Radiation dose metrics for plain head, chest, and abdomen CT scans: An initiative towards establishing institutional diagnostic reference levels

Surendra Dhungana[1*], Keshab Sharma[1], Sharmila Paudel[2]

[1]Department of Radiology and Imaging, Gandaki Medical College Teaching Hospital and Research Center, Pokhara, Nepal,
[2]Department of Community Medicine and Public Health, Gandaki Medical College Teaching Hospital and Research Center, Pokhara, Nepal

ABSTRACT

Introduction: Computed Tomography (CT) examinations contribute to the largest portion of radiation exposure among X-ray-based imaging modalities. This study aimed to explore the existing radiation dose metrics for plain head, chest and abdomen scans for creating institutional diagnostic reference levels. **Methods:** The CT parameters and dose metrics data were acquired from 226 patients of 15 years and above. The dose metrics, volume CT dose index (CTDIvol) and dose-length product (DLP) were obtained from the local picture archiving and communication system (PACS). The mean as well as the 2nd and 3rd quartile values of CTDIvol, DLP and effective dose were calculated. The DLP values were applied to K-coefficients to find out the effective dose; ED = K x DLP. **Results:** The 2nd and 3rd quartile values for CTDIvol are 43, 8.5, and 9.25; 43,10.6 and 10.9 mGy respectively, for head, chest and abdomen. The 2nd and 3rd quartile DLP values are 821, 341, and 497.5; 864.1, 397.6 and 579.7 mGy-Cm. The median effective doses are 1.72,4.77 and 7.46 mSv, and the institutional Diagnostic Reference Values (DRL) of effective dose are 1.81, 5.56 and 8.69 mSv for head, chest and abdomen respectively. **Conclusions:** The dose metrics of the plain head, chest and abdomen were reported for creating an institutional DRLs. This study points to the need for optimization of the chest and abdomen protocol; chest protocol for relatively higher CTDIvol and DLP values and abdomen for a higher DLP value.

Keywords: Achievable dose, CTDIvol, DLP, institutional DRLs.

***Correspondence:**
Mr. Surendra Dhungana
Department of Radiology and Imaging
Gandaki Medical College Teaching Hospital and Research Center, Pokhara, Nepal
Email: surendra.dhungana@gmail.com
ORCID iD: https://orcid.org/0000-0003-2316-4852

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INTRODUCTION

Computed tomography (CT) uses X-rays; high-frequency electromagnetic radiation to create detailed images of anatomical structure based on the attenuation coefficients of the scanned region. CT is an immensely useful cross-sectional imaging modality for disease diagnosis; the only concern is the radiation exposure. The radiation dose from CT should be periodically monitored and optimized as the focus is radiation safety to decrease the odds of associated stochastic risks.[1,2] CT examinations contribute to the largest portion of radiation exposure among X-ray-based medical imaging sources. In diagnostic radiology procedures including conventional radiography, dental x-rays, interventional radiology, diagnostic nuclear medicine and CT, CT accounted for 10% amongst all the procedures but contributed to 62.6% of the collective effective doses.[2,3] Furthermore, in recent days, CT has been replacing older radiography and fluoroscopy procedures. In latest CT scanners; the radiation dose from each procedure has been lowered. This decrease is due to a concerted effort involving technological advancements, increased awareness and the implementation of dose optimization strategies. Despite the dose reduction strategies; CT is still the largest contributor.

Modern CT scanners typically display two dose indices: volume CT dose index ($CTDI_{vol}$) in mGy and dose length product (DLP) in mGy-cm. The $CTDI_{vol}$ is based on one of two standard methyl methacrylate phantoms with diameters of 16 and 32cm for head and body, respectively. $CTDI_{vol}$ reflects the average radiation exposure per section and depends on the exposure factors, pitch, filtration, reconstruction algorithms, etc. DLP reflects the total radiation output for the examination and is the product of $CTDI_{vol}$ and scan length.[4,5] The obtained DLP can be applied to the specific values (K-Values) to determine the effective dose to the population for understanding the associated stochastic risks. These values can also be compared to published Diagnostic Reference Level (DRL) values of different countries to determine whether the amount of radiation that we are imparting to the patient is acceptable or there is a dire need for optimization of the CT protocol.[6-9]

The main objective of this study was to obtain median and third quartile $CTDI_{vol}$ and DLP values for plain CT head, chest and abdomen and also to calculate the achievable and DRL effective dose of this organization and compare the dose data nationally and internationally.

