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Comparison of Radiation Dose in CT Examinations at PIMS with European Commission Reference Doses

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Author`s Contribution

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ABSTRACT

Objective: To assess the radiation dose levels from common computed tomography (CT) examinations performed in the Radiology Department of Pakistan Institute of Medical Sciences (PIMS), and evaluate these according to diagnostic reference levels (DRLs) proposed by European Commission (EC) guidelines.

Methodology: The study was conducted at PIMS hospital, Islamabad, spanning eight weeks i.e August to October 2020 during which we collected scan parameters and dose profile data of 1506 adults undergoing CT examinations of head, neck, chest, and abdomen-pelvis regions, comprising of single- and multi-phase, contrast-enhanced and unenhanced studies. Values of CTDIvol, DLP, and scan lengths were extracted from the CT operators console. Dose indicators utilized by EC guidelines for DRLs include volume CT dose index (CTDIvol) and Dose Length Product (DLP) for single slice and complete examination radiation doses, respectively. Other control variables included gender, contrast enhancement, and phasicity of study. IBM SPSS package was used to obtain descriptive statistics such as mean and quartiles.

Results: DRLs calculated were: CTDIvol of 55, 11, 12, 9 & 11 mGy for the head, neck, chest, abdomen-pelvis & chest-abdomen-pelvis regions, respectively; DLP of 875, 431, 455, 889 & 903 mGy.cm for the head, neck, chest, abdomen-pelvis & chest-abdomen-pelvis regions, respectively.

Conclusion: This study describes institutional diagnostic reference levels for common CT exams in Islamabad and provides benchmark values for future reference. Our DRL values are mostly comparable to European and international DRLs, with slightly higher values noted in chest & abdomen-pelvis DRLs.

Keywords: CTDIvol, Computed Tomography, DLP, Diagnostic Reference Levels, Radiation Monitoring, Scan length.

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Introduction

Since the advent of computed tomography (CT) technology, particularly that of the newer generation multidetector CT (MDCT) scanners, there has been a progressively rising trend in its use because of its ability to scan large regions of the body within short periods and impart crucial information on patients for diagnosis and further management.[1] From emergency departments to routine outpatient department (OPD) visits, CT has become a key diagnostic tool of choice due to its versatility.[2]

Ionizing radiation forms the basis of image acquisition in CT studies and owing to its unique mechanism, it imparts substantial doses per scan. This fact coupled with the rising trend of its use leads to an increase in ionizing radiation dose exposure to patients undergoing

examinations.[3,4] There is evidence of near doubling of average annual effective dose imparted to the global population by medical procedures in the last 10-15 years.[4]

However, ubiquitous usage of CT scans, in particular, has meant a disproportionately large share (almost 50%) of total ionizing radiation exposure from medical procedures (to the population of United States) comes from CT examinations, which is in stark contrast to CT constituting significantly lower percentage (about 12%) of total diagnostic exams.[3] These trends of rising population dose from medical procedures are of concern due to the potential for radiation-induced malignancies.[5,6]

Further complicating these matters, there persist wide variations among radiation doses for CT across institutions and centers.[5,7] Standardization of radiation exposure from diagnostic imaging requires the development of a systematic approach to quantify and compare specific dose parameters against a benchmark, identify poor imaging protocols, take steps for optimization and revisit post-optimization.[8] International Commission on Radiological Protection in ICRP publication No.73 in 1996 proposed the concept of diagnostic reference levels (DRL) for medical imaging optimization, the underpinning principle for dose reduction being as low as reasonably achievable (ALARA).[1] DRLs are defined as the 3rd quartile (75th percentile) value of dose distribution data set[8] for a specific set of dose parameters, which in the case of CT examinations are volume CT dose index (CTDIvol) and Dose Length Product (DLP). For its application, ICRP states that DRLs "are not for regulatory or commercial purposes, not a dose restraint and not linked to limits or constraints".[9]

To further the cause of dose optimization, an ambitious concept of achievable doses (AD) was introduced by the United Kingdom's National Radiation Protection Board in 1999 as the benchmark to aim for in facilities where exposures are persistently below the DRLs.[10] They proposed that ADs be set at the median (50th percentile) of dose surveys.[8,10]

The significance of DRL as a radio-protective tool is already established since it allows dose profile assessment of imaging practices at various institutions. It serves the primary aim of identifying those outliers having mean (or median) dose parameters above the local, national or regional DRLs, signifying the need to modify protocols to reduce unusually high exposure.[8,11]

Furthermore, the establishment and application of the DRL process undertaken in European countries[12] as well as the United States have led to subsequent reviews with the demonstration of significant dose reductions (16-30%).[5,8,13] Appreciating the benefits of the DRL process, it is not surprising to note that regulatory bodies and organizations world over encourage its use while many countries have also adopted and published their own DRLs for institutional as well as regional dose variation assessment and subsequent follow-up surveys.[7,8,10,12]

Considering the importance of DRLs in dose optimization, it is imperative to establish DRLs for the population of Pakistan. To our knowledge there is no data available from any published work on CT DRLs in Pakistan, hence there is a need for an exploratory study in our population. This study explores institutional DRLs for most commonly performed adult CT examinations at PIMS using the two primary dose parameters of CTDIvol and DLP against European DRLs, and in doing so contribute towards the establishment of local and national DRLs.

