Original Article

Estimation of Anatomical Dimensions of the Thorax from Computed Tomography Images of the Adult and Pediatric Indian Population for Developing Optimal Radiological Protocols

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Abstract

Purpose: Ionizing radiation has been extensively used for medical diagnosis since its discovery in 1895; however, excessive use can lead to deleterious effects. Prior knowledge on radiological protocols based on simulations would be a practical tool for optimal use of radiation. **Materials and Methods:** Scan length of the thorax was measured from computed tomography (CT) topographic images and cross-sections at three levels of the thorax were measured from tomographic images of 500 adults and 340 children who had undergone CT thorax examinations using Centricity workstation software. The effective diameter (ED) of the thorax was calculated from anterio-posterior (AP) and transverse anatomical dimensions. **Results:** A 17% increase in scan length was observed for 6–10 years age group compared to 0–5 years, whereas there was marginal increase for 11–15 years of age. A 11.5% increase was observed for 16–18 years compared to 11-15 years age group. The cross-sectional phantom dimensions were calculated from ED measurements obtained from three regions of the thorax. **Conclusions:** This study has provided age- and gender-specific reference scan lengths, AP and transverse dimensions and ED for radiological examinations of the thorax. This information is useful to develop age- and gender-specific preset protocols and fabricate phantoms of the thorax for the pediatric and adult Indian population.

Keywords: Effective diameter, phantom, radiation safety, thorax

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Introduction

Ionizing radiation has been widely used for medical diagnosis and treatment over the past several decades since its discovery. Over the years, several imaging modalities have been included as modalities of choice in diagnosing diseases. Computed tomography (CT) has played an important role in diagnosing diseases as compared with other radiological procedures even though it imparts high radiation doses to patients.[1] Radiation dose from CT is of concern due to the increasing number of examinations performed each day and is a matter of concern for the patient, hospital personnel, the community at large and regulatory bodies. It is known that radiation effects are characterized by a threshold dose and can induce carcinogenesis. Children are more radiosensitive than adults, and the risk of them developing radiation-induced malignancies is two to three times higher than that of adults.[2] Radiation doses from CT are relatively high and technological advances in CT generally have not reduced radiation dose to patients unless dose optimization according to the physical parameters of the patient is performed by the CT operator.[3]

Radiation dose imparted to patients from CT procedures are calculated from CT dose index (CTDI) values that are measured using standard CTDI perspex phantoms. These phantoms are fabricated based on the "reference man" model in accordance with the International Commission for radiological protection (ICRP).[4] The "Reference man" was defined as "a healthy, young, adult male between 20 and 30 years of age

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weighing 70 kg and 170 cm in height based on a Western European or North American origin. However, this model is inappropriate for the vast majority of the population including women and children as they fall outside this definition. The ICRP also introduced computational phantoms of the reference male and female based on image data of real people. These reference phantoms were constructed after modifying the voxel models of two individuals whose body height and mass resembled the reference data.[5] Size-specific dose estimates have been recently introduced for estimating radiation dose from CT scanners which is based on cross-sectional image data.[6]

Knowledge on anatomical dimensions is important for planning radiological examinations as the risk of radiation exposure is linked to the area exposed. Over the last decade, both regulatory authorities and international organizations have emphasized the need for diagnostic Reference levels (DRL's) for all radiological procedures.[7-10] These DRLs are based on CTDI values and dose length product (DLP) for CT procedures; dose area product for radiography and angiography procedures. Radiation dose to patients can be effectively reduced when the operator selects the appropriate field of view and performs the procedure. Newer imaging modalities have radiological protocols with preset anatomical dimensions based on patient habitus to reduce the inadvertent selection of high-dose settings. These protocols can be altered according to the anatomical dimensions of the population under study. The current study intends to generate age- and gender-specific anatomical dimensions from CT images which would help to formulate preset protocols for all imaging modalities in the Indian context.

