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Evaluation of Aortic Arch Branching Variations with Computed Tomography Angiographies

Arcus Aorta Dallanma Varyasyonlarının Bilgisayarlı Tomografi Anjiyografiler ile Değerlendirilmesi

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ABSTRACT

Objectives: Typically, aortic arch gives off three branches from proximal to distal: the brachiocephalic trunk, the left common carotid artery, and the left subclavian artery. This study aimed to determine the prevalence of aortic arch (AA) branching variations in a large sample and to assess gender differences.

Materials and Methods: This study was conducted as a retrospective, observational radiologic-anatomy. The branching configurations were categorized as follows: Type 1: Normal configuration (left-sided aortic arch with standard branching), Type 2: Bovine arch, Type 3: Left vertebral artery variation, Type 4: Bovine arch with left vertebral artery variation, Type 5: Common origin of the right and left common carotid arteries, Type 6: Aberrant right subclavian artery, and Type 7: Right-sided aortic arch variations.

Results: A total of 744 patients (334 females, 44.9% / 410 males, 55.1%) were included in the study. In the study sample, AA was most prevalent in Type 1 branching. Type 1 prevalence rates were 98.2%, 98.3%, and 98.3% in females, males, and the overall population, respectively. Other branching variations encountered in the study were Type 2, Type 3, Type 6, and Type 7. The prevalence of these variations was 1.1%, 0.3%, 0.3%, and 0.1%, respectively. There was no statistically significant difference in the prevalence of branching variations between genders (p>0.05).

Conclusions: This study concluded that AA variants were rarely found in the study sample. Although they are often encountered asymptomatically and incidentally, we believe that knowledge of population prevalence differences will contribute to clinical and radiological assessments.

Keywords: Aortic arch, branching pattern, computed tomography angiography, variant anatomy

ÖZET

Amaç: Tipik olarak, arcus aorta proksimalden distale doğru üç dal verir: truncus brachiocephalicus, arteria carotis communis sinistra ve arteria subclavia sinistra. Bu çalışmanın amacı, geniş bir örneklemde arcus aorta (AA) dallanma varyasyonlarının yaygınlığını belirlemek ve cinsiyet farklılıklarını değerlendirmektir.

Gereç ve Yöntemler: Bu çalışma retrospektif, gözlemsel bir radyolojik anatomi çalışması olarak yürütülmüştür. Dallanma varyasyonları şu şekilde kategorize edilmiştir: Tip 1: Normal konfigürasyon (standart dallanmalı sol taraflı arcus aorta), Tip 2: Bovine ark, Tip 3: arteria vertebralis sinistra varyasyonu, Tip 4: arteria vertebralis sinistra ve Bovine ark, Tip 5: Sağ ve sol ortak carotis communis kökü, Tip 6: Aberan arteria subclavia dextra ve Tip 7: Sağ taraflı arcus aorta varyasyonları.

Bulgular: Çalışmaya toplam 744 hasta (334 kadın, %44,9 / 410 erkek, %55,1) dahil edildi. Çalışma örnekleminde AA en sık Tip 1 dallanma tipinde görüldü. Tip 1 yaygınlık oranları kadınlarda %98,2, erkeklerde %98,3 ve genel popülasyonda %98,3 olarak bulundu. Çalışmada karşılaşılan diğer dallanma varyasyonları Tip 2, Tip 3, Tip 6 ve Tip 7 idi. Bu varyasyonların yaygınlığı sırasıyla %1,1, %0,3, %0,3 ve %0,1 olarak bulundu. Dallanma varyasyonlarının yaygınlığı açısından cinsiyetler arasında istatistiksel olarak anlamlı bir fark yoktu (p>0,05).

Sonuçlar: Bu çalışma, AA varyantlarının çalışma örnekleminde nadiren bulunduğu sonucuna varmıştır. Her ne kadar sıklıkla asemptomatik ve tesadüfen karşılaşılsalar da, popülasyon yaygınlık farklılıklarının bilinmesinin klinik ve radyolojik değerlendirmelere katkıda bulunacağına inanıyoruz.

