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ORIGINAL ARTICLE

Establishment of institutional diagnostic reference level for computed tomography with automated dose-tracking software

Chong R. Liang, MSc, Priscilla X. H. Chen, MSc, Jeevesh Kapur, FRCR, Michael K. L. Ong, MSc, Swee T. Quek, FRCR, & Subhash C. Kapur, PhD

Department of Diagnostic Imaging, National University Hospital, Singapore

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Correspondence
Subhash C. Kapur, Department of Diagnostic Imaging, National University Hospital, Singapore 5, Lower Kent Ridge Road, Main Building 1, Level 2, Singapore 119074.
Tel: +65 8186 5765, +65 6772 3538; Fax: +65 6772 4288; E-mail: subhash_c_kapur@nuhs.edu.sg

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Abstract

Introduction: The aim of this study was to establish institutional diagnostic reference levels (DRLs) by summarising doses collected across the five computed tomography (CT) system in our institution. **Methods:** CT dose data of 15940 patients were collected retrospectively from May 2015 to October 2015 in five institutional scanners. The mean, 75th percentile and 90th percentile of the dose spread were calculated according to anatomic region. The common CT examinations such as head, chest, combined abdomen/pelvis (A/P), and combined chest/abdomen/pelvis (C/A/P) were reviewed. Distribution of CT dose index (CTDIvol), dose-length product (DLP) and effective dose (ED) were extracted from the data for single-phasic and multiphasic examinations. **Results:** The institutional DRL for our CT units were established as mean (50th percentile) of CTDIvol (mGy), DLP (mGy.cm) and ED (mSv) for single and multiphasic studies using the dose-tracking software. In single phasic examination, Head: (49.0 mGy), (978.0 mGy.cm), (2.4 mSv) respectively; Chest: (6.0 mGy), (254.0 mGy.cm), (4.9 mSv) respectively; CT A/P (10.0 mGy), (514.0 mGy.cm), (8.9 mSv) respectively; CT C/A/P (10.0 mGy), (674.0 mGy.cm), (11.8 mSv) respectively. In multiphasic studies: Head (45.0 mGy), (1822.0 mGy.cm), (5.0 mSv) respectively; Chest (8.0 mGy), (577.0 mGy.cm), (10.0 mSv) respectively; CT A/P: (10.0 mGy), (1153.0 mGy.cm), (20.2 mSv) respectively; CT C/A/P: (11.0 mGy), (1090.0 mGy.cm), (19.2 mSv) respectively. **Conclusions:** The reported metrics offer a variety of information that institutions can use for quality improvement activities. The variations in dose between scanners suggest a large potential for optimisation of radiation dose.

Introduction

Since the introduction of computed tomography (CT) in 1970s, it has shown a tremendous growth in various aspects. An example is the increasing trend of number of examinations done per year.[1–3] Clinicians show a preference in CT as it provides fast and accurate three dimensional data as compared to other medical imaging tools, hence allowing better patient management. Over the years, people are getting exceedingly concerned about the dose they received from CT examinations since it is associated with relatively high radiation doses and potential increased risk of carcinogenesis. To cope with growing medical exposure, International Atomic Energy Agency (IAEA, 2006)[4] and International Commission on Radiological Protection (ICRP, 2007)[5] have recommended the establishment of diagnostic reference levels (DRLs) as a tool for optimising the radiation dose delivered to patients while meeting the clinical objectives. The DRL process has been popularised in Europe, United States and United Kingdom and has been applied with good results.[6]

DRL is defined as dose levels for typical examinations for groups of standard-sized patients or standard

phantoms for broadly defined types of equipment.[7] The 75th percentile of a dose metric distribution is used as national DRL (NDRL) and the mean (or 50th percentile) within an institution is used as local DRL (LDRL) which would not exceed national DRL.[5] The establishment of NDRL should be comparable to international DRL and act as guidance for CT practice in such countries and their institutions. IPEM 2004[8] had set up the CT guidelines for DRL to promote the optimisation of CT dose to various examinations. Examination specific dose reference levels for patients can provide stimulus for monitoring and auditing of CT doses to promote improvement in radiation safety. As low as reasonably achievable (ALARA) is the guiding principle for achieving the lowest possible exposure to a particular clinical setting according to set protocols by repeated analysis of the dose metric data.[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.

