ORIGINAL RESEARCH

Bagcilar Med Bull 2021;6(2):118-124
DOI: 10.4274/BMB.galenos.2021.11.077.1

Evaluation of the Morphometric Measurements of Main Mediastinal Vascular Structures with Multi-detector Computed Tomography in Healthy Children

Sağlıklı Çocuklarda Mediastinal Ana Vasküler Yapıların Multi-dedektör Bilgisayarlı Tomografi ile Değerlendirilmesi

Kourosh Yaghouti[1], Filiz Çelebi[2], İbrahim Halil Sever[3], Nuri Çağatay Cimşit[4]

[1]Gayrettepe Florence Nightingale Hospital, Clinic of Radiology, İstanbul, Turkey
[2]Yeditepe University Hospital, Clinic of Radiology, İstanbul, Turkey
[3]İstanbul Florence Nightingale Hospital, Clinic of Radiology, İstanbul, Turkey
[4]Marmara University Pendik Training and Research Hospital, Clinic of Radiology, İstanbul, Turkey

Abstract

Objective: In this study, we aimed to evaluate the feasibility of the main pulmonary artery (MPA)/ascending aorta (AA) ratio measurement, which is 1:1 in adults, using the multi-detector computed tomographt in pediatric patients also.

Method: The study was approved by the Institutional Review Board (number: 09.2016.014, approval date: 08.01.2016) and informed consent was waived since the study was retrospective. IV contrast-enhanced pulmonary computed tomography images of 487 pediatric patients (0-18 years), which had been performed between January 2015 and February 2016 in our center, were retrospectively evaluated. The diameters of the AA, MPA, right and left pulmonary arteries, and thoracic aorta were measured separately.

Results: A positive correlation was determined between the diameters of mediastinal vascular structures and the patient age. The MPA/AA ratio was higher in the pediatric group when compared to adults, and this ratio was found to be higher than 1 in all pediatric cases.

Conclusion: The higher diameter of MPA when compared to AA in pediatric cases is thought to be responsible for MPA/AA ratio being greater than 1, and that should not be considered as pulmonary hypertension. We suggest a threshold of 1.06 for the MPA/AA ratio regarding the diagnosis of PH.

Keywords: Aorta, child, hypertension, pulmonary artery, tomography

Öz

Amaç: Çalışmada multi-dedektör bilgisayarlı tomografi kullanarak, erişkin yaş grubunda 1:1 olan ana pulmoner arter (APA)/asendan aorta (AA) oranının pediyatrik yaş grubunda uygulanabiliyor olup olmadığını araştırmayı amaçladık.

Yöntem: Çalışma için, Klinik Araştırmalar Etik Kurulu tarafından 08.01.2016 tarihinde 09.2016.014 sayılı yazı ile onay verilmiştir. Ocak 2015 ile Şubat 2016 tarihleri arasında hastanemize başvuran ve kontrastlı akciğer bilgisayarlı tomografisi çekilen pediyatrik yaş grubundan (0-18 yaş) 487 olgunun görüntüleri retrospektif olarak değerlendirilmiştir. AA, APA, sağ pulmoner arter, sol pulmoner arter, torasik aorta ve torasik vertebra çapları ayrı ayrı ölçülmüştür.

Bulgular: Ölçülen mediastinal vasküler yapı çapları ve hasta yaşı arasında pozitif korelasyonun varlığı tespit edilmiştir. APA/AA oranının, pediyatrik yaş grubunda erişkin yaş grubuna göre anlamlı olarak yüksek olduğu tespit edilmiştir. Çalışmamızda bu oran tüm pediyatrik yaş grupları arasında 1'in üzerinde bulunmuştur.

Sonuç: Pediyatrik yaş grubunda APA'nın AA çapından daha geniş olması nedeniyle APA/AA oranının 1'in üzerinde olan tüm olgularda pulmoner hipertansiyon ön tanısında bulunulmamalıdır. Bu oranın eşik değerinin 1,06 olarak kabul edilebileceğini önermekteyiz.