Anahtar Kelimeler: Arcus aorta, Dallanma varyasyonları, Bilgisayarlı tomografi anjiyografi, varyasyonel anatomi

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Introduction

The aortic arch (AA) is the second section of the aorta, where key arteries of the head, neck, upper extremities, and anterior thoracic wall branch. Typically, it gives rise to three branches: the brachiocephalic trunk (BCT), the left common carotid artery (LCC), and the left subclavian artery (LSA). The brachiocephalic trunk then divides into the right common carotid artery (RCC) and right subclavian artery (RSA).

During weeks 4–5 of embryological development, as the branchial (pharyngeal) arches form, their arteries—called aortic arches—arise from the distal truncus arteriosus. Later, six pairs of aortic arches emerge, one per branchial arch. The third arch forms the common carotid and proximal internal carotid arteries; the external carotid artery arises from it. Development of the fourth arch differs: the left forms the aortic arch between the left and right subclavian arteries; the right forms the proximal portion of the right subclavian artery. The right dorsal aorta and seventh segmental artery continue the subclavian artery (1).

Variations in the branching of the AA arise from developmental processes and are mostly asymptomatic. However, in some cases, variations in the aortic arch (bovine arch, left vertebral artery originating from the arch, aberrant subclavian artery) can cause dysphagia, dyspnea, and difficulties during surgical and endovascular interventions and catheterization (2, 3). Bovine arch has been reported to be significantly more common among embolic stroke patients (3). AA variations can lead to misdiagnosis in cerebrovascular patients and life-threatening complications in neck-thoracic surgery (4). Lu et al. (5) stated that in cases of aortic dissection involving branches of the AA, stent-graft application with specialized branching may provide a better endovascular treatment option. Variations in the aortic arch have been reported to be significantly associated with Stanford type B aortic dissection. Variational anatomy of the aortic arch has been reported to be associated with a higher percentage of dissection-related aortic repairs in patients with Stanford type B aortic dissection (6).

This study sought to determine the prevalence of aortic arch branching variations and assess gender differences, offering insights for clinical and radiological assessment and patient management.

Materials and Methods

This study was a retrospective, observational radiologic-anatomic study. Prior to initiating the study, approval was obtained from our institution's Non-Interventional Clinical Research Ethics Committee (Decision No: 2022-5/29).

Inclusion criteria: Patients seen between 01.12.2021 and 01.05.2022 with full-thoracic CT angiography for aortic dissection, trauma, or intra-thoracic pathologies.

Exclusion criteria: age under 18, low-resolution images, incomplete observation, compression pathology of the AA or branches, history of thoracic/cardiovascular surgery, aortic aneurysm, and congenital cardiovascular disease.

CT Technique

The present study was performed using a 128-slice multidetector CT scanner (Revolution Evo; GE Healthcare, Milwaukee, WI, USA). We used our institution's standard thoracic CT angiography protocol to evaluate the aortic arch. All scans were acquired with patients in the supine position during full inspiration. Intravenous iodinated contrast material (80–120 mL) was administered with an automated power injector at an appropriate flow rate to ensure optimal arterial enhancement. Scanning parameters included tube voltage (80–120 kV), rotation time (0.5 seconds), pitch factor (1.48), field of view (FOV) (370 mm), total scanning time (4.3 seconds), and total tube current (180 mAs). Images were reconstructed at a slice thickness of 1 mm.

CT Evaluation

CT image analysis was performed using the institutional picture archiving and communication system (Sectra PACS, Sectra AB, Linköping, Sweden). The branching patterns of the aortic arch were classified using the system described by Popieluszko et al. (2). An experienced radiologist (NB, >10 years of experience) and an anatomist (KÇ, >10 years of experience

Table 1. Aortic arch patterning variations distribution by gender

			AA Type					
			Type 1 Normal	Type 2 Bovine Arc	Type 3 Left Vertebral	Type 6 Aberrant Right Sub-clavian	Type 7 Right Arc	Statistics Results
Gender	Female	n	328	3	1	1	1	T=1.477, p=0.836
		%	98.2	0.9	0.3	0.3	0.3	
	Male	n	403	5	1	1	0	
		%	98.3	1.2	0.2	0.2	0	
Total		N	731	8	2	2	1	
		%	98.3	1.1	0.3	0.3	0.1	

in cardiovascular anatomy) reviewed images independently. Both observers were blinded to the clinical data during assessment.

