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FULL PAPER

Doses from cervical spine computed tomography (CT) examinations in the UK

JOHN R HOLROYD, BSc, MRes and SUE EDYVEAN, BSc, MSc

Centre for Radiation, Chemical and Environmental Hazards (CRCE), Public Health England, Chilton, Didcot, Oxfordshire, UK

Address correspondence to: John R Holroyd

E-mail: John.Holroyd@phe.gov.uk

Objective: To review doses to patients undergoing cervical spine CT examinations in the UK.

Methods: A data collection form was developed and distributed to medical physicists and radiographers via e-mail distribution lists. The form requested details of CT scanners, exposure protocols and patient dose index information.

Results: Data were received for 73 scanners. It was seen that 97% of scanners used automatic exposure control, and 60% of scanners used an iterative reconstruction technique for cervical spine examinations. The majority of scans were taken at 120 kV. The average patient dose indicators in terms of CT dose index (CTDI_{vol}) ranged from 3.5 to 39.7 mGy (mean value 16.7 mGy), and for the DLP, ranged from 87 to 1030 mGy cm (mean

value 379 mGy cm) as quoted for the standard 32 cm phantom.

Conclusion: The rounded third quartile value of the mean dose distributions from this study were a CT dose index (CTDI_{vol}) of 20 mGy and a dose-length product of 440 mGy cm as quoted for a 32 cm body phantom. These are significantly higher than those in the 2011 Public Health England CT dose survey when adjusted for phantom size. It is suggested that the existing national diagnostic reference levels for cervical spine CT should be amended, both with the new values and also to quote according to the 32 cm phantom.

Advances in knowledge: Proposed new national diagnostic reference levels are presented for cervical spine CT examinations.

INTRODUCTION

Public Health England (PHE) has previously undertaken three national surveys of patient doses from CT examinations in the UK, the latest of which was conducted in 2011 and published in 2014.¹ This provided updated national reference doses for CT for the UK. In 2016, these were formally adopted as national diagnostic reference levels (NDRLs) and published on the GOV.UK website.²

For the 2011 PHE CT survey,¹ information on the CT dose index (CTDI) phantom (16 or 32 cm diameter) was not collected. For most examinations, the CTDI phantom used is normally self-evident, in that a 32 cm phantom will be used for body examinations and a 16 cm phantom for head examinations.

However, in the ambiguous case of cervical spine examinations, the presumption of CTDI phantom size is not so easy, as both the head and body are included in the scan. Different scanners may present the dose data for a cervical spine scan for either of the two standard phantoms, depending on the manufacturer, model, or scanner protocol settings. Knowledge of the phantom chosen is important, as the reported

CTDI values between the two phantoms vary by a factor of approximately 2, with the dose to the 16 cm head phantom being the higher value.³

In the analysis stage of the 2011 PHE survey, there had been an awareness of the possibility of data being submitted based on either phantom size for the cervical spine scans, and the data were, therefore, inspected for obvious discrepancies, and corrected for these differences where possible. A 16 cm phantom was assumed to be used for the majority of cervical spine examinations, and the reference doses quoted accordingly.

Following the publication of the NDRLs, PHE received some enquiries from physicists from hospital trusts reporting that, despite undertaking careful optimisation work, they were unable to reduce doses below the cervical spine examination NDRL value for their scanners. They also noted that even among their own local scanners there was a variation in the size of CTDI phantom quoted for this examination. The enquirers requested further information from PHE regarding the methodology used to derive the NDRL value, focussing on the selection of CTDI phantom

used for the submission of cervical spine data to the PHE 2011 CT dose survey, and for which the national DRL is quoted.

The nature of these enquiries prompted a review of the existing data, and PHE subsequently decided to conduct a small-scale dose survey for CT cervical spine examinations, specifically requesting the phantom size quoted. The aim was to investigate if the current NDRL value was appropriate or should be updated. The additional benefit was to allow the collection of protocol information from current scanners with technologies such as wide-beam and iterative reconstruction techniques. These technologies were not in routine use when the previous study collected data in 2011.

METHODS AND MATERIALS

A recent CT dose survey carried out by the Institute of Physics and Engineering in Medicine (IPEM) used a standardised data collection form.⁴ As this would be familiar to the medical physics and radiographer communities, it was decided to use a similar data collection form and permission was obtained from IPEM to reuse the form, with suitable amendments for this survey.

