the eyes with the primary beam during routine brain CT examinations. In the UK this is accepted as good practice.<sup>12</sup> As a consequence, the dose to the lens of the eye in this centre is solely from scattered radiation. The 40% reduction in dose



**Figure 6** Chest scan with shield showing small degree of artifact.

to the lens claimed by the manufacturer of the shielding may have been based on CT brain scanning without the gantry angled to avoid the eyes, thus irradiating the eye with the primary beam. The difference between the manufacturer's claimed dose reduction (40%) and the reduction reported in this study (18%) probably stems from the use of an angled gantry and the consequent difference in the way the eye lens is irradiated during scanning. Typically, the dose to the lens without an angled gantry is about 30 mGy, whereas, during this study the mean dose to the lens without shielding was 6 mGy. Dose measurements on a PMMA anatomical head phantom on our scanner showed that the use of an angled gantry reduced the lens dose from  $74 \pm 4$  mGy to  $7.7 \pm 0.7$  mGy, a reduction in dose to the lens of a factor of about 10. The typical dose to the lens from a routine CT brain examination with an angled gantry is therefore relatively small when compared with the dose threshold required to produce lens opacities (0.5–2 Gy),<sup>4</sup> and even in patients who require multiple examinations, it is unlikely that any threshold dose will be approached. In centres that routinely use an angled gantry for brain CT; the use of the AttenuRad eye shield would produce a small reduction in the dose to the eye. However, it is difficult to see how the small reduction in dose can justify the cost of the shielding. In centres that do not use an angled gantry, a much greater dose reduction can be introduced by the use of an angled gantry than by the use of the AttenuRad shielding. Nevertheless, the eye shields may be useful for the small group of patients who cannot readily flex the neck and for whom the gantry cannot be angled enough to avoid the eyes. This would also include its use during "multislice" imaging of the head and neck where irradiation of the eyes is unavoidable.

The possible effect of artefact from the shield and potential dose reduction achievable during multislice techniques was not assessed.

## Conclusion

This study has shown that the radiation dose to the lens of the eye can be significantly reduced from the typical value by the use of optimized imaging techniques, especially the use of an angled gantry, and that the use of the AttenuRad shield could not be justified for routine use, due to the "single use" requirement of the manufacturer. There may be a role, however, for use of the shield in patients who cannot assume the standard head position or who may require repeated CT. The use of the shield may

be justifiable for those examinations where the orbit itself is not the target, but in which irradiation of the orbit is unavoidable, although we cannot advise whether artefacts are a problem when the shield is used in this way.

The results for the use of the thyroid shield show a significant dose saving without detriment to image quality. The relatively low cost of the shield and its ease of use indicate that its routine application is recommended in all cases.

## Acknowledgements

The authors thank Dr M. Reilly, Medical Imaging Altnagelvin Area Hospital, Dr A. Adas, Altnagelvin Area Hospital, and Mr W. Dillon, Department of Medical Illustration Altnagelvin Area Hospital.

## References

1. Rehani MM, Berry M. Radiation doses in computed tomography. The increasing doses of radiation need to be controlled. *BMJ* 2000;**320**:593–4.
2. International Commission on Radiological Protection, Managing patient dose in computed tomography Publication 87, vol. 31. Oxford: Pergamon Press; 2000. 3.3.7.57.
3. Department of Health, The Ionising Radiation (Medical Exposure) Regulations 2000. London: Department of Health; 2000.
4. Hopper KD, Neuman JD, King SH, Kunselman AR. Radioprotection to the eye during CT scanning. *AJNR Am J Neuroradiol* 2001;**22**:1194–8.
5. Hopper KD, King HS, Lobell ME, TenHave TR, Weaver J. The beast: in-plane X-ray protection during diagnostic thoracic CT—shielding with bismuth radioprotective garments. *Radiology* 1997;**205**:853–8.
6. European Commission, European Guidelines on Quality criteria for Computerised Tomography EC Report EUR 16262 (17–19), Luxembourg: European Communities; 1999.
7. Dosimetry Working Party of the Institute of Physical Sciences in Medicine, National protocol for patient dose measurements in diagnostic radiology. Chilton: NRPB; 1992.
8. Edyvean S, Lewis MA, Britten AJ, Carden JF, Howard GA, Sassi SA. *Type testing of CT scanners: methods and methodology for assessing imaging performance and dosimetry*. MDA Evaluation Report MDA/98/25, London: Medical Devices Agency; 1998.
9. National Radiation Protection Board, *Survey of CT practice in the UK. Part 3: normalised organ doses calculated using Monte Carlo techniques*. NRPB Report R250, London: HMSO; 1991.
10. Shrimpton PC, Edyvean S. CT scanner dosimetry. *Br J Radiol* 1998;**71**:1–3.
11. International Commission on Radiological Protection, 1990 Recommendations of the International Commission on Radiological Protection, Publication 60, Oxford: Pergamon Press; 1991.
12. Yeoman LJ, Howarth L, Britten A, Cotterill A, Adam EJ. Gantry angulation in brain CT: dosage implications, effect on posterior fossa artifacts, and current international practice. *Radiology* 1992;**184**:113–6.