There were many publications and studies related to patient doses done overseas. Currently, there is no such dose study or any CT DRLs established in Singapore. The aim of this study was to establish institutional DRLs through summarising doses collected across the five CT systems in our institution and optimise the CT doses in adult CT protocols through continuous monitoring by automated dose-tracking software. The institutional DRL will be periodically reviewed and revised on the bases of updated data reflecting changes in the dose management and applied technology.

Materials and Methods

CT systems

This study has been reviewed by the institutional ethics committee (Domain Specific Review Boards) and exempted for informed consent by the ethic committee.

Data were retrospectively collected from the five multislice CT (MSCT) systems in our institution. Details of the CT systems are shown in Table 1. All CT scanners were evaluated and tested for quality assurance and quality control protocols regularly for CT Dose Index volume ($CTDI_{vol)}$ and dose length product (DLP) and the variations in values were found to be within 10%. The institutional DRLs presented in this study are based on mean value (50th percentile) of the dose spread from all patients.

CT dose quantities

Dose quantities and units commonly used to set diagnostic levels were described recently and were accepted as reference dose values.[10] $CTDI_{vol}$ is a measure of the radiation output of CT system and is a quantity that can be measured on either a large (32 cm diameter) or small (16 cm diameter) plastic cylinder made up of poly methyl methacrylate (PMMA). Dose measurements were made at the centre and at the periphery, and these values were combined using a weighted average to produce a single estimate of radiation dose to that plastic cylinder. The $CTDI_{vol}$ was measured in the large phantom and was used as a reference for adult CT in the torso (chest, abdomen and pelvis). The $CTDI_{vol}$ measured in the small phantom was used as a reference for head and pediatric body CT for scanner manufacturers.[11] $CTDI_{vol}$ provided a very useful way to compare the doses delivered by various scan protocols used on different CT units used in this study. DLP is a combination of $CTDI_{vol}$ and the scan length to quantify the dose received by the patient. $CTDI_{vol}$ and DLP are readily available at the end of each CT examination as all vendors are now required to display those values on their interface. The effective dose (ED) is a quantity which is a risk metric and the computation of ED is performed by estimating organ absorbed dose, and then multiplying each of those by a tissue weighting factor.[11] These weighting factors are

Table 1. Details of CT systems used in our institution.

Scanner	Manufacturer	Model	Slices	Year of installation	Iterative reconstruction
a.	Siemens	Somatom Force	384	2015	ADMIRE
b.	Philips	iCT (1)	256	2013	iDOSE4
c.	Philips	iCT (2)	256	2010	iDOSE4
d.	Siemens	Somatom Sensation	64	2008	No
e.	Philips	Brilliance	64	2009	No

CT, computed tomography.

based on large epidemiological studies as well as current understanding of biological effects of radiation.

Data collection

All examination data for consecutive examination in adult (age >16 years) performed between May 2015 and October 2015 were extracted from an automated dose-tracking software database, the Radimetrics Enterprise Platform (Bayer Healthcare LLC, Whippany, NJ, USA). We were able to extract data such as patient gender, age, time of scan, scan protocol, scanner manufacturer and model, $CTDI_{vol}$, DLP and ED.

$CTDI_{vol}$ and DLP form the basis for reference doses set for the purposes of promoting optimisation of patient protection. In addition, values of ED for complete CT examinations are also useful for comparison with other types of radiological procedures. Radimetrics reads the $CTDI_{vol}$ and DLP value from the dose information page generated from the CT scanner. To calculate the ED, Radimetrics uses the library of Cristy phantoms and matches patients to a particular phantom on the basis of age, weight or diameter according to ICRP 103 tissue-weighting factors.[5]Data on patient weight and height were not recorded, so Radimetrics calculated the ED based on age and diameter in this study.