Materials and Methods

The study was conducted after approval from the institutional review board as a collaborative project involving the departments of Anatomy and Radiology. CT of the thorax images acquired from three multi-detector CT scanners namely Philips Brilliance 6 (Best, Netherlands), Siemens Somatom Emotion 16 (Erlangen, Germany), and GE 750HD Discovery (USA) were archived in the picture archival and communication system. The GE Centricity (USA) workstation software was used to measure the anatomical dimensions from CT thorax topographic and tomographic images. Significant differences in body proportions such as height, weight, and BMI are normally observed during the growth of a child; hence, the children were age-stratified in the study. The convenience sampling method was used as there was a limited time frame of 2 years to complete this study.

Scan lengths for thorax CT examination involved topographic measurement from the lowest part of T12 vertebra to T1 vertebra [Figure 1]. Cross-section measurement of thorax CT

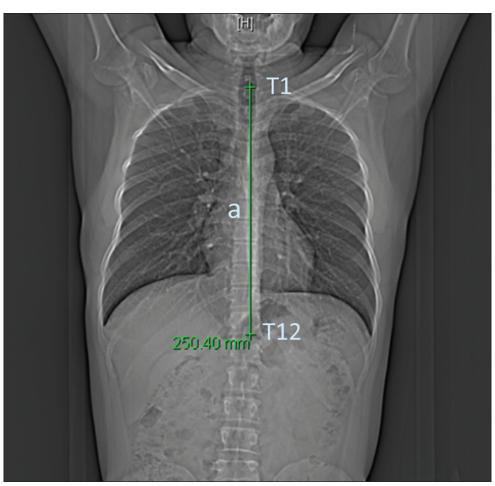

Figure 1: Scan lengths measured from computed tomographyof the thorax topographic images from the lowest part of T12 to T1 vertebra