METHODS

This cross-sectional convenience sampling study was carried out from September to November 2024 after obtaining Ethical approval from institutional review committee of Gandaki Medical College Teaching Hospital and Research Centre (GMCTHRC). The plain CT data of adults above 15 years were collected for head, chest and abdomen protocols from the CT-Scan Unit. The Canon-Prime Sp Acquillion scanner with 80 rows of detectors was used for the study. The CT-Scan acquisition parameters are given in Table 1. Dose parameters data were collected from the scanner console and local picture archiving and communication system (PACS). Age, sex, KVp, average mAs, pitch, $CTDI_{vol}$ and DLP were recorded for each patient. $CTDI_{vol}$ for head examinations is referenced to a 16 cm standard phantom (circular plastic -polymethyl methacrylate) and 32 cm for chest and abdomen.[10,11] The DLP values are the product of $CTDI_{vol}$ and scan length.[3] The DLP values were applied to the K-coefficient to calculate the effective dose as per the equation ED = K x DLP. The K-coefficients are only specific to the anatomic region scanned and age.[2,6,11-15]

The analysis was performed in Excel (Microsoft Office Professional Plus, Version 1808) and the statistical package for social sciences (SPSS) version 23.0 for Windows.

Table 1: CT parameters

Technical parameters	Head	Chest	Abdomen
Acquisition Slice thickness (mm)	0.5	0.5	0.5
Tube Voltage (KV)	120	120	120
Gantry rotation time (Seconds)	0.75	0.5	0.5
Average mAs	212.7	145.6	150.3
Pitch	0.64	0.9	0.86
*Automatic Exposure Control (AEC)	** On / Off	On	On
Beam Collimation	0.5 x 80 =4	0.5 x 80 =4	0.5 x 80 =4

*The dose reduction system for this CT model, is SURE Exposure during image acquisition phase and Adaptive Iterative Dose Reduction 3D (AIDR3D) in raw data and image space; **The data for head were acquired with both modes of AEC (on and off)

RESULTS

The study included a total of 226 patients; CT head 125 (55.3%), chest 47(20.8%) and abdomen 54(23.9%). The mean age of patients for head (70 males and 55 females), chest (16 males and 31 females) and abdomen (27 males and 27 females) is 51.2±20.5, 42.6±17.3 and 66.4±14.7 years respectively.

The mean $CTDI_{vol}$ for head, chest and abdomen is respectively is 39.9±7.5, 8.5±2.4, and 9.5±1.8 mGy. Similarly, the mean DLP is 785±152.9, 331.6±108.3 and 515.4±117.3 mGy-cm. The minimum and maximum range $CTDI_{vol}$ for head, chest and abdomen are: 9.6 and 51.6, 4.6 and 12.2, 6.6 and 14.5 mGy respectively. The minimum and maximum DLP for head, chest and abdomen are respectively: 202.2 and 971.7, 169.5 and 549.1, 341.8 and 852.2. The mean scan length for head, chest and abdomen is 19.7±2.6, 39±5.1 and 54.4±5.5 cm respectively. The mean effective dose to head, chest and abdomen is 1.6±0.3, 4.7±1.5 and 7.7±1.7 mSv respectively. (Table 2)

Table 2: Mean values of $CTDI_{vol}$, DLP, scan length and effective dose

Region	Mean $CTDI_{vol}$ (mGy)	Mean DLP (mGy-cm)	Average Scan Length (cm)	Phantom size (cm)	K-factors[6] ($mSvmGy^{-1}cm^{-1}$)	Mean Effective dose (mSv)
Head (n=125)	39.9±7.5	785±152.9	19.7±2.6	16	0.0021	1.6 ± 0.3
Chest (n=47)	8.5±2.4	331.6±108.3	39±5.1	32	0.014	4.7 ±1.5
Abdomen (n=54)	9.5±1.8	515.4±117.3	54.4 ± 5.5	32	0.015	7.7 ±1.7
Total	226					