The data collection form requested details of the hospital, scanner, and standard protocol settings for cervical spine CT

examinations. Space was provided to record individual patient doses for up to 30 patients, and to include details of any deviations from the standard protocol. Essential information was considered to be scanner identification, CTDI phantom used, and at least one dose metric—either CTDI_{vol} or dose-length product (DLP). Other information such as patient characteristics (e.g. age and weight) and protocol settings were requested in order to facilitate a more detailed analysis. Submissions were allowed for all size patients, rather than asking only for a “standard sized” patient, in keeping with the approach in the 2011 survey, and to ensure sufficient numbers of submissions. As an addition to the previous PHE dose survey, data were requested on the calibration of patient dose indicators displayed by the CT scanner. This information would help to provide assurance that the dose data provided to this survey, from the scanner console, were accurate. A measured CTDI_{vol} using a dosimeter and CTDI phantom, together with the corresponding console displayed CTDI_{vol}, was requested. This would ideally be for the cervical spine protocol, or if not available, the nearest protocol where a recent measurement had been made during routine quality assurance testing.

In addition to completing the data collection form, respondents were also invited to submit data in other electronic formats [e.g.

Table 1. Summary of CT scanners included in this survey

Manufacturer	Model	Number of detector rows	Number of scanners
GE	Discovery 750HD	64	6
	LightSpeed Pro 32	32	2
	LightSpeed VCT	64	11
	Optima CT660	64	6
	Revolution	256	1
Philips	Brilliance 64	64	1
	Brilliance ICT	128	1
	Ingenuity	64	1
	Ingenuity 128	64	2
Siemens	Somatom Definition (Dual Source)	64	1
	Somatom Definition AS	64	3
	Somatom Definition AS+	64	8
	Somatom Definition Edge	64	5
	Somatom Definition Flash	64	4
	Somatom Force	96	1
	Somatom Perspective	64	1
	Somatom Sensation 64	64	3
Toshiba	Aquilion	Unknown	1
	Aquilion 64	64	3
	Aquilion CX	64	2
	Aquilion CXL	64	1
	Aquilion ONE	320	6
	Aquilion Prime	80	3

Table 2. Choice of CTDI phantom used to calculate CTDI measurements by the scanners included in this survey

CTDI phantom	Number of scanners
16 cm head	4
32 cm body	69

CTDI, CT dose index.

obtained from local dose audits, Radiology Information Systems (RIS) or dose management software], if it was easier to do so providing the essential information was included.

The data collection form was piloted with one hospital trust and the feedback used to refine the form. The final form was distributed via the UK CT Users Group⁵ and the Medical-Physics-Engineering⁶ mailing lists. It was also distributed to members of the PHE working party on national dose surveys and DRLs. In addition, the survey was shared with the Society and College of Radiographers to communicate with the radiographer community. Data collection was during approximately a 3-month period between 10 October 2016 and 31 January 2017 and regular reminders were posted to the mailing lists.

RESULTS

Data were received from 42 hospitals relating to 73 scanners and 4299 individual patients. Data for 65 scanners were provided using the PHE data collection spreadsheet and data for 8 scanners were provided using a custom spreadsheet. The data from the custom spreadsheets were transposed into the PHE layout to combine the data together. Both DLP and CTDI_{vol} data were provided for 71 scanners, and DLP only data were provided for 2 scanners. Table 1 shows a summary of the CT scanners for which data were provided. All the completed data collection spreadsheets were combined into one spreadsheet for data analysis. Dose data were received based on the 16 and 32 cm CTDI phantoms. In order to combine all the dose results, the 16 cm doses were converted to a 32 cm diameter using the size specific dose estimate multiplication factor proposed by the American Association of Physicists in Medicine of 0.54 for this conversion.³

During the data analysis, the authors were made aware of an issue identified by the IPEM Radiotherapy Imaging Dose Working Party, with some older Toshiba scanners. These scanners reported

Table 3. Standard tube operating potential used by the scanners

Operating potential	Number of scanners
100 kV	7
120 kV	55
130 kV	1
135 kV	2
140 kV	3
Not stated/variable	5 (3/2)

The tube potential was not supplied for three scanners, and two scanners used automatic kV selection.

Table 4. Summary of CTDI calibration data provided

Number of scanners	27
Average error (%)	0
Standard deviation (%)	6
Minimum error (%)	-13
Maximum error (%)	17

CTDI, CT dose index.

a maximum CTDI_{vol} per acquisition on the console, rather than the average value (Tim Wood, personal communication 2017). This did not affect the total DLP, which was correctly generated from the average CTDI_{vol}. This misrepresentation of the mean CTDI_{vol} had been identified in the PHE 2011 survey,¹ and this current information confirmed that it still needed to be considered. The scanners affected by this issue were identified and removed from the CTDI_{vol} analysis. This excluded five scanners.

