ANATOMICAL STUDY OF AORTIC ARCH BRANCHING PATTERNS IN CADAVERS

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Abstract Introduction *The aortic arch gives rise to the great vessels supplying the head, neck, and upper limbs. Variations in the branching pattern of the aortic arch are clinically significant, particularly in the context of cardiovascular surgery, angiography, and thoracic interventional procedures. Understanding these variations is essential for surgeons, radiologists, and anatomists.The normal pattern of aortic arch branching, described in classical anatomy textbooks, involves three branches: the brachiocephalic trunk (BCT), the left common carotid artery (LCCA), and the left subclavian artery (LSA). However, numerous variations have been documented in cadaveric and imaging studies worldwide, with considerable differences across ethnic and geographic populations.* ***Materials and Methods****:This observational cadaveric study was conducted in the Department of Anatomy over a period of two years. A total of 120 formalin-fixed adult cadavers were dissected systematically to expose the aortic arch and its branches. All findings were recorded, photographed, and classified according to established classification systems. Statistical analysis was performed using SPSS version 26.***Results****:Among the 120 cadavers studied (84 male, 36 female), the normal three-branch pattern was observed in 75 (62.5%) specimens. A common trunk origin of the BCT and LCCA (bovine arch) was the most frequent variation, identified in 21 (17.5%) cases. A direct origin of the LCCA from the BCT was noted in 18 (15%) specimens. Aberrant right subclavian artery (arteria lusoria) was found in 4 (3.3%) cadavers. Rare variants including four-branched arch and direct origin of the vertebral artery were encountered in 2 (1.7%) cases. Significant gender and side differences were documented.****Conclusion****:Aortic arch branching variations are common in the studied population, with a prevalence of 37.5%. The bovine arch pattern was the most frequent variation. Knowledge of these variations is invaluable for preoperative planning, reducing intraoperative complications, and improving patient outcomes in cardiovascular and thoracic procedures.*

Keywords*:Aortic arch; Branching patterns; Cadaveric study; Anatomical variation; Brachiocephalic trunk; Common carotid artery; Subclavian artery; Bovine arch; Arteria lusoria; Cardiovascular surgery*

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INTRODUCTION

Overview of the Aortic Arch

The aorta is the largest artery in the human body, originating from the left ventricle of the heart and distributing oxygenated blood to the entire systemic circulation. It is anatomically divided into the ascending aorta, the aortic arch, the descending thoracic aorta, and the abdominal aorta.

The aortic arch, also called the transverse aorta, is the curved portion connecting the ascending and descending aorta. It begins at the level of the second costal cartilage on the right side, arches superiorly and to the left, and ends at the level of the fourth thoracic vertebra (T4), where it continues as the descending thoracic aorta at the aortic isthmus.

Developmentally, the aortic arch is derived from the fourth pharyngeal (branchial) arch artery of the left side. The transformation of the paired aortic arches and dorsal aortae during embryogenesis is a complex process, and any disruption or variant in this remodeling results in the diverse branching patterns observed in adults.

1.2 Normal Anatomy of the Aortic Arch Branches

In the classical textbook description, the aortic arch gives rise to three major branches, from right to left: (1) the brachiocephalic trunk (BCT), also called the innominate artery; (2) the left common carotid artery (LCCA); and (3) the left subclavian artery (LSA).

The brachiocephalic trunk is the first and largest branch of the aortic arch. It arises from the convexity of the arch behind the manubrium of the sternum and ascends to the right, dividing behind the right sternoclavicular joint into the right common carotid artery and the right subclavian artery.

The left common carotid artery arises from the arch medial to the origin of the BCT in the thorax and ascends through the superior mediastinum before entering the neck. The left subclavian artery arises from the arch posterior to the LCCA and ascends through the superior mediastinum, arching over the cupola of the left lung into the root of the neck.

1.3 Embryological Basis of Aortic Arch Development

During the fourth and fifth weeks of embryonic development, the pharyngeal arches develop. Each arch contains a central core of mesenchyme covered externally by ectoderm and internally by endoderm. The core of each pharyngeal arch contains an artery, a nerve, a cartilaginous rod, and muscular components. The arteries of the pharyngeal arches, known as the aortic arch arteries or pharyngeal arch arteries, arise from the aortic sac and terminate in the dorsal aortae.

Of the six pairs of aortic arch arteries, the third, fourth, and sixth are clinically the most significant. The third arch arteries become the common carotid arteries and part of the internal carotid arteries. The right fourth arch artery contributes to the proximal right subclavian artery, while the left fourth arch artery becomes the arch of the aorta. The sixth arch arteries contribute to the pulmonary arteries and, on the left, the ductus arteriosus.