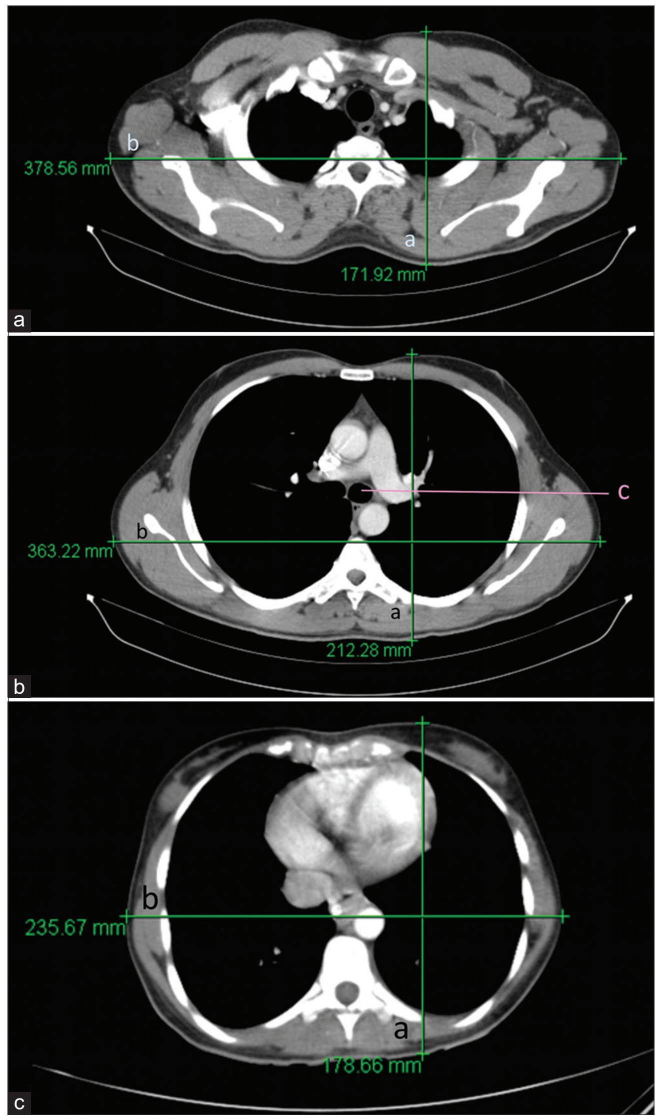

Figure 2: (a) Cross section measurement of the thorax computed tomography at *Level TH1*– apex of the lung in upper thorax; a: Anterioposterior dimension. b: Transverse dimension. (b) Cross-section measurement of thorax computed tomography at *Level TH2*– at carina of trachea c; a: anterioposterior dimension b: transverse dimension. (c) Cross section measurement of thorax computed tomography at *Level TH3*– at base of lung, confirmed by the presence of diaphragm in the next lower section; a: Anterioposterior dimension. b: Transverse dimension

involved measurements from tomographic images at three levels identified by specific and distinct landmarks [Figure 2a-c]. *Level TH1*– apex of the lung in the upper thorax (landmarks: air shadow of lung, sternum and spinous process of thoracic vertebra); *Level TH2*– at carina of the trachea; *Level TH3*– at base of the lung, confirmed by the presence of diaphragm in the next lower section. This section at the base of the lung was the lowest section of the thorax that is devoid of diaphragm on the right side. At each of the above three levels, measurements included (a) maximum anteroposterior (AP) distance in left parasagittal axis from the anterior-most point of skin to the skin on posterior aspect; (b) maximum transverse diameter of the thorax measured between the surface convexity of skin on both sides. The effective diameter (ED) of the thoracic wall was calculated from the AP and transverse dimensions by using the formula: ED = √ (AP dimension × Transverse dimension). The ED directly reflects the circumference of a measured region and can be used for estimation of the surface area of a cross-section for constructing the phantom model.[6]

Table 1: Computed tomography thorax scan length from topographic Image measurements (Tv) of pediatric and adult patients

Age (years)	*n*	Mean (mm)±SD	Range (mm)
0-5	80	158±41.3	73-279
6-10	100	185±37	120-321
11-15	100	217±32.3	143-367
16-18	60	242±36	120-322
Adult males	250	250±20.3	200-309
Adult females	250	224.2±20.1	179-321.4

SD: Standard deviation

Statistical analysis

Patient demographics such as identity, gender, age, and other measured variables were entered into a Microsoft Excel spreadsheet. Categorical variables, such as gender, were summarized using frequencies and percentages. Normally distributed quantitative variables were summarized using mean and standard deviation. Independent *t*-test was used to compare the means between two groups and one-way ANOVA was used to compare the means between more than two groups. For all the analyses, 5% levels of significance were considered to be significant. All statistical analyses were performed using STATA v 13.1 (StataCorp, Stata Statistical Software, College Station, TX, USA).

Results

We reviewed CT of the thorax scans of 500 adults (M = 250, F = 250) and 340 (M = 205, F = 135) children. In the pediatric group, 20 scans were measured in the 0–2 years category, and 20 scans in each numerical age year up to 18 years. Children were further sub-grouped into 0–5 years, 6–10 years, 11–15 years, and 16–18 years categories for analysis. Adults were categorized into adult males and adult females. Almost equal numbers of male and female gender were obtained in each age category.

Table 2: Antero posterior, transverse dimension and effective diameter of the thorax obtained at the three thoracic levels

