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Measurement of heart chambers and mediastinal vascular structures on raw axial chest MDCT in the pediatric age group

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SUMMARY

Determining the normal range of mediastinal vascular structures and heart chambers is important for accurate evaluation and diagnosis of cardiopulmonary diseases. The aim of this work was to determine the average sizes of heart chambers, mediastinal vascular structures, and the ratio of the main pulmonary artery-to-ascending aorta (MPA-to-AA) in children without congenital or acquired cardiopulmonary diseases on contrast-enhanced (CE) chest multidetector computed tomography (MDCT). In total, 356 participants (range 0-216 months) were enrolled. The interobserver correlation (ICC) analysis performed and P-value is considered significant if <0.05. The mean diameters for the left and right ventricle and atrium, ascending aorta, descending aorta at the level of the mediastinum, descending aorta at the level of the diaphragm, main pulmonary artery, right pulmonary artery, and MPA-to-AA ratio were revealed for 6 age groups. Mediastinal vascular structures have excellent and heart chambers have a substantial-to-excellent ICC agreement. The diameters of heart chambers and mediastinal vascular structures on CE-chest MDCT are easy to measure and might be used as a reference to refer patients for further investigations.

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Key words: Aorta – Pulmonary artery – Heart chambers – Multidetector computed tomography (MDCT) – Diameter

INTRODUCTION

Congenital or acquired cardiopulmonary diseases may alter the size of the heart chambers and mediastinal great vessels in the pediatric age. Reliable and reproducible methods for measuring these cardiovascular structures are critical not only for diagnosis and follow-up but also for determining the appropriate treatment strategies (Rossi and Vassanelli, 2003; Pritchett et al., 2003; Leung et al., 2008). These values might help clinician for assessing the cardiovascular pathologies in daily pediatric cardiology and radiology practice.

Heart chambers and mediastinal great vessels can be assessed by two-dimensional echocardiography, invasive conventional catheter angiography, electrocardiogram (ECG) gated, or non ECG-gated multidetector computed tomography (MDCT), cardiovascular magnetic resonance imaging (MRI). However, MDCT of the chest is one of the most commonly performed radiologic examinations in pediatric age, which is usually carried out to assess the lung, heart and extracardiac structures. Despite the fact

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that the heart and mediastinal vascular system are included in the axial chest MDCT, basal measurements are generally made by visual desicion in daily practice and cardiovascular findings are commonly underestimated (Choy et al., 2013; Sverzellati et al., 2016).

In the literature, normal values of mediastinal great vessles in children and young adults have been assessed by echocardiography (Poutanen et al., 2013), conventional catheter angiography (Rammos et al., 2005) and cardiac MRI (Voges et al., 2012). Besides, the normal ranges of heart chambers on raw-axial chest MDCT have been evaluated in adults (Dogan et al., 2006; Long et al., 2010; Al-Mousily et al., 2010). However, to our knowledge there is no study that has evaluated the normal sizes of heart chambers on raw axial CE-chest MDCT in pediatric patients. This is the first study in which the diameters of heart chambers have been evaluated in healthy children on raw axial chest MDCT.

In this study, we aimed to determine the normal values of the heart chambers [right atrium (RA), left atrium (LA), right ventricle (RV), and left ventricle (LV)] and mediastinal vascular structures [ascending aorta (AA), descending aorta at the level of the mediastinum (DA-m) and diaphragm (DA-d), main pulmonary artery (MPA), left pulmonary artery (LPA), right pulmonary artery (RPA)] in children according to their age groups who underwent CE-chest MDCT.

MATERIALS AND METHODS

Ethical approval of this retrospective study was obtained from the Ethical Committee of the Istanbul Medeniyet University, Goztepe Training and Research Hospital. The informed consent was waived.

Study Group

Between January 2015 and June 2018, all chest MDCTs with or without contrast agent administration of 1396 pediatric patients [aged under 216 months (18 years)] performed at the well-established pediatric institution of our hospital were retrospectively evaluated. The radiologic findings of pneumonia, minor trauma with mild pneumothorax and/or mild pleural effusion, and pulmonary nodule revealed on CE-chest MDCT included in the study. CE-chest MDCT of patients with the exact diagnosis of respiratory and systemic disease, congenital heart disease (intracardiac shunts, failure or heart valves stenosis), and pulmonary hypertension confirmed by echocardiography revealed from the hospital information system were excluded from the study. Examinations without contrast agent administration and with severe image artifacts were also excluded. The patients out of normal body height and weights according to their age reported in the hospital information system also excluded from the study. The remaining 356 CE-chest MDCT of the 1396 patients were included in the study (Fig. 1).

Demographic data such as sex, age with initial and exact diagnosis, echocardiography reports of patients are obtained from the hospital information system. The patients were divided into six groups according to their age: Group 1, 0-12 months (0-1 year); Group 2, 13-36 months (1-3 years); Group 3, 37-72 months (3-6 years); Group 4, 73-120 months (6-10 years); Group 5, 121-180 months (10-15 years) and Group 6, 181-216 months (15-18 years) (Table 1). According to the medical records, the body weight and height of all patients in the study group were within normal limits according to their age groups.

Chest Multidetector Computed Tomography Protocol

All examinations were performed with a 64 detectors MDCT machine (Discovery, GE Healthcare, Milwaukee, WI, USA). A 300 mg/ml of non-ionic contrast material (1-2 ml/kg and maximum volume of 20-50 cc) with an injection rate of 2-3 cc/second was administered via a peripheral vein. Bolus tracking technique was used and the region of interest was located in the descending aorta. The areas between the apex and the base of the lungs were scanned. Variable dose parameters were applied according to patient weight stated in our institutional pediatric protocol (range 30-60 mA and 80-120 kV) with dose reducing technique. The scan parameters were as follows: reconstruction interval 0.75, the pitch factor 0.67-1.72, rotation time 0.5-0.75 seconds, and the collimation 64 x 0.625 mm.