In addition to branching pattern classification, we systematically evaluated the origin, course, and spatial relationship of each major branch: the brachiocephalic trunk, left common carotid artery, and left subclavian artery. Evaluation was done on multiplanar reformatted (MPR) images in axial, sagittal, and coronal planes. Three-dimensional volume-rendered (VR) and maximum intensity projection (MIP) reconstructions were also reviewed. This provided a precise visualization of the aortic arch anatomy.

The branching configurations were categorized as follows:

Type 1: Normal configuration (left-sided aortic arch with standard branching)

Type 2: Bovine arch

Type 3: Left vertebral artery variation

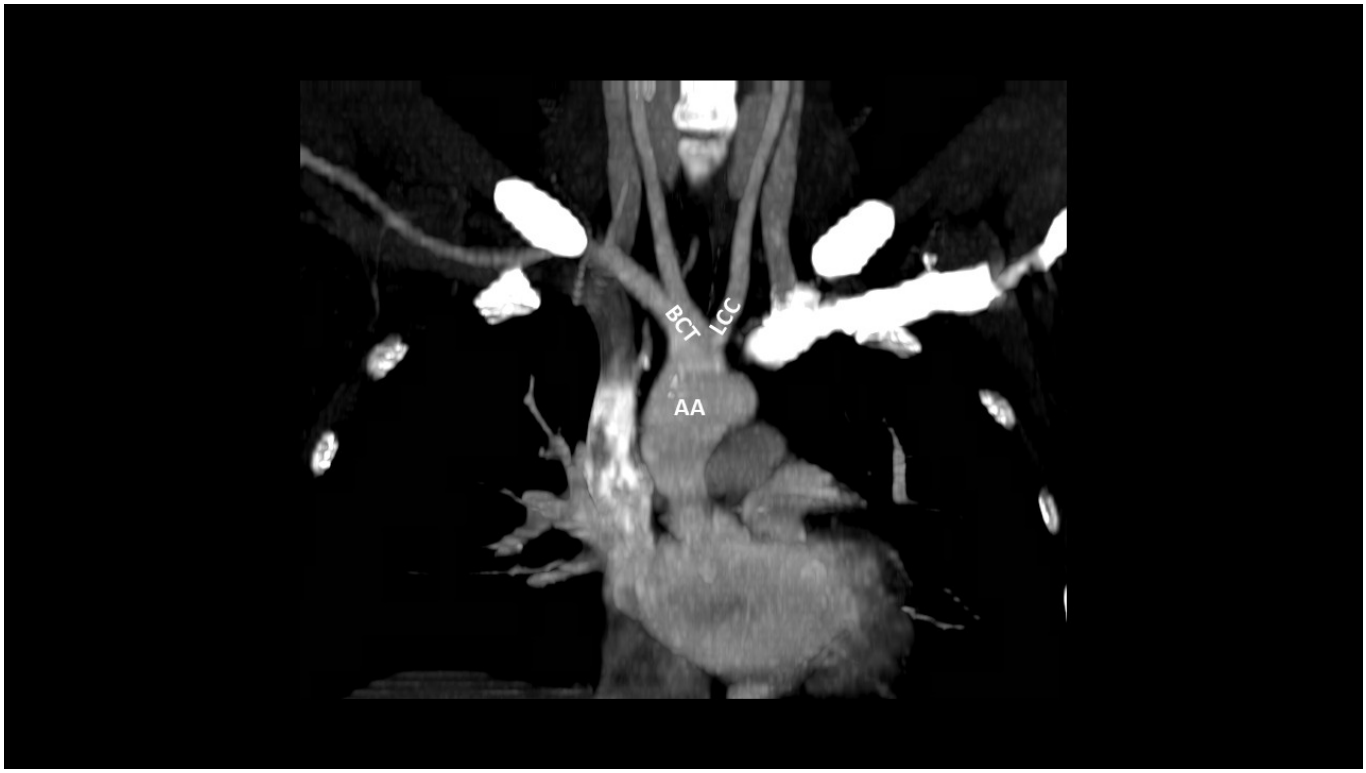


Figure 1. Coronal computed tomography angiography image shows a Type 2 (Bovine arch) branching pattern of the aortic arch. AA: Aortic arch, BCT: Brachiocephalic truncus, LCC: Left common carotid artery

