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ORIGINAL ARTICLE

Morphological Analysis of the Aortic Arch Branching Patterns in Different Populations - A cross-section study

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ABSTRACT

Background: There is a considerable anatomical variability in the aortic arch branching pattern within the same population and across populations with important clinical and surgical implications. This is important to understand variation in vascular surgeries, endovascular interventions and diagnostic imaging procedures.

Aim: To evaluate and classify the morphological patterns of aortic arch branching in a sample of 100 patients of different ethnic background to determine the frequency of common and variant configurations.

Methodology: Contrast-enhanced computed tomography (CT) angiograms of 100 patients were utilized in a cross sectional study using contrast enhanced CT angiograms from a tertiary care hospital. People with congenital heart disease or who had had previous vascular surgery were excluded. Standard classifications of branching patterns were used to classify the branching patterns according to the classical three branch pattern, the bovine arch variant, and other less commonly reported types.

Results: Of 100 patients, 68% showed the classical branching pattern of the brachiocephalic trunk, left common carotid artery and left subclavian artery. Most common among subjects of African descent, 22% of patients had the bovine arch configuration. 6% had a rare aberrant right subclavian artery, 4% had other atypical branching patterns, such as double aortic arch, or common origin of carotid and subclavian arteries.

Conclusion: Significant population related variations of aortic arch branching is highlighted by the study. However, the classical pattern continues to prevail over the field, but there are significant variations such as bovine arch and aberrant right subclavian artery which should be taken into consideration during pre-surgical planning as well as diagnostic evaluation. Future studies on more diverse populations and larger populations will better illuminate the embryological and clinical significance of these patterns.

Keywords: Considerable Anatomical Variability, Tomography, Subclavian artery, Morphological patterns

INTRODUCTION

The aortic arch is a critical anatomical structure from which the head, neck, upper limbs and parts of the thorax receive their major arterial supply[9]. The branching pattern of the aortic arch is normally described as the three vessel configuration, namely brachiocephalic trunk (or innominate artery), left common carotid artery, and left subclavian artery[1]. Yet, various morphological variations have been described in different populations and ethnic groups with significant clinical and embryological implications. These variations are not incidental findings

because they can markedly affect surgical planning, endovascular interventions, and the interpretation of imaging studies[8].

The so called 'bovine arch' is an aortic arch anomaly, aberrant subclavian arteries, and common trunks of carotid arteries may be asymptomatic but are challenging during cardiovascular, thoracic or head and neck procedures[7]. Such as an unrecognized aberrant right subclavian artery can cause complications in esophageal surgeries, catheter based interventions and trans-radial access procedures[6]. Virtually, likewise, variations in the origin of the vertebral arteries may complicate cerebral perfusion and interventions for subclavian steal syndrome or aortic dissection[4].

These variations are embryological in basis and are related to the complex remodeling of the pharyngeal arch arteries during fetal development[2]. Diverse aortic arch patterns can occur from minor deviations in the regression or persistence of these embryonic vessels. Though highly conserved, these developmental pathways are regionally diverse, influenced by genetic, ethnic and perhaps environmental factors.

Several studies have explored the prevalence of aortic arch variants but most are limited to certain geographic areas or confined to small sample size[3]. In addition, most previous studies have only focused on radiological assessment without correlation of findings among different ethnic population[11]. As clinical environment becomes more and more globalized, it is essential to know anatomical variability in context of broader demographic contexts to enhance patient safety and surgical outcomes[15].

This is the reason why in this cross-sectional study, we were interested in investigating and classifying the morphological pattern of aortic arch branching in a representative sample of 100 patients of different ethnic background. We sought to quantify the prevalence of common and variant branching patterns and to describe their distribution among different demographic subgroups using high resolution contrast enhanced CT angiography[12].

This study helps to add to the growing literature of anatomical and clinical information about aortic arch variants that influences surgical planning, endovascular technique refinement, and personalized patient care by elucidating the frequency and types of aortic arch variants.

MATERIALS AND METHODS

Study Design:

It was a descriptive cross sectional study conducted at the department of radiology in a tertiary care teaching hospital for six months from June 2024 to November 2024. The purpose was to assess the morphological variations in aortic arch branching pattern using contrast enhanced computed tomography (CT) angiography in a representative population.

Sample Size and Population:

Using non-probability purposive sampling, 100 patients were finally selected. Adult patients between 18 and 75 years of age who underwent thoracic CT angiography for non-emergent clinical indications such as evaluation of chest pain, aortic aneurysm screening or staging of thoracic malignancies were included. Patients with congenital cardiovascular anomalies, previous cardiothoracic surgeries or non-diagnostic image quality due to motion artifacts were excluded in order to avoid confounding anatomical changes.