Methodology

After procuring institutional ethical approval, in a period spanning 8 weeks from August to October 2020, we collected a data sample from 1506 adults undergoing CT exam in the Department of Diagnostic Radiology PIMS hospital in the capital territory of Islamabad. CT scanner model employed was Optima 540 16 slices multidetector-row CT (MDCT) [GE Healthcare, Chalfont St.Giles, Buckinghamshire, UK]. Non-probability consecutive sampling was performed for five most commonly performed CT examinations, having a frequency of at least 10 or more exams performed within the study period, of adult individuals (institutional protocol of age more than 12 years).

Dosimetry quantities measured were volume CT dose index (CTDIvol) and Dose length profile (DLP) with units of mGy and mGy.cm, respectively. Other variables included gender, scan region (detailed in Table I), intravenous contrast enhancement(+/-), total scan length(cm), tube voltage(kVp) and current(mAs), and exam phasicity (single-phase or multiphasic). Furthermore, we have included routine subregion protocols comprising of HRCT chest, CT pulmonary angiography (CTPA), multiphasic CT kidneys-ureters-bladder (KUB), and multiphasic liver exams, and

performed descriptive analysis for dose metrics & scan length on these routing protocols as well.

We performed descriptive statistics on the aforementioned variables using IBM SPSS version 21. Mean, median, range, quartiles and standard deviation were calculated for quantitative variables, in addition to rounded off 75th percentile values of dosimetry quantities which were presented as proposed DRLs for respective exam regions & sub-region protocols. While median values of dose metrics were displayed as proposed achievable doses. Due to the unavailability of previous reference dose profile data from Pakistan, results are compared to published European Commission12 and other international DRLs.[5,12,14-17]

Results

Pre-analysis assessment of data was performed as part of data cleaning which yielded a couple of aberrant values/outliers, which were excluded from descriptive analysis, such as a case of combined head-neck examination which turned out to be misclassified as neck region and imparted an unusually large aberrant value to respective regional data set.

A total number of 1505 observations were included in the study, a dominant (69%) proportion comprised of male individuals. Table I details the scan regions, subregion protocols, their respective frequencies and scan parameters. Head scans were the most frequent examination region by far. In the subregion routine CT protocols, HRCT chest was the most frequent examination, followed by KUB, multiphasic liver and CT pulmonary angiography (CTPA). Of the total exams, the majority of scans (1075 comprising 71.4%) were without intravenous contrast enhancement. The highest values of mean (1.7) and median (3) value for phasicity belonged to abdomen-pelvis examination and liver protocol,

Table I. Exam regions, subregion CT protocols, respective frequencies, parameters and their specific indications selected for this study.

Exam region	Frequency	Current/Voltage	Subregion CT protocols	Common clinical indications
Head	69.5% (1046)	207mAs/140kV	Brain	Stroke Space occupying lesion
Chest	9% (136)	163mAs/120kV	Chest routine Chest-High resolution CT Pulmonary Angiography	Lung cancer Interstitial lung disease Pulmonary embolism
Abdomen and Pelvis	12.4% (186)	152mAs/120kV	Abdomen routine Liver Kidneys-ureters-bladder	Abscess Hepatocellular carcinoma, liver metastasis Tumors/Stones/Colic
Chest-Abdomen-Pelvis (CAP)	8.2% (123)	155mAs/120kV	CAP routine	Cancer/Staging
Neck	0.9% (13)	133mAs/120kV	Soft tissues	Cancer

Table II. Descriptive statistics for dose profile accompanied by scan length according to exam region and phasicity

