

Multidetector computed tomography evaluation of aortic arch and branching variants

Aortik arkın ve dallanma varyasyonlarının çok kesitli bilgisayarlı tomografi ile değerlendirilmesi

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ABSTRACT

Background: This study aims to investigate the prevalence of variants of the aortic arch and its branches, as well as possible effects of sex on the prevalence.

Methods: Between January 2012 and January 2013, routine contrast-enhanced thoracic multidetector computed tomography images of 1,170 patients were analyzed retrospectively for the frequency of variants of aortic arch and its branching.

Results: The total rate of aortic arch variants was 10.9%. The most common variant was of the left vertebral artery originating directly from the aortic arch in 53 patients (4.5%), followed by the left common carotid artery originating from the brachiocephalic trunk in 30 patients (2.6%). The variant of left vertebral artery directly originating from the aortic arch was twice more frequent in males than in females.

Conclusion: The prevalence of variants of the aortic arch is high in the Turkish population. Aortic arch branching variants are critical clinical conditions requiring special attention of vascular surgeons, interventional radiologists, and head and neck surgeons. They should be diagnosed before interventional and surgical procedures. Multidetector computed tomography is a rapid and safe diagnostic modality for the evaluation of variants of the aortic arch and its branches.

Keywords: Anatomical variation; aortic arch; multidetector computed tomography.

ÖZ

Amaç: Bu çalışmada aortik arkın ve dallarının varyasyonlarının sıklığı ile cinsiyetin bu sıklığa olası etkileri araştırıldı.

Çalışma planı: Ocak 2012 - Ocak 2013 tarihleri arasında 1170 hastanın rutin kontrastlı toraks çokkesitli bilgisayarlı tomografi görüntüleri aortik arkın ve dallarının varyasyon sıklığı açısından retrospektif olarak incelendi.

Bulgular: Aortik ark varyasyonlarının toplam oranı %10.9 idi. En sık varyasyon 53 hastada (%4.5) aortik arkten direkt çıkan sol vertebral arter varyasyonuydu, bunu 30 hastada (%2.6) brakiosefalik trunkustan çıkan sol ana karotis arter varyasyonu takip etti. Aortik arkten direkt çıkan sol vertebral arter varyasyonu erkeklerde kadınlara kıyasla iki kat daha fazlaydı.

Sonuç: Türk nüfusunda aortik ark varyasyonlarının sıklığı yüksektir. Aortik arkın dallanma varyasyonları vasküler cerrahlar, girişimsel radyologlar ve baş boyun cerrahları tarafından özel dikkat gerektiren önemli klinik durumlardır. Varyasyonlara girişimsel ya da cerrahi işlemlerden önce tanı koyulması gereklidir. Çok kesitli bilgisayarlı tomografi aortik arkın ve dallarının varyasyonlarının değerlendirilmesi için hızlı ve güvenilir bir tanı yöntemidir.

Anahtar sözcükler: Anatmik varyasyon; aortik ark; çokkesitli bilgisayarlı tomografi.

The aortic arch and its branches develop during the first several weeks of fetal life.^[1] Branching pattern variants are usually detected incidentally by imaging

studies, and these mostly remain silent unless tracheal or esophageal compression is present or if they are associated with congenital heart diseases. Despite their



asymptomatic nature, it is of the utmost importance that such variants should be diagnosed before endovascular interventions and surgical procedures. In the classical anatomical configuration, the aortic arch is left-sided. A normal aortic arch has three branches that appear in the following order: (i) the brachiocephalic trunk (BT) which branches into the right common carotid artery (RCC) and right subclavian artery (RS), (ii) the left common carotid artery (LCC), and (iii) the left subclavian artery (LS). Variants of the aortic arch and related tracheal or esophageal compression can be visualized by noninvasive multidetector computed tomography (MDCT).^[2]

The prevalence of aortic arch variants has been investigated using cadaver studies, digital subtraction angiography (DSA) and conventional catheter angiography, and the rates reported in the literature for these variations have varied widely (3.7-49%).^[3-6] There are several studies that have investigated the diagnostic value of CT for the detection of aortic arch variants in the literature, but there are a limited number of studies that have focused on the use of MDCT which include large sample sizes.^[7-9]

In this study, we aimed to investigate the prevalence of aortic arch variants and its branches in a large sample size as well as evaluate the possible effects of gender on the prevalence rate.

