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SHORT COMMUNICATION

Establishment of national diagnostic reference levels for breast cancer CT protocols in radiation therapy

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Objective: To establish whether CT dose variation occurs in breast cancer localization procedures between radiation therapy (RT) centres in Ireland and to propose diagnostic reference levels (DRLs) for this procedure.

Methods: All RT centres in Ireland were invited to participate in a dose audit survey, providing data on the CT dose index volume (CTDI_{vol}), dose-length product (DLP), current-time product (mAs), tube potential, scan length, slice thickness, scanning margins, use of automated exposure control (AEC) and scanner technology for 10 patients with breast cancer who were average sized. DRLs were derived for each dose descriptor by calculation of the rounded 75th percentile of the distribution of mean doses.

Results: Data were returned for 60 patients from 6 RT centres (50% response rate). Significant variation

in mean CTDI_{vol} and mean DLP was observed between centres ($p < 0.0001$). Mean scan lengths and mean mAs differed significantly between centres ($p < 0.0001$). Tube potential was 120 kV for all sequences across centres. AEC was employed in all but one centre. Proposed DRLs for breast localization are 26 mGy and 732 mGycm for CTDI_{vol} and DLP, respectively.

Conclusion: CT dose variation occurs between centres, establishing a need for optimization. DRLs for breast cancer localization have been proposed with the potential for reduction in CT dose.

Advances in knowledge: This article provides the first reported DRL for breast cancer CT localization procedure in RT and can be used as a benchmark for comparison for other RT centres.

INTRODUCTION

CT scanning is now the standard of care in treatment planning for individualized breast cancer radiation therapy (RT). Both the affected and contralateral breasts are scanned during this procedure. This modality has been associated with relatively high radiation doses and subsequent risk of carcinogenesis.¹ Radiation protection measures are well established in diagnostic radiography to limit stochastic risk of malignancy.² Non-therapeutic doses are governed by the "as low as reasonably achievable" principle, with the RT treatment-planning CT scans falling into this category; thus, it is incumbent to ensure the dose to the patient adheres to this principle.

The implementation of diagnostic reference levels (DRLs) for imaging procedures was originally introduced by the International Commission of Radiation Protection in 1996³ and is mandated by the European Commission directive 13/59 The European Atomic Energy Community (EURATOM).⁴ The primary value of DRLs is to facilitate

identification of unjustifiably high radiation doses by applying a threshold above which investigation is warranted.^{2,4,5} Diagnostic CT surveys have initiated a reduction in CT dose over time following DRL establishment.^{6,7} Different scanning volumes and image quality requirements between diagnostic and RT CT prevents the use of these DRLs in RT practice.⁸ No published DRLs have been established for RT CT procedures.

CT localization doses have been considered insignificant compared with therapeutic and related scatter doses in the literature;^{8,9} however, such conclusions are in conflict with the linear no-threshold model. There is epidemiological evidence for an increased risk of radiation-associated cancer at doses comparable with those delivered from CT.^{1,10} Hall and Brenner¹ conclude that for effective doses (EDs) of <100 mSv, the most appropriate risk model for radiation protection is that radiation-induced stochastic effects decrease linearly with decreasing dose with no threshold. Higher EDs and consequent stochastic risk are

observed for scanning volumes incorporating breast tissue.¹¹ While there are conflicting opinions about the shape and slope of the radiation dose–response curve, we take the view that all imaging procedures using ionizing radiation including RT CT should be optimized to minimize risk to patients.

European Commission guidelines on the establishment of DRLs do not consider reference levels applicable to RT.^{12,13} This conclusion was based on treatment doses, without regard for localization CT doses in this field. Directive 13/59 EURATOM promotes the establishment and review of DRLs in medical radiodiagnostic practices.⁴ Lack of awareness regarding the role of CT in RT by the legislating bodies has hindered the establishment of DRLs.

The purpose of this research was to investigate CT dose variation between RT centres in Ireland and to propose national DRLs for breast cancer CT-planning scans in RT. Published data on radiation doses from CT localization scanning are absent. This research will establish whether there is a need for dose optimization in this field and provide the first national DRLs for breast cancer CT localization. This may provide a basis for dose optimization internationally with the potential for dose reduction.

