Original Article

JHSMR Journal of Health Science and Medical Research

Radiation Dose from Computed Tomography Scanning in Patients at Songklanagarind Hospital: Diagnostic Reference Levels

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Received 11 September 2019 ● Revised 20 September 2019 ● Accepted 25 November 2019 ● Published online 27 March 2020

Abstract:

Objective: To determine diagnostic reference levels (DRLs) of computed tomography (CT) radiation doses in terms of CT dose index volume ($CTDI_{vol}$) and dose length product (DLP) of CT scans of the head, chest and abdomen for patients at Songklanagarind Hospital, Thailand.

Material and Methods: This was a retrospective analysis of 463 randomly selected head, chest and abdominal CT stuides from 416 patients enrolled from July 1st to 31st 2017. The $CTDI_{vol}$, DLP and clinical indication for each CT study were conducted. The median and third quartile values were analysed and compared to the standard international DRLs. The DRL was defined as the third quartile value.

Results: The DRLs for $CTDI_{vol}$, and DLP of head, chest and whole abdominal CT were 57.5, 11.6 and 13.1 milliGray (mGy), and 1,102.6, 474.7 and 624.4 milliGray x centimetre (mGy.cm), respectively. The most common clinical indications were stroke (29.1%) for head CT and malignancy for both chest (73.6%) and abdominal CTs (49.6%).

Conclusion: The DRLs of each CT region were mostly below standard international DRLs of Australia, Europe, Japan, the United Kingdom and the United States. The clinical indication for malignancy had significant difference in the DLP values than other clinical indications in head and chest CT.

Keywords: computed tomography, CT dose index, dose length product, diagnostic imaging, diagnostic reference level, radiation dose

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J Health Sci Med Res 2020;38(2):135-143
doi: 10.31584/jhsmr.2020732
www.jhsmr.org

Introduction

Computed tomography (CT) was introduced in 1972 and multi-detector CT (MDCT) came about in 1998. Nowadays, both of these are considered as important diagnostic tools, and there has been an exponential rise in numbers of CT scans performed in the United States (US) of nearly 70 million in 2007.[1] They are a major source of ionizing radiation, as a 2009 US study found CTs alone (11.0% X-ray based imaging) being responsible for 75.0% of effective radiation doses from medical imaging.[2] Since then medical literature has increasingly focused on the significance of patient radiation doses.[3] More pediatric patients undergoing CT scans and rapid advancements in CT applications provide the main concern for biological adverse side effects and the risk of future cancers.[4-6] Although the association of ionizing radiation with subsequent development of cancer was based mainly on data obtained from studies of the Japanese atomic bomb survivors, patients should not be discourage from having appropriate diagnostic imaging with dose optimization.[7-11]

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) suggested 10-100 milliGray (mGy) is the absorbed dose for low-LET radiation to an individual from multiple whole body CT scans.[12] The International Commission on Radiological Protection (ICRP) proposed diagnostic reference levels (DRLs), defined as investigational levels applied to easily measured quantity using standard phantom or representative patient, expressed as volume CT dose index ($CTDI_{vol}$), dose length product (DLP) and effective dose[13,14] to help optimize radiation doses and identify unjustified doses. ICRP emphasized that DRLs should be derived from national or local data and the "As Low as Reasonably Achievable" or ALARA principle be adhered to so as to minimize potential hazards of ionizing radiation.

There were many countries in Western and Asian regions that have established and reported their national DRLs for adult CT studies: for example Australia, Northern Greece, Turkey, the United Kingdom (UK), other European countries, US, Iran, Malaysia, Japan, and India.[15-25] A study in Thailand in 2012 found CT radiation dose of head below international DRLs but those of CT chest and abdomen exceeded the international DRLs.[26] A 2011's study at five Thai university hospitals, including Songklanagarind Hospital, noted DRLs of adult brain, chest and abdominal CT varied widely but were within acceptable levels compared to international DRLs.[27]

The objective of this study was to obtain CT radiation DRLs in terms of $CTDI_{vol}$ and DLP of the most commonly carried out regions of CT scans for adult patients at Songklanagarind Hospital then to and compare then with both international and prior DRLs.

Material and Methods

The study was approved by the Human Research and Ethics Committee of the Faculty of Medicine, Prince of Songkla University, REC.: 61-176-7-4.

A retrospective descriptive study with analytic component of 463 CT scans of head, chest and abdomen at Songklanagarind Hospital was conducted. The enrollment period was from July 1st to 31st, 2017. Exclusion criteria were an age less than 15 years, contiguous chest- abdomen-pelvic CT scans and high-resolution CT (HRCT) of the chest.

A CT scanner of 80 slices manufactured by Toshiba, model Aquilion^{TM} PRIME with serial number BKA 1522134 installed in 2012 in our unit.