PATIENTS AND METHODS

In this study, we systematically reviewed the consecutive records of 1,200 patients for whom contrast-enhanced thoracic MDCT was performed for various indications at a university-affiliated hospital between January 2012 and January 2013. A total of 30 patients were excluded because their vascular structures could not be assessed due to motion artefacts or inadequate distribution of the contrast medium. In total, 1,170 patients (656 males and 514 females; mean age 41.7±23.2 years; range 1 to 97 years) who were diagnosed with variants of the aortic arch and its branches via contrast-enhanced MDCT were retrospectively analyzed. Moreover, 955 of these (81.6%) were ≥18 years old. The local ethics committee approved this retrospective study and waived the requirement for informed patient consent.

Thoracic CT was performed using the Siemens SOMATOM® Emotion® multidetector row CT scanner (16 slices) (Siemens AG, Munich, Germany) from the lung apices to the level of the lowest hemidiaphragm with the patient in a supine position. The scanning parameters were as follows: 130 kV, 62 effective (mAs), 16x0.6 mm collimation, pitch 1.5, a section thickness of 1 mm, a reconstruction interval of 0.8 mm, and a tube

rotation period of 0.6 seconds. The field of view was appropriately adjusted to the size of the patient, and an acquisition matrix of 512x512 was used. In addition, full inspiratory scans were obtained through an intravenous contrast medium in which a total volume of 60-70 mL of iodine-based, non-ionic contrast material (300 mg I/mL) was injected through an antecubital vein via a power injector at a rate of 2.5 mL/s. A fixed delay time of 10 seconds was used. Computed tomography was also carried out using low-dose radiation for the pediatric patients. Furthermore, the axial images were transferred into the picture archiving and communication system (PACS) and evaluated based on the axial and reformatted multiplanar reconstruction images. Moreover, all of the images were processed with standard mediastinal (width 400 HU; level 40 HU) and lung (width 1200 HU; level -600 HU) window settings. Additionally, the CT images of the 1,170 patients were evaluated for variations in the aortic arch branching pattern. Arch sidedness was assessed according to the position of the aortic arch with respect to the trachea as it crossed a main stem bronchus. An LCC originating from the BT was defined as the single origin of the LCC from the BT while a V-shaped origin for the BT and LCC was excluded. Furthermore, all image analyses were performed by a single radiologist.

Statistical analysis

Statistical analysis was performed using the SPSS version 15.0 software program (SPSS Inc., Chicago, IL, USA), and a *p* value of <0.05 was considered to be statistically significant. A chi-square test was used to determine the possible relationships among the variables, and the percentages of detectable aortic anomalies were also calculated.

RESULTS

Overall, 1,046 (89.4%) patients (464 females and 582 males) had a normal aortic arch, whereas vascular variants were present in 124 (10.6%) [50 females (4.3%) and 74 males (6.3%)]. In addition, 9.7% of the females (50/114) and 11.3% of the males (74/656) had branching variants (*p*=0.392). The frequency and gender distribution of the variations in our study are provided in Table 1.

The most common variant was the left vertebral artery (LV) originating directly from the aortic arch in 53 (4.5%) patients (15 females and 38 males). In these cases, the origin of the LV was proximal to the LS. Furthermore, we determined that four branches originated from the aortic arch: the BT, LCC, LV, and LS (Figure 1).

Table 1. Distribution of aortic arch variants in the patients

Variants	Number of males		Number of females		Total number	
	n	%	n	%	n	%
LV originating from the aortic arch	38	5.8	15	2.9	53	4.5
LCC originating from the BT	13	2	17	3.3	30	2.6
Aberrant right subclavian artery	18	2.7	8	1.6	26	2.2
Isolated right aortic arch	1	0.2	–	–	1	0.1
Right aortic arch and ALSA	2	0.3	1	0.2	3	0.3
Right aortic arch and persistent LSVC	1	0.2	1	0.2	2	0.2
Double aortic arch	–	–	3	0.6	3	0.3
Dextrocardia	1	0.2	5	1	6	0.5
Total number (%)	74	11.3	50	9.7	124	10.6

LV: Left vertebral artery; LCC: Left common carotid artery; BT: Brachiocephalic trunk; ALSA: Aberrant left subclavian artery; LSVC: Left superior vena cava.