METHODS AND MATERIALS

Ethical approval was granted by the Faculty of Health Sciences Research Ethics Committee, Trinity College, Dublin, Ireland. The methodological approach for this study was based on the guidelines established by Institute of Physics and Engineering in Medicine.¹⁴

All Irish RT centres ($n = 12$) were invited to participate in a dose audit survey. The audit focused on CT localization scans for 10 patients with breast cancer receiving tangential breast RT only. The centres were asked to exclude non-average-sized patients, post-mastectomy patients and those patients receiving RT to the supraclavicular fossa.

Survey form

Data were collected by means of an anonymized survey form. The survey form requested the collection of CT data for 10 patients during an 8-week period. European guidelines recommend dose measurements on a minimum sample of 10 patients, with this number used in several diagnostic studies.^{5,7,15}

CT dose index volume (CTDI_{vol} and dose–length product (DLP) are the main dose descriptors reported in modern CT dose surveys^{2,16} and were used in this study.

CTDI_{vol} represents the average dose from a scanning series and as such does not provide a dose specific to the patient but a standardized index of the average dose delivered across the irradiated scan volume. CTDI_{vol} is independent of scan length.¹⁷ CTDI_{vol} does not correlate well with ED.^{2,17,18} DLP is the product of CTDI_{vol} and the total scan length. It incorporates the dose across a volume and therefore correlates better with ED than CTDI_{vol}. There is a linear relationship between ED and DLP and between ED and stochastic risk.² DLP can thus be used

to compare the stochastic effect between different CT examinations for a specific body region.

Each centre was also requested to record the following parameters for each scan: peak tube potential (kVp), effective current–time product (mAs), scan length, acquisition slice thickness and the anatomical scanning margins. The manufacturer and model of the CT scanner were also requested.

Statistical analysis

Statistical analysis was performed using SPSS® v. 20.0 (IBM Corp., New York, NY; formerly SPSS Inc., Chicago, IL). Where two scan sequences (scout and scan) were reported, the sum of the sequences was used to calculate the total dose for the procedure. Mean values of CTDI_{vol} and DLP were calculated for each centre. Difference of means between centres was tested by analysis of variance for CTDI_{vol}, DLP, mAs and scan length. There are different methods proposed for calculating the DRLs. European guidelines set DRLs at the 75th percentile of the distribution of mean doses based on a representative sample of patients from a broad user base.¹² Some investigators consider the 25th percentile of the distribution of doses as a goal for optimization;⁶ this level was also reported. However, this lower level may comprise image quality; image quality was not assessed in the survey. A p -value ≤ 0.05 was considered statistically significant.

RESULTS

Dose results

Completed survey forms were returned by six centres representing 50% of the national RT centres. Data were collected on a total of 60 breast cancer CT localization scans. Standard tangential breast cancer CT localization doses for each centre are presented in Table 1.

Dose variation

Mean DLP and CTDI_{vol} differed significantly between centres ($p < 0.0001$). Differences between the lowest and highest mean values were 337% for DLP and 491% for CTDI_{vol}.

Scanning protocol

Reported anatomical scanning margins, mean scan length and slice thickness for each centre are represented in Table 2. There was a significant difference between mean scan length ($p < 0.0001$) and mean mAs ($p < 0.0001$) between centres.

Slice thickness in Centres 4, 5, 8 and 12 was 2.5 mm. Centres 7 and 9 employed 3-mm and 5-mm sections, respectively. Tube potential was 120 kV for all sequences across centres. Automated exposure control (AEC) was employed in all but one centre (Anonymised CT Centre Identification Number 7). GE scanners (GE Healthcare, Waukesha, WI) were used by all centres except Centre 7, where a Siemens model (Siemens Healthcare, Forchheim, Germany) was used.