Anahtar kelimeler: Aorta, çocuk, hipertansiyon, pulmoner arter, tomografi

Address for Correspondence: Kourosh Yaghouti, Gayrettepe Florence Nightingale Hospital, Clinic of Radiology, İstanbul, Turkey
E-mail: kourosh1333@hotmail.com **ORCID:** orcid.org/0000-0002-3882-3411 **Received:** 15.11.2020 **Accepted:** 07.01.2021

Cite this article as: Yaghouti K, Çelebi F, Sever İH, Cimşit NÇ. Evaluation of the Morphometric Measurements of Main Mediastinal Vascular Structures with MDCT (Multi-detector Computed Tomography) in Healthy Children. Bagcilar Med Bull 2021;6(2):118-124

Introduction

Pulmonary hypertension (PH) is a rare disorder with significant morbidity and mortality rates in newborns, infants, and children. In most of the pediatric patients, PH is either idiopathic or associated with congenital heart disease; rarely, it may be associated with other conditions such as connective tissue diseases and thromboembolic disorders (1).

Multi-detector computed tomography (MDCT) has been increasingly used for the evaluation of congenital and postoperative cardiac disorders in the pediatric age group. When the radiation dose used is particularly taken into consideration, obtaining most of the information through diagnostic screening as far as possible is important regarding patient care. The complete assessment of all structures observed on tomography carries critical importance whether they are related to the clinical indication or not. For example, the diameters of the mediastinal vascular structures (MVS) observed on computed tomography (CT) should be a part of the routine evaluation of the cardiomediastinal structures. The measurement and determination of these main vessels on MDCT have a high degree of reconciliation among different independent observers. Moreover, the measurements obtained through right heart catheterization, which is considered as the reference for the assessment of the pulmonary arterial tree, show a good correlation with the diameters of the vascular structures observed on CT (2,3).

As seen in MDCT, the ratio of the diameter of the main pulmonary artery (MPA) to the diameter of the ascending aorta (AA) has been generally considered as equal to or less than 1 in healthy adults. The MPA/AA ratios over 1 suggest the presence of PH. In children, PH has been clinically defined using the criteria also used in adults: The mean pulmonary artery pressure greater than 25 mmHg (4).

Patients with PH may be relatively asymptomatic or may manifest normal findings on physical examination (5). However, this disorder might have various underlying causes, and the manifestations might be delayed in the clinical course due to its non-specific findings and symptoms (dyspnea, syncope, chest pain, fatigue) (1,6,7).

MDCT has been used for the exclusion of secondary causes that might lead to PH in children diagnosed with PH (8). Meanwhile, it can also be used for the identification of asymptomatic patients who have not been diagnosed with PH. This information carries importance regarding the referral of the patient to the clinician. The treatment and follow-up of the patient can be initiated when the findings of hypertension are identified. Thus, the use of proper MPA/AA ratio in pediatric patients, which is determined based on the findings in MDCT performed for other reasons, has critical importance for the identification of high-risk pediatric patients.

In our study, it was aimed to determine the ratio of the MPA diameter to the diameter of the AA based on the morphometric measurements of main mediastinal vascular structures using the MDCT in healthy children.

Materials and Methods

The contrast-enhanced pulmonary CT images of 487 patients in pediatric age group (0-18 years), who had been admitted to our hospital between January 2015 and February 2016, were evaluated retrospectively. The study was approved by the Institutional Review Board (ethics committee no: 09.2016.014, approval date: 08.01.2016) and informed consent was waived since the study was retrospective.

Patients with disorders that could be considered to change the MPA/AA ratio, such as parenchymal pulmonary disease, congenital lung malformation (pulmonary hypoplasia, congenital diaphragmatic hernia), mediastinal mass, pulmonary parenchymal mass, the presence of significant artifacts that might have led to faulty measurement of MVS, and non-contrast investigations, were excluded from the study.

Four hundred eighty-seven cases were classified into four different age groups: 0-24 months, 2-6 years, 7-11 years, and 12-18 years. A different number of cases were present in each group. 64.5% of the cases were male and 35.5% were female.