Ethical Approval:

The Institutional Review Board (IRB) from the affiliated hospital approved the study protocol. All participants gave written informed consent before imaging, thus adhering to the Declaration of Helsinki ethical guidelines.

Imaging Protocol:

All CT angiograms were obtained from a 128 slice multi-detector computed tomography (MDCT) scanner (Siemens SOMATOM Definition Edge). Slice thickness of 0.6 mm, pitch of 0.9 and 120 kVp tube voltage were used for scanning parameters. Intravenous administration of a non-ionic iodinated contrast medium (Iohexol, 350 mgI/mL) at a rate of 4.5–5.0 mL/s was made using a pressure injector with a 30 mL saline flush. Bolus tracking with the region of interest (ROI) placed over the ascending aorta and a predefined threshold of 100 HU was used for triggering image acquisition.

Image Reconstruction and Analysis:

Standard post processing software was used to reconstruct the acquired axial images in multiplanar reformats (MPR), maximum intensity projection (MIP), and volume rendered (VR) images. All scans were reviewed independently by two experienced radiologists (both >5 years of experience in vascular imaging) to identify and classify the aortic arch branching patterns. The discrepancies were resolved by consensus.

Classification Criteria:

Categorized branching patterns were based on previously published morphological classifications.

- **Type I (Peculiar pattern):** Brachiocephalic trunk and its branches arise from the back of the left common carotid artery, which is then separated to form left common carotid and left subclavian arteries.

- **Bovine arch:Type II** - Brachiocephalic trunk and left common carotid artery arise from a common origin.
- **Aberrant right subclavian artery (Type III):** Right subclavian artery arising distally from aortic arch.
- **Other variants:** Included left vertebral artery directly from the arch, common trunk for carotid and subclavian arteries, and double aortic arches.

Data Collection and Statistical Analysis:

Age, sex and ethnicity were recorded as demographic data. Each aortic arch variant was calculated for frequency and percentage. Chi-square tests were used to assess associations between branching pattern and demographic variables with a $p < 0.05$ statistically significant. SPSS version 26.0 was used for data analysis.

RESULTS

This study included a total of 100 patients, of which 58 were males and 42 were females. The participants were 45.6 ± 13.2 years (range 18–73 years) of age. The patients included South Asians, Middle Eastern, Africans and Central Asian origin. Table 1 shows the five major categories in which the aortic arch branching patterns observed were classified.

The frequency of the different aortic arch branching patterns in 100 patients is summarized in Table 1. The most common pattern, 68% of cases, was the classical three branch pattern (Type I). In 22% of patients, the bovine arch variant (Type II) and in 6% the aberrant right subclavian artery (Type III). Three percent of cases had a direct origin of the left vertebral artery from the arch (Type IV). Only 1% of the patients had a rare variant such as a double aortic arch (Type V). The anatomical diversity that is important in clinical and surgical procedures is emphasized by these variations (Table 1).

The distribution of aortic arch branching patterns in 100 patients is shown in Table 2 according to sex. In males (67.2%) and in females (69%) the classical pattern (Type I) was nearly equally common. Females (23.8%) were slightly more frequent in bovine arch (Type II) than males (20.7%). Type III (Aberrant Right Subclavian Artery) was seen more in females (9.5%) as compared to males (3.4%). Male patients (5.1%) with the left vertebral artery directly arising from the arch (Type IV) and variant such as double aortic arch (Type V) were found only. These findings suggest that aortic arch variants occur to a minor degree in different ways between sexes (Table 2).

Table 1: Distribution of Aortic Arch Branching Patterns in 100 Patients

Branching Pattern	Frequency (n)	Percentage (%)
Type I: Classical pattern (three separate branches)	68	68%
Type II: Bovine arch variant	22	22%
Type III: Aberrant right subclavian artery (ARSA)	6	6%
Type IV: Left vertebral artery directly from arch	3	3%
Type V: Double aortic arch / other rare variants	1	1%

Table 2: Aortic Arch Branching Patterns by Sex (n = 100)

Branching Pattern	Males (n = 58)	Females (n = 42)	Total (n = 100)
Type I: Classical pattern	39 (67.2%)	29 (69.0%)	68 (68%)
Type II: Bovine arch	12 (20.7%)	10 (23.8%)	22 (22%)
Type III: Aberrant right subclavian	2 (3.4%)	4 (9.5%)	6 (6%)
Type IV: Left vertebral from arch	3 (5.1%)	0 (0%)	3 (3%)
Type V: Double aortic arch / rare	2 (3.4%)	0 (0%)	2 (2%)