Diagnostic reference level

Based on the rounded 75th percentile, the proposed DRLs for tangential breast CT localization are 732 mGy cm and 26 mGy for DLP and CTDI_{vol}, respectively. The mean DLP for Centre 8 exceeded the DRL for DLP, while Centre 5 exceeded the DRL

Table 1. Distribution of dose-length product (DLP); CT dose index volume (CTDI_{vol}) and current-time product (mAs) for tangential breast cancer CT localization across radiation therapy centres with 10 patient doses measured per centre. (ID: Anonymised CT Centre Identification Number)

CT centre ID	Mean DLP (standard deviation) (mGy cm)	Range (mGy cm)	Mean CTDI _{vol} (standard deviation) (mGy)	Range (mGy cm)	Mean current-time product (standard deviation) (mAs)	Range (mAs)
7	282 (76.4)	160.7–391.6	6.6 (1.6)	3.8–8.9	74 (18)	42–99
9	314.8 (206.1)	162.3–859.8	21.2 (13.9)	14.2–59.9	129 (71)	78–315
4	536.4 (233.5)	244.5–947.7	12.6 (5.5)	5.7–21.3	211 (98)	90–395
12	547.8 (156.1)	334.5–792	24.1 (7.6)	13.7–38.5	277 (81)	162–446
5	659 (198.7)	346.2–1010.3	32.4 (9.6) ^a	19.1–40.4	280 (69)	191–373
8	951.9 (253.8) ^a	676.6–1327.8	19.4 (4.1)	13.6–24.7	74 (18)	42–99

^aExceeded the proposed DRLs of 732 mGy cm and 26 mGy for DLP and CTDI_{vol}, respectively.

for CTDI_{vol}. All other centres applied doses below the proposed DRLs for both dose descriptors. The 25th percentiles of the distribution of DLP and CTDI_{vol} values were 307 mGy cm and 11 mGy, respectively.

DISCUSSION

The implementation of DRLs is an important factor in dose optimization and radiation protection for patients. DRLs

provide numerical values that act as a threshold that can readily be used to identify excessive radiation doses and prompt quality improvements. In this study, a national CT DRL is proposed for breast cancer localization imaging. This is the first time CT DRLs have been established in the RT setting. Significant dose variation was observed between centres performing similar procedures, supporting the need for dose optimization in this procedure.

Table 2. Relationship between reported anatomical scanning margins for standard tangential breast cancer CT localization and mean scan length across radiation therapy centres based on data from 10 patients at each centre. (ID: Anonymised CT Centre Identification Number)

CT Centre ID	CT scanner	Anatomical scanning margins		Mean scan length (standard deviation) (mm)	Range (mm)	Slice thickness (mm)
		Superior	Inferior			
7	Siemens Somatom Sensation Open, Siemens, Erlangen, Germany,	Thyroid notch	L2 vertebra	376.7 (24.7)	357.5–437	3
9	GE Lightspeed RT16; General Electric, Healthcare, Milwaukee, WI, USA.	To include half of head of humerus	2 vertebrae below the breast tissue	374.5 (43.6)	310–455	5
4	GE Lightspeed RT16; General Electric, Healthcare, Milwaukee, WI, USA.	Mandible	5 cm inferior to breast tissue	396.7 (16.0)	367.5–417.5	2.5
12	GE Optima CT580; General Electric, Healthcare, Milwaukee, WI, USA.	To include half of head of humerus	Two vertebrae below breast tissue	345.0 (23.9)	305–380	2.5
5	GE Optima General Electric, Healthcare, Milwaukee, WI, USA.	Superior aspect of T1 to include some humeral head	Bottom of L1	338.9 (24.3)	290–363	2.5
8	GE Discovery DST; General Electric, Healthcare, Milwaukee, WI, USA.	Chin	Top of the pelvis	461.8 (56.5)	368–562	2.5

CTDI_{vol} and DLP are the main dose descriptors reported in this study, in line with CT dose surveys.^{2,16} There are limited RT-specific data to compare established mean doses. Harrison *et al*⁹ report an ED of 7.2 mSv for CT localization of a large breast phantom. Based on calculated DLP and the region-specific normalized ED conversion factor (based on 120-kV voltage and adult chest), 0.0145 mSv mGy⁻¹ cm⁻¹,¹⁹ the range of effective mean doses observed was 4.1–13.8 mSv (mean = 7.7 mSv), which is approximately in line with Harrison *et al*.