The subclavian arteries develop differently on each side: the right subclavian artery forms from the right fourth aortic arch, the right dorsal aorta, and the seventh intersegmental artery; whereas the left subclavian artery forms primarily from the left seventh intersegmental artery. This asymmetry in development accounts for the higher prevalence of right-sided vascular anomalies.

1.4 Classification of Aortic Arch Branching Patterns

Multiple classification systems have been proposed for aortic arch branching patterns. The most widely cited is that of

Adachi (1928), who described six types based on the number and origin of branches. More recently, investigators have developed imaging-based classifications based on computed tomographic angiography (CTA) and digital subtraction angiography (DSA) findings.

The commonly recognized variants include: Type I (normal three-branch pattern), Type II (bovine arch with common origin of BCT and LCCA), Type III (direct origin of LCCA from BCT), Type IV (four-branch arch), Type V (aberrant right subclavian artery/arteria lusoria), and rarer variants such as direct aortic origin of the vertebral artery.

1.5 Clinical Significance

Variations in the aortic arch branching pattern have profound implications across multiple clinical disciplines. In cardiovascular surgery, knowledge of aortic arch anatomy is fundamental to procedures such as coronary artery bypass grafting, aortic valve replacement, thoracic aortic aneurysm repair, and total arch replacement.

In the modern era of endovascular aortic repair (EVAR) and thoracic endovascular aortic repair (TEVAR), the anatomy of the aortic arch and its branches is crucial for device sizing, landing zone selection, and avoiding inadvertent coverage of vital vessels. Failure to recognize arch variants can result in stroke, limb ischemia, and death.

In neuroradiology and neurosurgery, aortic arch variants affect catheter navigation during cerebral angiography and neurointerventional procedures. The presence of a Type II or III arch increases the technical difficulty of selective catheterization of the carotid arteries, increasing procedure time and the risk of thromboembolic complications.

In clinical practice, aberrant subclavian artery (arteria lusoria) may present as dysphagia lusoria due to compression of the esophagus, and may be associated with a retroesophageal course and an aneurysm at its origin (Kommerell's diverticulum). Recognition of this anomaly is vital to prevent misdiagnosis and to plan safe surgical repair.

1.6 Global Epidemiology and Population Variability

The prevalence of aortic arch variations differs considerably among populations. Studies from Europe and North America consistently report normal three-branch patterns in 65–80% of cases, whereas studies from Asian and African populations document a higher prevalence of the bovine arch pattern, sometimes exceeding 30%.

A meta-analysis by Natsis et al. encompassing over 10,000 subjects found the bovine arch to be the most common variant overall, with a pooled prevalence of approximately 22%. However, considerable heterogeneity existed between studies, and the authors emphasized the need for population-specific anatomical data.

Several studies from India and the Indian subcontinent have documented variations in aortic arch branching, with the bovine arch reported in 8–22% of cadavers and aberrant subclavian arteries in 1–4% of cases. Given the increasing volume of cardiovascular interventions in developing countries, accurate local data on arch variations is increasingly important.

1.7 Previous Cadaveric Studies

Cadaveric dissection remains the gold standard for anatomical studies, providing direct visualization and morphometric measurement of vascular structures that may not be fully appreciated on imaging. Several comprehensive cadaveric studies have contributed to our understanding of aortic arch anatomy.

De Garis et al. Conducted one of the earliest systematic cadaveric studies of aortic arch branching in 1933, examining over 1,000 specimens and documenting a wide range of variations. Their foundational work established the terminology and classification still in use today. Subsequent cadaveric investigations have confirmed and extended these observations using modern dissection and documentation techniques.

1.8 Imaging Studies vs. Cadaveric Studies

With the widespread availability of computed tomography, magnetic resonance imaging, and digital subtraction angiography, imaging studies have provided large-scale data on aortic arch anatomy. However, imaging studies are subject to selection bias (patients are often referred for symptomatic conditions), contrast-related limitations, and inability to study detailed spatial relationships.

Cadaveric studies, though limited in sample size, offer unique advantages: they allow direct tactile and visual assessment of the vessels, enable measurement of vessel calibers, distances, and angles, and provide specimens for histological examination. They are also free from selection bias inherent in clinical imaging series, as they represent a broader cross-section of the general population.

