

Evaluation of aortic arch morphologies by computed tomographic angiography in Turkish population

Türk toplumunda aortik ark morfolojilerinin bilgisayarlı tomografik anjiyografi ile değerlendirilmesi

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ABSTRACT

Background: The aim of this study was to evaluate the aortic arch morphologies in the Turkish population using the computed tomography angiography technique.

Methods: Between August 2009 and August 2019, a total of 2,037 (1,003 males, 1,034 females; mean age: 52.8±20.3 years; range, 3 months to 100 years) thoracic computed tomography angiography scans were retrospectively analyzed. The findings were classified as described previously in the literature. The prevalence of aortic arch morphologies and possible relationship with sex were analyzed. The prevalence of variations reported in previous studies was compared with the current study.

Results: The normal aortic arch pattern (type A), observed in 1,562 cases (76.7%), was determined statistically significantly more in males than females ($p<0.05$). The most common variation, bovine aortic arch (type B1) which observed in a total of 315 cases (15.5%), was determined statistically significantly more in females than males ($p<0.05$). The second most frequent variation, in which the left vertebral artery originates directly from the aortic arch (type C1) was detected in 97 cases (4.7%). There was also observed to be aberrant right subclavian artery in 21 cases (1%), right-sided aortic arch variation in seven cases (0.4%), and double aortic arch anomaly in four cases (0.1%). In terms of the reported frequency of type B variation, a significant difference was determined between the current and previous studies in Türkiye ($p<0.05$).

Conclusion: With the largest sample size to date, this study provides comparative information about the prevalence of aortic arch patterns in the Turkish population.

Keywords: Aberrant right subclavian artery, anatomy, aortic arch, bovine arch, computed tomography angiography, double arch.

ÖZ

Amaç: Bu çalışmada, bilgisayarlı tomografik anjiyografi tekniği ile Türk popülasyonundaki aortik ark morfolojileri değerlendirildi.

Çalışma planı: Ağustos 2009 - Ağustos 2019 tarihleri arasında toplam 2,037 (1003 erkek, 1034 kadın; ort. yaş: 52.8±20.3 yıl; dağılım, 3 ay - 100 yıl) toraks bilgisayarlı tomografik anjiyografi görüntüleri retrospektif olarak incelendi. Bulgular literatürde tariflenen şekilde sınıflandırıldı. Aortik ark morfolojilerinin prevalansı ve cinsiyet ile muhtemel ilişkisi incelendi. Bu çalışmada saptanan bulgular, daha önceki çalışmalarda bildirilen varyasyon prevalansı ile karşılaştırıldı.

Bulgular: Normal aortik ark deseni (tip A) 1,562 olguda (%76.6) saptanmış olup, erkeklerde sıklığı istatistiksel olarak anlamlı düzeyde daha fazlaydı ($p<0.05$). Toplam 315 olgu (%15.5) ile en sık saptanan varyasyon bovine aortik arkus (tip B1) olup, kadınlarda sıklığı istatistiksel olarak anlamlı düzeyde daha fazlaydı ($p<0.05$). İkinci en sık görülen varyasyon, vertebral arterin aortik arkta doğrudan köken alması olup (tip C1), 97 olguda (%4.7) saptandı. Ayrıca 21 olguda (%1) aberran sağ subklaviyan arter, yedi olguda (%0.4) sağ taraflı aortik ark varyasyonu, dört olguda (%0.1) ise çift aortik ark anomalisi saptandı. Tip B varyasyon ile ilgili olarak, bu çalışma ve Türkiye’de daha önce yapılmış çalışmalarda bildirilen prevalanslar arasında anlamlı bir fark izlendi ($p<0.05$).

Sonuç: Bugüne kadar yapılmış en geniş olgu serisiyle bu çalışma Türk popülasyonunda saptanan aortik ark morfolojilerinin prevalansına ilişkin karşılaştırmalı bilgi sağlamaktadır.

Anahtar sözcükler: Aberran sağ subklaviyan arter, anatomi, aortik ark, bovine aortik arkus, bilgisayarlı tomografik anjiyografi, çift arkus.