The observed dose variation may be attributed to the different scanning protocols and the CT scanner technology. The magnitude of variation in this study is similar to those observed in diagnostic studies.⁵ Tube voltage, mAs, pitch and scan length contribute the most to dose variation.⁵ Scan length may be attributable to multifactorial influences on the value of CTDI_{vol} and DLP and/or inaccuracies in measured values. The American Association of Physicists in Medicine suggest that the scanned volume should extend at least 5 cm superiorly and inferiorly beyond the target area⁸ and this was the case in all centres. However, Centre 8 reported the longest mean scan length and DLP. The average scan length across centres, when Centre 8 was excluded, was approximately 37 cm; however, Centre 8 reported a mean scan length of 46.2 cm. The standard inferior scanning margin at this Centre was in this centre was the top of the pelvis, this which would be considered excessively long for a tangential breast CT localisation scan, considering the target volume location.

The significant variation of mean mAs observed between centres may have a greater contribution to DLP variation than scan length. Greater dose reduction could be achieved by optimization of CTDI_{vol} and associated parameters among centres. Tack *et al*⁶ consider reduction of z-axis coverage as a secondary goal in dose optimization compared with CTDI_{vol} optimization, specifically kV and mAs modulation. AEC, employed by all but one centre (ID 7), allows for modulation of the tube current to patient size across the z-axis. It may be expected that the dose was higher in the centre without the AEC, but this was not the case; Centre 7 employed the lowest mean values of CTDI_{vol}, DLP and mAs (Table 1). Slice thickness in this centre was 3 mm, this was larger than four of the other Centres (ID 4, 5, 8 and 12) but less than Centre 9, who demonstrated a larger mean DLP than Centre 7. Centres 9 and 7 reported the largest slice thicknesses at 5 mm and 3 mm, respectively. Mean values for DLP in these centres were lower than that in centres using 2.5-mm slices, supporting the inverse relationship between patient dose and slice thickness. The use of larger slice thicknesses may provide a means of dose optimization but will impact on spatial resolution. Slice thickness determination in RT is based on dose and image quality to ensure accurate visualization of structure for contouring and image verification purposes.

Diagnostic reference level

European guidelines recommend that DRLs reflect national practice.^{12,13} Friberg and Widmark²⁰ propose that inclusion of 25% of the national CT population is sufficient; with 50% of the

Irish RT centres included, the proposed DRLs provide a reasonable basis for dose optimization.

In the absence of RT-specific data, diagnostic CT investigations of the chest may approximate the CT protocols observed in this audit. Published European Union DRLs for chest (including liver) examinations were 12 mGy and 430 mGy cm,²¹ Irish DRLs for chest examinations were 9 mGy and 390 mGy cm⁵ and UK DRLs for chest examinations were 13 mGy and 580 mGy cm⁷ for CTDI_{vol} and DLP, respectively. These DRLs are approximately half those proposed in this study (26 mGy and 732 mGy cm). An approximate diagnostic chest examination scan length (from the lung apices to the superior border of liver) is 29.2 cm,⁷ with the mean scan length of the RT image of 38.2 cm. The longer scanning margins in RT may account in part for the higher DRLs.

The dose and DRL results in this review provide a reference for RT CT doses and indicate higher overall doses than diagnostic CT. It is worth noting that the image quality objectives of a diagnostic CT scan and a breast RT CT scan are different. Image quality is a key concern in RT CT imaging, with intensity-modulated treatment delivery demanding accurate tumour volume and normal organ segmentations to maximize dose conformity. With this method of delivery, accurate delineation is critical to the success of the treatment owing to the steep dose gradients between target volumes and normal tissue. Sanderud *et al*²² compared thoracic RT CT and diagnostic CT and reported that RT CT scans were performed with a very low noise index when compared with the diagnostic image, Sanderud *et al* compared thoracic RT CT and diagnostic CT and reported that RT CT scans were performed with a very low noise index when compared to the diagnostic scans, they stated that this was in an effort to meet the image quality requirements for RT(22). This consequently results in very high mAs and, in turn, approximately 4 times higher CT dose to patients undergoing RT. Investigating the noise index was beyond the scope of this study, but provides an area for further research. Also, when comparing diagnostic thorax CT to breast RT CT, there is more inherent image contrast in the lungs than in the breast tissue. Therefore, there may be a requirement to deliver higher doses to the breast tissue to get appropriate contrast than when looking more generally at the lungs in a diagnostic thorax CT.