Table 3: Distribution of Aortic Arch Variants by Ethnicity

Branching Pattern	South Asian	Middle Eastern	African	Central Asian	Total
Type I: Classical	35	12	10	11	68
Type II: Bovine Arch	6	4	10	2	22
Type III: Aberrant Right Subclavian	1	1	3	1	6
Type IV: Left Vertebral from Arch	2	1	0	0	3
Type V: Rare Variants	1	0	0	1	2
Total Patients per Ethnic Group	45	18	23	14	100

Distribution of aortic arch branching variants among four ethnic groups is shown in table 3. Among all groups, South Asian (35 out of 45) and Central Asian (11 out of 14) exhibited most classical pattern (Type I) and were most common. A likely ethnic predilection was indicated by the fact that the bovine arch (Type II) was most common in

African patients (10 out of 23). All groups showed the aberrant right subclavian artery (Type III) but the incidence was slightly higher in Africans. Only South Asian and Middle Eastern patients had the left vertebral artery arising from the arch (Type IV). Type V variants were restricted to South Asian and Central Asian individuals. Ethnic variation in aortic arch anatomy was shown in these results with the potential for clinical significance in diagnosing and treating (Table 3).

DISCUSSION

This study was demonstrated demographic associations of morphological variability of aortic arch branching patterns among different populations. The classical aortic arch branching pattern is the most prevalent (68%) and was observed in 100 patients analyzed in a cross sectional analysis with contrast enhanced CT angiography but a large proportion of patients had anatomical variants which emphasizes the need to perform individualized anatomical assessment in clinical and surgical practice[13].

Over two thirds of the participants displayed the classical three branch pattern in which brachiocephalic trunk, left common carotid and left subclavian arteries arose independently from the aortic arch[11]. This is consistent with global literature, which reports this configuration in 65–80% of the population depending on geographic and ethnic composition. We find that the classical pattern was dominant in our South Asian subgroup (77.8%) and the high frequency of the classical pattern in this region makes our region a good reference standard for surgical planning anatomical expectation in this population[14].

Second most common was the bovine arch variant, in which the brachiocephalic and left common carotid arteries arose from a common origin (22%)[15]. This variant was notably found predominantly in African participants (43.4% of their subgroup) which is in agreement with studies suggesting higher prevalence of this configuration in subjects of African descent. As a clinical entity, the bovine arch has been associated with technical difficulties during aortic arch interventions with carotid stenting and thoracic endovascular aortic repair (TEVAR) secondary to the commingled vascular origin leading to altered hemodynamics and catheter navigation angles[10].

Well documented embryological variant, aberrant right subclavian artery (ARSA), occurs in 6% of patients, due to anomalous regression of the fourth right aortic arch. The most common location for the aberration is as the last branch from the aortic arch, course posterior to the trachea and esophagus, and presents with dysphagia lusoria[16]. Although patients were asymptomatic, this variation is important to recognize during procedures such as central venous catheterization, esophageal surgery, and transradial angiography to avoid iatrogenic injury[17].

The occurrence of the left vertebral artery directly from the aortic arch (3%) and double aortic arch or other rare variants (2%) underscores the embryological complexity of aortic development[18]. The vertebral artery, which normally originates from the subclavian artery, has a direct aortic origin which can affect posterior cerebral circulation and vertebrobasilar insufficiency during planning of neurovascular interventions. The clinical relevance of the double aortic arch variant in the pediatric population is significant as it is associated with respiratory and swallowing problems[19].

The differences were slight but noteworthy in sex. Only males had rare variants and a direct origin of the vertebral artery, while the prevalence of females with the aberrant right subclavian artery was slightly higher (9.5% vs. 3.4% in males). These observations, though not statistically significant in our sample, deserve to be more thoroughly explored in future larger studies to see if sex does influence vascular development[20].Another important point that ethnic diversity in our sample brought to light was anatomical distinctions. In South Asian and Central Asian patients the classical pattern was more common, in African patients the bovine arch was much more so. These results support that ethnicity affects aortic arch morphogenesis via genetic and epigenetic factors during embryologic development.

CONCLUSION

In summary, this study demonstrates that there is significant anatomical variability in aortic arch branching patterns with correlation to ethnicity and to a lesser extent, sex. These findings help fill in the growing knowledge of vascular anatomy in different populations and the importance of personalized anatomical knowledge for improving procedural safety and patient care. These variants will need to be further elucidated through future multicenter studies with larger sample sizes and genetic analyses to further elucidate their developmental mechanisms and clinical implications.

DECLARATION

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Authors contribution
Each author of this article fulfilled following Criteria of Authorship:

1. Conception and design of or acquisition of data or analysis and interpretation of data.
2. Drafting the manuscript or revising it critically for important intellectual content.
3. Final approval of the version for publication.

All authors agree to be responsible for all aspects of their research work.

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