The MDCT investigations of the patients were performed by the 256-detector MDCT (Siemens, the Somatom Definition Flash, Germany) equipment. The contrast agent was then administered through the antecubital vein at a dose equivalent to the patient's age and speed of 0.5-1 mL/sec using an automated syringe. Detector collimation of 128x0.6 mm, tube voltage of 120 KV, a gantry rotation of 0.28 sec., tube current of 50-148 mA, and the pitch value of 3.2 were used as the imaging parameters during tomographic examination in pediatric cases with body weight up to 30 kg. In pediatric cases having a body weight over 30 kg, detector collimation of 32x1.2 mm, tube voltage of 120 kV, a gantry rotation of 0.5 sec, tube current of 50-148 mA, and the pitch value of 1.4 were used. The obtained MDCT images were sent to the workstation through the network.

The images were reconstructed at a thickness of 3 mm and with a reconstruction interval of 3 mm.

The CT images were retrospectively evaluated by two radiologists, one with more than 10 years experience and the other with one-year experience in thoracic radiology. All measurements were performed using the contrast-enhanced images and at the axial plane. The AA, the MPA, the right and left pulmonary arteries, the thoracic aorta (TA), and the thoracic vertebra (TV) at the same level were measured. AA and TA were measured transversely at the level of the right pulmonary artery. MPA was measured at its widest point, perpendicular to its longitudinal axis, and at the distal level of the postvalvular segment (Figure 1). The right and left pulmonary arteries were measured at their widest points and perpendicular to the longitudinal axis. The anteroposterior (AP) corpus diameter of the TV was measured at the cross-sectional level that the pulmonary bifurcation was observed.

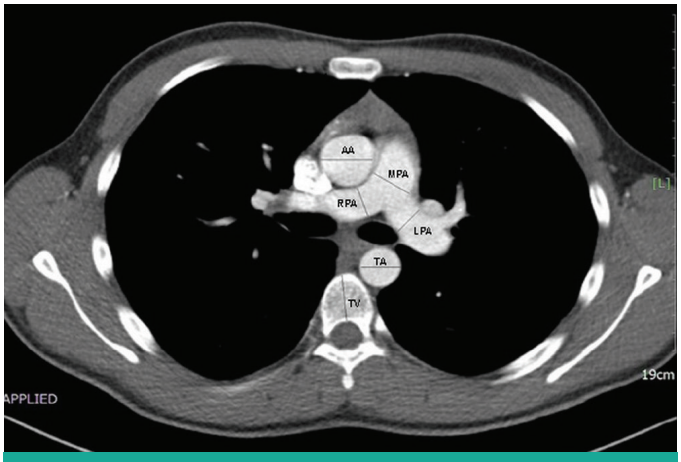

Figure 1. The measurement levels of the mediastinal vascular structures

Statistical Analysis

SPSS 21.0 software was used for statistical analysis. During the evaluation of the study data, the Kolmogorov-Smirnov normality test was used for the identification of the descriptive statistical methods (frequency, percentage, mean, standard deviation) together with conformity with a normal distribution. For comparison of qualitative data, the Pearson chi-square and Fisher's Exact tests were used. For quantitative data and comparison of the parameters between two groups, the Mann-Whitney U test was used. For the comparison of quantitative data among more than two groups of parameters which were not in conformity with a normal distribution, the Kruskal-Wallis test was used. The results were evaluated within the confidence interval of 95% and at a significance level of $p<0.05$.

Results

In our study, contrast-enhanced MDCT images of a total of 487 cases were evaluated. The mean age of the patients was 118.5±64 (1-216) months. Of the patients, 314 (64.5%) were male and 173 (35.5%) were female. Twenty six (5.3%) patients were in the 0-24 months age group, 146 (30%) were in the 2-6 years age group, 105 (21.6%) were in the 7-11 years age group, and 210 (43.1%) were in the 12-18 years age group.