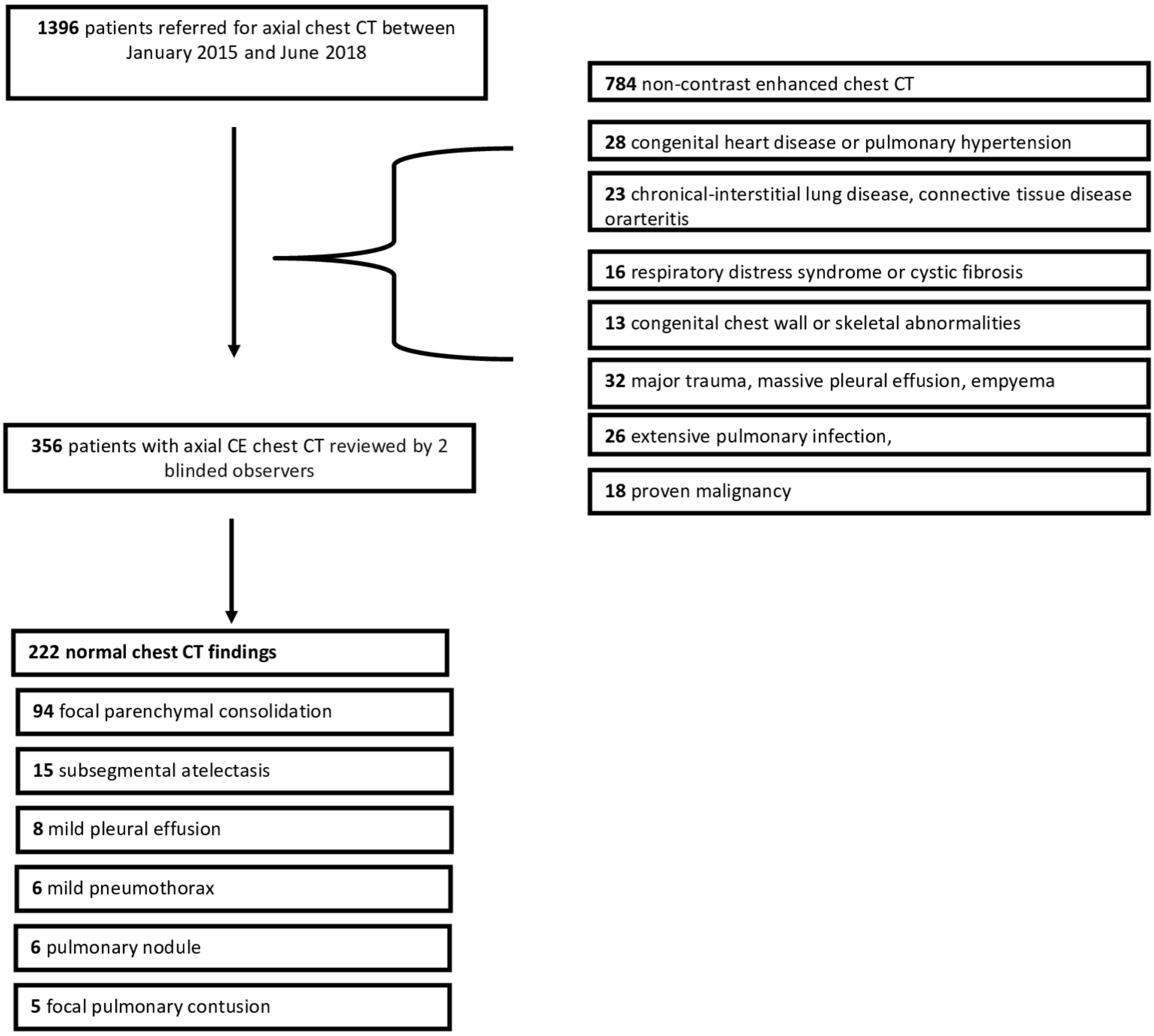

Fig. 1.- Study flow chart with the inclusion and exclusion of the patients.

Table 1. Demographic data of the study groups.

Group	Age Groups (months)	Number (%)	Mean age ± SD (months)	Female n (%)	Male n (%)
Group 1	0 - 12	53 (15)	6.1 ± 2.8	15 (28.3)	38 (71.7)
Group 2	13 - 36	62 (17)	21.4 ± 6.5	23 (37.1)	39 (62.9)
Group 3	37 - 72	45 (13)	55.3 ± 10.6	22 (48.9)	23 (51.1)
Group 4	73 - 120	56 (16)	93.8 ± 12.4	32 (57.1)	24 (42.9)
Group 5	121 - 180	70 (20)	148.5 ± 19	33 (47.1)	37 (52.9)
Group 6	181 - 216	70 (20)	199.8 ± 11.1	22 (31.4)	48 (68.6)
Total	0 - 216	**356 (100)**	94.9 ± 72.1	147 (41.3)	209 (58.7)

Results are presented as number (%) and mean ± SD where applicable.

Measurements

Two radiologists, blinded to the patient's clinical findings and diagnosis, measured the diameters of mediastinal vascular structures and heart chambers independently. All the measurements were performed on raw axial CE-chest MDCT after image reconstruction of 1.25 mm slice thickness on a workstation (Centricity, GE Healthcare, Milwaukee, WI, USA) at standardized mediastinal window settings (window level, 30-40 HU; and window width of 300-400 HU). The diameter of LV and RV were measured as the greatest distance between the interventricular septum and lateral wall from inner to inner contour perpendicular to the long axis of the ventricle, LV below the level of the mitral valve and RV on midventricular level (Fig. 2). LA and RA were measured in its largest anterior-posterior dimension from inner-to-inner contour to emulate linear LA measurement taken on M-mode echocardiography and two-dimensional parasternal views (Fig. 3) (Lu et al., 2012). The largest diameter of pulmonary arteries was measured on the axial plane, perpendicular to their long axis. MPA was measured at 2-3 millimeters above the pulmonary valve, RPA and LPA were measured 1.5-2 cm after the pulmonary artery bifurcation (Fig. 4). AA and DA-m measured at the level of pulmonary artery bifurcation (Fig. 5a), and DA-d measured at the level of diaphragm (Fig. 5b). The mean MPA-to-AA ratio was also calculated according to all age groups.