The second most frequent variant was the LCC originating from the BT in 30 (2.6%) patients (17 females and 13 males). This pattern included two branches of the aortic arch, with the common stem dividing into either the RS and RCC or the LCC and LS (Figure 2).

Twenty-six (2.2%) patients (8 females and 18 males) had an aberrant right subclavian artery (ARSA) variant in which the last branch of the aortic arch ran rightwards and upwards from the posterior esophagus (Figure 3).

In addition, we found that six patients (0.5%) had dextrocardia, one (0.1%) had an isolated right aortic arch, and three (0.3%) (including two children) had a right aortic arch and aberrant LS variant in which this artery originated from the proximal descending aorta and ran leftward from the posterior esophagus (Figure 4).

We also discovered that two patients (0.2%) had a right-sided aortic arch along with a persistent left

superior vena cava (LSVC) and that three (0.3%) pediatric patients had a double aortic arch. In these cases, the ascending aorta divided into two arches (anterior and leftward in one and posterior and rightward in the other) and passed to either side of the esophagus and trachea where they reunited to form the descending aorta (Figure 5).

Moreover, we found a statistical correlation between the patients with a LV originating directly from the aortic arch variant and gender ($p=0.01$) as this anomaly was observed twice the male patients. However, none of the other variants were not significantly associated with gender ($p=0.47$).

DISCUSSION

In this retrospective study, a total of 124 patients (10.6%) had variants of the aortic arch and its branches. These variants are usually asymptomatic and are detected incidentally, but when they lead to tracheal or esophageal compression, clinical symptoms may appear. In spite of their asymptomatic nature, it is

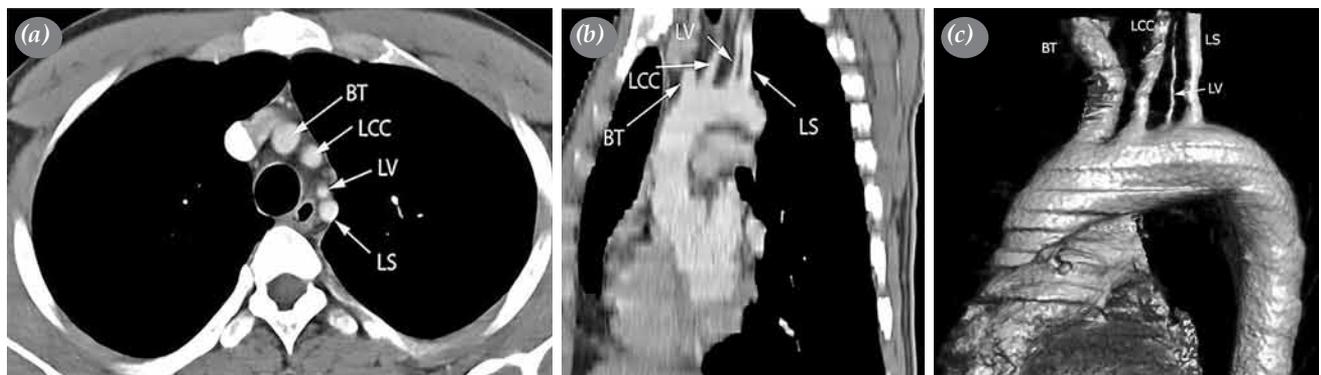


Figure 1. (a) Axial, **(b)** reformatted oblique sagittal, and **(c)** coronal volume-rendered multidetector computed tomographic images of a patient with the left vertebral artery arising directly from the aortic arch. BT: Brachiocephalic trunk; LCC: Left common carotid artery; LV: Left vertebral artery; LS: Left subclavian artery.