All CT scans of adults, fulfilling inclusion and exclusion criteria during the study period, were assigned serial numbers for a total of 1,136 CT scans. Computer generated random selection of these serial numbers fulfilled the calculated total sample size of 463 as well as the categorized sample size. CT data of only selected serial numbers were manually collected from the Picture Archiving

and Communications system at the Department of Radiology, Faculty of Medicine, Songklanagarind Hospital, Prince of Songkla University.

Independent variables were demographic data including gender and age of patients and the clinical indications for each CT study. The clinical indications were categorized into trauma, infection/inflammation, malignancy, congenital, stroke and others (miscellaneous). The examples of others category are chronic headaches in head CTs, pleural effusion, sarcoidosis in chest CT, chronic abdominal pain, obstruction, anemia, ureteric stones, aneurysms and myomas in abdominal CTs.

The radiation dose parameters provided from the CT scanner were collected: $CTDI_{vol}$ (units: mGy), and dose length product (DLP) (units: mGy.cm). The DRL was defined as the 3rd quartile of patient dose distribution (median) for each protocol. A total sample size of 463 was established by equation from available data and further stratified proportionately into the three CT categories. The effective dose (unit milliSievert) which was the biological dose determining the overall long term risk was also calculated by multiplying DLP by conversion co-efficient factor for respective anatomical regions.[27]

The categorical variables such as like demographic data were presented as counts and percentages. Mean± standard deviation, median and inter-quartile range (IQR) of the $CTDI_{vol}$ and DLP values were calculated and tabulated. The DRLs obtained by our study were compared to the prior 2011 study at our CT unit and to international DRLs.[15,18-21,27] Our DRLs and the clinical indications for each CT anatomical region were analyzed using the Kruskal-Wallis rank sum test. A p-value of <0.05 was considered to be statistically significant.

Results

Demographic data and clinical indication distribution according to CT anatomical regions were shown in Table 1 and 2.

The median (interquartile range) DLP in different clinical conditions were shown in Table 3. In head CT, the DLP in patients with malignancy was significantly higher than stroke, trauma, infection/inflammation, congenital anomaly, and other conditions (p-value<0.05). Whereas, the DLP of chest CT or whole abdominal CT in patients with malignancy were not significantly different from another conditions (p-value>0.05).

The $CTDI_{vol}$, DLP and effective dose of head, chest and whole abdominal CT in different phases were shown in Table 4. Numbers of CT studies with $CTDI_{vol}$ and DLP above the third quartile (DRLs) were shown in Table 5.

Table 1 Demographic data of the participants

Data	Head CT	Chest CT	Whole abdomen CT	Total CT
No. of patients	210	71	135	416
No. of CT scans	254	72	137	463
Male, n (%)	98 (47.0)	38 (54.0)	56 (42.0)	192 (46.0)
Age (years), mean±S.D.	57.6±19.7	59.4±16.8	54.9±15.8	57.0±18.0

CT=computed tomography, No.=number, n=number of patients, S.D.=standard deviation

Table 2 Clinical indication distribution according to computed tomography anatomical regions

Clinical indications	Head CT Number (%)	Chest CT Number (%)	Whole abdomen CT Number (%)
Malignancy	59 (23.0)	12 (17.0)* 41 (57.0)**	68 (50.0)
Stroke	74 (29.0)	N/A	N/A
Trauma	73 (29.0)	–	12 (9.0)
Infection/inflammation	15 (6.0)	16 (22.0)	42 (31.0)
Congenital anomaly	16 (6.0)	1 (1.0)	1 (1.0)
Others	17 (7.0)	2 (3.0)	14 (10.0)

*Scan length covering entire chest only

**Scan length covering entire chest+upper abdomen down to inferior pole of right kidney

CT=computed tomography, N/A=not applicable

Table 3 Comparison of dose length product (mGy.cm) according to clinical indications

Clinical indications	Head CT (mGy.cm)	Chest CT (mGy.cm)	Whole abdomen CT (mGy.cm)
Malignancy	2,067 (1,920, 2,161)	326 (267, 474)* 357 (278, 473)**	992 (604, 1,467)
Stroke	1,048 (981, 1,103)	N/A	N/A
Trauma	1,069 (1,009, 1,115)	N/A	1,174 (914, 1,416)
Infection/inflammation	1,953 (1,033, 1,080)	276 (258, 349)	1,072 (649, 1,620)
Congenital anomaly	1,026 (978, 1,080)	479 (only 1 case)	2,247 (only 1 case)
Others	1,322 (1,048, 2,113)	517 (345, 679)	1,500 (1,221, 1,416)

Data are presented as median (interquartile range)