The 2nd quartile values for $CTDI_{vol}$ are 43, 8.5, and 9.25, and the 3rd quartile values are 43, 10.6 and 10.9 mGy respectively for head, chest and abdomen. Similarly, 2nd quartile DLP values are 821, 341, and 497.5, and 3rd quartile values are 864.1, 397.6 and 579.7 mGy-cm. The institutional achievable (median) effective doses are 1.72, 4.77 and 7.46 mSv for head, chest and abdomen respectively. Similarly, the institutional Diagnostic Reference Values (DRL) or 75th percentile values for effective dose are 1.81, 5.56 and 8.69

mSv. (Table 3)

Table 3: The 2nd and 3rd Quartile $CTDI_{vol}$ and DLP values and institutional achievable and DRL effective doses

Examination		Head	Chest	Abdomen
$CTDI_{vol}$	2nd Quartile	43	8.5	9.25
	3rd Quartile	43	10.6	10.9
DLP	2nd Quartile	821	341	497.5
	3rd Quartile	864.1	397.6	579.7
K-factors[6] ($mSvmGy^{-1}cm^{-1}$)		0.0021	0.014	0.015
Achievable dose(mSv)- 2nd Quartile		1.72	4.77	7.46
Diagnostic reference level (mSv)- 3rd Quartile		1.81	5.56	8.69

DISCUSSION

The radiation dose parameters of plain head, chest and abdomen from a single center GMCTHRC in the mid-western region of Nepal were reviewed for the purpose of knowing the institutional diagnostic reference level for $CTDI_{vol}$, DLP and effective dose. This research findings could contribute to local and national DRL and also allow other centers for comparison. The established DRL values of few countries and comparison with this organization is given in Table 4. The technical specifications for each protocol were mentioned to ensure that comparisons between facilities remain valid. The analysis throughout was done mainly considering 2nd and 3rd quartile values of $CTDI_{vol}$ and DLP as recommended by the International Commission on Radiological Protection (ICRP publication 135) and agreed internationally to be considered for DRL and median value of effective dose as achievable dose; however, the mean values of $CTDI_{vol}$, DLP, and effective doses were also calculated as many researches are still considering mean values for comparison.

Table 4: Third Quartile $CTDI_{vol}$ and DLP comparison with the Diagnostic Reference level (DRL) of other nations

Nation	Head		Chest		Abdomen	
	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)
GMCTH (This organization)	43	864.1	10.6	397.6	10.9	579.7
Australia[16]	52	880	10	390	13	600
Japan[14]	85	1350	15	550	20	1000
USA*[17]	57	1011	15	545	20	1004
Korea[18]	52.2	969.8	7.6	250	11	540
West China[19]	50.1	818	8.4	302	**	**
South India[20]	47	1041	**	**	12	550
Ethiopia[21]	53	1210	13	635	16	822

*USA values were size-specific and the values mentioned here are of size-unspecified category; ** Not available

The use of 120 kV only across all three examinations in this study allowed the comparison of the impact of mAs and pitch on radiation dose. Similarly, beam collimation (0.5 x80=4 cm) and acquired slice thickness (0.5 mm) were consistent for all examinations. Image quality reference parameter for AEC was chosen standard among the options provided: standard, low dose and high quality in this Canon's system for all cases.[22] The pitch, average mAs and gantry rotation time (0.75 sec for head and 0.5 sec for chest and abdomen) varied among procedures. At a fixed kV, the radiation dose is directly proportional to the mAs. The higher the mAs, the $CTDI_{vol}$ becomes higher as the photon flux is increased.[23] The higher $CTDI_{vol}$ observed in the head CT directly correlates with the higher averaged mAs and the lowest pitch, indicating more overlapping volume (Table 1). Chest and abdomen have higher pitch and lower mAs values and consequently lower $CTDI_{vol}$ than head. The DLP depends upon the $CTDI_{vol}$ and scan length. Scan length was maximum for the abdomen, followed by the chest and least for the head.