Received: July 11, 2021 Accepted: January 23, 2022 Published online: April 27, 2022

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Cite this article as:

Terzioğlu E, Damar Ç. Evaluation of aortic arch morphologies by computed tomographic angiography in Turkish population. *Türk Gogus Kalp Dama* 2022;30(2):167-175

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The aortic arch (AArch) and branches develop in the first few weeks of intrauterine life.^[1] In classic anatomy, the AArch has localization on the left side. The left AArch is formed with regression of the distal component of the primitive right fourth arch of the embryonic double AArch system (Figure 1).^[2] There may be branching pattern variations together with chromosomal anomalies and congenital heart diseases, and the majority are detected incidentally. If there are no findings of airway-esophageal compression such as dyspnea-dysphagia lusoria, there would be no clinical problems.^[3,4]

Although these variations are usually harmless, they should be known before surgical or endovascular interventions.^[3] While planning endovascular treatment of thoracic aorta aneurysm and/or dissections, branching patterns must be carefully examined before stent graft placement to be able to avoid potential complications.^[5] As prolonged reperfusion time, particularly in stroke patients, negatively affects the course of the patient, the presence of difficult AArch patterns can cause loss of time for mechanical thrombectomy.^[6] Variations in AArch and associated potential cardiac anomalies can be visualized with airway-esophageal compression multidetector computed tomography (MDCT).^[7]

A search in PubMed using the keyword “aortic arch anomalies” yielded more than 8,800 results in literature under different titles. In a meta-analysis of 51 cadaver and radiological imaging studies of AArch variations conducted on different populations, normal arch anatomy was reported at a rate of 80.9%.^[8]

In the present study, we aimed to investigate AArch and its branching patterns in the most extensive case series examined to date in the population of the southeast Anatolian region of Türkiye and to examine the potential relationship between the sex and AArch patterns.

PATIENTS AND METHODS

This single-center, retrospective study was conducted in Radiology Department of Gaziantep University, Faculty of Medicine located in the Southeast Türkiye between August 2009 and August 2019. Initially, a total of 2,072 cases who underwent thoracic computed tomography (CT) angiography imaging were screened. All the cases were evaluated in respect of AArch patterns on 64 consecutive MDCT images. Of these cases, 35 were excluded from the study due to the presence of a para-aortic mass affecting the aortic configuration, a history of AArch surgery, V1 segments of the vertebral arteries (VAs) not included

in the imaging area, or low-quality images due to movement artefacts or insufficient distribution of diluted contrast material within the artery. Finally, a total of 2,037 cases (1,003 males, 1,034 females; mean age: 52.8±20.3 years; range, 3 months to 100 years) were included. The CT examinations were made with a 64-detector device (VCT XTe Light Speed; General Electric, Milwaukee, WI, USA). In adult population (age >18 years), contrast material was administered to the left or right antecubital vein as 120 mL non-ionic solution with 300 mg/mL iodine concentration in bolus form of 4 mL/sec followed by 40 mL saline with an automatic injector (Covidien LF Optivantage DH, OH, USA). The image parameters were collimation: 40 mm (64×0.625), rotation time: 0.35 sec, pitch value: 1, X-ray tube: 100-120kV and 150-600 auto mAs, detector thickness: 0.625 mm, and reconstruction interval: 0.625 mm. In pediatric population (age <18 years), pediatric CTA protocols have been used. Following acquisition of axial images, three-dimensional (3D) surface images were formed in all cases. All the data were post-processed on an appropriate workstation (Vitrea). The images were analyzed by two fourth-grade radiology residents and the final diagnosis was established with consensus.

In the literature, there is no consensus on AArch pattern variations and they are classified in different ways with numerical or letter grouping. The system used in this study was the classification system described by Wang et al.,^[9] in which branching

