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Original research article

Establishment of national diagnostic reference levels (DRLs) for radiotherapy localisation computer tomography of the head and neck

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ARTICLE INFO

Article history:
Received 25 September 2017
Received in revised form
11 May 2018
Accepted 21 July 2018
Available online 22 August 2018

Keywords:
Radiotherapy
CT localisation
Diagnostic reference levels
Head and neck

ABSTRACT

Aim: The aim of this research is to establish if variation exists in the dose delivered for head and neck (HN) localisation computed tomography (CT) imaging in radiation therapy (RT); to propose a national diagnostic reference levels (DRLs) for this procedure and to make a comparison between the national DRL and a DRL of a European sample.

Background: CT has become an indispensable tool in radiotherapy (RT) treatment planning. It is a requirement of legislation in many countries that doses of ionising radiation for medical exposures be kept 'As Low As Reasonably Achievable'. There are currently no dose guidelines for RT localisation CT of the HN.

Materials and methods: All RT departments in Ireland and a sample of European departments were surveyed. Dose data on CT dose length product (DLP); dose index volume (CTDIvol); current time product; tube voltage and scan length was acquired for ten average-sized HN patients from each department. DRLs were proposed for DLP and CTDIvol using the rounded 75th percentile of the distribution of the means.

Results: 42% of Irish departments and one European department completed the survey. Significant variation was found in the mean DLP, CTDIvol and scan lengths across the Irish departments. The proposed Irish DRL is 882 mGy cm and 21 mGy and the European department DRL is 816 mGy cm and 21 mGy, for DLP and CTDIvol, respectively.

Conclusions: Variation exists in doses used for HN RT localisation CT. DRLs have been proposed for comparison purposes with the aim of dose optimisation.

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https://doi.org/10.1016/j.rpor.2018.07.012
1507-1367/

1. Background

Computed tomography (CT) has become an indispensable tool in oncological imaging. Head and neck (HN) radiotherapy (RT) patients are reliant on this method of imaging for treatment planning, treatment response assessment and follow up. A significant number of HN patients are now treated using intensity modulated techniques; this necessitates the need for high quality CT images to aid accurate tumour and normal tissue delineation.

CT is associated with high radiation doses and subsequent risk of carcinogenesis.[1] A National Cancer Institute study estimates that 29,000 excess cancer cases could result from patients exposed to CT scans in the United States in 2007 alone.[2] Cumulative radiation exposure in excess of 75 mSv has been estimated to increase cancer mortality in the general population by 7.3%,[3] this necessities that, where possible, CT dose should be kept to a minimum.[4,5] The CT dose when compared to the therapeutic treatment is minute; however, it is not insignificant when considered in the linear-no-threshold model. RT localisation CT scans fall under the 'non-therapeutic' dose category and, as such, are governed by the 'As Low As Reasonably Achievable' (ALARA) principle.

The International Commission of Radiation Protection (ICRP),[6] the International Atomic Energy Agency (IAEA)[7] and The European Council Directive 13/59 EURATOM[8] established legislation to protect patients against the dangers of excessive ionising radiation from medical exposures through adherence to the ALARA principle. This Directive is based on the stochastic effect of radiation; these occur without a dose threshold, and increase in probability with increasing dose.[9] The ICRP introduced the use of diagnostic reference levels (DRL) for imaging procedure. DRL is defined as a level intended to identify situations where the patient dose or administered activity is unusually high.[10] The objective of a DRL is to help avoid excessive radiation dose that does not contribute additional clinical information. While DRLs are not mandatory in all countries, their use is endorsed by many professional and regulatory organisations, including the ICRP, The Australian Radiation Protection and Nuclear Safety Agency; American College of Radiology, American Association of Physicists in Medicine, UK Health Protection Agency and IAEA.