The distributions of the MDCT measurements together with the MPA/AA and MVS/TV ratios according to gender were shown in Table 1 and Figures 2 and 3. The measurement results of MPA, AA, right and left pulmonary arteries, TA, and TV were found to be statistically significantly higher in males compared to females ($p<0.05$). The MPA/AA was determined to be significantly higher in females compared to the males ($p<0.05$).

Table 1. The distributions of the measurements of the patients according to gender

	Male (n=314)					Female (n=173)					
	Mean	Median	Standard deviation	Minimum	Maximum	Mean	Median	Standard deviation	Minimum	Maximum	p
MPA (mm)*	20.04	20.00	4.06	10.40	33.00	18.76	18.70	3.83	8.10	28.50	**0.002**
AA (mm)	19.26	19.50	3.93	9.00	30.00	17.53	17.50	3.65	8.10	27.70	**<0.001**
Right pulmonary artery (mm)	12.30	12.00	2.78	6.50	22.80	11.21	11.00	2.50	4.50	17.00	**<0.001**
Left pulmonary artery (mm)	12.67	12.50	2.70	6.00	20.00	11.42	11.00	2.46	5.50	19.00	**<0.001**
Thoracic aorta (mm)	15.15	15.40	3.46	6.50	25.40	13.16	13.00	3.03	6.00	23.00	**<0.001**
Thoracic vertebra AP (mm)	19.90	20.00	3.75	9.30	28.50	17.75	17.80	3.21	7.00	26.00	**<0.001**
MPA*/AA† ratio	1.05	1.04	0.13	0.65	1.54	1.08	1.08	0.13	0.70	1.46	**0.006**

*MPA: Main pulmonary artery, †AA: Ascending aorta, AP: Anteroposterior

When all cases were taken into consideration, the calculated mean MPA/AA ratio was 1.06 and was 1.07 (±0.11) in 0-24 months age group, 1.09 (±0.13) in the 2-6 years age group, 1.06 (±0.12) in the 7-11 years age group, and 1.03 (±0.13) in the 12-18 years age group. The distributions of the MDCT measurements together with the MPA/AA (Figure 4) and MVS/TV ratios according to the age groups were shown in Table 2. No statistically significant differences were found to be present between the 0-24 months age group and the 2-6 years age group ($p>0.05$), the other age groups were statistically significantly different from each other regarding AA, right and left pulmonary arteries, and TA ($p>0.05$). All age groups were different from each other regarding MPA and TV ($p<0.05$). The 2-6 years age group was found to be statistically significantly different when compared to the 7-11 years age group; the differences among other groups were not statistically significant regarding MVS/TV ($p>0.05$).

When the relationships between gender and age groups were analyzed, it was found that in males that the 2-6 years and 12-18 years age groups were statistically significantly different from each other ($p<0.05$), and the differences among the other age groups were not significant ($p>0.05$) regarding MPA/AA ratio. No significant differences were present between the 0-24 months age group and the 2-6 years age group ($p>0.05$), the other age groups were statistically significantly different from each other regarding the MPA, AA, right and left pulmonary arteries, TA, and TV ($p<0.05$). The 2-6 years age group was significantly different from the 7-11 years age group regarding the MVS/TV ratio ($p<0.05$), the differences between the other age groups were not statistically significant ($p>0.05$).