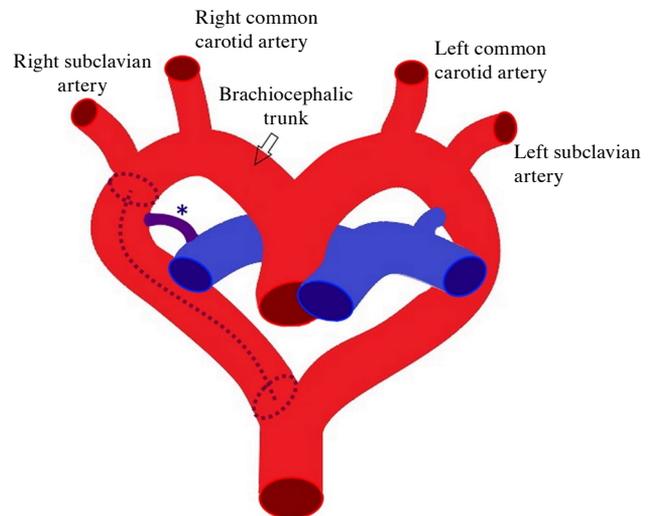


Figure 1. Schematic representation of the embryonic double aortic arch system development. With a regression involving the distal segment of the primitive right fourth arch (dotted lines and circles) and the right ductus arteriosus (*), the embryonic double aortic arch system evolves into a normal left aortic arch.

patterns are assigned letters and numbers from A to E, considering the prevalence and AArch branching pattern (Figure 2).

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 22.0 software (IBM Corp., Armonk, NY, USA). Continuous variables were expressed in mean ± standard deviation (SD) or median (min-max), while categorical variables were expressed in number and frequency. Qualitative and quantitative variables were investigated using the chi-square test, Mann-Whitney U test or the Kruskal-Wallis test. A *p* value of <0.05 was considered statistically significant.

RESULTS

There was no statistically significant difference in the mean age between the two sexes (*p*>0.05).

A total of 1,562 (76.7%) patients were classified as type A branching pattern. This pattern represents classic AArch branching, originating from the brachiocephalic trunk (BT), left common carotid artery (LCCA), and left subclavian artery (LSA), respectively. In the remaining 475 (24.3%) patients, various other patterns of AArch were observed (Table 1). Type A pattern was determined statistically significantly more in males than females (*p*<0.05).

There may be other accompanying anomalies in type B branching pattern where the BT and LCCA separate from a common root. In 315 (15.5%) cases, type B1 classification was made with no other accompanying variations. A total of 19 (0.9%) cases were classified as type B2, in which the BT and LCCA emerged from a common root, and the left VA (LVA) emerged as a separate branch from the AArch between the