Diagnostic DRLs exist in many countries and there is some literature investigating DRLs in RT thorax and breast imaging[11,12] but no attempts have been made to introduce dose audit in HN RT CT imaging. Different scanning volumes, protocols and image quality requirements between diagnostic and RT CT do not support the use of diagnostic imaging (DI) DRLs in RT practice.[13]

The localisation CT scan range encompasses the tumour volume, with a volume of normal tissue superiorly and inferiorly. HN region contains many Class I & II radiosensitive organs including the brainstem, hypothalamus, optic chiasm, salivary and endocrine glands[13]; thus, it is an important anatomical region in which to optimise dose.

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.[14] This use of the third quartile is also based on previous work in DI.[7,15,16] The ICRP recommend that DRLs are based on relevant local, regional or national data and that national DRLs should be compared to international DRLs to ensure that CT practice is optimised and standardised.

2. Aim

The purpose of this research is to investigate CT dose variation between RT departments in Ireland, to propose a national DRL for CT HN cancer localisation in RT and to compare this DRL to a sample of European departments. This DRL provides a basis for dose optimisation with the potential for dose reduction.

3. Materials and methods

Ethics approval was granted by the Faculty of Health Sciences Research Committee of Trinity College Dublin. The methodology used in this research was based on the guidelines from the ICRP[6] and European guidelines.[14] All radiation therapy departments in Ireland ($n = 12$) and a European sample ($n = 25$) were invited to participate in an anonymised dose audit survey of 10 average-sized HN patients (excluding neurological patients) over a six week period.

A sample of 10 patients is the minimum number recommended by European guidelines[14] and this figure is based on previous work that established diagnostic CT dose reference levels in Ireland.[17]

In diagnostic studies, DRLs are proposed based on two primary dosimetry metrics: CT dose index volume (CTDIvol) and dose length product (DLP).[7,15,16] CTDIvol specifies the radiation intensity used to perform a specific CT examination. For a given scanner and a set of acquisition parameters, the CTDIvol is fixed and independent of patient size and scan length. Although it is not a direct gauge of patient dose it allows users to compare different scanners and scan protocols.[18] DLP is the product of CTDIvol and scan length and can be used as an indicator of patient dose from a CT scan.

Each participating department was asked to record general information on the CT scanner made and model. Specific information was sought for each scan; disease site, CTDIvol, DLP, peak tube potential (kVp), effective current-time product (mAs), scan length (mm); anatomical scanning range, acquisition slice thickness and if automatic exposure control (AEC) was used.

Data analysis was performed using SPSS v. 20.0 (PASW, Chicago, IL). The proposed DRL was based on the rounded 75th percentile of the CTDIvol and DLP for each scan recorded by the department. The European data was used to calculate the DLP for comparison purposes only. Two sample t-tests were carried out to assess whether the mean DLP, CTDIvol and mean scan length differed significantly between departments. A p value of $p < 0.05$ was considered statistically significant.

4. Results

Surveys were returned by five of the twelve Irish RT departments, representing 42% of the national departments. One Irish department that failed to return the survey indicated

Table 1 – Distribution of dose-length product (DLP); computed-tomography dose index: volume (CTDIvol) and current-time product (mAs) for head and neck cancer. CT localisation across the radiotherapy departments.

CT Department ID	Mean DLP (standard deviation) (mGy cm)	Range (mGy cm)	Mean CTDIvol (mGy)	Range (mGy)	Mean current-time product (standard deviation) (mAs)	Range (mAs)
A	1146** (364)	857–1912	3*	2–5	Not provided	80–400
B	818 (54)	713–878	23**	20–25	265 (19)	228–276
C	524 (63)	429–618	Not provided	Not provided	220 (0)	220–220
D	877 (259)	509–1441	19	16–22	Not provided	Not provided
E	578 (158)	379–771	15	10–20	165 (41)	123–222
European	756 (107)	522–913	21	21	Not provided	Not provided

*The mean CTDIvol for department A was not used for the calculation of the proposal national DRLs due to the use of a non-standard definition of CTDIvol.
**Exceeded the proposed Irish DRLs of 882 mGy cm for DLP and 21 mGy for CTDIvol.

they did not have the necessary number of HN patients to complete the audit in the six week period and one department returned data on only nine patients' scans. Department C neglected to provide the CTDIvol data for the acquired scans. Three departments included data from neurological patients ($n = 7$), these patients were excluded as the scan length for these localisation protocol would differ significantly from HN protocols. The CTDIvol values provided for Department A were inconsistent with data provided for the DLP and scan length for this department. Due to the anonymised nature of the survey, this data could not be queried and, therefore, was not included in the DRL CTDIvol calculation. Data on forty two eligible HN patients from the Irish departments were analysed. One European Department responded, providing data on ten patients. A summary of the HN CT localisation scan doses for each department are presented in Table 1.