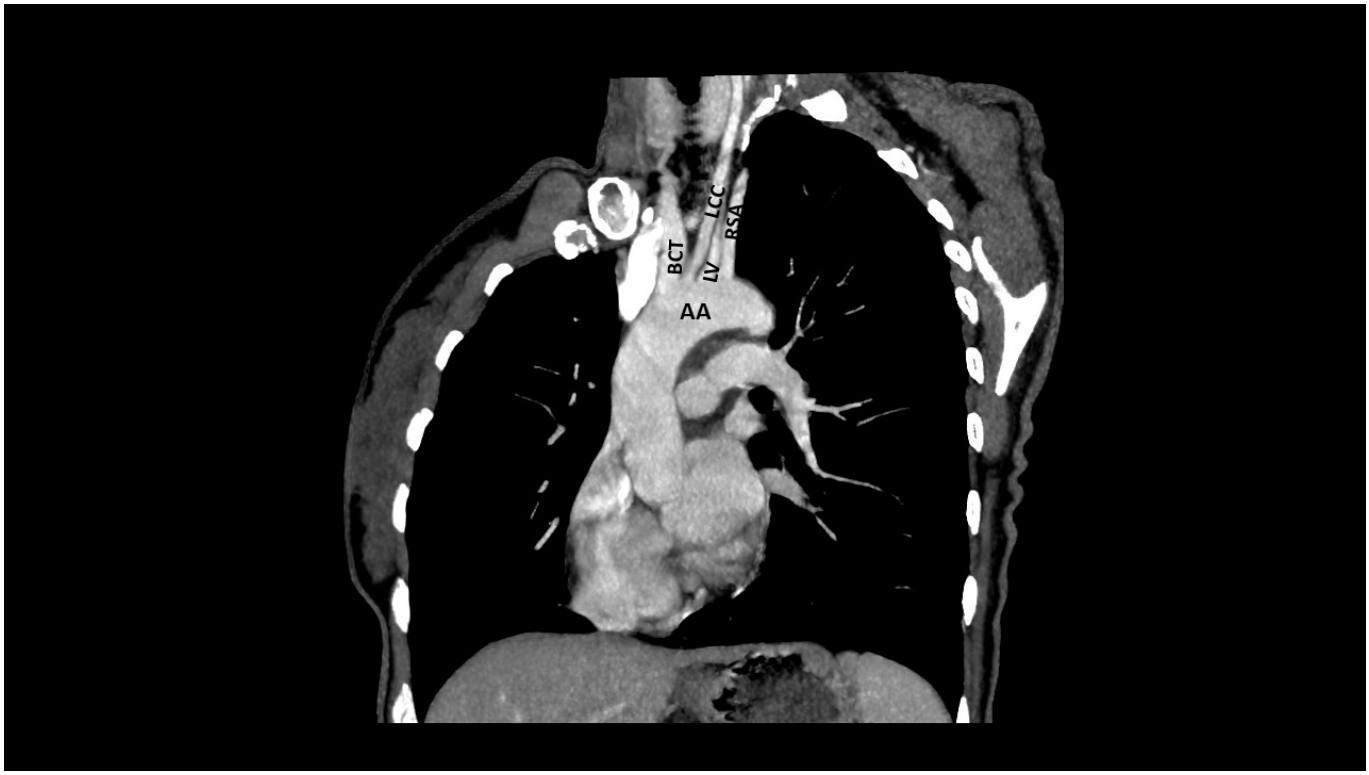


Figure 2. Coronal computed tomography angiography image shows a Type 3 aortic arch branching pattern. AA: Aortic arch, BCT: Brachiocephalic truncus, LCC: Left common carotid artery, LV: Left vertebral artery

Type 4: Bovine arch with left vertebral artery variation

Type 5: Common origin of the right and left common carotid arteries

Type 6: Aberrant right subclavian artery

Type 7: Right-sided aortic arch variations

Any additional branching variations outside this classification were also identified and recorded. Observers resolved discrepancies by consensus. Interobserver and intraobserver agreement were evaluated using Cohen's kappa (κ) statistics. Interobserver agreement between the two evaluators was excellent (κ = 0.89). Intraobserver agreement across repeated assessments was also high (κ = 0.91). These findings indicate strong consistency and reliability in image interpretation.