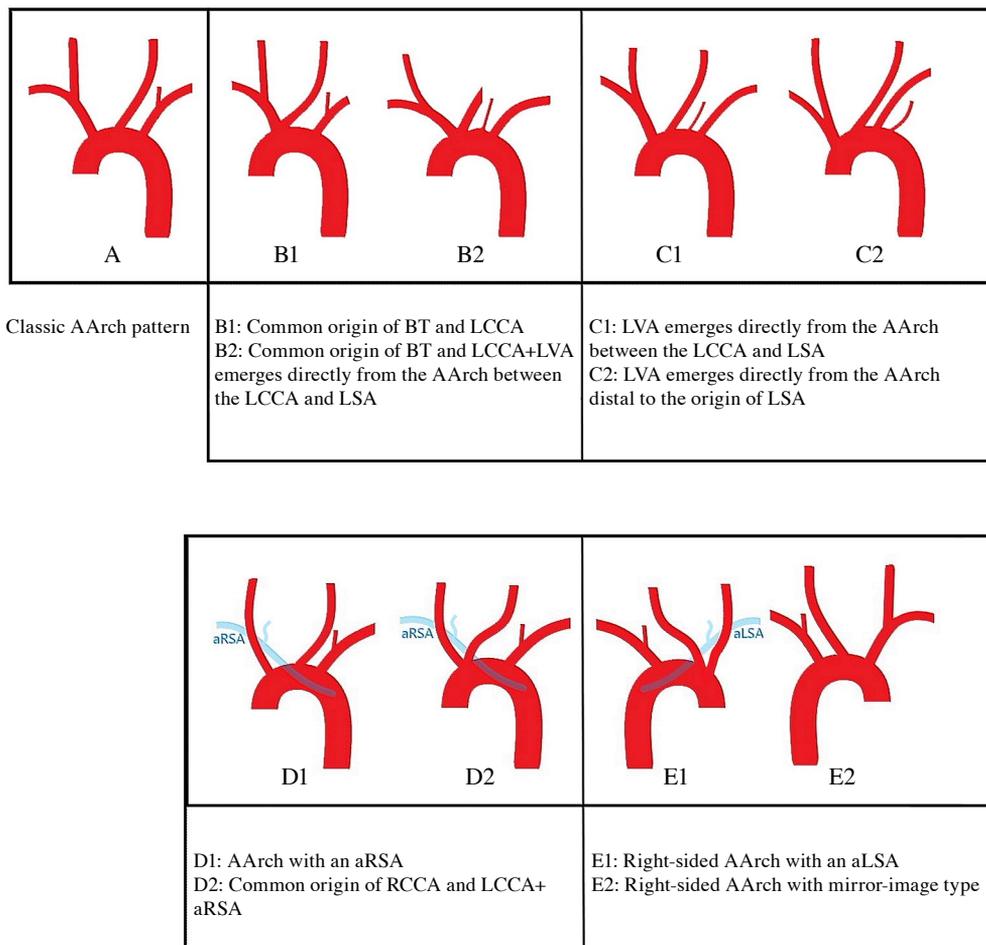


Figure 2. The image shows the categorization of the aortic arch patterns observed in the present study. AArch: Aortic arch; BT: Brachiocephalic trunk; LCCA: Left common carotid artery; LVA: Left vertebral artery; LSA: Left subclavian artery; aRSA: Aberrant right subclavian artery; RCCA: Right common carotid artery; aLSA: Aberrant left subclavian artery.

Table 1. Variations of aortic arch patterns

AArchP		n	%
A	Classic AArch pattern	1562	76.7
B	B1: Common origin of BT and LCCA	315	15.5
	B2: B1 + LVA emerges directly from the AArch between the LCCA and LSA	19	0.9
C	C1: LVA emerges directly from the AArch between the LCCA and LSA	97	4.76
	C2: LVA emerges directly from the AArch distal to the origin of LSA	3	0.14
D	D1: AArch with an aRSA	21	1.0
	D2: Common origin of RCCA and LCCA + aRSA	8	0.4
E	E1: Right-sided AArch with an aLSA	3	0.15
	E2: Right-sided AArch with mirror-image type	4	0.24
Double arch		4	0.24
SIT		1	0.05

AArchP: Aortic arch patterns; BT: Brachiocephalic trunk; LCCA: Left common carotid artery; LVA: Left vertebral artery; LSA: Left subclavian artery; RCCA: Right common carotid artery; aRSA: Aberrant right subclavian artery; aLSA: Aberrant left subclavian artery; SIT: Situs inversus totalis.

LCCA and LSA (Table 1). Type B variation was determined statistically significantly more in females than males ($p < 0.05$).

In type C classification, the LVA branch arises directly from the AArch. The LVA emerging as a separate branch from the AArch between the LCCA and LSA is classified as type C1 variation, and this was determined in 97 (4.76%) patients. The LVA emerging as a separate branch from the AArch distal to the origin of LSA is classified as type C2 variation, and this was determined in three (0.14%) patients (Figure 3, Table 1).

Type D variation represents the branching pattern observed as an aberrant right subclavian artery (aRSA) as the last branch emerging from the

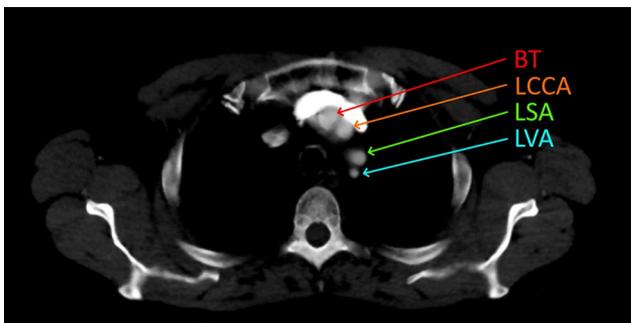


Figure 3. Axial computed tomographic angiography image shows LVA arising directly from the aortic arch distal to the origin of LSA (Type C2 aortic arch pattern).

BT: Brachiocephalic trunk, LCCA: Left common carotid artery; LSA: Left subclavian artery; LVA: Left vertebral artery.