Statistical analysis

SPSS version 20.0 software (IBM Corporation, Armonk, NY, USA) was used for statistical analysis. The results were expressed as the mean of both observers' measurements and presented as the mean ± standard deviation. Pearson's correlation analysis was used to evaluate the relationship between the age and the measurements. Analysis of variance (ANOVA) test was used to compare the measurements of six age groups. A two-way mixed model was used to evaluate intraclass correlation (ICC) analysis to evaluate the agreement between two readers. ICC coefficient value higher than 0.8 indicates excellent, between 0.8-0.6 indicates substantial, between 0.6-0.4 indicates moderate, and lower than 0.4 indicates poor agreements. Results were accepted as statistically significant if the p-value is lower than 0.05.

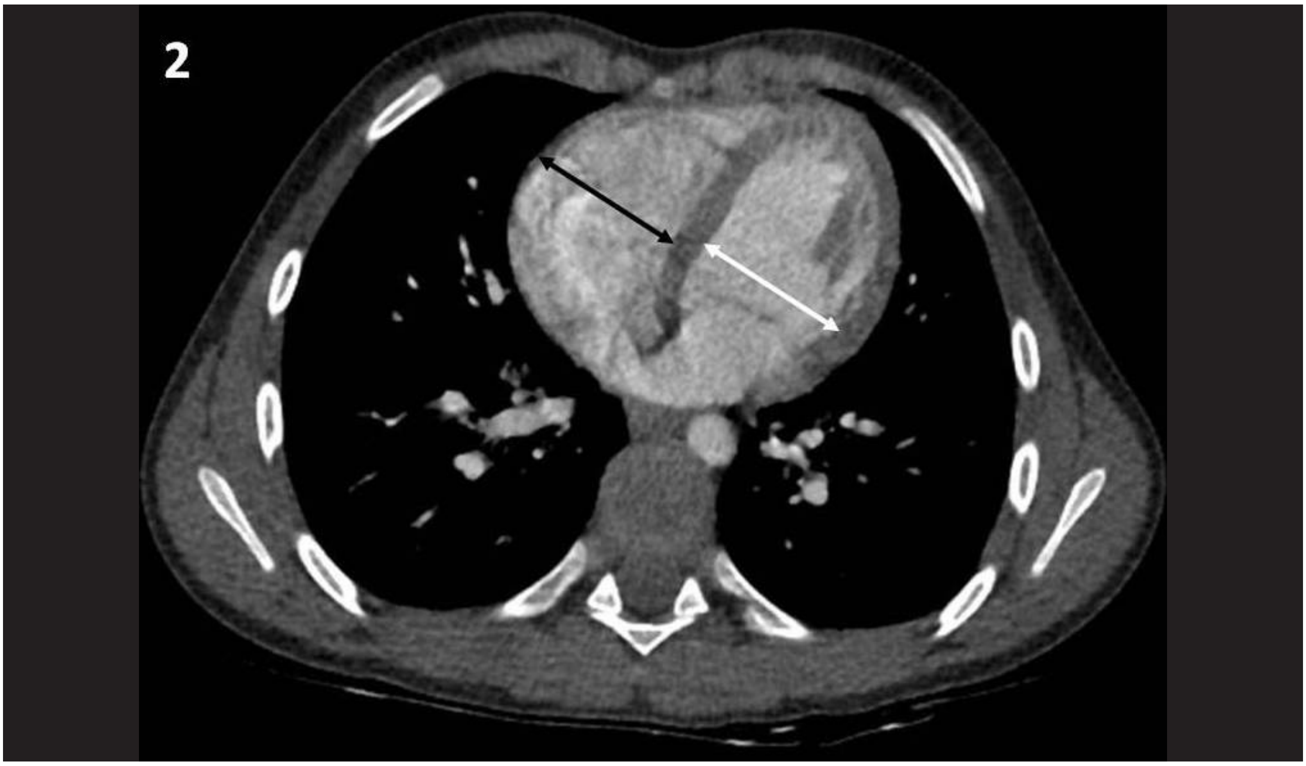

Fig. 2.- Contrast enhanced chest MDCT image demonstrates the measurement of the right (black arrow) and left (white arrow) ventricle between interventricular septum and lateral wall from inner to inner contour perpendicular to the long axis of the ventricle, left ventricle below the level of the mitral valve and the right ventricle on midventricular level.

