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Research Article

Establishment of facility reference level in computed tomography in selective examinations in a single institution in South Australia: A preliminary study

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ABSTRACT

Introduction: The objective of this study is to provide preliminary data for the establishment of LDRL or FRL for $CTDI_{vol}$ and DLP for one scanner in our institution.

Methods: Data was retrospectively collected from one CT scanner (Toshiba Aquilion One Vision 320-slice, installed in 2015) in our institution from 26 December 2016 to 26 June 2017. Examinations were separated as contrast and non-contrast studies, and single phasic for single acquisition or multiphasic for more than one acquisition. The common CT examinations, including chest, chest abdomen/pelvis, and abdomen/pelvis were reported. Examinations such as CT colonoscopy, CT pulmonary angiogram, CT gating angiography, CT chest and abdomen/pelvis non-contrast, CT high resolution lung and CT renal colic were excluded from the study. This is mostly due to a low number of examinations and the use of different exposure factors and/or techniques. The median mean (50^{th} percentile), and 75^{th} percentile for the dose spread were calculated according to the examination.

Results: There was a total of 1571 CT examinations performed between 26 December 2016 and 26 June 2017 using the Toshiba scanner in our institution. 262 examinations met the inclusion and exclusion criteria. The examinations and our institutional DRLs for our Toshiba scanner (established as median value of $CTDI_{vol}$ and DLP), were distributed as CT chest contrast (n=67, 25.6%, 6mGy, 219.1mGy.cm), CT chest non-contrast (n=41, 15.6%, 5.7mGy, 190.6 mGy), CT abdomen/pelvis contrast (single phase) (n=49, 18.7%, 6.5 mGy, 330.5 mGy.cm), CT abdomen/pelvis contrast (multi-phase) (n=33, 12.6%, 8.93 mGy, 1037.5 mGy.cm), CT abdomen/pelvis non-contrast (n=12, 4.6%, 10.1 mGy, 289.9 mGy.cm) and CT chest and abdomen/pelvis (n=60, 22.9%, 7.15 mGy, 619.4mGy.cm).

Conclusions: The preliminary data provided information that our own institution and others can use for quality improvement activities. Future research is required to allow for further analysis to include more CT examinations in various scanners.

Introduction

Computed tomography (CT) was introduced in the early 1970s and soon became a very powerful clinical tool for screening, diagnosis, therapy and patient management [1, 2]. In emergency departments alone, clinicians show a preference in CT because of its ability to significantly impact on the diagnostic confidence and admission decisions for the patients [3-7]. However, CT is associated with relatively high radiation doses, causing concerns regarding the risk of carcinogenesis [8, 9]. Therefore, sensible use of this imaging modality requires strict adherence to the tenets of radiation protection: justification, optimisation

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and minimisation, ensuring that the risk to patients does not outweigh the benefit gained from the technique [8, 9].

Not until recent years, Australian adults DRLs for Multi-detector CT (MDCT) were established from data obtained in 2011 via the National Dose Reference Levels[10-12]. Doses are routinely estimated by using standard 16- or 32-cm diameter polymethylmethacrylate cylinder phantom representing "average" patients [10, 11]. In CT, this parameter, known as the volume CT dose index ($CTDI_{vol}$), approximates the average dose to a cross section of a phantom [10, 11]. Dose-length product (DLP) is the product of the $CTDI_{vol}$ and the scan length for a group of scans along z-axis [10, 11]. Currently, these two parameters are displayed on CT dose reports for each scan. Although these parameters are tagged to individual examinations that the patient undergoes, they do not represent the patient's dose, but rather the dose to one of the standard phantoms. Depending on the size of the patient, relative to the size of the phantom used to report $CTDI_{vol,}$ the actual radiation dose to the patient might be significantly different [13-18]. $CTDI_{vol}$ values are now primarily useful as a quality assurance tool to compare radiation doses from different manufactures, different scanner outputs and most importantly different protocols [13-18].