AArch. Subtype D1 variation, in which only aRSA is observed, was determined in 21 (1%) patients. In the type D2 variation, in addition to aRSA entity, the RCCA and LCCA originate from a common root (Figure 4a, b). This variation was determined in eight (0.4%) patients (Table 1).

Right-sided AArch (R-AArch) is evaluated as type E in this classification. Type E1, in which there is aberrant LSA (aLSA) of R-AArch was observed in three (0.15%) patients (Figure 5). The mirror-image type of R-AArch branching pattern is classified as type E2 and was determined in four (0.24%) patients (Table 1).

Double AArch anomaly was determined in four cases (0.1%) (Figure 6 a,b). In one (0.05%) case, there was situs inversus totalis (SIT) (Table 1).

A significant relationship was found between sex and the AArch branching patterns. Type A classic branching pattern was determined statistically significantly more in males than females. Type B variation, described as bovine arch, was determined statistically significantly more in females than males ($p < 0.05$) (Table 2).

The prevalence of AArch patterns observed in our study and reported in previous imaging studies including ≥ 1000 subjects in the literature is summarized comparatively in Table 3. Regarding the prevalence of both type A and B AArch patterns, comparisons were made between present study and the studies conducted in different regions of Türkiye.^[3,10-12] While the prevalence of classical

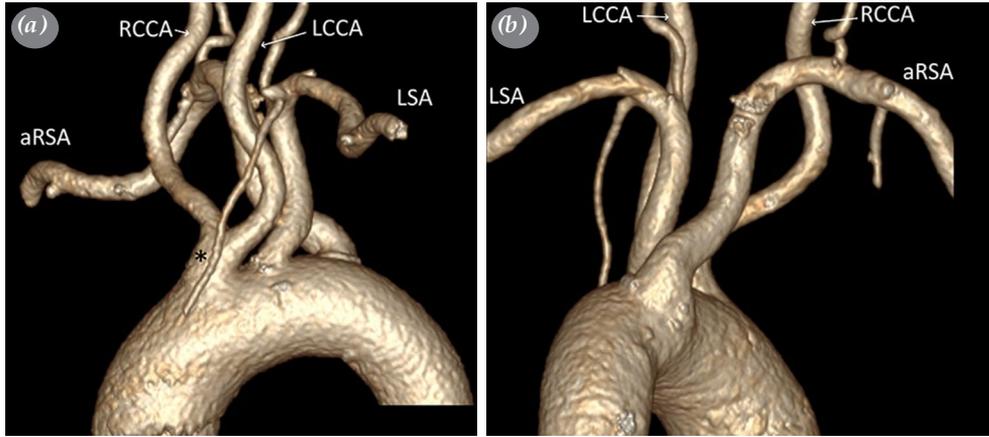


Figure 4. 3D volume rendered images from left oblique (a) and posterior aspect (b) reveal aRSA concomitant with common trunk (*) of right and left common carotid arteries (Type D2 aortic arch pattern).

RCCA: Right common carotid artery; LCCA: Left common carotid artery; LSA: Left subclavian artery; aRSA: Aberrant right subclavian artery.

type A pattern showed no statistically significant difference ($p>0.05$), the frequency of type B variation differed significantly ($p<0.05$).

DISCUSSION

Aortic arch pattern variations are often observed. Ethnic, social, and environmental factors have been

shown to have an effect on the rates of variations.^[5] Studies conducted on different ethnic groups and in different geographic regions support this view, as different rates of variations have been reported.^[3,9-16]

Type A is accepted as the normal branching pattern and is the most widespread with a prevalence of 89.9% reported in a meta-analysis on this subject. In this pattern, the first branch is the BT (it separates into two main branches of RSA and RCCA), the second branch is the LCCA, and the third and final branch is the LSA.^[8] In the current study, the prevalence of type A, known as the normal branching pattern, was determined to be 76.7%.