*Scan length covering entire chest only

**Scan length covering entire chest+upper abdomen down to inferior pole of right kidney

CT=computed tomography, N/A=not applicable

Table 4 Volume computed tomography dose index, dose length product, and effective dose of computed tomography head, chest and whole abdomen

Region	Phase (n)	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	Effective dose (mSV)
Head CT	Non-contrast (186)	55.8 (52.3, 57.5)	1,048.7 (99.7, 1,102.6)	2.5 (2.3, 5.5)
	Non-contrast and contrast-enhanced (68)	57.5 (52.3, 57.5)	2,113.0 (1,990.0, 2,188.0)	4.9 (4.6, 5.1)
	Total (254)	55.8 (52.3, 57.5)	1,089.9 (1,009.2, 1,924.6)	2.5 (2.3, 4.4)
Chest CT	Contrast (72)	7.9 (6.2, 11.6)	317.0 (260.6, 474.7)	5.4 (4.4, 8.1)

Table 4 (continued)

Region	Phase (n)	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	Effective dose (mSV)
Whole abdomen CT	Plain (17)	9.6 (7.8, 26.8)	397.8 (299.1, 488.7)	6.0 (4.5, 7.3)
	Arterial (20)	9.2 (7.6, 13.0)	324.9 (223.9, 469.2)	4.8 (3.3, 7.0)
	Venous (56)	9.4 (7.7, 13.2)	449.2 (351.7, 624.4)	6.7 (5.3, 9.4)
	Delayed (44)	13.1 (9.1, 16.5)	340.0 (257.2, 547.3)	5.1 (3.9 8.2)
	Total (137)	9.4 (7.7, 13.2)	1,091.7 (677.8, 1,521.7)	16.4 (10.2, 22.8)

Data are presented as median (interquartile range)

CT=computed tomography, $CTDI_{vol}$=CT dose index volume, DLP=dose length product, mGy=milliGray (unit for $CTDI_{vol}$), mGy.cm=milliGrayx centimetre (unit for DLP), mSV=milliSievert (unit for effective dose), n=number of patients

Table 5 Number of computed tomography studies with computed tomography dose index volume, and dose length product above third quartile (diagnostic reference levels)

DRLs	Head CT	Chest CT	Whole abdomen CT
$CTDI_{vol}$ (mGy) above third quartile	>57.5	>11.6	>13.2
n (%)	63 (24.8)	18 (24.8)	34 (24.8)
DLP (mGy.cm) above third quartile	>1,102.6	>474.7	>624.4
n (%)	54 (21.3)	18 (25.0)	34 (24.8)

CT=computed tomography, $CTDI_{vol}$=CT dose index volume, DRL=diagnostic reference levels, DLP=dose length product, mGy=milliGray (unit for $CTDI_{vol}$), mGy.cm=milliGray x centimetre (unit for DLP), mSV=milliSievert (unit for effective dose), n=number of studies

Discussion

The rapidly increasing number of CT scans causes more concern for patient radiation doses coupled with their adverse effects. The ICRP proposed DRLs as a way for optimization and justification of CT radiation doses, with emphasis on obtaining DRLs from existing, local data. A study by Najafi et al.[22] in 2014 of 24 MDCT centers in Iran analyzed 885 reports. In terms of DLP, the DRLs of an adult age group were 700, 290, 330, and 550 mGy.cm for the head, sinus, chest, abdominal and pelvis CTs respectively. Most cases were less than the international reference values of Australia and European countries.[15,19] Another study aimed to establish the first DRLs for CT examinations in adult and pediatric patients in Turkey from 167 hospitals found that adult head CT doses and many pediatric CT doses were higher than European Commission recommendation.[17] A few studies suggested to replace alternative imaging examination in clinically non-indicated CT scans or using the tube current modulation to reduce the CT radiation dose in children or patients undergoing multiple CT scans.[28,29] A 2011's study in Thailand encouraged CT units including Songklanagarind Hospital to maintain their own DRLs due to the wide variability.[27] Our study gave the updated CT radiation data of the CT unit at Songklanagarind Hospital in Table 6 and provided a larger sample population as well as correlation with clinical

Table 6 Comparison of the diagnostic reference levels in computed tomography imaging of head, chest and whole abdomen

CT Anatomical region	DRLs of Songklanagarind Hospital		International DRLs				
	This study	Previous study in 2011[27]	UK (2011)[18]	EC (2014)[19]	US (2017)[27]	Australia (2013)[15]	Japan (2015)[21]
Head CT							
$CTDI_{vol}$ (mGy)	57.5	45.0	60.0	60.0	56.0	60.0	85.0
DLP (mGy.cm)	1,102.6	1,089.0	970.0	970.0	962.0	1,000.0	1,350.0
Chest CT							
$CTDI_{vol}$ (mGy)	11.6	8.6	12.0	10.0	13.0	15.0	15.0
DLP (mGy.cm)	474.7	355.0	610.0	400.0	469.0	450.0	550.0
Whole abdomen CT							
$CTDI_{vol}$ (mGy)	13.2	11.3	15.0	25.0	15.0	15.0	20.0
DLP (mGy.cm)	624.4	552.0	745.0	800.0	755.0	700.0	1,000.0