To cope with exceeding concerns about the dose that patients receive from CT, diagnostic reference levels (DRLs) were established as benchmarks for radiation protection and optimization of patient imaging [10, 11, 13-16]. DRLs were first mentioned and recommended by the International Commission on Radiation Protection in 1990 and were then recommended by International Atomic Energy Agency in 2006 [8, 9]. DRLs are determined by using a collection of patient dose data at the 75th percentile point of the dose spread. This means that 75% of the dose data are below the DRL value [9]. DRLs are intended to provide guidance on what is achievable with current good practice rather than optimum performance and helps to identify unusually high radiation doses or exposure levels (as seen in the rest of the 25% of cases). Hence, regular patient dose monitoring and image quality assessment will lead to optimal doses and meaningful DRLs and reduction of unnecessary patient exposures. A local DRL (LDRL) or facility reference level (FRL) is the median dose delivered to a standard patient undergoing a specific routine diagnostic exposure at a specific facility [13, 14]. FRLs are then used to define the institutional or local facility doses and provide a comparative dose metric for optimisation strategies [13, 14]. In other words, the median value delivered to the patient correlates to our FRL. The 75th percentile of a dose metric distribution is used as national DRL (NDRL) [13, 14]. The NDRLs are defined by calculating the 75th percentile of the FRLs submitted to the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) [12]. Should our FRLs lie above these NDRLs, it suggests that we are delivering a higher dose than 75% of other institutions in Australia [12].

There have been several studies and overseas publications relating to DRLs and patient dose management, especially in the United States and European countries. In Australia, state-based dose optimisation projects were run by the Royal Australian and New Zealand College of Radiologists (RANZCR) involving Queensland, South Australia and Victoria from 2009-2012 [19, 20]. These reports collected data from 16 sites across Australia and New Zealand and site-specific feedback was obtained [20]. One available peer-reviewed publication arising from this initiative was reported [19]. The article investigated four adult examination protocols, including non-contrast brain, CT pulmonary angiography, CT lumbar spine, and CT urography [19]. Although site specific dose feedback is annually provided, no study has been published in a major public hospital in South Australia surveying common adult CT examinations, including chest, chest abdomen/pelvis, and abdomen/pelvis. The aim of this current study is to provide preliminary data for the establishment of FRL for $CTDI_{vol}$ and DLP for our current Toshiba Aquilion One Vision 320-slice scanner.

Materials and Methods

Ethics

This research study has been reviewed and waived for informed consent by the institutional ethics committee (Southern Adelaide Clinical Human Research Ethics).

Materials

Data was retrospectively collected from one CT scanner (Toshiba Aquilion One 320-slice, installed in 2015) in our institution from 26 December 2016 to 26 June 2017. This scanner was regularly serviced and tested for quality control and quality assurance. The FRL presented in this study are based on the median value of the dose spread from all patients, collected from the 26 December 2016 to 26 June 2017.

Dose quantities

$CTDI_{vol}$ is a measure of the radiation output from the CT scanner and can be measured using either a large (32cm diameter) or small (16cm diameter) plastic cylinder made up of polymethylmethacrylate [10, 11]. Dose measurements were made at the centre and at the periphery of the phantom [10, 11, 13-15]. These measurements are then combined using a weighted average to produce a single estimate of radiation dose to that plastic cylinder [13-15]. As this project is only a preliminary study, we only focused on the $CTDI_{vol}$ measured in the large phantom as a reference for adult CT in the torso (chest, abdomen and pelvis areas) [13-15]. DLP is based on $CTDI_{vol}$ factors in the length of the scan [13-15].

Data collection

All CT scans data for chest, abdomen and pelvis examinations in adults (age > 15 years) performed between 26 December 2016 and 26 June 2017 using the Toshiba scanner were extracted for data analysis. Examinations were separated as contrast and non-contrast studies, and single phasic for single acquisition or multiphasic for more than one acquisition. The common CT examinations, including chest, chest abdomen/pelvis, and abdomen/pelvis were reported. Examinations such as CT colonoscopy, CT pulmonary angiogram, CT gating angiography, CT chest and abdomen/pelvis non-contrast, CT high resolution lung and CT renal colic were excluded from the study, mostly due to a low number of examinations and the use of different exposure factors and/or techniques. The median mean (50th percentile), and 75th percentile for the dose spread were calculated according to the examination.