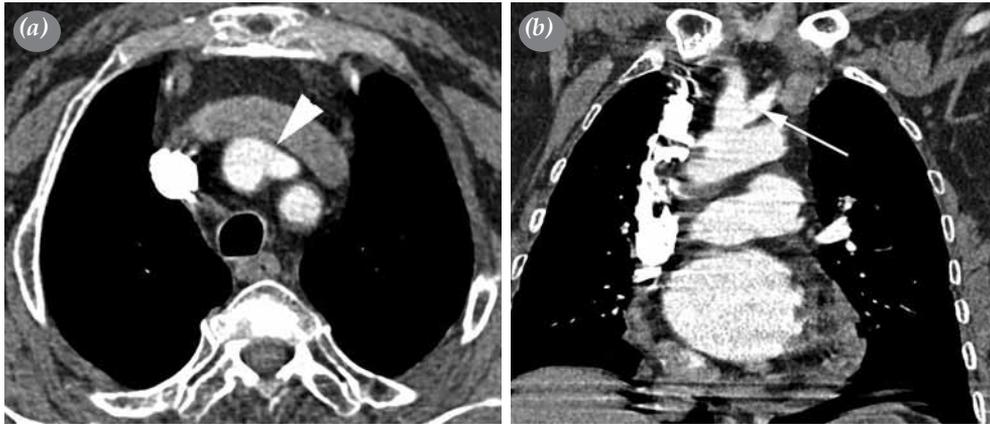


Figure 2. (a) Axial and (b) reformatted oblique coronal multi-detector computed tomographic images of a patient showing the left common carotid artery originating from the brachiocephalic trunk (arrows).

important that these variants be diagnosed prior to performing endovascular interventions and surgical procedures in order to prevent complications, especially those associated with vertebral artery injuries during cervical spine surgery.

Complex embryological development of the aortic arch and its branches may result in multiple variations.

Both Edwards in 1948^[10] and Barry in 1951^[11] studied this issue. They noted that blood was pumped by the heart into the embryonic primitive truncus arteriosus, which led to a dilated aortic sac. The six paired aortic arches that are present during the first three weeks of embryonic life drifted apart and ran through the aortic sac to the posterolateral and reunited dorsal aortic root.

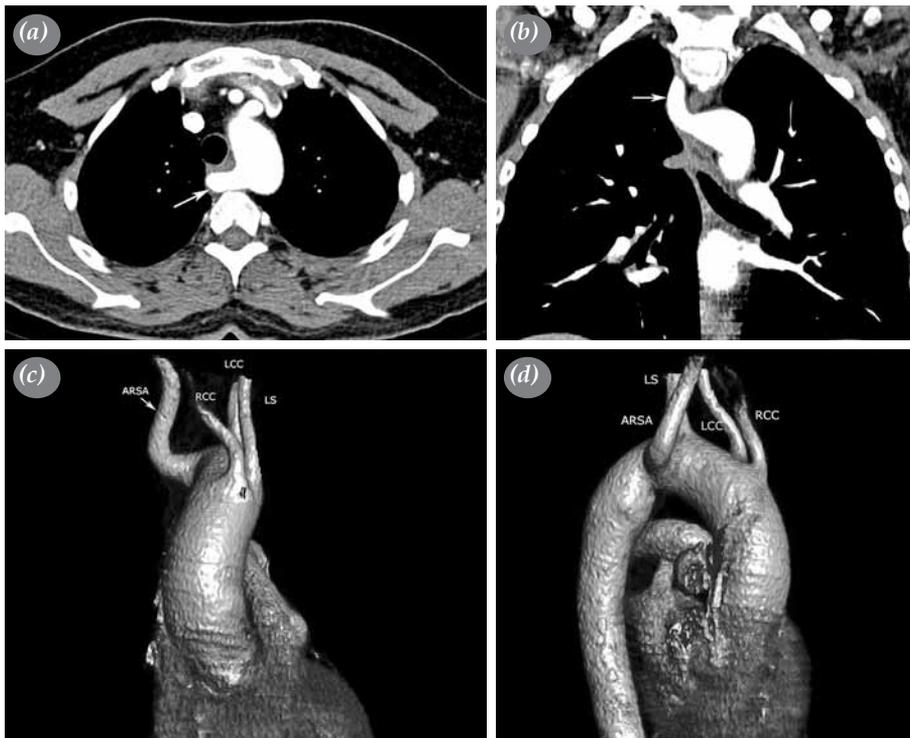


Figure 3. (a) Axial and (b) reformatted coronal multiplanar (c) posterior and (d) anterior coronal volume-rendered multidetector computed tomographic images of a patient showing the aberrant right subclavian artery variant (arrow). ARSA: aberrant right subclavian artery; RCC: Right common carotid artery; LCC: Left common carotid artery; LS: Left subclavian artery.