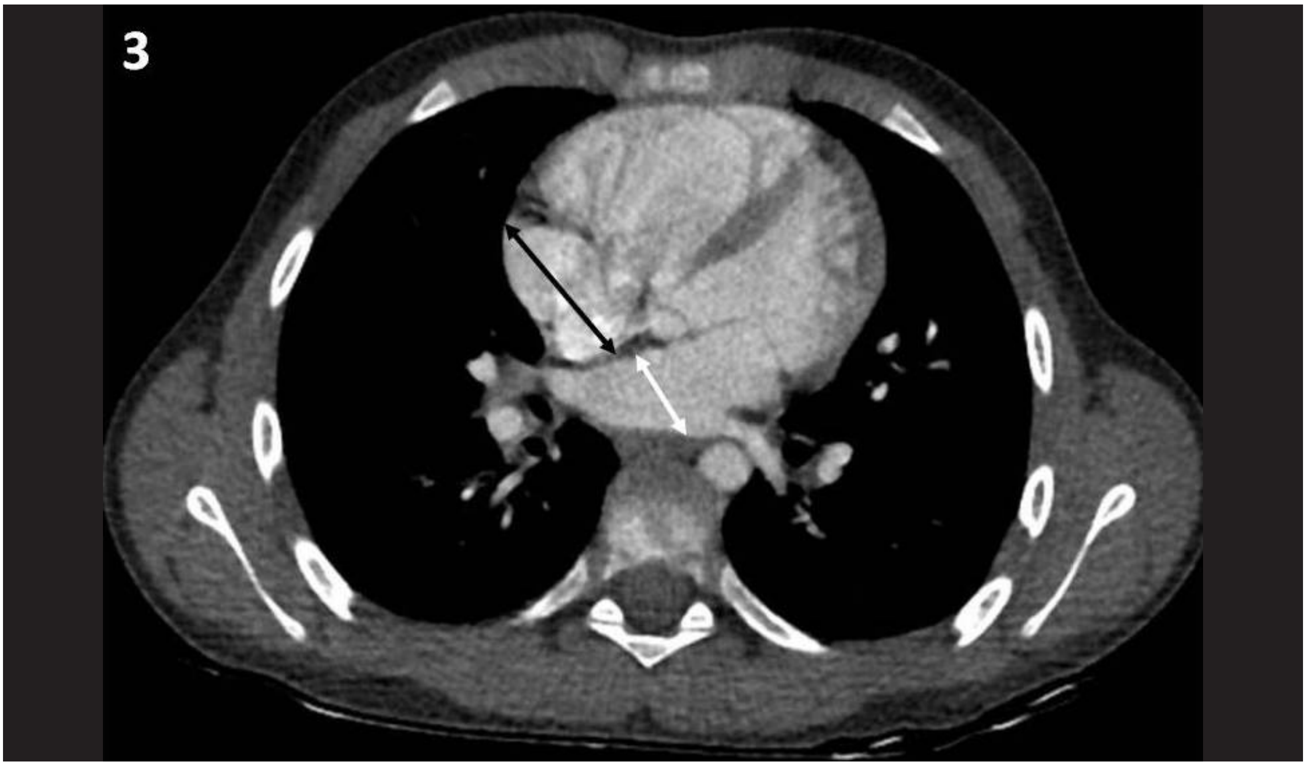

Fig. 3.- Contrast enhanced chest MDCT image demonstrates the measurement of the right (black arrow) and left (white arrow) atrium in its largest anterior-posterior dimension from inner to inner contour.

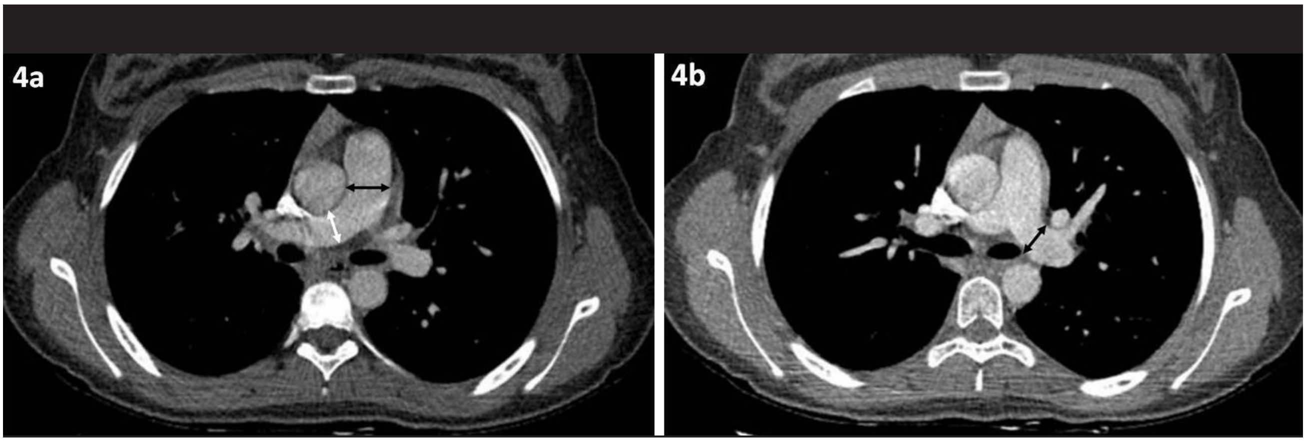

Fig. 4.- Contrast-enhanced chest MDCT image demonstrates the measurement of the main (**a**, black arrow), right (**a**, white arrow) and left pulmonary artery (**b**, black arrow) perpendicular to their long axis.

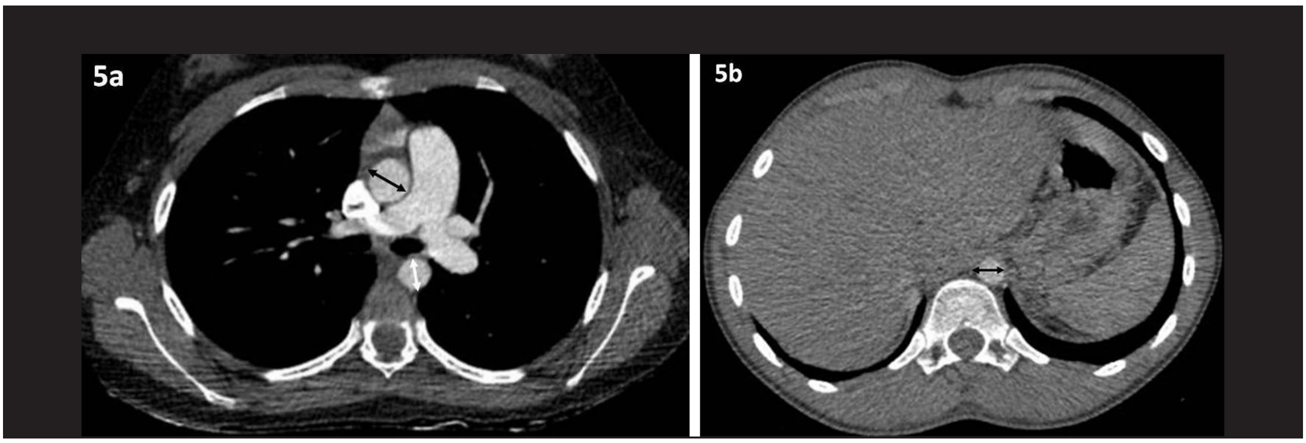

Fig. 5.- Contrast-enhanced chest MDCT image demonstrates the measurement of the ascending (**a**, black arrow**)**, proximal descending aorta (**a**, white arrow) at the level of pulmonary artery bifurcation and distal descending aorta at the level of diaphragm (**b**, black arrow).