EXAM AREA & PHASICITY		Volume CT Dose Index $CTDI_{vol}$ (mGy)		Dose-Length Product DLP (mGy.cm)		Scan Length L (cm)	
		Mean/SD[a]	Range	**Mean/SD[a]**	Range	**Mean/SD[a]**	Range
HEAD	Single	-	-	789 / 174	497-1995	14.6 / 1.9	11.5 - 27.5
	Multiphase	-	-	1788 / 610	593 - 4724	28.8 / 10	11.6 - 68
	All	52 / 7.4	41.4 – 82.5	851 / 331	497 - 4724	15.5 / 4.6	11.5 – 68
CHEST[b]	Single	-	-	339 / 116	92 - 651	30 / 5.6	13.5 – 53
	Multiphase	-	-	588 / 256	139 - 1235	54.4 / 15.4	25.8 - 89.6
	All	10.2 / 4.6	2.6 - 46.5	372 / 165	92 - 1235	33.4 / 11.3	13.5 - 89.6
ABDOMEN-PELVIS[c]	Single	-	-	421 / 140	201 - 983	45.6 / 11.2	13.5 - 38.5
	Multiphase	-	-	978 / 323	350 - 2040	98.6 / 32.3	25.5 - 190.5
	All	8.6 / 2	5.6 - 15	646 / 359	201 - 2040	67.5 / 34.4	13.5 - 190.5
CHEST-ABDOMEN-PELVIS	Single	-	-	556 / 183	237 - 1000	61.3 / 12.7	29.8 - 119
	Multiphase	-	-	1160 / 500	459 - 2490	112.7 / 35.5	43.5 - 187.5
	All	8.9 / 2.6	6.5 - 17	747 / 425	237 - 2490	77.1 / 32.5	29.8 - 187.5
NECK	Single	-	-	285 / 105	157 - 431	24.3 / 5.8	18.0 - 34.9
	Multiphase	-	-	478 / 125	332 - 641	44.1 / 5.3	38.5 - 50.5
	All	9.8 / 1.9	7.6 - 13.8	374 / 149	157 - 641	31.5 / 11.3	18 - 50.5

a. SD=standard deviation
b. Chest includes CTPA and HRCT sub-regions
c. Abdomen-pelvis includes liver and KUB sub-regions

respectively.

Tables II contains mean, standard deviation and range for the dose metrics and scan lengths pertaining to different anatomical regins, organized according to phasicity. Table III details median and 75th percentile values for subregion protocols against those described by Public Health England.[16] Of note, the highest DLP value was imparted by chest-abdomen-pelvis examinations and multi-phase liver protocol, while the highest CTDIvol was utilized by head exams. The analysis further yielded the highest variability (defined by the coefficient of variance) of DLP & scan length for the chest-abdomen-pelvis region, which corresponds well with the largest expanse of this examination region, while the least variability was observed for head examinations.

With regards to the analysis of scan length (mentioned in Tables II-III), all the regional multiphasic exams demonstrated less than double mean length compared to their monophasic counterparts, except for abdomen-pelvis scans, wherein a higher proportion of three or more phase studies imparted by liver & KUB protocols resulted in more than double multiphasic mean scan length when compared to their single-phase counterparts. In table IV,

Table III: Dose metrics and scan length in the form of AD and DRLs of routine CT protocols in comparison to DRLs from United Kingdom[16].

CT protocol (No. cases)	Volume CT Dose Index $CTDI_{vol}$ (mGy)			Dose-Length Product DLP (mGy.cm)			Scan Length L (cm)	
	50th Percentile	75th percentile	UK[16]	50th Percentile	75th percentile	UK[16]	50th Percentile	75th percentile
HRCT-CHEST (70)	11.4	12.8	12	370	437	350	29.3	31.4
CTPA (9)	8.4	12.5	13	360	553	440	36.6	56.8
LIVER (39)	8.7	9.5	14	1057	1153	910	106.4*	117.8
KUB (43)	8.8	10	13	547	757	1150	57.4*	76.1

* = for multiphasic exams of liver & KUB, cumulative scan length for whole exam was used

Table IV: Comparison of mean scan length (in centimeters) for the most commonly performed CT examinations analyzed by our study with international published studies.

	Our study*	Semnan, Iran[15]	Cameroon[19]	Tanzania[20]	Greece[20]	Italy[20]
Head	15.5	14.6	20	21.1	14.3	12.9
Chest	33.4	30.6	36	55.8	20.7	22.3
Abdomen-Pelvis	67.5	33.9	44	70.4	22	22.7
CAP	77.1	-	-	-	-	-
Neck	31.4	13.8	-	-	-	-

***** - inclusive of multiphasic studies

Table V: Summary of 50th (AD) and 75th (DRL) percentile dose profile data compared to international DRLs