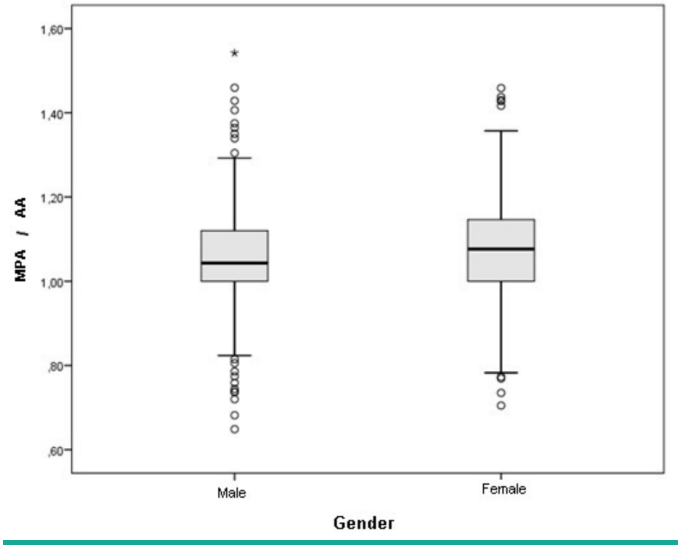

Figure 2. The distribution of the MPA/AA ratio according to gender

MPA: Main pulmonary artery, AA: Ascending aorta

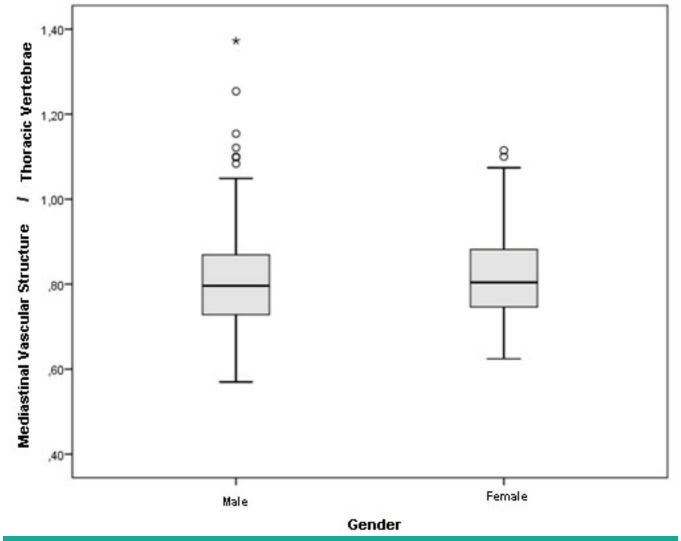

Figure 3. The distribution of the MVS/TV ratio according to gender

MVS: Mediastinal vascular structures, TV: Thoracic vertebrae

Table 2. The distributions of the measurements of the patients according to the age groups

	0-24 months		2-6 years		7-11 years		12-18 years	
	Mean	±	Mean	±	Mean	±	Mean	±
MPA (mm)*	13.39	3.58	16.57	2.36	20.01	2.73	22.23	3.20
AA (mm)†	12.50	3.15	15.26	2.07	18.95	2.40	21.61	2.65
Right pulmonary artery (mm)	7.85	2.05	9.83	1.57	12.04	1.96	13.79	2.14
Left pulmonary artery (mm)	8.27	2.31	10.04	1.53	12.46	1.71	14.12	2.02
Thoracic aorta (mm)	8.97	2.17	11.43	1.62	14.50	1.98	17.19	2.38
TV AP (mm)	12.82	2.42	16.10	1.76	18.77	1.95	22.23	2.49
MPA/AA ratio	1.07	0.11	1.09	0.13	1.06	0.12	1.03	0.13
MVS‡ /TV§ ratio	0.80	0.12	0.79	0.11	0.83	0.09	0.81	0.10

‡MVS: Mediastinal vascular structures, §TV: Thoracic vertebrae, *MPA: Main pulmonary artery, †AA : Ascending aorta, AP: Anteroposterior