Examinations were separated as single phasic for single acquisition or multiphasic for more than one acquisition. Brief scans obtained to determine the peak time for contrast injection were excluded as acquisitions.

The mean (50th percentile), 75th percentile and 90th percentile of the dose spread were calculated according to anatomic regions. The common CT examinations on regions such as head, chest, combined abdomen/pelvis (CT A/P) and combined chest/abdomen/pelvis (CT C/A/P) were reported. Examinations such as CT colonography and high-resolution lung were excluded from the study because the number of such scans was only 210, which was 1.3% of the total number of examinations.

Results

There were 15940 adult CT examinations that were evaluated from May to October 2015. These exams were performed over five multislices CT scanners, whereas three (a, b, c) were equipped with iterative reconstruction (IR) technique and other units (d and e) were with other dose reduction techniques such as (CARE DOSE4, and DOSE RIGHT) as shown in Table 1. The examinations were distributed as CT head (n = 6920, 43.4%), CT A/P (n = 5033, 31.6%), CT C/A/P (n = 2803, 17.6%), CT chest (n = 1184, 7.4%) (Table 2). The results revealed significant discrepancies in dose values among the CT scanners, which can be mainly attributed to variations in the examination protocols and the different kinds of scanners.

The mean, 75th percentile and 90th percentile of $CTDI_{vol}$ (mGy), DLP (mGy.cm) and ED (mSv) for single-phasic and multiphasic studies were compared and were reported in Table 3 with the exception of CT chest done on Siemens Somatom 64-slice (scanner d) due to a mixing data error. This table summarises various percentile values of doses in different CT examinations that can be used as a reference bench mark.

$CTDI_{vol}$ values for multiphasic examinations were equal or slightly higher than single phasic examinations. For multiphasic CT head, the DLP and ED are approximately twice of single phasic. The DLP and ED for multiphasic CT A/P and CT chest are slightly more than double of single phasic because there were typically two to four acquisitions for multiphasic. For CT C/A/P, the DLP and ED are slightly less than double of single phasic. This is due to lesser scan coverage for the 2nd and subsequent acquisitions in multiphasic. The DLP and the ED for multiphasic CT A/P is higher than multiphasic CT C/A/P because the number of acquisition in CT A/P is higher than CT C/A/P.

Mean (50th percentile) $CTDI_{vol}$, DLPs and EDs were also presented and compared across different CT systems (Figs. 1–3). The results showed that the examinations

Table 2. Number of examinations done on each CT system from May 2015 to October 2015.

Scanner	Head	Chest	CT A/P	CT C/A/P	Total
a.	159	174	684	410	
b	508	300	1145	866	
c.	1569	565	1427	756	
d.	927	–	958	693	
e.	3757	145	819	78	
Total	6920	1184	5033	2803	15940
Percentage	43.41%	7.43%	31.57%	17.58%	

CT, computed tomography; CT A/P, CT abdomen and pelvis; CT C/A/P, CT chest, abdomen and pelvis.

Table 3. Radiation dose metrics.

Area and examination type	No. of examinations	$CTDI_{vol}$ (mGy)			DLP(mGy.cm)			Effective dose (mSv)		
		Mean	75th percentile	90th percentile	Mean	75th percentile	90th percentile	Mean	75th percentile	90th percentile
Head										
Single phasic	6305	49	51	53	978	1057	1109	2.4	2.6	2.8
Multiphasic	615	45	52	53	1822	1988	2249	5.0	5.1	6.9
All	6920	49	51	53	1052	1079	1170	2.6	2.7	3.0
Chest										
Single phasic	1018	6	7	10	254	295	408	4.9	5.5	7.3
Multiphasic	166	8	9	13	577	697	1069	10.0	13.2	18.3
All	1184	6	7	10	291	322	491	5.5	6.0	9.1
CT A/P										
Single phasic	3084	10	12	15	514	643	817	8.9	11.4	13.7
Multiphasic	1949	10	12	14	1153	1406	1786	20.2	25.0	31.1
All	5033	10	12	15	761	985	1415	13.3	17.0	25.0
CT C/A/P										
Single phasic	2360	10	12	15	674	823	990	11.8	14.5	19.4
Multiphasic	443	11	13	16	1090	1349	1684	19.2	25.1	30.7
All	2803	10	12	15	740	894	1116	13.0	16.1	21.0

$CTDI_{vol}$, CT dose index volume; DLP, dose length product; CT A/P, CT abdomen and pelvis; CT C/A/P, CT chest, abdomen and pelvis.