The most common AArch variation determined in this study, with a prevalence of 15.5%, was Type B1, where the BT and LCCA have a common origin. This variant is named “bovine arch” in the literature and its overall frequency has been reported to be 13.6%.^[8] The frequency of the B1 aortic pattern has been reported to be higher in South America (24.2%) and in African populations (26.8%), compared to Caucasian populations.^[8] Thoracic aorta aneurysms are seen more frequently in individuals with bovine AArch, and with the determination of rapid growth, this variation is accepted as a marker or a risk factor for complications.^[17,18] In terms of frequency of type B AArch variation, it seems to have significant differences even in different regions of Türkiye ($p<0.05$) (Table 3).^[3,10-12] The presence of the Type B AArch variation is a disadvantage in the management of thromboembolic events in the

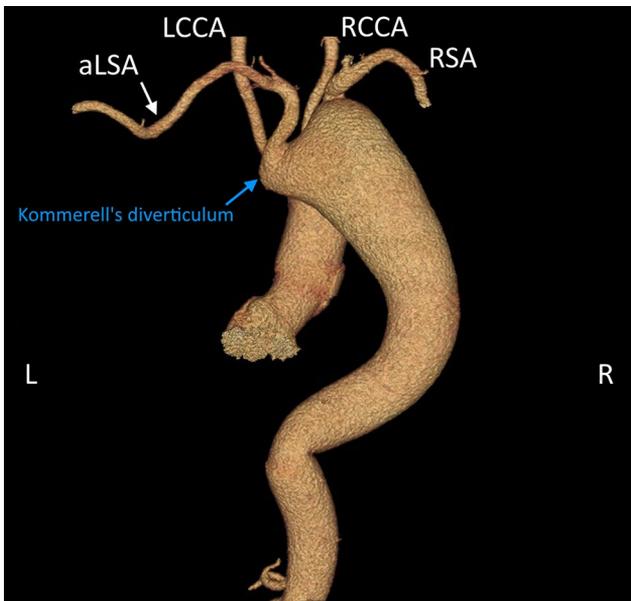


Figure 5. 3D volume rendered image demonstrates the right aortic arch from posterior side. The Kommerell's diverticulum is accompanying aLSA (Type E1 aortic arch pattern).

aLSA: Aberrant left subclavian artery; LCCA: Left common carotid artery; RCCA: Right common carotid artery; RSA: Right subclavian artery.

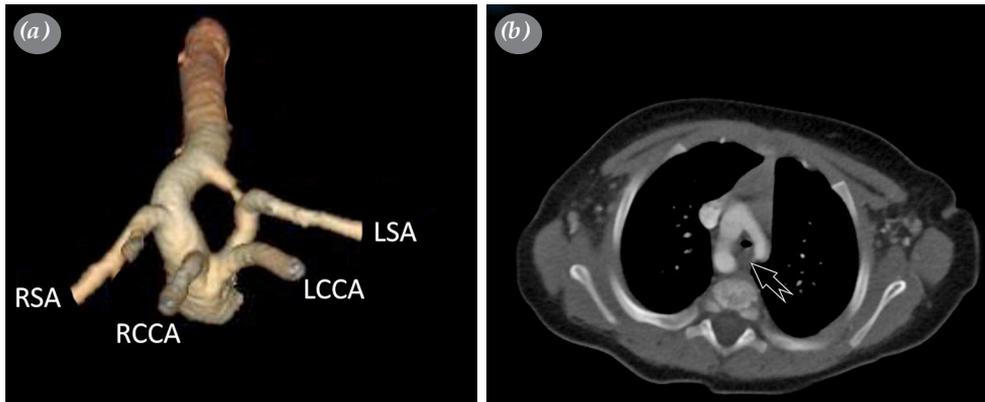


Figure 6. (a) 3D volume rendered image shows double aortic arch which has an atretic left arch component from cranio-caudal projection. (b) Axial computed tomographic angiography image of the same patient demonstrates trachea and esophagus (arrow) surrounded by the double aortic arch.

RSA: Right subclavian artery; RCCA: Right common carotid artery; LCCA: Left common carotid artery; LSA: Left subclavian artery.

left anterior circulation of the brain, since LCCA is difficult to catheterize.^[6]