RESULTS

In this retrospective study CE-chest MDCT examinations of 356 patients with a male: female ratio of 1.8: 1 (209 male and 147 female). The mean patient age was 94.9 ± 72.1 (range 2 to 216 months). The distribution of patients in age groups is demonstrated in Table 1. Preliminary clinical diagnosis were as follows; pneumonia (n = 164, 34%), minor trauma (mild pneumothorax, mild pleural effusion) (n = 90, 18%), chronic cough (n=74, 15%),interstitial lung disease (n = 58, 12%), congenital heart disease or pulmonary hypertension (n = 42, 9%), respiratory distress (n = 31, 6%), lung metastasis (n = 27, 6%). Chest CT findings of the patients in the study group were as follows: normal CT findings (n = 222, 62%), focal parenchymal consolidation (n=94, 26%), subsegmental atelectasis (n = 15, 4%), mildpleural effusion (n = 8, 3%), mild pneumothorax (n = 6, 2%), pulmonary nodule (n=6, 2%), and focal pulmonary contusion (n = 5, 1%) (Fig.1).

The mean diameters of mediastinal vascular structures and cardiac chambers for all groups were measured by two observers and the ICC values among observers demonstrated in Tables 2 and 3. The ICC analysis revealed that the measurements of mediastinal vascular structures have excellent (ICC between 0.887 - 0.956) and heart chambers have substantial-to-excellent (ICC between 0.681 - 0.958) agreement.

The mean diameters of each cardiovascular structure, revealed by the sum of the measurements of two observers, showed high, positive, and statistically significant correlations with the patients' age ($p < 0.001$) (Table 4). But there was no statistically significant correlation between the MPA-to-AAratio and the patients' age ($p = 0.782$) (Table 4). When we evaluated the differences between the diameter of the left and right pulmonary artery, there was no statistically significant difference ($p = 0.853$). The mean diameters of mediastinal vascular structures and

Table 2. The mean diameter of the vascular structures and the ratio of the pulmonary artery to ascending aorta with intraclass correlation coefficients analysis among the two observers.

		AA (mm)	DA-m (mm)	DA-d (mm)	MPA (mm)	RPA (mm)	LPA (mm)	MPA/AA
Group 1	Observer 1	10.7 ± 1.75	7.94 ± 1.34	6.85 ± 0.91	11.32 ± 1.77	7.08 ± 1.17	7.51 ± 1.41	1.07 ± 0.18
	Observer 2	11.23 ± 1.59	7.08 ± 1.11	7.11 ± 0.97	11.23 ± 1.86	7.62 ± 1.47	7.66 ± 1.39	1 ± 0.12
Group 2	Observer 1	13.27 ± 1.98	9.78 ± 1.46	8.29 ± 1.23	13.29 ± 2.41	9.3 ± 2.33	9 ± 1.51	1.01 ± 0.19
	Observer 2	13.73 ± 1.87	9.5 ± 1.38	8.45 ± 1.13	13.34 ± 2.22	9.58 ± 2.32	9.27 ± 1.48	0.98 ± 0.15
Group 3	Observer 1	14.73 ± 3.12	11.71 ± 1.96	9.49 ± 1.56	15.73 ± 2.65	11.2 ± 3.28	10.64 ± 1.71	1.09 ± 0.24
	Observer 2	16.33 ± 2.71	11.22 ± 1.63	10.02 ± 1.49	15.89 ± 2.62	11.87 ± 3.27	11.18 ± 1.54	0.98 ± 0.16
Group 4	Observer 1	16.96 ± 2.65	13.55 ± 1.81	10.93 ± 1.45	17.29 ± 3.28	12.61 ± 3.5	11.5 ± 2.19	1.04 ± 0.24
	Observer 2	19.04 ± 2.44	12.8 ± 1.67	11.52 ± 1.5	17.48 ± 3.12	13.38 ± 3.25	12.63 ± 2.03	0.92 ± 0.14
Group 5	Observer 1	20.01 ± 3.12	15.77 ± 2.21	12.86 ± 1.96	20.53 ± 3.56	13.4 ± 2.94	12.79 ± 2.06	1.04 ± 0.22
	Observer 2	22.04 ± 2.73	15.17 ± 2.01	13.89 ± 2.04	20.91 ± 3.35	14.61 ± 2.87	14.3 ± 2.04	0.95 ± 0.12
Group 6	Observer 1	22.33 ± 2.82	17.91 ± 2.3	14.86 ± 1.87	21.3 ± 2.68	15.14 ± 3.49	13.71 ± 2.32	0.96 ± 0.13
	Observer 2	23.97 ± 2.19	17 ± 1.99	16.07 ± 2.48	22.31 ± 2.92	16.01 ± 3.21	15.46 ± 2.08	0.93 ± 0.11
Total		17.4 ± 4.8	12.9 ± 3.7	11.2 ± 3.3	17.1 ± 4.6	12 ± 3.9	11.5 ± 2	1.02 ± 0.47
ICC (95% CI)		0.935 (0.810-0.938)	0.946 (0.924-0.961)	0.942 (0.901-0.963)	0.956 (0.945-0.65)	0.887 (0.781-0.933)	0.887 (0.781-0.933)	0.691 (0.533-0.785)
P		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Results are presented as mean ± SD. **P:** p value of ICC. Abbreviations: **AA:** ascending aorta, **DA-m:** descending aorta at the level of the mediastinum, **DA-d:** descending aorta at the level of the diaphragm, **MPA:** main pulmonary artery, **RPA:** right pulmonary artery, **LPA:** left pulmonary artery, **MPA/AA:** the MPA-to-AA ratio.

heart chambers with the MPA-to-AA ratio for all six age groups are shown in Tables 5 and 6. There was no significant difference between age groups and the MPA-to-AA ratio.