Head CT scans exhibited the highest 3rd quartile $CTDI_{vol}$ and DLP values amongst the three scanned regions at this organization and also among all the countries compared (Table 4). This signifies that a substantial X-ray photon flux is required to address the need for high contrast resolution to visualize subtle differences in brain tissue. Furthermore, overlapping scans are usually acquired for head scans (pitch 0.64 at this organization) to improve image quality, reducing artefacts and increasing signal-to-noise ratio. These overall contributed to the need for higher radiation output from the scanners.

Chest CT scans showed the lowest 3rd quartile $CTDI_{vol}$ amongst the three scanned regions in our study. Similarity is seen in comparison to other countries. The inherent contrast is high for chest structures, achieving diagnostic images with lesser photons flux. A relatively higher pitch (0.9) in our protocol is to reduce the total scan time, allowing for shorter breath-holds and minimizing the impact of involuntary motion. This represents a balance between radiation dose efficiency and blurring due to motion artefacts.

Abdomen CT scans have intermediate $CTDI_{vol}$ amongst the three scanned regions. This is consistent with the findings of the different countries compared herein. The averaged mAs of 150.3 (Table 1) is observed, which is slightly higher than the chest but lower than the head, indicating moderate photon flux typically used for abdominal imaging to provide sufficient contrast resolution for soft tissue differentiation. The pitch of 0.86 suggested overlapping scans, although to a lesser extent than the head. This overlap aims to enhance image quality, particularly in reducing artefacts and improving the detection of subtle lesions within the abdomen. Intermediate mAs provides a good balance between image quality (low noise for low-contrast resolution) and radiation dose.

GMCTH had the lowest third quartile $CTDI_{vol}$ and DLP for head among all the countries compared (except for China with DLP of 818). Similarly, the least $CTDI_{vol}$ for abdomen was noted; however, DLP values varied. The DLP values are higher than those of Australia, Korea and India, and it might be due to our departmental protocols, as abdomen included both upper abdomen and pelvis. To reduce ambiguity in abdomen DLP, it is recommended to state upper abdomen, pelvis or abdomen pelvis as a whole. The $CTDI_{vol}$ and DLP values for chest were in between amongst the countries compared. All these data indicate that CT dose descriptors are not on the higher side for this organization. The Canon's scanner model at this hospital uses AEC-^{Sure} Exposure reducing radiation output during the acquisition phase and use of AIDR3D in image space, helping to achieve better image quality at low doses.[24] Despite these, we need to optimize the protocols with higher $CTDI_{vol}$ and DLP, following the principle As Low as Reasonably Achievable (ALARA).

The mean $CTDI_{vol}$, DLP and effective dose were lower for head and abdomen scans at this organization meanwhile the values for chest were higher in comparison to a study performed at Tribhuvan University Teaching Hospital Nepal.[25] The mean dose metrics for head were consistently lower in comparison to other studies performed in Nepal; however, we were unable to relate chest and abdomen data as they considered either contrast studies or plain head study.[26,27]

The limitation of this study is that no data were obtained for patient dimensions and size-specific dose estimation (SSDE) was not considered, which would have improved the accuracy of the dose estimate.[28] We calculated effective dose using E=K x DLP for convenience, and this has limitations as it could underestimate dose in comparison to the standard organ-dose based technique.[6,29] We also considered CT of patients 15 years and above, so the dose metrics of children are not available. The national diagnostic reference levels (NDRLs) are unavailable for Nepal to date, so comparison could not be done.

CONCLUSIONS

The dose metrics of the plain head, chest and abdomen were reported for the purpose of creating an institutional DRLs. This study points to the need for optimization of chest protocol for relatively higher $CTDI_{vol}$ and DLP values; and abdomen protocol for higher DLP values.

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AUTHORS' CONTRIBUTIONS

SD and KS conducted the literature review and conceptualized the study. SD and KS performed data collection. SD, KS and SP carried out data analysis, interpretation, and preparation of results. SD, KS and SP drafted the manuscript, which was reviewed and approved by all authors. All authors take full responsibility for the integrity and accuracy of the work.

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