CT=computed tomography, $CTDI_{vol}$=CT dose index volume, DRL=diagnostic reference levels, DLP=dose length product, EC=European Commission, mGy=milliGray (unit for $CTDI_{vol}$), mGy.cm=milliGray x centimetre (unit for DLP), UK=United Kingdom, US=United States

indications. The DRLs from our srtudy were below inter national DRLs, especially Japan.[21] Head CTs had $CTDI_{vol}$ slightly higher than the US[20] and DLP above those of Australia[15], UK[18], EU[19], and US[20]. Our DRLs of all three CT regions have increased from the prior study.[27]

Non-contrast head CTs were performed mostly for strokes followed by trauma and malignancy. Most CT scans in other categories had only non-contrast phase. The total effective dose was not high due to a low conversion factor of the non-radiosensitive brain. Additional contrast enhanced venous phase indicated for malignancy and infection/inflammation had twice the dose of non-contrast studies alone as CT parameters and scan lengths were still the same as non-contrast studies.

All chest CT scans had contrast enhanced venous phase with longer scan length of the chest including upper abdomen down to the inferior pole of right kidney. No significant difference among the clinical indications (p-value=0.84 to 0.99) in chest CTs may be due to near identical protocols. For example, insignificant difference between the two protocols for malignancy versus others (p-value=0.84 and 0.90, respectively) was due to almost equal scan lengths of both protocols. Whole abdominal CTs had the highest total effective dose due to longer scanning area, high conversion coefficient of many intra-abdominal organs with high tissue weighting factors and multiple phases. Both DLP and effective dose of abdominal CTs including all phases was the highest. The venous phase had the highest DLP as it covered whole abdomen whereas other phases did not. No statistically significant differences among clinical indications in abdominal CT were seen.

The CT DRL values in our unit were below DRLs from the UK[18], EU[19] and Australia[15]. Head CTs had $CTDI_{vol}$

slightly above that of the US[20] and DLP above the UK[18], EU[19], US[20] and Australia[15]. The reason for this may be the scan length scanning the patient down until C2 the spine in indications for trauma or others. The DRLs of all three CT regions of our study were lower than those of Japan.[21] This fact could be significant as international reference levels were derived from Caucasian people. Taking this into consideration more studies in Asian countries needs to be conducted. The DRLs of this study were higher than the prior study of 2011.[27] Different CT machines, CT parameter settings to obtain diagnostic quality images and rapidly changing protocols were likely causes.

The proportions of CT scans with radiation dose (DLP) above the DRLs were quite high: head CTs (21.3%), chest CTs (25.0%) and whole abdominal CTs (24.8%). A retrospective analysis of CT parameters and clinical indications will help to both identify and address the reasons for preventive high CT radiation doses.

Our study was limited by exclusion of HRCT of the chest and contiguous chest abdominal and pelvic CT scans. Future studies could be inclusive of more anatomical regions, techniques and indications in the rapidly evolving field of medical imaging. A CT dose index registry maintained with regular review of CT studies above DRLs is recommended. Periodic studies to optimize radiation dose as well as a review of CT protocols by radiologists, medical physicists and technicians especially when new hardware or software is installed is required. CT dose on digital display of annual quality control procedures of the CT scanner should be verified by qualified medical physicists.

We also emphasizes clear communication between radiologists and clinicians, in concerns to the patient details and clinical indications, in order to optimize scan parameters, avoid unnecessary scanning phases and recommend alternate options where possible.

Conclusion

Our study showed the DRLs of CT scans in adults at Songklanagrind Hospital were; $CTDI_{vol}$ 57.50 mGy, DLP 1,102.60 mGy.cm for head CTs, $CTDI_{vol}$ 11.63 mGy, DLP 473.10 mGy.cm for chest CTs and $CTDI_{vol}$ 13.15 mGy, DLP 1,467.00 mGy.cm for abdominal CTs. The most common clinical indications were: stroke (29.1%) for head CTs and malignancy for both chest (73.6%) and whole abdominal (49.6%) CTs. Our DRLs were mostly below international DRLs of Australia, Europe, Japan, the UK and the US. There were significant differences in the DLP values of indication for malignancy versus other clinical indications in both head CTs and chest CTs.

Acknowledgement

We would like to thank the staff and mentors from the Departments of Radiology, Faculty of Medicine, Prince of Songkla University for their kind support.

Conflict of interest

The authors declare that there is no conflict of interest, regarding the publication of this article.

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