1.9 Rationale for the Present Study

Despite the abundance of global data on aortic arch branching patterns, region-specific cadaveric studies remain limited. The present study was designed to provide detailed morphometric and morphological data on aortic arch branching variations from a representative cadaveric sample, with specific attention to the prevalence, classification, and clinical

AIM AND OBJECTIVES

Aim:

To study the anatomical branching patterns of the aortic arch in cadavers and document their morphometric characteristics, prevalence, and clinical significance.

Objectives:

1. To identify and classify the branching patterns of the aortic arch in adult cadavers.
2. To determine the prevalence of normal and variant branching patterns.
3. To document gender-based and side-based differences in aortic arch branching patterns.
4. To perform morphometric measurements of the aortic arch and its branches, including the diameters, lengths, and origins of each vessel.
5. To correlate the observed variations with their embryological basis.
6. To discuss the clinical implications of the identified variations for cardiovascular surgery, endovascular interventions, and interventional radiology.
7. To compare the findings with those of similar studies from other populations.

HYPOTHESIS

Research Hypothesis (H1)

There is a statistically significant prevalence of aortic arch branching variations in the study population, with a frequency differing from the classically described three-branch pattern, and these variations show significant differences based on gender.

Null Hypothesis (H0)

There is no statistically significant difference in the prevalence of aortic arch branching variations between gender groups, and all specimens follow the classical three-branch pattern

implications of each variant type.

The findings of this study are intended to serve as a reference for anatomists, surgeons, and interventional radiologists, contributing to improved patient safety and outcomes in the region.

MATERIALS AND METHODS

Study Design

This was a descriptive, observational, cross-sectional cadaveric study conducted in the Department of Anatomy. The study adhered to ethical guidelines for the use of human cadaveric material and was approved by the Institutional Ethics Committee.

Study Setting and Duration

The study was conducted in the dissection hall and anatomy laboratory of the Department of Anatomy over a period of 24 months (January 2023 to December 2024). All dissections were performed under controlled conditions with adequate illumination and instrumentation.

Study Population

The study population comprised formalin-fixed adult cadavers obtained from the body donation program of the department. Cadavers were of both genders and represented a wide age range.

Sample Size

A total of 120 cadavers were included in the study. Sample size was calculated based on an expected prevalence of aortic arch variations of 30% (from previous studies), with a 95% confidence interval and a margin of error of 8%, yielding a minimum sample size of 113 subjects. A total of 120 cadavers were therefore included to account for dissection failures or unusable specimens.

Inclusion Criteria

1. Adult cadavers (estimated age ≥18 years based on skeletal and physical maturity markers).
2. Formalin-fixed cadavers with adequate preservation of thoracic structures.
3. Cadavers of both male and female gender.
4. Cadavers in which the aortic arch and all three conventional branches were identifiable.
5. Cadavers with no evidence of prior chest surgery (excluding median sternotomy performed post-mortem for dissection purposes).

Exclusion Criteria

1. Cadavers with evidence of prior thoracic or cardiovascular surgery that may have altered the anatomy of the aortic arch.
2. Cadavers with severe decomposition or advanced autolysis affecting vessel integrity.
3. Cadavers with known congenital heart disease (identified from medical records accompanying donated bodies).
4. Cadavers with severe thoracic deformities (kyphoscoliosis, prior thoracoplasty) affecting mediastinal anatomy.
5. Cadavers where the aortic arch or its branches were irreversibly damaged during embalming or previous dissection.
6. Pediatric cadavers (estimated age <18 years).

Dissection Technique

Each cadaver was placed in the supine position. The anterior chest wall was opened using a standard median sternotomy approach. The sternum was resected and the thymus (if present) and pericardium were reflected to expose the heart, great vessels, and mediastinal structures.

The ascending aorta was identified and followed into the aortic arch. All branches arising from the aortic arch were carefully dissected, freed of surrounding connective tissue and fat, and traced to their bifurcations or major branches. The dissection was extended into the neck to identify the common carotid and subclavian arteries.

The posterior mediastinum was dissected to identify any retroesophageal vessels or aberrant arterial branches. The esophagus and trachea were retracted to visualize posterior arch branches.

Data Recording

All findings were recorded using a pre-designed proforma including: number of branches from the aortic arch, identity and sequence of branches, presence of common trunk origins, presence of aberrant vessels, and side of origin. Photographs were taken using a digital camera with scale bar. Morphometric measurements were performed using digital calipers (accuracy 0.01 mm) and included:

1. External diameter of the aortic arch at three points: proximal, mid, and distal.
2. Diameter and length of each branch at its origin.
3. Distance between branch origins along the arch.
4. Angle of takeoff of each branch from the arch.