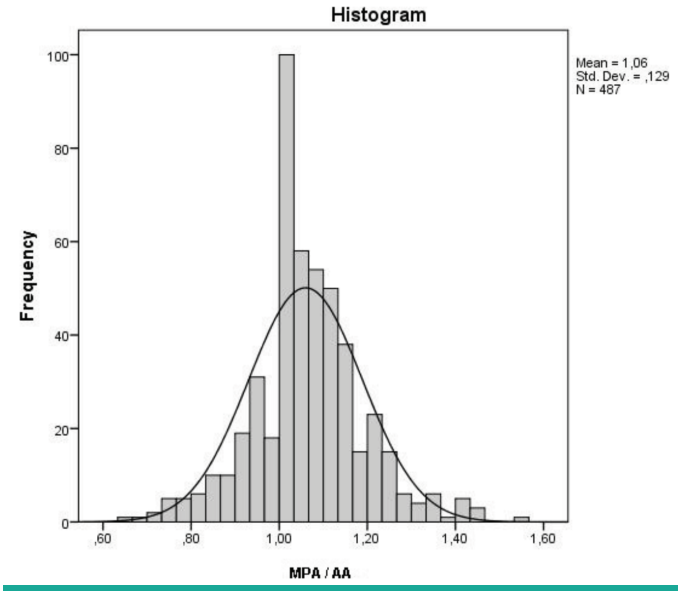

Figure 4. The distribution of the calculated MPA/AA ratio in all cases included in the study

MPA: Main pulmonary artery, AA: Ascending aorta

In females, no significant differences were found to be present among the age groups regarding the MPA/AA ratio (p>0.05). There was no difference between the 7-11 years and the 12-18 years age groups (p>0.05), the other age groups were different from each other regarding MPA (p<0.05). There were no differences between the 7-11 years and 12-18 years age groups and between the 0-24 months and 2-6 years age groups regarding AA (p>0.05), the other age groups were different from each other (p<0.05). No significant differences were present between the 0-24 months and 2-6 years age groups (p>0.05), the other age groups were found to be different from each other (p<0.05) regarding the right and left pulmonary arteries, TA, and TV. A statistically significant difference was found between the 0-24 months and the 7-11 years age groups (p<0.05), the other age groups were not different from each other (p>0.05) regarding the MVS/TV ratio.

In patients within the 0-24 months age group, no differences were found between males and females regarding MPA, AA, right and left pulmonary arteries, TA, TV, the MPA/AA and MVS/TV ratios (p>0.05). In patients within the 2-6 years age group, no differences were found between males and females regarding MPA, AA, right and left pulmonary arteries, the MPA/AA and MVS/TV ratios (p>0.05). The TA and TV measurements were found to be statistically significantly higher in males when compared to females (p<0.05). In patients within the 7-11 years age group, no differences were found between males and females regarding MPA, AA, right pulmonary artery, the MPA/AA and MVS/TV ratios (p>0.05). The left pulmonary artery, TA and TV measurements were found to be statistically significantly higher in males when compared to females (p<0.05). In patients within 12-18 years age group, no differences were found between males and females regarding the MPA/AA and MVS/TV ratios (p>0.05). The measurements of MPA, AA, the right and left pulmonary arteries, TA, and TV were found to be statistically significantly higher in males when compared to females (p<0.05).

A negative significant correlation at a level of 22.6% was determined between age and MPA/AA ratio (r=-0,226, p=0,001). No significant relationship was determined between age and the MVS/TV ratio (p>0.05). A significant positive correlation at a level of 81.1% was determined between age and the AA (r=0.811, p<0.001). A significant positive correlation at a level of 70.9% was present between age and the MPA (r=0.709, p<0.001). A significant positive correlation at a level of 73.6% was present between age and the right pulmonary artery (r=0.736, p<0.001). A significant positive correlation at a level of 75.6% was determined between age and the left pulmonary artery (r=0.756, p<0.001). A significant positive correlation at a level of 85.3% was present between age and the TA (r=0.853, p<0.001). A significant positive correlation at a level of 85.6% was found between age and the TV AP (r=0.856, p<0.001).

Discussion

One of the most significant contributions of MDCT in the pediatric age group is the assessment of the cardiovascular system. In this age group, motion artifacts and administration of low-dose contrast agent are among the limitations of CT angiography. However, with the invention of MDCT, these problems have been overcome. Therefore, in infancy and pediatric age group, MDCT has become one of the first investigations for the diagnosis of cardiovascular pathologies (9). In the newborn period, MPA may be wider than AA. Since the pulmonary arterial pressure is high due to the physiologic circulation of the fetus, an increase in the diameter of MPA may be observed.