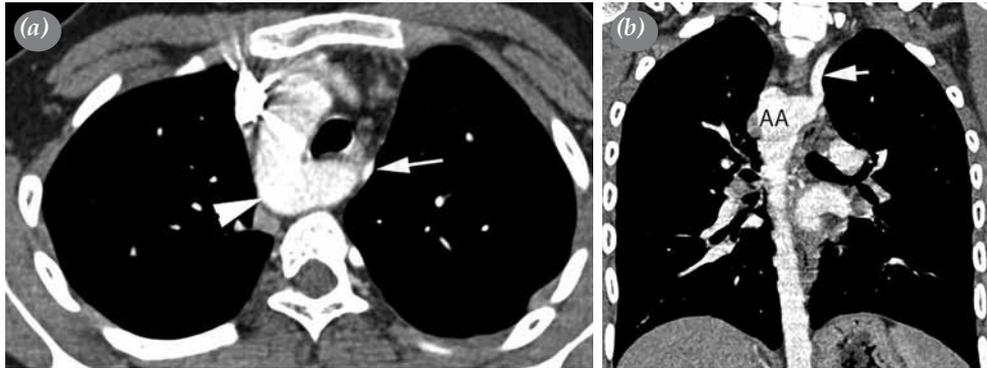


Figure 4. (a) Axial and (b) reformatted coronal multidetector computed tomographic images showing a right-sided arch with the aberrant left subclavian artery (arrows). AA: Aortic arch.

They also found that the fourth aortic arch was dilated due to regression and differentiation processes in the aortic arches, and the definitive aortic arch was formed at eight weeks.^[10] The majority of vascular variants result from the lack of regression of these aortic arches different segments or an abnormal regression process.

The prevalence of aortic arch variants has also been investigated via DSA and CT in studies involving cadavers, and a normal arch was reported in between 49.7 and 51.7% of African Americans^[12,13] and 66.9 and 82.4% of American Caucasians.^[3,4,6,13-19] In our study, 89.4% of the patients had a normal aortic arch while nearly 10% of patients had aortic arch variations. This result was higher than in the study by Nelson and Sparks^[3] (5.8%), but it was lower than what Thomson^[18] in an English cadaver series (17.6%) and Natsis et al.^[5] in a Greek angiography series (17%) found.

The most common variant was the LV originating directly from the aortic arch. In a study of 1,001 CT angiography (CTA) scans, Ergun et al.^[20] concluded that the second most frequently seen variant was the

LV originating from the aortic arch, which occurred in 5.1% of their patients, whereas the LCC originating from the BT was the most common variation. However, while we detected a correlation between gender and this artery when it originated from the aortic arch, they did not observe the same correlation. In another study composed of 193 Japanese-American male cadavers, Nelson and Sparks^[3] agreed with our findings and found that the most common variation was the LV originating from the aortic arch (3.1%). However, the majority of studies have reported that this is the second most common variant, with a prevalence rate of between 2.5 and 8%.^[5,19] In addition, Natsis et al.^[5] reported that this variant occurred at a rate of 0.8% in their study that utilized DSA, which to our knowledge is lowest prevalence rate in the literature. Their findings, however, could be the result of misinterpretations of vertebral artery occlusions when the DSA was performed.

The second most frequently seen variant in our study was the LCC originating from the BT in 2.6%