Results

There was a total of 1571 CT examinations performed between 26 December 2016 and 26 June 2017 using the Toshiba scanner in our institution. 262 examinations met the inclusion and exclusion criteria. The examinations were distributed as CT chest contrast (n=67, 25.6%), CT chest non-contrast (n=41, 15.6%), CT abdomen/pelvis contrast (single phase) (n=49, 18.7%), CT abdomen/pelvis contrast (multi-phase) (n=33, 12.6%), CT abdomen/pelvis non-contrast (n=12, 4.6%) and CT chest and abdomen/pelvis (n=60, 22.9%).

The mean, median, and 75th percentile of $CTDI_{vol}$ (mGy), and DLP (mGy.cm) for all these included studies are reported in (Table 1). This table summarises various percentile values of radiation doses in different CT examinations that can be used as a dose reference benchmark.

The DLP values for multiphasic examinations such as CT Abdomen/Pelvis and CT Chest were reported to be more than double of single phasic examinations. This is because there were commonly two to four subsequent acquisitions in these multiphasic protocols. The DLP values for multiphasic CT Abdomen/Pelvis are higher than multiphasic CT Chest, Abdomen/Pelvis because the number of subsequent acquisitions in CT Abdomen/Pelvis is higher (also has more coverage) than CT Chet, Abdomen/Pelvis.

Table 1: FRL and DLP median, mean value (50th percentile) and 75th percentile values for CT Abdomen/Pelvis, CT Chest, and CT Chest, Abdomen/Pelvis examinations

		Plain Abdomen/Pelvis	**Single Phase Abdomen/Pelvis**	**Multiphasic Abdomen/Pelvis**	**Plain Chest**	**Contrast Chest**	**Chest Abdomen/Pelvis**
Institutional Median Value (FRL)	CTDIvol	10.1	6.5	8.93	5.7	6	7.15
	DLP	289.9	330.5	1037.5	190.6	219.1	619.4
Institutional 50th percentile (Mean)	CTDIvol	9.78	8.09	11.8	6.71	6.26	8.15
	DLP	362.7	394.9	1428.6	236.6	229.8	767.8
Institutional 75th percentile (NDRL)	CTDIvol	12.47	9.6	16.15	9.5	8.55	10.87
	DLP	337.53	471.5	2044.8	333.5	319.7	1043.6

CT, computed tomography, FRL, facility reference level

Discussions

This paper establishes preliminary data of FRL for $CTDI_{vol}$ and DLP for the Toshiba scanner in our institution. DRLs have been defined by the ICRP as an investigational tool that applies to an easily measured quantity using a standard phantom or representative patient [9]. It is intended for use as a simple test for identifying situations where the levels of patient dose are unusually high [9]. This definition therefore suggests that DRL is not a dose limit but rather a reference level to help CT operators for optimisation and minimization of radiation doses. It shows the total dose to the patient for an examination [8, 9]. Although the impact of patient size on radiation dose is well-established, NDRLs have previously provided only one value for each examination, based on a standard-size phantom representing an "average" patient [15-18]. This is also a main limitation of this preliminary study. Size-based DRLs will allow other institutions to optimize protocols so that the resultant dose is commensurate with the size of the patient, thus avoiding unnecessary radiation exposure to the patient [15-18].

Furthermore, the specific manufacturer, and model of the scanner may lead to substantial variations in radiation outputs owing to inherent tube housing, filtration, collimation and number of detector rows [15-18]. This ultimately means that the preliminary data obtained from our Toshiba scanner might not be comparable with the data from other scanners in our institution. As a result, $CTDI_{vol}$ and DRLs across all other scanners in our institution could be established and systematically analysed for any statistical differences.