Statistical Analysis

Statistical analyses were performed using the SPSS software package [version 23.0 for Windows (IBM Corp., Armonk, NY, USA)]. Continuous variables were expressed as mean ± standard deviation (SD) or median (interquartile range), as appropriate. Categorical variables were presented as frequencies and percentages. The Shapiro–Wilk test was used to assess the normality of data distribution. Differences in continuous variables between groups were analyzed using the independent-samples t-test or one-way analysis of variance (ANOVA), depending on data distribution. The chi-square test, or Fisher's exact test when appropriate, was used to evaluate the relationship between sex, age groups, and aortic arch branching variations.

Inter- and intraobserver agreement for branching classification used Cohen's kappa (κ): 0.81–1.00 = excellent, 0.61–0.80 = good, 0.41–0.60 = moderate, <0.40 = poor. Significance set at $p < 0.05$; analyses at 95% confidence.

Results

A total of 744 patients (334 females, 44.9% / 410 males, 55.1%) who met the inclusion criteria were included in the study. The mean age was 57.78 ± 17.92 years for females and 57.30 ± 18.78 years for males, with no statistically significant difference between genders ($p>0.05$).

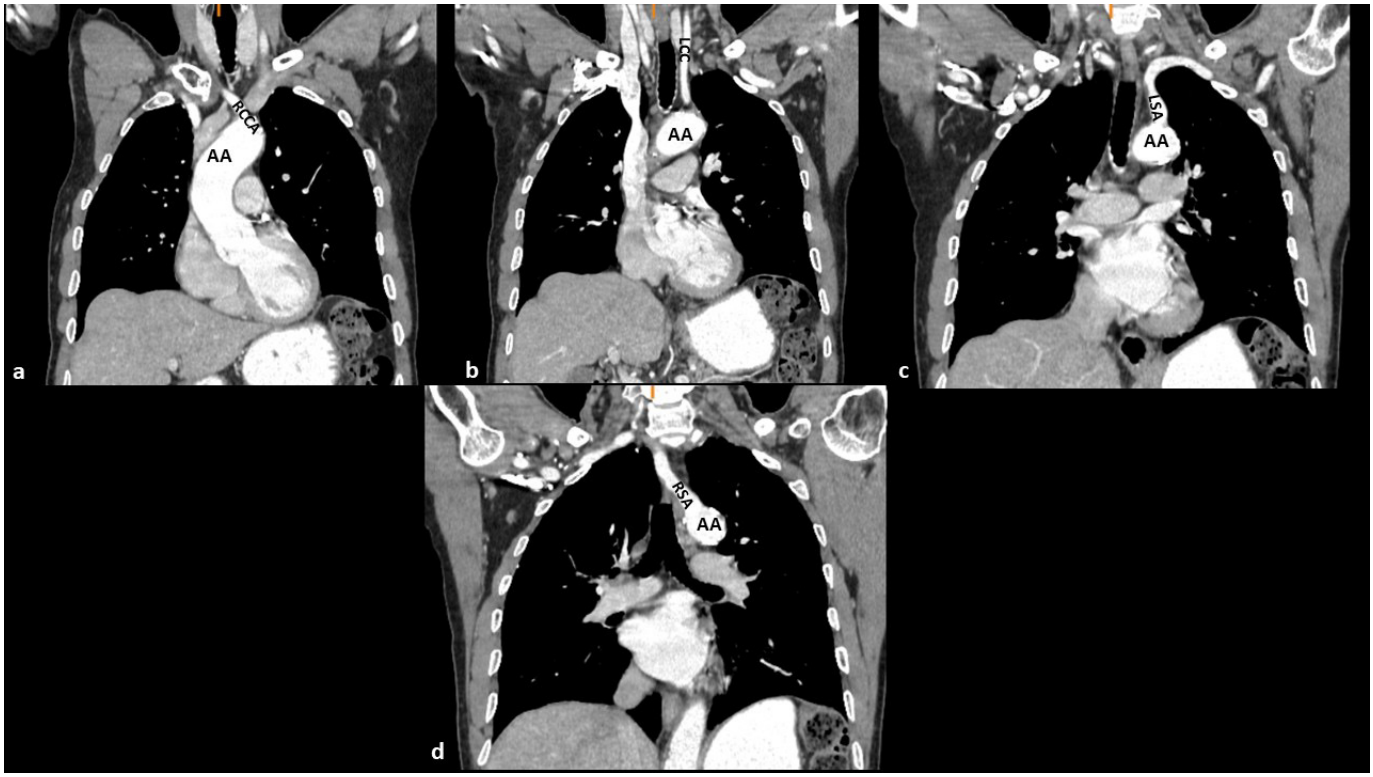


Figure 3. Coronal computed tomography angiography image shows a Type 6 aortic arch branching pattern. (a) AA: Aortic arch, BCT: Brachiocephalic truncus (b) AA: Aortic arch, LCC: Left common carotid artery (c) AA: Aortic arch, LSA: Left subclavian artery (d) AA: Aortic arch, RSA: Right subclavian artery

In the study sample, AA was most prevalent in Type 1 (normal) branching. Type 1 prevalence rates were 98.2%, 98.3%, and 98.3% in females, males, and the overall population, respectively.

Other branching variations encountered in the study were Type 2 (Fig. 1), Type 3 (Fig. 2), Type 6 (Fig. 3), and Type 7 (Fig. 4). The prevalence of these variations was 1.1% (n=8, female=3 / male=5), 0.3% (n=2, female=1 / male=1), 0.3% (n=2, female=1 / male=1), and 0.1% (n=1, female=1 / male=0), respectively. There was no statistically significant difference in the prevalence of branching variations between genders (T=1.477, p=0.836) (Table 1).

Discussion