	Our study		European Commission[12] 2014	United States[14] 2018	Semnan, Iran[15] 2019	Tobruk, Libya[4] 2018	United Kingdom[16] 2019	Saudi Arabia[17] 2015	Nigeria[5] 2018
	AD[a]	DRL[a]							
Head									
$CTDI_{vol}$	50	55	60	56	46	-	60	-	61
DLP	761	875	1000	962	723	1999	970	-	1310
Neck					[b]		[b]		
$CTDI_{vol}$	10	11	-	19	40	-	21	-	-
DLP	389	431	500	563	572	-	440	-	-
Chest									
$CTDI_{vol}$	9	12	10	13	12	-	12	18	17
DLP	338	455	400	469	377	2285	610	630	735
Abdomen-Pelvis									
$CTDI_{vol}$	8	9	25	15	12	-	15	15	20
DLP	527	889	800	755	524	2840	745	800	1486
CAP									
$CTDI_{vol}$	7	11	-	15	-	-	10	16	-
DLP	584	903	-	947	-	3117	1000	1040	-

a - AD = achievable dose (median value); DRL = Diagnostic reference level
b - cervical spine protocol for fractures was utilized

mean scan length values from our institution were compared with other international studies[15,19-20], revealing that the head and chest region scan lengths were similar, while those of abdomen-pelvis and neck region were 2-2.5 times higher than those of other countries, which likely explains the significantly higher dose values observed for these regions at our institution.

Table V summarizes our proposed diagnostic reference levels (75th percentile value) and proposed achievable dose (50th percentile value) for dose metrics organized according to anatomical regions, inclusive of all phases & sub-regions, alongside results from other countries and regional DRLs. Limited comparative data was available on scan length about neck and chest-abdomen-pelvis examinations.

Discussion

Henceforth, we disclose a summary of radiation dose data for adult CT dose metrics from a large number of commonly performed examinations at the Radiology Department of Pakistan Institute of Medical Sciences. In the current lack of loco-regional or national diagnostic reference levels, we offer fairly large sample-based single institution dose metrics in the form of proposed DRLs and achievable doses, organized according to anatomical regions, routine protocols, and exam phasicity. The results presented here may be utilized by respective oversight and health care quality organizations with the intent of future radiation dose benchmark establishment.

Meanwhile, other imaging facilities of Pakistan may currently utilize this summary dose data in two ways, as suggested by Smith-Bindman R, et al.[7] Firstly, they may simply compare their dose distributions (median values) to our reported 75th percentile diagnostic reference values. If their values exceed the corresponding benchmarks, subsequent review of protocols and scanner settings should be ensured. Secondly, similar to the pattern in United Kingdom[7], while setting scanner parameters for patients, overseeing technologists could compare the prescan CTDIvol & DLP values from the scanner with our reference values. If they turn out to be higher than our 75th percentile values in absence of valid clinical or patient-specific indications to suggest otherwise, a radiologist or medical physicist could be taken on board to evaluate possible aetiology and any remedial actions applicable.

Furthermore, we give detailed statistics on scan length as a primary variable for commonly performed CT examinations and protocols, owing to its wide variability and significant effects on total exam dose imparted[18] as well as being a variable sparsely discussed among published literature about DRLs. This variable may be considered while analyzing higher-than-usual dose metrics and implementing remedial actions. Thus, we provide three different metrics related to dose data from this large data set of CT examinations to help other institutions & centres in understanding the etiological factors responsible for higher than typical doses.

Another unique dimension of this study was the separate inclusion and subsequent analysis carried out for routinely performed CT protocols, such as CTPA, HRCT chest, CT KUB & multiphasic liver exams, which are infrequently studied hence with limited comparison available. Table III gives median and 75th percentile values for the primary variables studied for these routinely used CT protocols as further benchmarks within the major anatomical regions.

Results of this study were compared to European Commission12 DRLs as well as other published international dose metrics[4,5,14-20] and presented as a tabulated form in table IV & V. In summary, 75th percentile values of both radiation dose parameters (CTDIvol and DLP) for head, neck & chest-abdomen-pelvis regions were comparable to those mentioned in other international studies, whereas, for abdomen-pelvis examinations, 75th percentile CTDIvol in our study was significantly less than in all the other studies, in contrast, DLP values were slightly higher compared to the European Commission[12] & Saudi Arabian[17] studies and significantly more compared to United States[14], United Kingdom[16] and Iran's[15] DRLs. Also noteworthy are values of CTDIvol and DLP for chest examinations, where our values were slightly higher than European Commission[12] and Iran's[15] DRLs, while significantly lower when compared to others.[14-17] These observations call for dose optimization strategies directed at the two anatomical regions and updating institutional protocols & practices to bring dose metrics in line with international DRLs. Thus, one beneficial purpose of studying diagnostic reference levels is served.

Conclusion

Our study established institutional radiation dose data from commonly performed CT examinations and comparing them to those of the European Commission as well as other internationally available diagnostic

reference levels. In doing so, we establish institutional DRLs, contribute to local and national DRLs, and identified those protocols which imparted unusually high doses, such as multiphasic liver protocol and abdomen-pelvis exams warranting further dose optimization strategies. Scan length is another variable we studied alongside the usual dose metrics to paint a detailed picture regarding CT exams. Future recommendations include larger-scale multicenter and national level dose-related data acquisition for the establishment of national DRLs, and application of size-specific dose estimate to further standardize population-level CT radiation dose exposures.

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