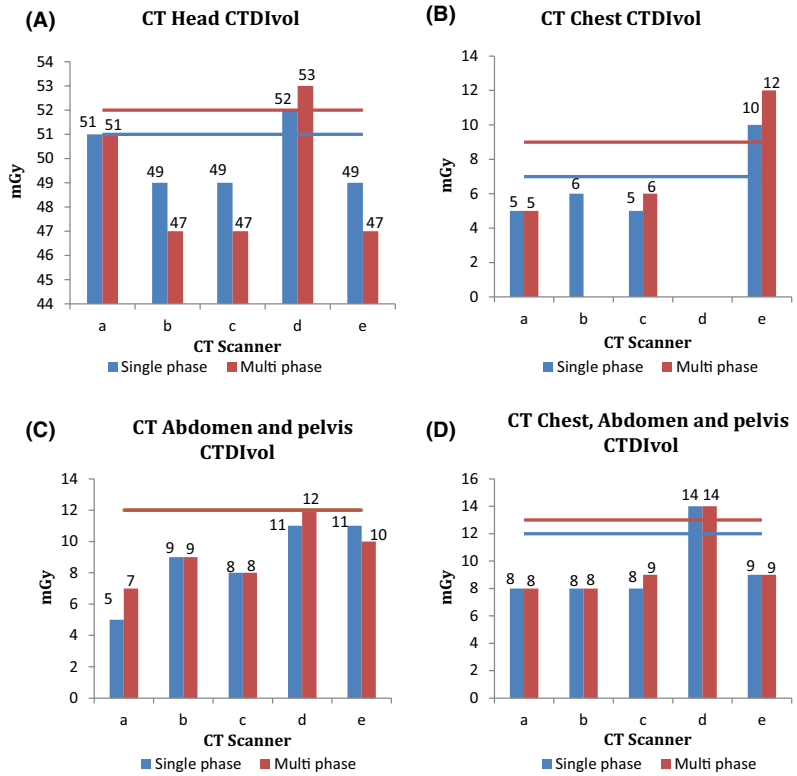

Figure 1. Mean $CTDI_{vol}$ distribution for examinations done on the five computed tomography (CT) systems. (A) CT head. (B) CT Chest. (C) CT Abdomen/Pelvis. (D) CT Chest/Abdomen/Pelvis. Blue and red lines represent 75th percentile value.

performed with the 384-slice CT has the lowest mean $CTDI_{vol}$ (except $CTDI_{vol}$ in CT head) and DLPs which are all below the summarised 75th percentile data. This is due to its new detector (2× Stellar Infinity detector with 3D Anti-Scatter collimator) and dose saving features such as Advanced Modeled Iterative Reconstruction