In our study, we aimed to demonstrate the presence of a negative correlation between MPA/AA ratio and increasing age in the pediatric age group. Also, we aimed to calculate the mean values of thoracic vascular structures, together with the positive correlations of these values with increasing age and the inter-gender variations. In none of the cases included in our study, a suspicious finding regarding PH was identified in computed tomographic images. To our

knowledge, the relationships between pediatric age groups, the mean values of thoracic vascular structures and MPA/AA ratio have not been discussed in the literature.

Truong et al. (10), in the study that they conducted on 3.171 adult cases in 2011, aimed to determine a reference value for the MPA/AA ratio and verified this value as 0.9. In another study conducted by Edwards et al. (3), it was concluded that the increase in MPA diameter was not correlated with age increase. However, the patient ages in their study group ranged between 11 years and 90 years, and few patients were in the pediatric age group. On the other hand, in our study, a significant correlation for the MPA / AA ratio was determined in the pediatric age group, contrary to the results of the study conducted by Edwards et al. (3).

In our study, the mean MPA/AA ratio was found to be 1.06, and in all age groups this ratio was above 1 (in the 0-24 months age group, 1.07 (±0.11), in the 2-6 years age group, 1.09 (±0.13), in the 7-11 years age group, 1.06 (±0.12), in the 12-18 years age group 1.03 (±0.13). The results obtained in our study suggest that the statement related to adults that the MPA/AA ratio should be 1 or less than 1 is not valid for the pediatric age group.

Ichida et al. (11), in their study related to echocardiography in pediatric age group, determined that the MPA/AA ratio decreased with increasing age. The results revealed a significant relationship between the MPA/AA ratio and age. Compton et al. (4), in measurements of 200 healthy children that they performed with MDCT in 2015, calculated the MPA/AA ratio to be greater than 1 and close to 1.09 in all pediatric age groups. We calculated this ratio as over 1 and obtained similar results. Compton et al. (4), Fitzgerald et al. (12), and Akay et al. (2), in their studies, stated that no statistically significant difference was present between the MPA/AA ratio and gender. However, in our study conducted with 487 cases, we determined that this ratio was statistically significantly higher in females when compared to males ($p<0.05$) (1.08 in females vs. 1.05 in males).

When we investigated the relationship between the MPA/AA and age groups, we determined that this ratio was statistically significantly higher in the 2-6 years age group when compared to the 12-18 years age group. No other significant difference was determined among the other age groups. Akay et al. (2), in their study conducted on the pediatric age group in 2009, in accordance with our study, showed the presence of a positive correlation between AA, MPA, right and left pulmonary arteries, TA, TV, and age ($p<0.001$). We also determined that these vascular structures were positively correlated with age ($p<0.001$). On the other hand, Akay et al. (2) in their study, found no statistically significant difference in these vascular structures related to gender. On the contrary, in our study, we determined that the diameters of MPA, AA, right and left pulmonary arteries, TA, and TV were significantly higher in males compared to females ($p<0.05$).

When we investigated the changes related to age in both genders, we determined in males that no significant differences were present between the 0-24 months age group and the 2-6 years age group regarding the diameters of MPA, AA, right and left pulmonary arteries, TA, and TV. The other age groups were found to be different from each other. On the other hand, in females, no significant differences were present between the 0-24 months and 2-6 years age groups regarding the diameters of right and left pulmonary arteries, TA, and TV. The other age groups were different from each other ($p<0.05$). The study conducted by Fitzgerald et al. in the pediatric age group revealed that TA and the TV width measured at the level of pulmonary artery bifurcation increased with age (12). Also in our study, it was found that TA and TV AP diameters increased consistently with increasing age ($p<0.001$).

Our study had a limitation. Since PH could not be excluded in the cases included in our study, a negative MPA/AA ratio could not allow us to rule out the absence of PH. However, when our criteria for exclusion from the study are taken into consideration, we have the opinion that we have excluded many conditions that could be predisposing factors for PH.