The mean DLP and mean CTDIvol differed significantly between participating Irish departments ($p < 0.002$; $p < 0.049$, respectively). Based on the rounded 75th percentile of the DLP (based on data from 42% of national departments) and CTDIvol (based on data from 33% of national departments) from the Irish departments, the proposed Irish DRLs are 882 mGy cm for DLP and 21 mGy for CTDIvol. Department A exceeded the proposed DRL for DLP, while Department B exceeded the DRL for CTDIvol. The European department rounded 75th percentile of the DLP and CTDIvol were 816 mGy cm and 21 mGy, respectively.

Anatomical scanning range, mean scan length and acquisition slice thickness for HN CT localisation scans for each department are shown in Table 2. All but one of the Irish departments had a predefined anatomical scan range regardless of the disease location. Mean scan lengths differed significantly between the Irish departments ($p < 0.0001$). The European department individualised the scan length to the patient's site of disease.

Slice thickness of 2 mm was the smallest and 3 mm was the largest used. The European department and four out of five Irish department used AEC (Department C did not use AEC). The mean current time product data was not proved by three departments (two Irish or the European department) as a result, this was not used for statistical comparison. Variation in scanner manufacturer was observed, General Electric scanners were used in Department A and D, Siemens in Department B and E, Philips in Department C and Toshiba in the European Department.

5. Discussion

All imaging procedures using ionising radiation, including RT localisation CT, should be optimised to minimise risk to patients according to the linear-no-threshold model. The results of this study prove that a wide variation exists in doses used for HN CT in RT and, therefore, supports the establishment of RT CT DRLs. National DRLs is proposed for RT CT localisation imaging in the HN region with the aim to aid efficient dose optimisation. This is the first time that DRLs are established in this area.

Table 2 – Anatomical scanning range, mean scan length and acquisition slice thickness for head and neck CT localisation scans for each radiation therapy departments.

CT Department ID	Anatomical scan range		Mean scan length (standard deviation) (mm)	Range (mm)	Slice thickness (mm)
	Superior	Inferior			
A	Clear of skull	Clear of carina	413 (26)	250–440	2.5
B	Superior orbital ridge	Inferior aspect of supraclavicular fossa	303 (11)	220–364	2
C	Clear skull (site dependent)	Generally 5 cm below expected inferior border of treatment field	403 (49)	330–477	3
D	Clear of skull	Clear of carina	456 (112)	285–637	2.5
E	Superior aspect of frontal sinus	Clear of carina	347 (23)	303–357	3
European	Site dependent	Site dependent	352 (48)	286–477	3

A Nordic study proposed that national DRLs should include data from 5 to 25% of each of the participant country's departments.[19] Friberg et al. also stated that inclusion of 25% of the national CT population is adequate to establish DRLs.[20] This study based the DRL on dose data from 25 to 42% of national departments (3–5 departments from a total of 12 departments, nationally) which, based on the literature, is deemed sufficient to propose DRLs reflective of national practice.