DISCUSSION

In daily clinical practice, two-dimentional echocardiography is commonly used as a first-line imaging tool for diagnosis and follow-up of the disorders of the heart and the mediastinal great vessels. However, its operator-dependent quality and impaired acoustic window limit the performance. Besides, conventional catheter angiography due to invasiveness and containing ionizing radiation has limited use (Bacher et al., 2011). Also, MRI is a non-invasive, ionized radiation-free imaging tool widely used in assessment of the heart structures and great vessels in children with congenital heart disease. However, cardiac MRI requires longer scanning time and deeper anesthesia compared with MDCT (Sanborn et al., 2005).

On the other hand, CE-chest MDCT has become one of the most preferred diagnostic choice in the assessment of congenital or acquired cardiopulmonary disease in the pediatric age population (Fitzgerald et al., 1987; Frush and Herlong, 2005; Paterson and Frush, 2007; Karazincir et al., 2008). CE-chest MDCT has led to an expanded application to evaluate lung in congenital heart disease in the pre-operative or postoperative period compared to two-dimentional echocardiography, conventional catheter angiography, and cardiac MRI (edwards et al., 1998; Ng et al., 1999; Gilkeson et al., 2003; Poutanen et al., 2013). Nevertheless, MDCT has some advantages and disadvantages in clinical practice. The main disadvantege is the exposure to ionizing radiation, especially in younger children because of the higher sensitivity to radiation. However, by the advances in detector technology and dose reduction techniques, MDCT provides an increase in temporal and spatial resolution, motion artifact, and a decrease in ionizing radiation.

Table 3. The mean diameter of the heart chambers with intraclass correlation coefficients analysis among the two observers.

		LV (mm)	RV (mm)	LA (mm)	RA (mm)
Group 1	Observer 1	13.68 ± 2.53	21.23 ± 3.3	17.94 ± 2.62	14.21 ± 3.16
	Observer 2	17.68 ± 2.83	20.6 ± 3.79	22.83 ± 3.66	16.81 ± 3.17
Group 2	Observer 1	17.19 ± 3.72	24.26 ± 3.18	21.55 ± 4.02	16.84 ± 3.24
	Observer 2	21.11 ± 3.57	24.92 ± 3.89	26.22 ± 3.96	18.55 ± 2.66
Group 3	Observer 1	20.02 ± 3.51	28.67 ± 4.95	26.64 ± 5.5	18.87 ± 3.45
	Observer 2	24.69 ± 3.67	30.31 ± 5.48	31.84 ± 4.31	22.4 ± 3.97
Group 4	Observer 1	22.93 ± 4.69	32.96 ± 4.62	27.66 ± 5.33	20.98 ± 4.47
	Observer 2	28.18 ± 4.04	34.69 ± 4.9	35.21 ± 5.18	24.62 ± 4.49
Group 5	Observer 1	25.62 ± 5.31	37.03 ± 5.15	30.43 ± 5.67	22.39 ± 4.12
	Observer 2	32.3 ± 5.18	38.83 ± 5.51	39.81 ± 6.35	27 ± 5.26
Group 6	Observer 1	27.9 ± 5.78	39.84 ± 4.91	31.63 ± 5.87	23.04 ± 4.41
	Observer 2	33.57 ± 5.41	42.27 ± 6.02	41.94 ± 5.7	27.96 ± 4.93
Total		24.2 ± 6.6	32 ± 8.5	30 ± 7.3	21.5 ± 5.2
ICC (95% CI)		0.958 (0.933-0.972)	0.777 (0.018-0.917)	0.768 (0.216-0.898)	0.681 (0.147-0.876)
P		<0.0001	<0.0001	<0.0001	<0.0001

Results are presented as mean ± SD. **P:** p value of ICC. Abbreviations: **LA:** left atrium, **LV:** left ventricle, **RA:** right atrium, **RV:** right ventricle.

Table 4. Mean diameters of the diameters of vascular structures and heart chambers and correlation with age.

	Measurements (mm)	r	P value
AA	17.4 ± 4.8	0.888	<0.0001
DA-m	12.9 ± 3.7	0.903	<0.0001
DA-d	11.2 ± 3.3	0.896	<0.0001
MPA	17.1 ± 4.6	0.834	<0.0001
RPA	12 ± 3.9	0.798	<0.0001
LPA	11.5 ± 2	0.811	<0.0001
MPA/AA	1.02 ± 0.47	-0.015	0.782
LV	24.2 ± 6.6	0.790	<0.0001
RV	32 ± 8.5	0.835	<0.0001
LA	30 ± 7.3	0.789	<0.0001
RA	21.5 ± 5.2	0.688	<0.0001

Results are presented as mean ± SD. **r**: correlation coefficient, **p:** p value of Pearson's test. Abbreviations: **LA:** left atrium, **LV:** left ventricle, **RA:** right atrium, **RV:** right ventricle.

Table 5. The mean diameter (mm) of the vascular structures and the ratio of the pulmonary artery to ascending aorta in each group.

	AA	DA-m	DA-d	MPA	RPA	LPA	MPA/AA
Group 1	10.9 ± 1.5	7.9 ± 1	7 ± 1	11.3 ± 1.7	7.3 ± 1.3	7.6 ± 1.3	1.03 ± 0.12
Group 2	13.6 ± 1.7	9.7 ± 1.1	8.4 ± 1	13.5 ± 2	9.4 ± 2.2	9.2 ± 1.2	0.99 ± 0.15
Group 3	15.3 ± 2	11.4 ± 1.7	10 ± 1.5	15.8 ± 2.5	11.5 ± 3.2	10.9 ± 1.5	1.04 ± 0.16
Group 4	17.9 ± 2.3	13.2 ± 1.5	11.2 ± 1.4	17.4 ± 3.1	13 ± 3.3	12.1 ± 1.9	0.97 ± 0.18
Group 5	20.1 ± 2.7	15.5 ± 1.9	13.4 ± 1.9	20.8 ± 3.3	14 ± 2.7	13.5 ± 1.8	1.11 ± 1.01
Group 6	23.2 ± 2.2	17.5 ± 1.9	15.5 ± 1.9	21.9 ± 2.4	15.6 ± 3.2	14.6 ± 2	0.95 ± 0.09
p	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.408

Results are presented as mean ± SD. **P:** p value of ANOVA test. Abbreviations: **AA:** ascending aorta, **DA-m:** descending aorta at the level of mediastinum, **DA-d:** descending aorta at the level of diaphragm, **MPA:** main pulmonary artery, **RPA:** right pulmonary artery, **LPA:** left pulmonary artery, **MPA/AA**: The MPA-to-AA ratio.