Age in years	*n*	AP dimension (mm)		Transverse dimension (mm)		Effective diameter (mm)
		Mean±SD	Range	Mean±SD	Range	
Level TH1						
0-5	80	87±10.04	65-119.2	203±24	136-289	133
6-10	100	103.4±2	61-164.3	243.4±42	100-342	159
11-15	100	125±25	86-210	300±43	148-390	193
16-18	60	137±28.3	93-235.4	336±44.4	229-484	214
Adult females	250	161±26	144-306	352.1±39.4	206-464	238
Adult males	250	165±20.4	159-259	358±32	185-472	243
Level TH2						
0-5	80	111±18	83-147	187±24	133-258	144
6-10	100	135±19.4	94-186	232±33	151-324	177
11-15	100	164±24	120-232	288±37	217-391	218
16-18	60	181±24	143-263	321±42.2	230-469	241
Adult females	250	198±26	144-306	337±39.4	206-464	259
Adult males	250	206±20.4	159-259	348±27	267-454	268
Level TH3						
0-5	80	126±13.2	93-156	174±21.3	119-236.2	148
6-10	100	150.4±18.3	109.4-203.2	214.1±25.1	163-296.4	179
11-15	100	178±21.4	139-245.4	260±35	191.2-374	215
16-18	60	195.3±24.2	159.2-282.1	288±41	215-416.3	237
Adult females	250	208.3±21.3	158.2-275	305±40.2	195-431.2	252
Adult males	250	216±23	158.2-278	313±30	230-434	264

AP: Antero posterior, SD: Standard deviation

The scan length from topographic images of CT of the thorax is tabulated in Table 1. The mean scan length increased progressively from 0 to 5 years age group to 18 years of age. A 17% increase in scan length was observed for 6–10 years age group compared to 0–5 years; similarly, a 17.3% increase was observed for 11–15 years age group compared to 6–10 years age group. A 11.5% increase was observed for 16–18 years age group compared to 11–15 years age group. The mean scan length was higher in adult males than adult females.

The measured AP and transverse dimensions at levels TH1, TH2, TH3, and ED are tabulated in Table 2. These measured values were useful for fabricating a phantom model of the pediatric and adult thorax. The ED showed a steady increase from the 0 to 5 years age group to 18 years age group in children. In adults, the ED was more in adult males compared to adult females. *At level TH1*, the ED increased by 1.19 times from 0 to 5 years age group to 6–10 year age group. There was an increase by 1.21 times in ED from 6 to 10 years age group to 11–15 year age group. There was an increase by 1.10 times in ED from 11 to 15 years age group to 16–18 year age group. Among adults, there was an increase by 1.02 times in ED from females to males. At level TH2, ED increased by 1.22 times from 0 to 5 years age group to 6–10 year age group. There was an increase by 1.23 times in ED from 6 to 10 years age group to 11-15 year age group. There was an increase by 1.10 times in ED from 11–15 year age group to 16-18 year age group. Among adults, there was an increase by 1.03 times in ED from females to males. At level TH3, ED increased by 1.2 times from 0 to 5 years age group to 6–10 years age group. There was an increase by 1.2 times in ED from 6 to 10 years age group to 11–15 years age group. There was an increase by 1.1 times in ED from 11 to 15 years age group to 16–18 years age group. Among adults, there was an increase by 1.04 times in ED from females to males. The ED data have been represented as age-specific phantoms in Figure 3.

Discussion

To the best of our knowledge, this is the first study to measure anatomical dimensions of the thorax in the pediatric and adult Indian population from CT images of the thorax for generating age- and gender-specific reference values which could be utilized for optimizing radiological imaging protocols and designing of phantoms. The scan lengths reported in this study for different age groups is useful to calculate the DLP in CT scanners, as DLP is the product of volume CTDI and scan length. In chest radiography, the scan length is useful in the automatic selection of collimation using positive beam limitation based on the age group. Significant differences in scan length were observed between the Indian and NRPB data of the pediatric population. In this study, the scan length for 0–1, 5, 10 years and adults was 124, 172, 202, and 237 cm, respectively, compared to 156, 186, 231, and 247 cm as reported in NRPB. The NRPB pediatric scan length data were measured only for ages 0–1, 5, and 10 years in a small sample size of 16,[8] however our study involved a sample size of 340 children and scan length was measured in four age-stratified groups ranging from 0 to 18 years. Livingstone *et al*. reported a mean scan length of 36.1 cm for CT thorax in the adult Indian population which was higher than the values reported in the present study.[11] They, however, did not stratify the scan lengths according to different age groups as done in the current study. The ED calculated from the cross-sectional images was similar to those reported by AAPM 204 [Table 3].[6]