The variations in dose across the RT department, is similar to that observed in Irish DI CT. Many factors can contribute to this variation including made, model and scanner technology and scanning protocols. Foley et al. suggested that pitch, scan length, tube current and current-time product contribute most to dose variation.[17] Slice thickness and pitch are closely linked. Slice thickness varied from 2 to 3 mm across departments. Departments (C, E and F) that used the largest slice thickness of 3 mm had the lowest mean DLP. Smaller slice thickness is more favourable for contouring with improved resolution in the z-axis. The departments (A and D) using 2.5 mm slice thickness recorded the highest DLP. Depending on the conformity of the RT planning technique, it could be argued that there is a requirement to have two separate DRL for H&N CT images, one for conformal RT and one for arc therapy based on the potential for different slice thickness and image quality requirements. The RT planning technique used in the departments was not investigated in this study. A decision to change the acquisition slices thickness, thus increasing dose, needs to be balanced against the need to obtain a good quality image for accurate visualisation of organs at risk (OAR) and target volumes for contouring and patient dose calculations.

Tack et al. suggested that reduction of z-axis coverage was of lesser importance in dose optimisation compared with CTDIvol optimisation, in particular kV and mAs modulation.[21] AEC was used by four of the five Irish departments and the European department. AEC was not used in the Department C, however they recorded the lowest DLP, suggesting this department may have effective dose management in place in the absence of AEC technologies. AEC aims to optimise the dose delivered; with the tube current adjusted as the patient attenuation changes in the z-axis, this is particularly useful in the contour change between the neck and shoulder areas. Departments utilising AEC would be expected to have a lower DLP than those using fixed current. It can then be concluded in this case that, while AEC is contributory to the variation in DLP, it is not the sole cause. Due to the lack of mAs data provided from some departments, it is difficult to assess its impact on dose variation in this study. Some AEC technologies also adjust tube voltage. This method of adjustment is not suitable for RT purposes, as it is difficult to maintain a HU-value to electron density correspondence in the treatment planning system and should be avoided.

DRLs proposed in this study act as a benchmark for departments to review doses and consider if they can further optimise their imaging protocols and related patient dose. Constant revision of DRLs is necessary as technology improves. Optimisation and understanding of techniques need to keep pace with technological advances. The UK has a fully developed set of DI CT DRLs, with 5-yearly reviews. Current DRLs are less than half of those from a 1980's survey and current adult doses are on average 10% lower than those in 2005.[22] This illustrates the impact DRLs have on dose reduction when implemented. This optimisation process requires collaboration from physicists, radiation therapists and radiation oncologists to ensure the ALARA principle of balancing patient dose and image quality for modern RT techniques is achieved.

In the absence of RT specific data a comparisons may be made with neck/C-spine DI DRLs. An Irish study reported national DRL for C-spine imaging of 420 mGy cm and 19 mGy,[17] published EU data for C-spine of 460 mGy cm and 70 mGy,[14] Australian national data for neck CT of 600 mGy cm and 30 mGy[23] and an USA study of 12 facilities recorded neck DRLs of 650 mGy cm and 23 mGy.[24] The DI DLR for CTDIvol are similar to the results of this study (21 mGy) apart from the EU data, which is over double that of the other results. The EU data was published in 2000 and is now outdated with the introduction of new dose optimisation technologies.[14] The RT DRL for DLP of 882 mGy cm, is larger than any of the diagnostic results. This finding is similar to the RT CT breast audit, with diagnostic DRLs approximately half of that proposed by the RT survey.[11] A study comparing DI and RT CT imaging in the thorax found that radiation dose in RT was four times higher than DI CTs.[12] The variation in this study could suggest that the RT scan length is longer than that of the DI protocols. The majority of the RT departments scanned superiorly to clear the skull, as opposed to the level of the temporomandibular joint in the case of DI neck imaging margins.[23] All but one of the Irish departments had a standard anatomical scan range, regardless of tumour location, with ranges varying across departments. Three out of five Irish departments cleared the skull with the superior border of their scanning range. The brain receives the largest organ dose during CT of the head, therefore, by decreasing the superior scanning limit this dose can be reduced.[1] The European department stated their anatomical scanning range is patient dependent and recorded the third shortest mean scan length. A significant difference was observed in mean scan lengths between Irish departments. This suggests that there is scope to optimise scan length and individualise the range to the specific tumour location. The literature states that the scanned volume should be at least 5 cm superiorly and inferiorly to the treatment volume.[13] As scan length is linked to DLP, decreasing scan length could decrease the radiation dose.[25]

Sanderud et al.[12] suggested that the lack of patient body mass index (BMI) specific modified CT protocols in thoracic RT planning was the main reason for higher patient dose in the RT setting when compared to DI. The departments in our survey were asked to provide data on average-sized patient, with no specific BMI criteria given. BMI may have less impact in the HN region when compared with the thorax; however, it is another factor that warrants consideration when RT departments are optimising the RT CT protocols.