Table 6. The mean diameter of the heart chambers in each group.

Heart chambers (mm)	LV	RV	LA	RA
Group 1	15.7 ± 2.2	20.9 ± 3.2	20.4 ± 2.5	15.5 ± 2.8
Group 2	19.3 ± 3.2	24.6 ± 3.3	24 ± 3.4	17.8 ± 2.4
Group 3	22.4 ± 3.1	29.5 ± 4.9	31.4 ± 4.5	20.6 ± 3.5
Group 4	25.6 ± 3.6	33.8 ± 4.5	31.4 ± 4.5	22.8 ± 4
Group 5	28.8 ± 4.5	37.9 ± 5.1	35 ± 5.3	24.8 ± 4.2
Group 6	30.7 ± 5.1	41.1 ± 5.1	36.8 ± 4.8	25.5 ± 4.3
p	<0.0001	<0.0001	<0.0001	<0.0001

Results are presented as mean ± SD. **P:** p value of ANOVA test. Abbreviations: **LV:** left ventricle, **RV:** right ventricle, **LA:** left atrium, **RA:** right atrium.

Measurements of Heart Chambers

Two-dimensional echocardiography is usually employed to assess the size and function of the heart chamber in a daily pediatric cardiology practice. However, it can underestimate or overestimate the values of the measurement when compared with the MRI, which is accepted as the reference diagnostic modality (Lang et al., 2005; Kawel-Boehm et al., 2015). In the literature, measurement of LV in adult patients on non ECG-gated chest MDCT has been assessed in limited studies (Huckleberry et al., 2012; Kathiria et al., 2015; Murphy et al., 2016). To our knowledge, there is no study that has evaluated the normal ranges of cardiac chambers on raw axial CE-chest MDCT in pediatric patients. In our study, we measured the diameters of heart chambers on raw axial images without multiplanar reconstruction. Although recently developed advanced post-processing software programs, including volume-rendered and multiplanar reconstruction images, provide better image quality (Burrill et al., 2007; Karazincir et al., 2008), the diameters derived from the raw-axial images proved to be more practical, because extra time is needed for the multiplanar reconstruction and post-processing. Huckleberry et al. (2012) reported that raw axial measurements of the LA and LV were found superior to measurements on multiplanar reconstruction (areas under ROC was 0.82 for LV and 0.87 for LA). In our study, we found statistically significant correlations between the diameter of cardiac chambers and patients' age ($p < 0.001$). Although the measurements of the right ventricle and both atriums had relatively lower ICC values compared with the left ventricle, measurements of heart chambers showed substantial-to-excellent (ICC between 0.681-0.958) ICC value. We believe that a relatively lower interobserver agreement is associated with a more complex geometry of the right ventricle and both atria. The other reason may be cardiac pulsation and respiratory artifacts. ECG-gated CE-chest MDCT can be preferred for better imaging quality and synchronization of the cardiac cycle (Torres et al., 2017). However, Lu et al. (2009) demonstrated a high correlation between non-gated and gated end-diastolic diameter ratios, area, and volume measurements of ventricles. Kathiria et al. (2015) also reported that non-gated CE-chest MDCT scan can be used to recognize LV enlargement with the reported value of LV diameter, a sensitivity of 78%, specificity of 100% compared with two-dimentional echocardiography. In another study by Murphy at al. (2016) with the assessment of LV diameter measured on a raw axial CE-chest MDCT comparison with cardiac MRI reported that there was a good correlation between the measurement of raw axial CE-chest MDCT and cardiac MRI with a sensitivity of 93% and a specificity of 88%.

On the other hand, ECG-gated MDCT technique has some limitation as a longer acquisition time than comparable protocols without ECG-gating and a greater patient radiation dose (Lu et al., 2009). Longer scanning time in pediatric age patients may require sedation and cause increased respiratory artifacts. Despite the better temporal and spatial resolution of newer scanners, respiratory and the cardiac motion artifacts can still be seen. When all there benefits and limitations are taken into consideration, ECG-gated CE-chest MDCT is not still performing in routine radiology practice for the assessment of cardiopulmonary and congenital heart disease in our department. The measurement of the heart chambers should be a component of the radiology reporting for non ECG-gated MDCT studies.

Measurements of Mediatinal Great Vessels

Systemic or inflammatory diseases such as Takayasu arteritis, Marfan syndrome, Turner syndrome, Loey-Dietz syndrome may be presented with changes of the diameter of the heart chambers and mediastinal great vessels (Dean, 2007; Johnson et al., 2007; Matura et al., 2007; Civilibal et al., 2008). These structures can be measured on routine raw-axial CE-chest MDCT, and further assessment should be recommended. A limited number of MDCT study evaluated the size of the normal thoracic aorta in healthy children and determined that the ranges of thoracic aorta measurements increased significantly with age, and the result of our study shows concordance with these studies (Matura et al., 2007; Akay et al., 2009; Compton et al., 2015; Kawel-Boehm et al., 2015; Bayindir et al., 2016). Our study shows statistically significant and positive correlations between the diameter of the aorta in all levels and age groups with an excellent interobserver agreement for all levels of aorta similar to previous studies (Fitzgerald et al., 1987; Compton et al., 2015; Bayindir et al., 2016). Measurement of the aorta at all levels on an axial plane will help the clinicans to rapid assessment of the incidental aortic pathologies such as a stenosis and/or aneurysmal dilatation in busy daily practice.