Due to their role in blood supply to the head and neck, upper extremities, and anterior thoracic wall, AA variations are critical in regional surgery. Therefore, studies on AA variations using samples from different populations and geographic regions are available in the literature and remain relevant today.

In the literature, the highest prevalence of AA was reported in cadaveric (78.3%) and radiological (80.9%) studies, and it was found to be in Type-1 (normal) alignment (2). In studies conducted in Turkey, the prevalence of Type-1 was reported as 85.2% by Ergün et al. (7) and 76.12% by Açar et al. (8). Geographically, Type-1 was highest in Asia with 86.9% and lowest in South America with 69.5% (2). Nelson and Sparks (9) reported this rate as 94.3% in a Japanese-American sample. In our study, the prevalence of Type 1 was 98.3%. Although the result from the study is higher than those from the population and geographical studies in the meta-analysis, Nelson and Sparks (9) is similar to the rate reported.

In the literature, Type 2 (Bovine Arc) was determined to be the second most prevalent AA branching variation in both cadaver (14.4%) and radiological (13.1%) studies. Geographically, Type 2 was reported to be highest in African populations at 26.8% and lowest in Asian populations at 7.4% (2). Nelson and Sparks (9) reported a Type 2 prevalence of 1% in Japanese-American males, and Nizankowski et al. (10) reported a Type 2 prevalence of 0.9% in Polish males. In our study, the prevalence of Type 2 was 1.1%. This result is similar to that of Nelson and Sparks (2001)



Figure 4. Three-dimensional computed tomography angiography image shows a Type 7 right sided aortic arch. (a) anterior (b) posterior view. AA: Aortic arch, TA: Thoracic aorta, LCC: Left common carotid artery, RCC: Right common carotid artery, LSA: Left subclavian artery, RSA: Right subclavian artery

and Nizankowski et al. (10), but appears lower than that of other studies. Although infrequent, clinical symptoms associated with this variation have been reported and are primarily attributed to widening of the upper mediastinum (11). The Type 2 (Bovine Arc) variant of AA has been documented to make carotid stenting more difficult and risky by creating a narrow loop involving the CT and LCC arteries during stenting via the femoral approach. Furthermore, patients with the Type 2 pattern are more likely to require hemiarch replacement surgery for the treatment of AA conditions, including aortic dilatation, dissection, intramural hematoma, and aortic rupture (12).