In previously conducted studies, the mean MPA/AA ratio was determined by measuring the MPA and AA for the prediction of PH. In the adult age group, the limit value for MPA/AA has been determined as 1. The values greater than 1 for this ratio has been suggested to create suspicion for PH. However, this ratio should not be used in the pediatric age group. In our study, it was determined that this ratio was greater than 1 in healthy children, contrary to the adult age group. Also, even though the MPA/AA ratio was negatively correlated with age, the threshold value was calculated to be 1.06 in all age groups.

Conclusion

We do not favor using MDCT for an investigation when PH is suspected in the pediatric age group. On the other hand, we have the opinion that the changes determined in the MPA/AA ratio should take place in the radiology reports for enabling appropriate patient monitoring. We suggest that

cases with MPA/AA ratio 1.06 and over in MDCT should be evaluated regarding PH.

Ethics

Ethics Committee Approval: The study was approved by the Institutional Review Board (ethics committee no: 09.2016.014, approval date: 08.01.2016).

Informed Consent: Informed consent was waived since the study was retrospective.

Peer-review: Externally and internally peer-reviewed.

Authorship Contributions

Concept: K.Y. N.Ç.C., Design: K.Y., Data Collection or Processing: İ.H.S., F.Ç., Analysis or Interpretation: İ.H.S., F.Ç., Literature Search: İ.H.S., F.Ç., N.Ç.C., Writing: K.Y., Manuscript Review and Revisation: N.Ç.C.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study has received no financial support.

References

1. Ivy DD, Abman SH, Barst RJ, Berger RM, Bonnet D, Fleming TR, et al. [Pediatric pulmonary hypertension]. Turk Kardiyol Dern Ars 2014;42(Suppl 1):153-164.
2. Akay HO, Ozmen CA, Bayrak AH, Senturk S, Katar S, Nazaroglu H, et al. Diameters of normal thoracic vascular structures in pediatric patients. Surg Radiol Anat 2009;31(10):801-807.
3. Edwards PD, Bull RK, Coulden R. CT measurement of main pulmonary artery diameter. Br J Radiol 1998;71(850):1018-1020.
4. Compton GL, Florence J, MacDonald C, Yoo SJ, Humpl T, Manson D. Main Pulmonary Artery-to-Ascending Aorta Diameter Ratio in Healthy Children on MDCT. AJR Am J Roentgenol 2015;205(6):1322-1325.
5. Tan RT, Kuzo R, Goodman LR, Siegel R, Haasler GB, Presberg KW. Utility of CT scan evaluation for predicting pulmonary hypertension in patients with parenchymal lung disease. Medical College of Wisconsin Lung Transplant Group. Chest 1998;113(5):1250-1256.
6. Grubstein A, Benjaminov O, Dayan DB, Shitrit D, Cohen M, Kramer MR. Computed tomography angiography in pulmonary hypertension. Isr Med Assoc J 2008;10(2):117-120.
7. Ng CS, Wells AU, Padley SP. A CT sign of chronic pulmonary arterial hypertension: the ratio of main pulmonary artery to aortic diameter. J Thorac Imaging 1999;14(4):270-278.
8. Chaudry G, MacDonald C, Adatia I, Gundogan M, Manson D. CT of the chest in the evaluation of idiopathic pulmonary arterial hypertension in children. Pediatr Radiol 2007;37:345-350.
9. Frush DP, Herlong JR. Pediatric thoracic CT angiography. Pediatr Radiol 2005;35(1):11-25.
10. Truong QA, Massaro JM, Rogers IS, Mahabadi AA, Kriegel MF, Fox CS, et al. Reference values for normal pulmonary artery dimensions by noncontrast cardiac computed tomography: the Framingham Heart Study. Circ Cardiovasc Imaging 2012;5(1):147-154.
11. Ichida F, Aubert A, Denef B, Dumoulin M, Van der Hauwaert LG. Cross sectional echocardiographic assessment of great artery diameters in infants and children. Br Heart J 1987;58(6):627-634.
12. Fitzgerald SW, Donaldson JS, Poznanski AK. Pediatric thoracic aorta: normal measurements determined with CT. Radiology 1987;165(3):667-669.