In the 2011 survey, data relating to 182 scanners were submitted; of these, 45% had less than 64 detector rows. However, in this survey only two scanners (3%) had less than 64 detector rows, suggesting that many Trusts have replaced their scanners in the last 6 years.

The 2011 survey assumed that the 16 cm head phantom was primarily used by scanners to determine the CTDI_{vol} value for a cervical spine examination. However, Table 2 shows the phantom choice of the scanners included in this survey, which indicates that most current scanners use the 32 cm body phantom for presenting CTDI_{vol} values for cervical spine examinations. It was also apparent that this was not specific for a particular manufacturer or model, with at least one scanner model with submitted data for both phantom sizes.

Table 3 shows the choice of operating potential used. 75% of the scanners operated at 120 kV, with a roughly equal number at tube voltages above and below. Two scanners used automatic kV selection. The results show that 120 kV was the preferred setting for the cervical spine examination; this is the same result as in the 2011 survey.

The other protocol information provided indicated that 98% of scanner protocols used helical scanning, and no protocol included the use of contrast for cervical spine examinations.

The previous PHE dose survey¹ did not request data on the accuracy of the displayed CTDI_{vol} and DLP measurements. The assumption was made that the reported doses will have been

Table 5. Numbers of scanners in this survey which used automatic exposure control or iterative reconstruction

Parameter	Used	Not used	No response
Automatic exposure control	62	2	9
Iterative reconstruction	36	24	13

Table 6. Summary of IR setting

Manufacturer	IR name	Scanners	Mode	Min	Max
GE	ASIR	15	ASIR 40%	ASIR 20%	ASIR 40%
Philips	iDOSE	3	Level 4	Level 4	Level 4
Siemens	SAFIRE	7	3	2	3
Siemens	ADMIRE	1	3	3	3
Toshiba	AIDR	8	Standard	Standard	Standard

IR, iterative reconstruction.

Only scanners operating at 120 kV were included apart from the one scanner using ADMIRE, which used an automatic operating potential selection which was not described.

checked during equipment quality assurance checks and that any significant errors would have been rectified. In this survey, information was requested on the latest CTDI_{vol} measurement made on the CT scanner. Details were requested on the measured and reported CTDI_{vol} values for the standard cervical spine protocol, or for the most similar protocol. Table 4 summarises the information received. The vast majority of scanners had CTDI values measured within a few percent of the displayed values, with only four scanners having an error greater than $\pm 10\%$. As data were not corrected for error in the previous PHE CT dose survey, it was decided not to correct the data for this single exam survey. However, analysis performed without those scanners with a discrepancy greater than 10% showed no significant effect on the final results, and therefore, this aspect did not need to be considered for the application of the final reference values.

Information was requested on the use of two techniques which, when used, can provide scope for dose reduction: automatic exposure control (AEC) and iterative reconstruction and the results are summarised in Table 5. This indicated that almost all scanners used AEC and the majority used iterative reconstruction.

The standard protocol setting for those scanners using iterative reconstruction is summarised in Table 6. The most common protocol setting, together with the minimum and maximum, are shown.

Figure 1. Histogram of CTDI_{vol} measurements (32 cm body phantom). The solid vertical bar shows the current NDRL (converted to a 32 cm phantom size) and the dashed bar shows the third quartile value of the dose distribution from this study. CTDI, CT dose index; NDRL, national diagnostic reference level.

The average CTDI and DLP values for each scanner were calculated and plotted on histograms (Figures 1 and 2). The CTDI_{vol} measurement data were separated into bins of 5 mGy width, and DLP data into bins of 100 mGy.cm. The solid vertical bars represent the current national DRLs (converted to a 32 cm phantom size) and the dashed bars represent the third quartile values of the dose distribution from this study.

Table 7 shows the summary statistics for dose measurements using both the mean and median values obtained for each scanner.

To see whether the choice of reconstruction technique had an influence on patient dose, the dose data were split into two sets depending on the reconstruction technique used, and the results for the third quartile of the distributions are shown in Table 8.

DISCUSSION

In the 2011 study, 85% of scanner protocols used AEC, 95% used helical scanning and 1% used contrast for cervical spine examinations. In this study, 96% used AEC, 98% used helical scanning, and no scanner protocols included the use of contrast. There is a clear consensus that these are appropriate protocol settings to use for this CT examination.

Figure 2. Histogram of DLP measurements (32 cm body phantom). The solid vertical bar shows the current NDRL (converted to a 32 cm phantom size) and the dashed bar shows the third quartile value of the dose distribution from this study. DLP, dose-length product; NDRL, national diagnostic reference level.