Thepulmonaryarteryisoneoftheotherimportant great vascular structure of the mediastinum. The increased diameter of pulmonary artery has been reliably accepted criteria for the diagnosis of pulmonary hypertension, since the dilatation is one of the important radiologic sign in adulthood (Ng et al., 1999; Chaudry et al., 2007).

Although right heart catheterization is accepted as a gold standard technique in the evaluation of the pulmonary hypertension, a good correlation with a good interobserver agreement of the measurement of pulmonary artery on MDCT has been shown in many studies (Edwards et al., 1998; Ng et al., 1999; Karazincir et al., 2008; Truong et al., 2012). Therefore, MDCT can be accepted as a reliable, non-invasive imaging technique in the evaluation of pulmonary hypertension compared to right heart catheterization especially in children (Compton et al., 2015; Caro-Dominguez et al., 2016).

In the assessment of pulmonary artery diameter in pediatric age, different results have been published about the relationship between the MPA diameter and the patient age (Edwards et al., 1998; Ng et al., 1999; Karazincir et al., 2008). In the literaure, the diameter of pulmonary arteries were measured in raw axial CE-chest MDCT in limited studies (Akay et al., 2009; Bayindir et al., 2016). Bayindir et al. (2016) evaluated 520 pediatric patients and demonstrated a remarkable correlation between the diameter of MPA and the patient's age ($p < 0.001$) and revealed the mean value of LPA is higher than RPA for each age groups ($p < 0.001$). Akay et al. (2009) also showed significant correlations between the diameters of MPA, RPA, LPA, and the patient's age in their study. In the same study, it is also found that there was no significant difference between the diameter of LPA and RPA. In our study, we found statistically significant difference between the diameters of MPA, RPA, and LPA for all age groups ($p < 0.001$). However, no statistically significant difference was found between the diameter of LPA and RPA ($p = 0.853$). We reached high ICC values for measuring pulmonary arteries similar to the study by Bayindir et al. (2016), but our ICC values for LPA and RPA measurements were relatively lower.

In recent years, not only measurements of the AA and MPA , but also the ratio of the MPA-to-AA are suggested to be mentioned in clinical practice. It is calculated by dividing the diameter of the MPA at the level of pulmonary bifurcation by the diameter of the ascending aorta. Because, in pulmonary hypertension, pulmonary arteries show enlargement without aortic dilatation with an exception in neonatal period, as MPA may be larger than AA because of the increased pulmonary arterial vascular pressure during fetal life (Compton et al., 2015).

The MPA-to-AA ratio has been suggested to be a reliable sign of pulmonary hypertension in adults with the 92% specificity and 96% positive predictive value if it is higher than 1 (Ng et al., 1999). It is also mentioned that the MPA-to-AA ratio should be accepted as 1.1 for the highest diagnostic accuracy in adults (Boerritger et al., 2010). In the study by Pırınc et al. MPA-to-AA ratio was mentioned to be minimum 0.44 cm, maximum 1.41 cm among all individuals aged between 18 and 89 years (Pirinc et al., 2020). Andsignificant difference has been found between age 18-39 years (0.9±0.18) and 40-60 years (0.81±0.15) in the same study (Pirinc et al., 2020).

However, normal range of this ratio has been evaluated by a few studies in children and different results have been revealed from adults (Compton et al., 2015; Bayindir et al., 2016; Caro-Dominguez et al., 2016). Bayindir et al. (2016) reported that the normal value of the MPA-to-AA ratio for healthy pediatric patients was 0.93 ± 0.09 without a statistically significant difference among age groups and genders. In the study by Compton et al. (2015), MPA-to-AA ratio of 200 healthy children without proven pulmonary hypertension has been defined as 1.085, which is higher than 1 in all age groups. More recently, Caro-Dominguez et al. (2016) evaluated the MPA-to-AA ratio with the age and gender-matched groups (44 children proved pulmonary hypertension by right heart catheterization and 44 children without pulmonary hypertension) and revealed that the study group has a significantly higher MPA-to-AA ratio (1.46) than the control group (1.11). The ratio of MPA-to-AA showed difference between adult and pediatric age groups in the study by Caro-Dominguez et al. (2016). It is also mentioned that, the ratio of 1.3 has a positive predictive value of 97% and specificity of 98% for the diagnosis of pulmonary hypertension which is higher than 1 (Caro-Dominguez et al., 2016). In our study, we revealed that the MPA-to-AA ratio was 1.02 ± 0.47. Although Compton et al. (2015) and Caro-Dominguez et al. (2016) were suggessted to have significant difference between age groups, we found no significant difference between ages like Bayindir et al. (2016).

There are a few limitations of our study. One of the main limitations is measurements of the heart chambers are obtained on an raw axial image without doing multiplanar reconstruction. But we thought that the measurement on a raw axial plane rather than on a multiplanar reconstructed image is more practical and easy in the daily practice of high volume radiology and pediatric cardiology clinics. Also, we believe that measurement errors may be seen if readers had poor practice in creating multiplanar reconstruction images and standardized measurements in routine clinical practice. The second limitation is images acquired randomly in any phase of the cardiac cycle instead of the diastolic phase on ECG-gated chest MDCT or cardiac MRI. Although many studies have revealed that ECG-gated MDCT is accurate in the assessment of heart chambers, non ECG-gated CE-chest MDCT is more frequently used to assess cardiovascular and/or pulmonary diseases in routine daily clinic. We know that ECG-gated MDCT is rarely preferred with the indication of congenital heart disease in pediatric patients, and we do not suggset using ECG-gated MDCT to assess the normal diameters of mediastinal vascular and cardiac structures. In our institute, most of the pediatric patients with various clinical indication are referred to non ECG-gated CE-chest MDCT, and the diameters of mediastinal great vessels and heart chambers assessed on raw axial CE-chest MDCT. In conclusion, mean diameters of cardiac chambers and mediastinal vascular structures can be used as a reference in routine radiology practice to refer patients for further investigations, such as echocardiography or right heart catheterization to early diagnosis of cardiovascular and/or pulmonary disease.

Ethical Standards. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national guidelines on human experimentation in Turkey and with the Helsinki Declaration of 1975, as revised in 2008.

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