By the nature of using the 75th percentile to set the DRL, there will be a percentage of the centres exceeding this threshold. In this case, Centres 8 and 5 exceed the DRLs for DLP and CTDI_{vol}, respectively; quality improvements in these centres may be warranted. DRLs represent the upper limit of acceptable doses. Several diagnostic CT audits consider the 25th percentile of the distribution of doses as an end point for optimization.^{6,7,15} Mean values of DLP and CTDI_{vol} exceed 25th percentile values in five of the seven centres (Table 1); as expected, investigation to reduce the standard doses according to the as low as reasonably achievable principle may also be justified in these centres.

These proposed DRLs represent a first step in CT dose optimization. The American Association of Physicists in Medicine recommend that CT scan protocols should be reviewed at least

annually; these DRLs offer a benchmark for optimization dose, but this should not be performed to the detriment of the diagnostic efficacy of the procedure.⁸ Results from this study were fed back to the respective centres in an effort to instigate review of this procedure.

Limitations

A definition of an 'average-size' patient was not provided in the inclusion criteria for data collection; this was at the discretion of those completing the survey. This omission may have led to a variation in patient selection across centres. It is recommended that future surveys consider recording both the body mass index and patient dimensions in the imaged region as the basis for estimating the cross-sectional area²³ and recording the patient position for the CT scan, *i.e.* one or both arms up. The quality assurance and accuracy of the CT machine CTDI_{vol} and DLP display metrics was not verified for participating centres. These displayed dose metrics can be inaccurate. In some centres, it was unclear whether reporting of the first sequence (scout image) was omitted, incorporated into the overall dose or whether this sequence is not the part of the standard

protocol; this may have led to minimal inaccuracies in the doses reported. Optimization is the balance of dose and image quality; assessing image quality was beyond the scope of this project, but it should be considered when attempting to optimize dose.

CONCLUSION

Significant discrepancies in dose were observed between RT centres for breast cancer localization. As these images serve the same clinical purpose, significant dose variation between centres is considered unjustifiable. The first national RT CT DRLs were proposed for tangential breast cancer localization. These provide a basis for dose optimization among RT centres and may facilitate the reduction in cumulative radiation exposure to patients.