Table 7. Dose results of this survey

Parameter from each scanner	Number of scanners	Summary parameters from all scanners			
		Min	Max	Median	75th percentile
Mean CTDI	60	3.5	39.7	15.6	20.1
Median CTDI	60	3.4	39.6	15.1	20.0
Mean DLP	67	87	1030	365	438
Median DLP	67	84	1003	356	429

CTDI, CT dose index; DLP, dose-length product.

Information is provided based on the mean and median dose values obtained for each scanner. All data are presented for the 32 cm phantom.

Figures 1 and 2 show the distribution of CTDI_{vol} and DLP values obtained in this survey. The distributions are comparable to the 2011 survey with a wide range of dose index measurements being used in clinical practice. The ratio of the third quartile to the first quartile was 1.7 for CTDI_{vol} and 1.5 for DLP in this study and 1.7 for CTDI_{vol} and 1.6 for DLP in the 2011 survey.

Information on the use of modern iterative reconstruction (IR) techniques was not requested in the 2011 survey as this was a relatively new technique first introduced in around 2008.⁷ However, the results of this study show that 60% of scanners in this study are routinely using this reconstruction technique, demonstrating that it has rapidly been adopted by hospital radiology departments. This is comparable to a study conducted in Australia which found 69% of scanners used iterative reconstruction.⁸ Iterative reconstruction is claimed to allow a dose reduction whilst still maintaining a similar image quality to conventional filtered back projection reconstructed images.^{7,9}

Table 8 shows that the use of iterative reconstruction resulted in a reduction of 24% on the third quartile value of the mean CTDI_{vol} values, but only 4% of the DLP value. This indicates that the use of iterative reconstruction has a positive effect on dose reduction. However, the range of CTDI_{vol} values for IR (3.5–39.7 mGy) and for FBP (6.6–31.4 mGy) are wide and overlapping, indicating the use of IR is only one of many factors available for dose optimisation for many scanners. It is also interesting to note that the use of IR is associated with an increase in scan length. Although the authors are unaware of a technical explanation for this, it may be prudent to ensure scan length is not unnecessarily increased when changing to an IR technique.

The tube current used for diagnostic image quality, and hence CTDI_{vol}, is strongly linked to the patient cross-sectional

dimensions. Due to the difficulty of measuring the patient dimensions, patient weight is often used as a surrogate, and it is therefore important to capture CTDI_{vol} data for similar patient weights. Although a standard patient size was not requested specifically for inclusion in the study, the data collection form did request information on patient weight where possible. Patient weight is not routinely measured and stored electronically; and this was evident from this study where weight information was only provided for two scanners. In an approach similar to that used in the 2011 PHE dose survey, it was assumed for this study that, providing dose data were submitted for at least 15 patients, the average dose would be a reasonable approximation of the dose to a typical patient. This excluded six scanners, with dose data for less than 15 patients, from the dose analysis.

Traditionally, the NDRL has been set at the third quartile value of the distribution of scanner mean doses. More recently, a publication by the International Commission on Radiological Protection¹⁰ entitled “Diagnostic Reference Levels in Medical Imaging” advocated the use of median values in place of mean values, in terms of the data submitted from each scanner. The results of the minimum, maximum, median and 75th percentile, from the full distribution of scanners, are almost identical regardless as to whether the mean or median data from the scanner submissions are used as shown in Table 7. Therefore, the choice of using either mean or median values will not affect the results of this study. The use of the distribution of mean values is retained for this study as the aim is to establish whether the existing NDRL, which was set using mean values, requires updating.

The assumption that the 16 cm phantom was used for the majority of CTDI_{vol} measurements in the previous CT dose survey does not appear to have been valid. Of the scanners included in this dose survey, 95% used the 32 cm phantom. All

Table 8. Third quartile of mean dose values, separated by reconstruction technique

Reconstruction technique	Number of scanners		Third quartile values	
	CTDI _{vol}	DLP	CTDI _{vol} (mGy)	DLP (mGy.cm)
FBP	22	24	21 (5.4)	471 (130.1)
Iterative reconstruction	28	31	16 (6.8)	452 (167.8)
			(<i>p</i> < 0.05)	(<i>p</i> = 0.65)

CTDI, CT dose index; DLP, dose-length product; FBP, filtered back-projection.

The figures in brackets are the standard deviations.