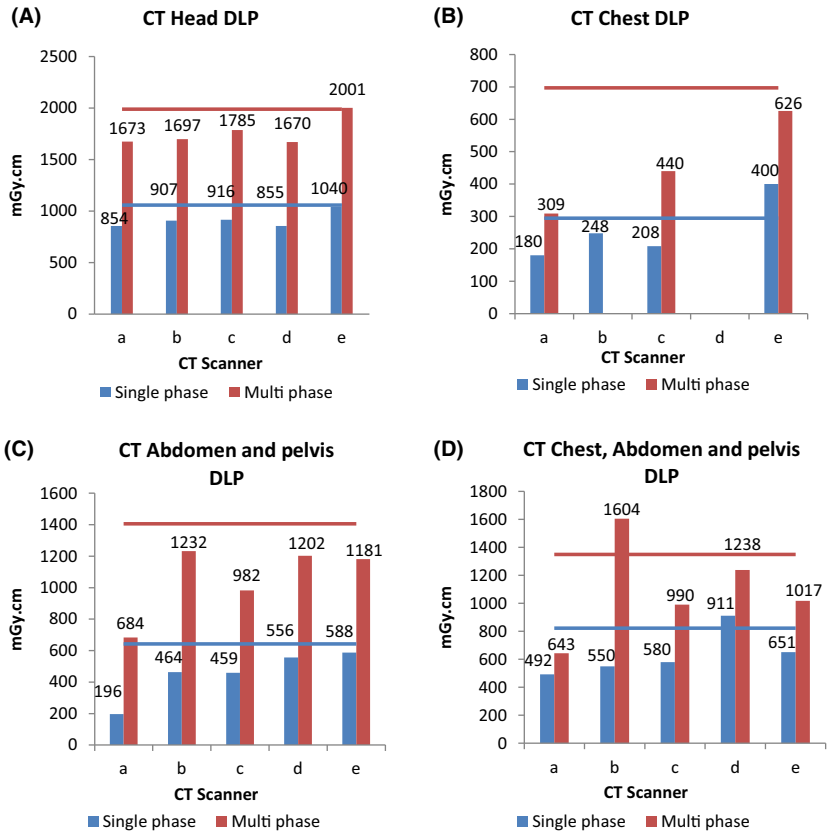

Figure 2. Mean dose-length product distribution for examinations done on the five computed tomography (CT) systems. (A) CT head. (B) CT Chest. (C) CT Abdomen/Pelvis. (D) CT Chest/Abdomen/Pelvis. Blue and red lines represent 75th percentile value.

(ADMIRE), automated tube voltage selection and automated tube current modulation (CARE 4D and CARE kV). Philips 64-slice (scanner e) CT without IR technique has the highest mean DLP and ED in CT head for both single phasic and multiphasic examinations even though the $CTDI_{vol}$ for CT head is relatively low. This implied a longer scan length being used. It also has the highest mean value in $CTDI_{vol}$, DLP and ED for CT chest with the highest mean $CTDI_{vol}$ exceeding summarised 75th percentile data in both single phasic and multiphasic examinations. This suggested the use of higher scan parameters such as kVp and mAs and a need for dose optimisation of the CT chest protocol. Philips 256-slice CT (scanner b) has highest mean DLP in multiphasic CT A/P and CT C/A/P (with CT C/A/P exceeding 75th percentile tremendously) due to high volume of tri-phasic/quad-phasic scans done. Siemens 64-slice CT (scanner d) without IR technique has the highest mean $CTDI_{vol}$ for CT C/A/P which is exceeding 75th percentile value. The scanning protocols which exceed 75th percentile require closer attention and dose optimisation.

Discussion

DRL as defined by ICRP as 'a form of investigation level, applied to an easily measured quantity, usually the absorbed dose in air or tissue-equivalent material at the surface of a simple standard phantom or a representative patient'.[5] This suggests that DRL is not a dose limit but rather a benchmark to help operators for optimisation of radiation doses. Our results revealed a wide range of values across different types of scanners. This is in line with some data published in Ireland.[12] Variations may occur depending on type of scanners and protocols used. The specific make and model of the CT scanner may lead to some variation in doses owing to inherent differences such as filtration, beam geometry, number of detector rows and scattered X-rays. Variations among the two identical 256-slice CT demonstrate that dose differences are not just attributed to the CT scanner design, but can be due to variations in scanning parameters and protocols such as those used in combined CT chest/abdomen/pelvis studies. A process of continuous audit is recommended to guide the appropriateness of our