The second most commonly observed variation (4.9%) in the current study was the type C (C1+C2) arch pattern, in which the LVA emerges directly from the AArch rather than the LSA. According to a meta-analysis, the prevalence of this pattern was reported as 2.9%, and B2 pattern in which the LVA was observed together with bovine arch, as 0.4%.^[8] The emergence

of the LVA is more often between the LCCA and LSA, but it may also originate from the distal of the LSA origin. In 97 (4.76%) patients in the current study, the LVA was determined proximal of the LSA (type C1), and in three (0.14%) patients, originating from distal (type C2). In a catheter angiography study by Natsis et al.,^[19] the incidence of type C arch pattern was reported to be extremely low at 0.79%. This could be explained by the fact that aortic origin LVAs could not be catheterized in the procedure. In contrast to the LVA, variations associated with the RVA are observed less often.^[20] No RVA of AArch origin was determined in the current study. Although there are a few case reports of bilateral VA originating from the AArch, these variations are extremely rare.^[21,22]

The total prevalence of variations of the LVA emerging directly from the AArch (C1+C2+B2) was determined to be 5.8% in the current study. This rate was 3.3% in a meta-analysis^[8] and 5.6% in a study by Wang et al.^[9] Other than the accustomed location of the VA origin, as there is usually a strong relationship with the difference in the level of entry to the transverse foramen, this creates a danger for cervical region surgery and vascular interventional procedures.^[23,24] Entry of the left VA to the transverse foramen at high levels increases the likelihood of dissection or obstruction during rotation movement of the neck. These findings are supported by a study by Komiyama et al.,^[25] in which it was reported that VA origin was related to VA dissection.

The prevalence of type D variation (D1+D2), in which aRSA is observed, was determined to be 1.4% in the current study. This rate has been reported to

Table 2. Association between frequency of the aortic arch patterns and sex

AArchP	Sex				p
	Male		Female		
	n	%	n	%	
A	827	79.8	735	73.4	
B1	133	12.8	182	18.2	
B2	9	0.9	10	1.0	
C1	48	4.6	49	4.9	
C2	3	0.3	0	0.0	
D1	7	0.7	14	1.4	0.012
D2	3	0.3	5	0.5	
E1	2	0.2	1	0.1	
E2	1	0.1	3	0.3	
Double arch	3	0.3	1	0.1	
SIT	0	0.0	1	0.1	

AArchP: Aortic arch patterns; SIT: Situs inversus totalis; P<0.05: Pearson chi-square test.

Table 3. Prevalence of aortic arch patterns reported in present study and the previous imaging studies including ≥1000 subjects in the literature

	Terzioğlu et al.*	Wang et al.	Müller et al.	Rea et al.	Vucurevic et al.	Boyaci et al.	Celikyay et al.	Ergun et al.	Karacan et al.	Berko et al.
Country/ year	Türkiye/ 2020	China/ 2016	Germany/ 2011	Italy/ 2014	Serbia/ 2013	Türkiye/ 2015	Türkiye/ 2013	Türkiye/ 2013	Türkiye/ 2014	USA/ 2009
AArchP										
n	2037	2370	2033	1359	1266	1170	1136	1001	1000	1000
A (%)	76.7	83.8	86.7	71	74.7	89.4	74.4	85.2	79.2	66.5
B1 (%)	15.5+	9.6	8		15.56	2.6+	21.1+	7.8+	14.1+	25.8
B2 (%)	0.9+	0.6	-	23.5	-	-	0.4+	-	1.2+	1.6
B3 (%)	-	0.04	-		-	-	0.2+	-	-	-
B4 (%)	-	0.04	-		-	-	-	-	-	-
C1 (%)	4.76	4.7	4.2	3	3.6	4.5	2.9	5.1	4.1	6.1
C2 (%)	0.15	0.17	0.05		0.08	-	0.1	-	-	-
C3 (%)	-	0.08	-		2.2	-	-	-	0.1	-
D1 (%)	1	0.5	1		0.4		0.4	0.7	0.6	0.8
D2 (%)	0.4	0.2		0.5	-	2.2	0.3	-	0.7	0.4
D3 (%)	-	0.08			-		0.1	-	-	-
E1 (%)	0.15	0.08	0.05	0.5	0.3	0.3	0.1	0.1	-	0.1
E2 (%)	0.2	-	-		-	-	-	-	-	-
RM	CTA	CT	CT	CTA	CT/DSA	CT	CT/CTA	CTA	CTA	CTA

* Present study (gray column); AArchP: Aortic arch patterns; RM: Radiological modality, +: The frequency of type B variation differed significantly between the studies conducted in different regions of Türkiye, including the present study (p<0.05, One sample chi-square test).