Table 9. Summary of cervical spine CT NDRLs in the UK: existing and proposed

UK national DRLs	Quoted for 32 cm phantom		Quoted for 16 cm phantom	
	CTDI _{vol} (mGy)	DLP (mGy cm)	CTDI _{vol} (mGy)	DLP (mGy cm)
Existing	(15)	(324)	28	600
Proposed	20	440	(37)	(815)

AAPM, American Association of Physicists in Medicine; CTDI, CT dose index; DLP, dose-length product; DRL, diagnostic reference level; PHE, Public Health England.

Current value taken from the 2011 PHE CT survey is published for a 16 cm phantom. The actual proposed value from this study will be given for the 32 cm phantom. The conversion to the other phantom in each case is given in brackets, using the 0.54 factor from AAPM (2014).

data in this study are converted to a 32 cm phantom size and the third quartile value of the CTDI_{vol} is 20 mGy (32 cm phantom). The value presented in the 2011 study, and the current NDRL, is 28 mGy (16 cm phantom); this converts to a value of 15 mGy for a 32 cm phantom, which is significantly lower than the value from this study.

The current NDRLs, from the 2011 study, for cervical spine were based on data from 37 scanners for CTDI_{vol} and 54 scanners for DLP (6 and 9% respectively, of the scanners in the UK at the time)¹ compared to 60 and 67 scanners respectively in this study. As more recent data on the number of scanners in the UK are not available, if it is assumed that the total number has not increased, the number of scanners in this study would represent 10% and 11% of the scanners in the UK. This suggests that the data in this study gives a similar representation of practice across the UK, and it is appropriate to propose the values in this paper as updated NDRLs for cervical spine; namely 20 mGy and 440 mGy cm for CTDI_{vol} and DLP respectively based on the 32 cm CTDI phantom. The proposed NDRLs are compared to the existing values in Table 9.

It is useful to compare the proposed NDRLs in this study for the UK, to other national studies that have been undertaken. National DRLs for cervical spine CT examinations have been proposed in a number of other countries and are summarised in Table 10. The values from Belgium were based on a 32 cm CTDI phantom. For other countries, it was not clear, from the respective publications, whether the choice of phantom was monitored for these studies, so a combination of 16 and 32 cm

phantom data may be included. This makes it difficult to provide a useful comparison. Table 10 shows the results in this study are similar to those obtained in Ireland but lower than the values in Australia, Belgium, USA and Switzerland.

There are some limitations of this study. Only an estimated 10% of the total number of CT scanners in the UK were included. This could indicate a potential bias, as those centres who had spent time on dose optimisation may be more likely to respond and therefore, the results in this study may not truly represent national practice. However, this is a limitation of any survey carried out on a voluntary basis. This study included a greater number of scanners compared to the previous dose survey which set the current national DRL.

An additional limitation of this study is that there were no restrictions in terms of weight or patient size in the data collected. This could result in the average dose for a scanner not being representative of a standard-sized patient. DRLs should be set for standard size patients,¹⁰ however, in a voluntary national dose audit, the goal of obtaining sufficient data for a representative value provides a tension on the restrictions for data submission. Since this survey was intended to provide an update to the 2011 CT survey, in terms of just one clinical indication and body region, the same methodology was followed, and therefore, whilst weight data were set as a desirable submission, it was not essential. In order to help improve the reliability of the data, the minimum sample size for analysis was set at a greater value than for the 2011 survey.

CONCLUSION

The rounded third quartile value of the dose distributions from this study were a CTDI_{vol} of 20 mGy and a DLP of 440 mGy cm for a 32 cm body phantom. These are significantly higher than those in the 2011 PHE CT dose survey. Given the difference, and also that the 32 cm phantom was used for most of the dose measurements, whereas the 16 cm phantom was assumed to be the default in the 2011 study, it is suggested that the existing NDRLs should be amended. Consideration should also be given to setting future NDRLs for cervical spine CT using a 32 cm phantom as this appears to be the far more common phantom used in clinical practice for this examination. A learning point from this study is that CTDI phantom size cannot be assumed for cervical spine examinations. A recommendation would be that the phantom size should be recorded for all patients and examinations.

Table 10. Summary of cervical spine CT NDRLs outside the UK

Country	National DRL	
	CTDI _{vol} (mGy)	DLP (mGy cm)
Ireland ¹¹	19	420
Netherlands ¹²	–	321
Switzerland ¹³	30	600
USA ¹⁴	30	663
Australia ^{a15}	30	600
Belgium ¹⁶	25	450

CTDI, CT dose index; DLP, dose-length product; NDRL, national diagnostic reference level.

^aThe value for Australia was for a neck examination, which is taken to be approximately equivalent to a cervical spine examination.

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