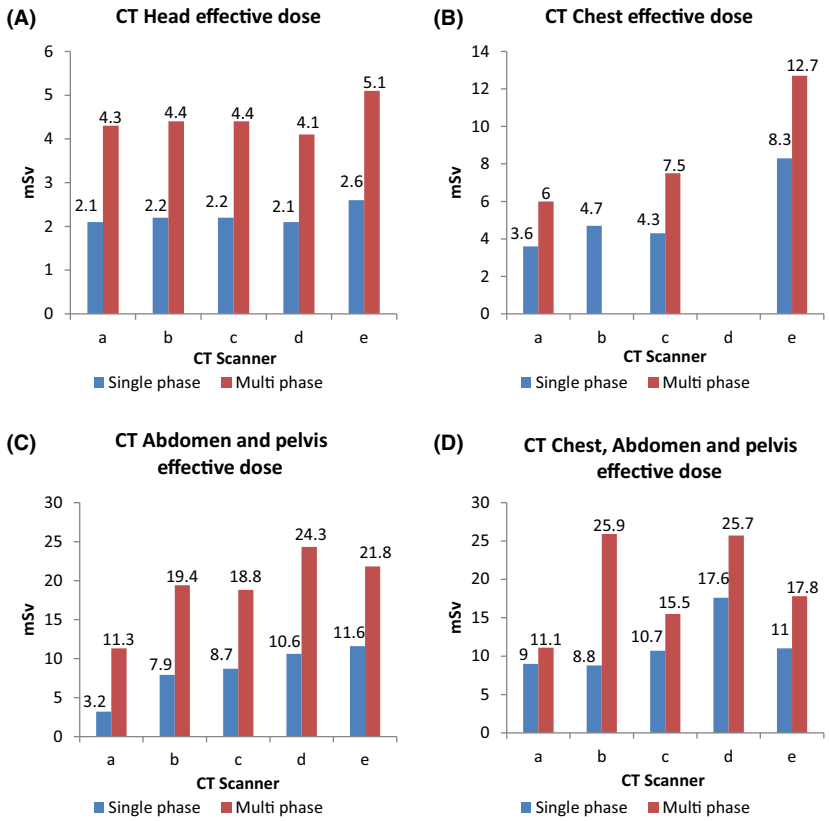

Figure 3. Mean effective dose distribution for examinations done on the five computed tomography (CT) systems. (A) CT head. (B) CT Chest. (C) CT Abdomen/Pelvis. (D) CT Chest/Abdomen/Pelvis.

scanning parameters and to avoid unnecessarily high doses being delivered.[13] In addition, it is also important to ensure that similar diagnostic quality images are being produced across the CT systems and the DRLs produced by each CT system are within the institutional limits.

There are considerable data and benchmarks available internationally for comparison. Table 4 shows comparison data of $CTDI_{vol}$ and DLP from ICRP,[5] Ireland,[12] Australia,[14] Japan,[15] and University of California Medical Centre (UCMC)[16] in United States (US). Our 75 percentiles for all reported examinations are notably below Japan and UCMC DRLs. This may be due to our relatively small patient habitus compared to US patients. There are also three high-end CT systems (scanner a, b, c) equipped with latest radiation dose reduction hardware and software in our institution. The views on how to define optimised scanning protocols may be different in Japan, UCMC and us, which could account for these dose differences. For CT head, our $CTDI_{vol}$ level is below ICRP, Ireland and Australia while DLP is slightly higher. This means our scan length for CT head is longer than international recommendation. For all other exams, our dose levels are comparable to or in fact some are below the recommendations from ICRP, Ireland and Australia.

As highlighted in Table 3, the radiation dose for CT A/P and CT C/A/P in multiphasic studies is high across all the centres. Certain steps may be taken to lower such doses, including proper planning for multiphasic studies, to ensure their utility and diagnostic value. For some of the phases, the scan length can be reduced, focusing on the anatomical region to be assessed. Close collaboration of clinicians, radiologists and physicists is essential in modifying and optimising exposure factors such as mAs, kVp and use of IR techniques while maintaining good diagnostic image quality. Further studies may be conducted to understand the impact of all these measures.