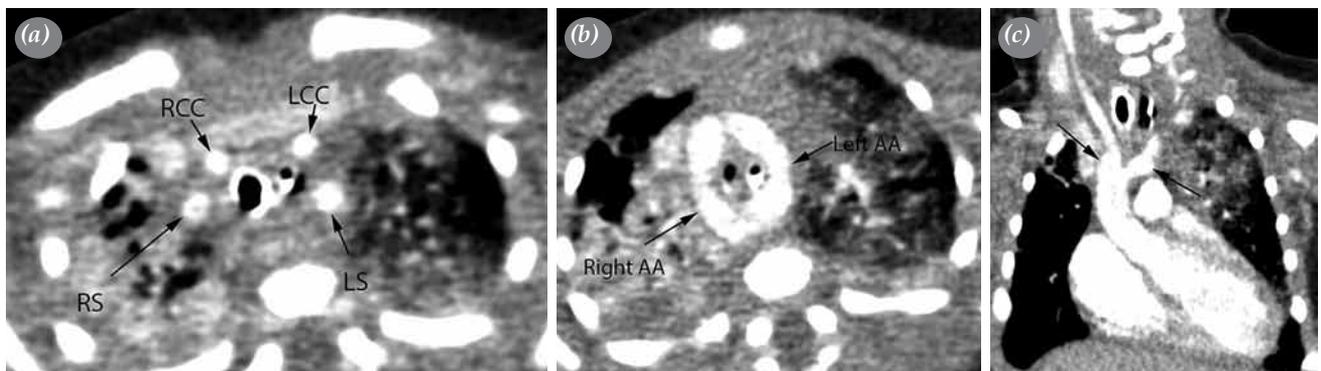


Figure 5. (a) Axial and (b) reformatted coronal multidetector computed tomographic images revealing a double aortic arch. The axial image shows symmetrical arch vessels in the thoracic inlet. RS: Right subclavian artery; RCC: Right common carotid artery; LS: Left subclavian artery; LCC: Left common carotid artery; AA: Aortic arch.

of the patients. This is commonly referred to as a “bovine arch”, which is a misnomer. It actually refers to the “bovine arch” anomaly, which is a large BT that includes the innominate artery, LCC, and LS and originates from the aortic arch. Müller et al.^[7] proposed the term “truncus bicaroticus” for this variant, but this would also be a misnomer since this would include the RS along with two CCAs. Many studies have reported that the second most common variant is the LCC originating from the BT, but these contain a wide variety of prevalence rates that range from 0.9 to 45.6%.^[13,19] However, if a V-shaped origin for the BT and LCC were also included, this percentage would be higher. Layton et al.^[21] reported that V-shaped branching was present in 13% of their patients. While the lowest published rates for this variant were 1% in a study of 193 cadavers of Japanese-American origin and 0.9% in a Polish cohort of 453 specimens,^[3,13] the highest reported rate was 45.6% in a series by Williams and Henry^[19] that included 80 American Caucasian males.

In addition, we observed the ARSA variant in 26 of our patients (2.2%). Although aberrant vascular variants may compress the trachea and esophagus, some patients may remain asymptomatic. Weinberg^[22] reported an ARSA incidence rate of 2%, which was consistent with our findings. However, Celikyay et al.^[8] reported a rate of just 0.8%. This difference can be attributed to the fact that our study population with aortic arch variants was mainly composed of patients living in the southeastern Anatolian region of Turkey.

Aortic arch variants leading to tracheal and esophageal compression are known as vascular ring abnormalities, with the possible culprits being the ARSA, paired aortic arch, right aortic arch, and aberrant LS.^[23] In addition, vascular rings are the major cause of airway obstruction in neonates, and the severity of the clinical manifestations varies according to the degree of compression.^[24] Early diagnosis, therefore, is of utmost importance. Noninvasive MDCT may be useful for detecting vascular variants as well as tracheal and esophageal compression. In our study, we detected a double aortic arch in three pediatric patients and a right aortic arch associated with an aberrant LS in two others.

One limitation of our study was that all of the patients had previously undergone thoracic CT for various reasons; therefore, we did not perform this again as it would have been inappropriate for healthy individuals due to the radiation exposure. Thus, our study results did not precisely reflect the prevalence of variation in a healthy population as other angiographic and CT imaging studies have done. On the other

hand, the main strength of the present study is that it includes the large study population among the studies investigating the variants of the aortic arch by MDCT.

Conclusion

The prevalence of aortic arch variants is high in the Turkish population, which should necessitate that vascular surgeons, interventional radiologists, and head and neck surgeons pay special attention to these anomalies. Hence, these variants should be diagnosed before interventional and surgical procedures. Furthermore, incidentally-detected vascular variations should always be reported when found during routine CT scans. Our findings also indicated that MDCT, a rapid, safe diagnostic modality for the evaluation of aortic arch variants and their branches, produces reliable outcomes because of the contribution of reformatted multiplanar reconstruction images.

Declaration of conflicting interests

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