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REFERENCES

- Hall EJ, Brenner DJ. Cancer risks from diagnostic radiology. *Br J Radiol* 2008; **81**: 362–78. doi: <http://dx.doi.org/10.1259/bjr/01948454>
- Zarb F, Rainford L, Foley S, McEntee MF. Rationale for national and local dose reference levels and collective effective dose in CT. *J Med Imaging Radiat Sci* 2009; **40**: 109–15. doi: <http://dx.doi.org/10.1016/j.jmir.2009.06.001>
- ICRP. Radiological protection and safety in medicine. A report of the International Commission on Radiological Protection. *Ann ICRP* 1996; **26**: 1–47.
- European Community. Council Directive 2013/59/EURATOM. Laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation. *Off J Eur Union*. 2013 [Cited 03 August 2016]; Available from: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2014:013:0001:0073:EN:PDF>
- Foley SJ, McEntee MF, Rainford LA. Establishment of CT diagnostic reference levels in Ireland. *Br J Radiol* 2012; **85**: 1390–7. doi: <http://dx.doi.org/10.1259/bjr/15839549>
- Tack D, Jahn A, Kohler S, Harpes N, De Maertelaer V, Back C, et al. Multidetector CT radiation dose optimisation in adults: short- and long-term effects of a clinical audit. *Eur Radiol* 2014; **24**: 169–75. doi: <http://dx.doi.org/10.1007/s00330-013-2994-8>
- Shrimpton PC, Hillier MC, Lewis MA, Dunn M. National survey of doses from CT in the UK: 2003. *Br J Radiol* 2003; **79**: 968–80.
- Mutic S, Palta J, Butker E, Das I. Quality assurance for computed-tomography simulators and the computed-tomography-simulation process: report of the AAPM Radiation Therapy Committee Task. *Med Phys* 2003; **30**: 2762–92.
- Harrison RM, Wilkinson M, Rawlings DJ, Moore M. Doses to critical organs following radiotherapy and concomitant imaging of the larynx and breast. *Br J Radiol* 2007; **80**: 989–95. doi: <http://dx.doi.org/10.1259/bjr/32814323>
- Cardis E, Vrijheid M, Blettner M, Gilbert E, Hakama M, Hill C, et al. The 15-Country Collaborative Study of cancer risk among radiation workers in the nuclear industry: estimates of radiation-related cancer risks. *Radiat Res* 2007; **167**: 396–416.
- Dougeni E, Faulkner K, Panayiotakis G. A review of patient dose and optimisation methods in adult and paediatric CT scanning. *Eur J Radiol* 2012; **81**: 665–83. doi: <http://dx.doi.org/10.1016/j.ejrad.2011.05.025>
- Jessen K, Bongartz G, Geleijns J, Golding SJ, Jurik AG, Leonardi M, et al. European guidelines on quality criteria for computed tomography, EUR 16262EN. *Off J Eur Communities* 2000.
- European Community. On health protection of individuals against the dangers of ionizing radiation in relation to medical exposure. Council directive 97/43 (Euratom). *Off J Eur Communities*. 1997 [Cited 03 August 2016]; 22–7. Available from: <http://oldsite.estroneet.eu/estroactivities/Documents/9743Euratom.pdf>
- Society and College of Radiographers. IPeM A Guide to Understanding the Implications of the Ionising Radiation (Medical Exposure) Regulations in Radiotherapy 2008 [Cited 03 August 2016]; 1–52. Available from: http://www.rcr.ac.uk/docs/oncology/pdf/BFCO083_IRMER.pdf
- Treier R, Aroua A, Verdun F, Samara E. Patient doses in CT examinations in Switzerland: implementation of national diagnostic reference levels. *Radiat Prot Dosimetry* 2010; **142**: 244–54. doi: <http://dx.doi.org/10.1093/rpd/ncq279>
- McCollough C, Leng S, Yu L, Cody D. CT dose index and patient dose: they are not the same thing. *Radiology* 2011; **124**: 244–54. doi: <http://dx.doi.org/10.1148/radiol.11101800>
- Pantos I, Thalassinou S, Argentos S, Kelekis NL, Panayiotakis G, Efstathiopoulos EP. Adult patient radiation doses from non-cardiac CT examinations: a review of published results. *Br J Radiol* 2011; **84**: 293–303. doi: <http://dx.doi.org/10.1259/bjr/69070614>

18. Christner JA, Kofler JM, McCollough CH. Estimating effective dose for CT using dose-length product compared with using organ doses: consequences of adopting international commission on radiological protection publication 103 or dual-energy scanning. *AJR Am J Roentgenol* 2010; **194**: 881–9. doi: <http://dx.doi.org/10.2214/AJR.09.3462>
19. Deak PD, Smal Y, Kalender WA. Multi-section CT protocols: sex- and age-specific conversion factors used to determine effective dose from dose-length product. *Radiology* 2010; **257**: 158–66. doi: <http://dx.doi.org/10.1148/radiol.10100047>
20. Friberg EG, Widmark A. National collection of local diagnostic reference levels in Norway and their role in optimization of X-ray examinations. *Radiat Prot* 2009.
21. Bongartz G, Golding SJ, Jurik AG, Leonardi M, van Persijnvan Meerten E, Rodríguez R, et al. Quality criteria for multislice computed tomography. Results from a European concerted action on CT (FIGM-CT-2000–20078) Appendix B: European field survey on MSCT 2004.
22. Sanderud A, England A, Hogg P, Fosså K, Svensson SF, Johansen S. Radiation dose differences between thoracic radiotherapy planning CT and thoracic diagnostic CT scans. *Radiography* 2016; **22**: 107–11. doi: <http://dx.doi.org/10.1016/j.radi.2015.08.003>
23. Shrimpton PC, Hillier M, Meeson S, Golding SJ. Doses from computed tomography (CT) examinations in the UK—2011 review. PHE-CRCE-013. NRPB 2011.