Limitations

The study was based on retrospective data collected over 6 months. A longer period would have allowed more data collection and strengthened this study. In addition, there was no record of patient weight and height within the study, which may influence the automatic exposure control

Table 4. Institutional diagnostic reference levels (DRLs) [$CTDI_{vol}$ (mGy) and DLP (mGy.cm)] and comparison with international DRLs.

	Exam	Head	Chest	Abdomen/ Pelvis	Chest/Abdomen/ Pelvis	Multiphasic Abdomen/Pelvis
ICRP[5]	$CTDI_{vol}$	60	30	35	–	–
	DLP	1050	650	780	–	–
Ireland 2010[12]	$CTDI_{vol}$	58	11	12	12	13
	DLP	940	390	600	850	1120
Australia[14]	$CTDI_{vol}$	60	15	15	30	–
	DLP	1000	450	700	1200	–
Japan 2015[15]	$CTDI_{vol}$	85	15	20	18	15
	DLP	1350	550	1000	1300	1800
United States(UCMC)[16]	$CTDI_{vol}$	62	17	17	–	17
	DLP	1120	610	860	–	1790
Institutional 50th percentile	$CTDI_{vol}$	49	6	10	10	10
	DLP	980	255	515	675	1155
Institutional 75th percentile	$CTDI_{vol}$	51	7	12	12	12
	DLP	1060	295	645	825	1410

All values are rounded to the nearest integer. All exams are single phase studies except multiphasic abdomen/pelvis. CTDIvol, CT dose index volume; DLP, dose length product; ICRP, International council on radiation protection; UCMC, University of California Medical Center.

and DLP values reported. It is a single centre feasibility study performed on multiple scanners with different imaging parameters. One of the inherent limitations of this study is that only Siemen's and Philips CT scanners were reviewed. Our institute does not have any Toshiba or GE CT scanners and further multicenter studies may be performed for a comprehensive analysis of all commercially available CT scanners. The comparison of our institutional dose reference level with other countries DRLs is not straight forward. The patient dose surveys conducted by other institutions for establishing DRLs appear to be different from our study (Table 4). There is little guidance on statistical methodology used in such surveys or how their DRLs were obtained. Although the case load in our institution varies greatly in terms of type of cases, including oncology and emergency cases, the DLPs reflect the standard CT protocols used in these studies. We do not have any specific protocols for oncology patients in our institution. We did not assess size-specific dose estimates (SSDEs), so are unable to account for the absorbed dose. Our CT request indications were not included which can affect scan parameters that can lead to higher or lower DLP values. The data also did not exclude single acquisition study that were repeated due to technical and patient related factors such as motion artefacts or body habitus; which can attribute to higher DLP value for some studies. The collected patient data included data from old and new technology CT units, so that the established institutional dose reference level is representative of all radiological practice in the institution. However, our results reflect the reduced DLP in the studies which used IR and the reduction appears to be significantly less as compared to non-IR scanners. We have not included institutional DRLs for paediatric examinations as patient dose level may vary considerably as a function of age, size or weight due to lack of standardisation of these groups. Our summary data might not be appropriate for facilities with a specific case mix – for example a cardiac centre that only performs cardiac CT.

Conclusion

This paper presents a preliminary data collected in our institution in order to establish institutional DRL for commonly performed procedures according to anatomical regions. The regular review of these institutional DRLs at local and regional level can provide a feedback loop that ensures a good practice for radiation safety for patients especially after replacement of equipment and changes in protocols. Although there are authoritative societal DRLs from US, Europe, UK, Australia and Japan that other institutions can follow, the reported metrics offer a variety of information that represents patient characteristics in Singapore. Local institutions can use it for quality improvement activities. Local institutions can compare their dose distributions to our reported values to determine whether their doses are within this attainable range. If distributions are considerably higher, institutions can consider reviewing their protocols and scanning settings. Since DRLs are a useful tool for dose optimisation, a coordinated effort between radiologists, technologists and medical physicist must be applied to achieve lowest possible radiation dose without affecting image quality and patient care. We hope our institutional CT DRLs data can add value to the creation of national CT DRLs in Singapore.

Conflict of Interest

The authors declare no conflict of interest.

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