In the literature, Type 3 (Left Vertebral) was determined to be the third most prevalent AA branching variation in both cadaveric (3.9%) and radiological (2.1%) studies. Geographically, Type 3 has been reported to be highest in the Middle East at 4% and lowest in North American populations at 1.9% (2). Natsis et al. (13) reported a Type 3 prevalence of 0.79% in Greece, and Nizankowski et al. (10) reported a prevalence of 1.3% in Poland. In our study, the prevalence of Type 3 was 0.3%. This result is similar to Natsis et al.'s, but indicates a lower prevalence of Type 3 in the study sample than in all other studies. The Type 3 pattern of AA is a variant that should be of particular focus for neurovascular interventionalists and neurosurgeons. Variations in aortic arch branching significantly influence the guidance and navigation of the guiding catheter to the target carotid system, particularly the common carotid artery (CCA), during mechanical thrombectomy procedures. The type 3 aortic arches often complicate femoral access, necessitating consideration of alternative approaches such as brachial access. Thoracocervical computed tomography angiography (CTA) enables pre-procedural assessment of aortic arch morphology and branching angles, supporting optimal device placement and associated with higher procedural success rates and shorter catheterization times. Additionally, thoracocervical CTA not only identifies the occluded vessel but also assesses the anatomical suitability of potential access routes, thereby aiding in selecting the most appropriate approach and facilitating catheter navigation (14). Vertebral artery injury is a well-known complication of extended lateral decompression during anterior cervical spine surgery, and Type 3 is of significant clinical importance because it can lead to blood loss and permanent neurological deficits (5). Radiologically, the vertebral artery can be mistakenly considered occluded or diseased when catheterization is avoided during angiography or when it remains outside the field of interest during

noninvasive studies such as CT angiography, MR angiography, or Doppler sonography (15, 16).

The prevalence of Type-6 (Aberrant RS) has been reported in the literature to be 1.0% in cadaver (1%) and 0.9% in radiological studies. Geographically, Type-6 has been reported to be highest in African populations at 1.4% and lowest in South American populations at 0.2% (2). The 0.3% Type-6 prevalence in our study falls within the range reported in the literature and is similar to that observed in South American population assessments. In the type 6 pattern, the laryngeal artery (RS) arises from the AA as the most distal artery and crosses the midline to reach the right side. It tends to course posterior to the esophagus, making it a retroesophageal RS (13). Although the type 6 pattern is usually asymptomatic, it can compress the esophagus and trachea, leading to dysphagia, cough, or shortness of breath (17). Esophageal compression on the RS can create a fistula, leading to lethal upper gastrointestinal bleeding (18). The type 6 pattern may be associated with changes in the course of the recurrent laryngeal nerve. In this condition, the right laryngeal nerve fails to form a loop around the RS, and this is called a "non-recurrent laryngeal nerve" (19).

In the literature, the prevalence of Type 7 (Right Arc) has been reported in cadaveric (0.3%) and radiological (0.2%) studies. Geographically, Type 7 has been reported to be highest in North America at 0.4% and lowest in European populations at 0.1% (2). In our study, the prevalence of Type 3 was 0.1%, within the range reported in the literature and consistent with that in European samples. Although Type 7 is quite rare, it has not been associated with any clinical presentation (13).

Conclusions

This study concluded that AA variants were rarely found in the study sample. Literature data and our findings demonstrate the need for specific evaluation of AA variants across samples from different populations and even within different geographic regions within those populations. Although they are often encountered asymptomatically and incidentally, we believe that knowledge of population prevalence differences will contribute to clinical and radiological assessments.

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Ethical Approval: Prior to initiating the study, approval was obtained from our institution's Non-Interventional Clinical Research Ethics Committee (Decision No: 2022-5/29).

Conflict of interest statement: There are no conflicts of interest for the writers to report.

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