be 0.7% in the general population.^[8] In a study that evaluated 102 aRSA variations, CCAs emerging from a common body (type D2) were seen at 20%, and the variant of RVA emerging from the common body of the CCA at 13.7%.^[26] Of 29 patients in the current study with aRSA, the D2 variant was present in eight (27%). While a retro-esophageal course is seen in 80% of aRSA, the remainder have a course between the trachea and esophagus or adjacent to the anterior of the trachea.^[27] In all the patients with type D AArch pattern in the current study, the RSA had a retro-esophageal course. By compressing the esophagus, aRSA can cause dysphagia, and this is known as “dysphagia lusoria”.^[28] Another condition associated with aRSA is the non-recurrent inferior laryngeal nerve, which is a variation of the vitally important recurrent inferior laryngeal nerve, which must be carefully protected in thyroid surgery.^[29]

The prevalence of R-AArch (type E) was determined as 0.39% in the current study. This rate has been reported as 0.2% in the general population.^[8] Patients with type E1 R-AArch are

usually asymptomatic. Type E2 R-AArch is seen together with cyanotic congenital heart diseases.^[9] In a study of 11,276 children with cyanotic congenital heart disease, the frequency of R-AArch was determined as 4.2%.^[30]

Some other variations not determined in the current study have been reported in other studies in literature. Type B3 and B4 bovine arch variations, described by Wang et al.,^[9] and type C3, in which the thyroid ima artery originates from the AArch, were not determined in the current study. In addition, type D3, which represents a combination of aRSA and type C1, was not observed in this study. The variation of LCCA and LSA originating from a common body (double BT) was reported at 2.84% in a study by Vučurević et al.,^[14] and at 0.2% by Berko et al.^[15] Vučurević et al.^[14] also reported a pattern of five separate aortic branches (RSA, RCCA, LCCA, left VA and LSA) in eight patients (0.63%).^[14,15] In another large-scale study, Ergun et al.^[11] reported a branching pattern in seven patients where the RSA and RCCA emerged directly as separate branches without an accompanying aRSA.

It is thought that ethnicity may play a partial role in these rare variations.

In four cases (0.24%) in the current study, double AArch anomaly was determined, which is not included in the Wang et al.^[9] classification. In three of these cases with double AArch, the left arch was observed to be atretic subtype, and in the other case the double arch was co-dominant.

There were some potential limitations to this study which can usually be dealt with as follows. First is that this study was retrospective in nature and was based on CT angiography images of the patients taken previously for various reasons. Therefore, the results may not fully reflect the rates in healthy individuals. In addition, as previously mentioned, the relationship of bovine AArch with thoracic aorta disease has come to the fore in recent years. Therefore, there can be expected to be a relatively slight increase in the prevalence of bovine AArch in patients applied with thoracic CT angiography. Second is that the AArch branching classification was made according to the system of Wang et al.,^[9] which is based on some relatively common variations. To better understand the clinical importance of variations, it may be necessary to modify and develop this system.

In conclusion, although the prevalence of aortic arch pattern variations shows geographic variability, it is usually high. The majority of these variations are not clinically significant, but are important in patients planned to undergo head and neck surgery in particular or interventional radiological procedures, and head-neck surgeons and interventional radiologists must be informed about these anomalies before the planned surgery or interventional radiological procedure. Vascular variations determined incidentally during routine contrast enhanced computed tomography scans must always be reported. The findings of this study showed that in the evaluation of aortic arch variations and branches, multidetector computed tomography is a rapid and reliable diagnostic method, which produces reliable results, as it contributes to multiplanar reformatted reconstruction images. According to the results of the present study, significant differences were observed between sexes and the population living in different regions of Türkiye regarding the prevalence of some aortic arch patterns mentioned above.

Ethics Committee Approval: The study protocol was approved by the Gaziantep University, Faculty of Medicine Ethics Committee (No: 2020/500). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Study development, data collection, design, interpretation and writing the manuscript - E.T.; Data analysis, statistics, interpretation, writing and editing the manuscript - Ç.D.

Conflict of Interest: The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Funding: The authors received no financial support for the research and/or authorship of this article.

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