As anticipated, 25% of the departments exceeded the proposed national DRL for DLP (Department A) and for CTDIvol (Department B, with Department D close to the DRL). Dose optimisation and a review of HN scanning protocol in these departments is warranted with the aim of dose reduction in

line with the DRL, while maintaining image quality. Department C had a mean DLP of just 60% of the DRL. The ICRP recommends a local review of image quality if a department is consistently significantly below the DRL; this may apply to Department C and E.[6] With the increasing use of modulated RT in HN patients, obtaining a good quality image at CT has never been more critical. Contouring of target volumes and OARs for this treatment technique requires a low noise image for precision and accuracy.

Effective dose illustrates the radiation detriment of a particular examination averaged over gender and age. It facilitates the comparison of the biological effect of different types of imaging modalities. It is argued that CTDIvol and DLP are not a useful measurement of the dose absorbed[26] but there is a linear relationship between effective dose and DLP, and effective dose and stochastic risk.[16] Therefore, DLP could be used to compare the stochastic effect between HN CT localisation scans. Based on the mean DLP from each Irish department, the estimates of the effective doses ranged from 2.67 to 5.84 mSv (mean = 4.02 mSv). Effective dose was estimated based on k values (for normalised effective dose conversion) reported by ICRP 103 (0.0051 mSv mGy^{-1} cm^{-1} for adult neck examinations with 120 kV voltage).[27] A UK study estimated the effective dose from a larynx RT localisation CT to be 1.4 mSv.[28] The scan length for this study was 180 mm which may account for the lower effective dose when compared to our study (mean scan length 381 mm).

While the European data provided an interesting comparison, no published European therapeutic DRLs exist and a single department may not be representative of the European wide data. The proposed Irish DRL for DLP is marginally greater than that of European DRL (882 mGy cm v 816 mGy cm, respectively), illustrating some need for further optimisation in the Irish setting. The DRL for CTDIvol are the same.

RT dose surveys of thorax and breast CT localisation imaging has indicated wide variations in dose.[11,12] Such variations are unjustified given the same clinical requirements of the images.[16] This study demonstrated that similar dose variation occurs between RT Departments for HN CT localisation imaging, therefore establishing the need for DRLs and dose optimisation.

The quality assurance procedures and the accuracy of the CT machine DLP and CTDIvol outputs were not assesd in this survey. These parameters can be inaccurate if strict quality assurance procedures are not adhered to. This factor may have played a role in the inconsistent CTDIvol data provided from Department A. This department may have reported a non-standard definition for this parameter. Participating departments were asked to provide data on ten average sized patients. A definition of 'average' size was not provided and this may have resulted in heterogeneity in the patient sample provided from different departments. Only one European department completed the survey and not all of the surveys were completed in full; this is a limitation of the study. There was four different makes of CT scanners used in this study. This may also contribute to the dose variation. Effective optimisation requires a review of both patient dose and image quality to ensure that the objectives of CT imaging is achieved. Image quality was not assessed in this research but remains a key consideration in this equation.

6. Conclusions

The variation in CTDIvol, DLP and scanning protocol in HN cancer RT localisation CT imaging across Irish departments warrant the establishment of DRLs. It may be necessary to consider BMI specific modified RT CT protocols and this area warrants further investigation. This research proposes DRLs for RT CT imaging in the HN region and provides a platform for dose comparison and optimisation of CT localisation protocols.

Conflict of interest

None declared.

Financial disclosure

None declared.

Acknowledgements

Thank you to the radiotherapy departments that participated in the study.

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