There are considerable DRLs and benchmarks available internationally for our comparison. (Table 2) provides a domestic and international comparison of our median $CTDI_{vol}$ and DLP values with ICRP (2007), Ireland (2010), United Kingdom (2006), European (2006), Singapore (2017), Japan (2015), UCMC (2015), Canada (2016), ACA AAPM (2013), EU (2014), NCRP (2012), Greece (2014) and nationally with ARPNSA (2015) [8, 9, 12, 20, 22-30]. Our institutional median values, also known as, our FRL are considerably lower than all other countries and well below our NDRL. For some phases, the scan length can be reduced, focusing on the anatomy of interest. Close collaboration of radiologists, physics and radiographers is essential in maintaining our optimization of patient radiation dose

Table 2: Domestic and International comparisons of NDLP values

		Plain Abdomen/Pelvis (A/P)	Single Phase A/P	Multiphasic A/P	Plain Chest	Contrast Chest	Chest, Abdomen, Pelvis
ICRP (2007)[9]	CTDIvol		35				
	DLP		780				
Ireland (2010)[21]	CTDIvol		12	13			12
	DLP		600	1120			850
United Kingdom Study (2006)[22]	CTDIvol		19		18		
	DLP		472				
European (2006)[8]	CTDIvol		35		30		
	DLP		780		650		
Singapore (2017)[23]	CTDIvol		12	12		7	13
	DLP		643	1786	295		1349
Japan (2015)[24]	CTDIvol	20	20	15	15		18
	DLP	1000	1000	1800	550		1300
UCMC (2015)[25]	CTDIvol		17	17	17		
	DLP		860	1790	610		
Canada (2016)[26]	CTDIvol	13	13		9.5		12
	DLP	609	609		362		931
ACR-AAPM (2013)[27]	CTDIvol	25	25		21	21	
	DLP						
EU (2014)[28]	CTDIvol	25	25				
	DLP	800	800				
NCRP (2012)[29]	CTDIvol		25	25			
	DLP						
Greece (2014)[30]	CTDIvol		16	16	14	14	17
	DLP		760	760	480	480	1020
Australia (2018)[12]	CTDIvol		15	15	30		
	DLP		700	450	1200		
Institutional 75th percentile (NDRL)	CTDIvol	12.47	9.6	16.15	9.5	8.55	10.87
	DLP	337.53	471.5	2044.8	333.5	319.7	1043.55

$CTDI_{vol}$, volume computed tomography index, DLP, dose length product, FRL, facility reference level, NDRL, national diagnostic reference level.

Limitations

The project was a preliminary study, based on retrospective data collected over six months period. A longer timeframe, a larger selection of CT examinations, and an inclusion of all other scanners in the institution would have allowed more data to be collated and analysed. This would help to enhance the validity and reliability of our study. Furthermore, our institute does not have all commercially available CT scanners. Therefore, a multi-centre study could be performed in the future to provide a more comprehensive analysis and establishment of DRLs in South Australia. The comparison of our institutional DRLs was not thorough as some other countries utilized different scanning protocols, scanners and reporting methods. There was little to no declarations of how their DRLs were obtained. In this preliminary study, we were also not able to account for absorbed doses as size-specific dose estimates (SSDE) were assessed. We have, however, not included institutional DRLs for paediatric examinations as the DRLs may vary significantly due to the paediatric patient's size, weight and age.

Conclusions

This study presents a preliminary data collected in our institution, aiming to establish an FRL for one specific scanner for adult CT examinations of the torso (chest, abdomen and pelvis areas). The data shows that our institutional 75th percentile (NDRL) for both $CTDI_{vol}$ and DLP are lower compared to other established bench values. This study allows our institution and other facilities to effectively compare our patient doses with national and international benchmarks. This study also allows us to optimize our CT protocols, resulting in lower doses at the appropriate image quality. Future work includes expanding the analysis to include more CT examinations in various scanners.

Disclosures of Conflicts of Interest

The authors declare no conflicts of interest

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