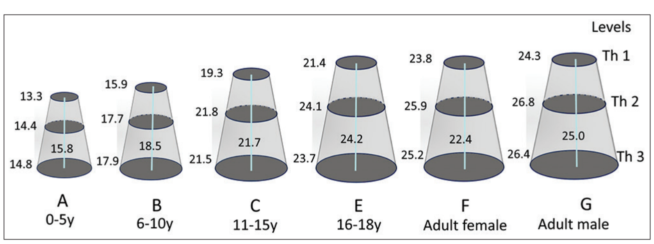

Figure 3: Age-specific phantoms models obtained from effective diameter values at different regions of the thorax

Conclusions

This study has provided age- and gender-specific reference scan lengths, AP and transverse dimensions, and ED for radiological

Table 3: Comparison of effective diameter between AAPM 204 and present study

Effective diameter (cm) (present study)	Effective diameter (cm) AAPM 204
12	11.7
12.4	12.2
13.6	13.7
14	13.7
14.2	13.7
13.3	14.2
14.2	14.2
14.4	14.7
14.7	14.7
14.8	14.7
15.1	14.7
15.8	15.7
16	15.7
16.7	16.7
16.9	17.2
17.9	17.6
17.7	18.1
17.8	18.1
18.7	18.6
19.9	19.6
19.3	20.6
21.5	21.6
21.9	21.6
21.8	21.8
23.7	23.6
24.1	24.6
24.3	25.6
25.9	26.6
26.4	26.6

examinations of the thorax. This information is immensely useful to develop age- and gender-specific preset protocols and fabricate phantoms of the thorax for the pediatric and adult Indian population. The method employed to estimate ED is reproducible when compared to methods adopted by AAPM 204. Significant differences in dimensions of the thorax were observed between the Indian and European populations as studied by NRPB 67. This information is useful to develop age- and gender-specific preset protocols and fabricate phantoms of the thorax for the pediatric and adult Indian population.

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Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Livingstone RS, Dinakaran PM, Cherian RS, Eapen A. Comparison of radiation doses using weight-based protocol and dose modulation techniques for patients undergoing biphasic abdominal computed tomography examinations. J Med Phys Assoc Med Phys India 2009;34:217-22.
2. Huda W. Dose and image quality in CT. Pediatr Radiol 2002;32:709-13.
3. McCollough CH, Primak AN, Braun N, Kofler J, Yu L, Christner J. Strategies for reducing radiation dose in CT. Radiol Clin North Am 2009;47:27-40.
4. International Commission for Radiological Protection (ICRP) Publication 23. Report of the Task Group on Reference Man; 1975.
5. International Commission for Radiological Protection (ICRP) Publication 110. Ann. ICRP; 2009;39.
6. Boone JM, Strauss KJ, Cody DD, et al., eds.; American Association of Physicists in Medicine (AAPM). Size-specific dose estimates (SSDE) in pediatric and adult body CT examinations: report of AAPM Task Group 204. Avilable from: www.aapm.org/pubs/reports/rpt_204.pdf. Published 2011. [Last accessed on 2020 Dec 12].
7. ICRP Publication 103. The 2007 Recommendations of the International Commission on Radiological Protection; Ann ICRP 200**7;37:1-332.**
8. Shrimpton P, Hillier M, Lewis M, Dunn M. National survey of doses from CT in the UK: 2003. Br J Radiol 2007;79:968-80.
9. United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and Effects of Ionizing Radiation: United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR) Report to the General Assembly, with Scientific Annexes. Vol. 1. Sources. New York, NY: United Nations; 2008.
10. European Guidelines on Quality Criteria for Computed Tomography EUR 16262 EN; 1999. Avilable from: http://www.drs.dk/guidelines/ct/quality/Page032.htm. Accessed on December 12, 2020.
11. Livingstone RS, Dinakaran PM. Radiation safety concerns and diagnostic reference levels for computed tomography scanners in Tamil Nadu. J Med Phys 2011;36:40-5.