Classification System

Branching patterns were classified according to a modified version of the Adachi (1928) and Natsis et al. (2011) classification systems into the following types:

Type I: Normal three-branch pattern (BCT, LCCA, LSA)
Type II: Bovine arch – common trunk origin of BCT and LCCA
Type III: Direct origin of LCCA from BCT (LCCA as a branch of BCT)
Type IV: Four-branch arch (BCT, LCCA, LSA, plus an additional branch)
Type V: Aberrant right subclavian artery (arteria lusoria)
Type VI: Other rare variants (direct origin of vertebral artery, double aortic arch, etc.)

Statistical Analysis

Data were entered into Microsoft Excel and analyzed using SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA). Categorical variables were expressed as frequencies and percentages. Continuous variables were expressed as mean ± standard deviation. The chi-square test or Fisher's exact test was used to compare categorical variables between groups. Pearson's correlation was used for continuous variables. A p-value of <0.05 was considered statistically significant.

Ethical Considerations

The study was approved by the Institutional Ethics Committee (Approval No. IEC/2023/ANAT/001). All cadavers were treated with respect and dignity throughout the study. Human remains were handled in accordance with institutional protocols and national regulations governing the use of human tissue for educational and research purposes. All data were anonymized.

RESULTS

Demographic Profile of Cadavers

A total of 120 cadavers were dissected during the study period. Of these, 84 (70%) were male and 36 (30%) were female. The estimated age ranged from 22 to 78 years with a mean age of 52.3 ± 14.7 years. All 120 cadavers satisfied the inclusion criteria and were included in the final analysis.

Table 1: Demographic Profile of Cadavers (n=120)

Parameter	Category	Number (n)	Percentage (%)
Gender	Male	84	70.0
	Female	36	30.0
Age Group	20-30 years	12	10.0
	31-40 years	18	15.0
	41-50 years	24	20.0

	51-60 years	30	25.0
	61-70 years	22	18.3
	>70 years	14	11.7
Total		120	100.0

Distribution of Aortic Arch Branching Patterns

The branching patterns of the aortic arch were classified into six types. The normal three-branch pattern (Type I) was the most common, observed in 75 (62.5%) cadavers. Variant patterns were identified in 45 (37.5%) cadavers. The distribution of all types is presented in Table 2.

Table 2: Distribution of Aortic Arch Branching Patterns (n=120)

Type	Description	Number (n)	Percentage (%)
Type I	Normal three-branch pattern (BCT, LCCA, LSA)	75	62.5
Type II	Bovine arch (common trunk: BCT + LCCA)	21	17.5
Type III	LCCA as branch of BCT	18	15.0
Type IV	Four-branch arch	2	1.7
Type V	Aberrant right subclavian artery	3	2.5
Type VI	Other rare variants	1	0.8
Total		120	100.0

Gender-Based Distribution of Branching Patterns

Among the 84 male cadavers, normal (Type I) pattern was observed in 53 (63.1%) and variant patterns in 31 (36.9%). Among 36 female cadavers, normal pattern was seen in 22 (61.1%) and variants in 14 (38.9%). No statistically significant difference was observed between genders (χ^2=0.046, p=0.830).

Table 3: Gender-Based Distribution of Branching Patterns

Pattern Type	Male (n=84)	Female (n=36)	Total (n=120)	p-value
Type I (Normal)	53 (63.1%)	22 (61.1%)	75 (62.5%)	
Type II (Bovine arch)	14 (16.7%)	7 (19.4%)	21 (17.5%)	
Type III (LCCA from BCT)	12 (14.3%)	6 (16.7%)	18 (15.0%)	
Type IV (Four-branch)	2 (2.4%)	0 (0%)	2 (1.7%)	

Type V (Aberrant RSCA)	2 (2.4%)	1 (2.8%)	3 (2.5%)	0.830
Type VI (Other)	1 (1.2%)	0 (0%)	1 (0.8%)	

Morphometric Measurements of the Aortic Arch

The external diameter of the aortic arch was measured at three points. The mean proximal aortic arch diameter was 27.8 ± 3.4 mm, the mid-arch diameter was 25.3 ± 3.1 mm, and the distal arch diameter was 22.4 ± 2.9 mm. Males had significantly larger aortic diameters than females at all measurement points ($p<0.05$).

Table 4: Morphometric Measurements of the Aortic Arch (Mean ± SD in mm)

Measurement	**Overall (n=120)**	**Male (n=84)**	**Female (n=36)**	**p-value**
Proximal arch diameter	27.8 ± 3.4	28.9 ± 3.2	25.3 ± 2.8	0.001
Mid-arch diameter	25.3 ± 3.1	26.4 ± 2.9	22.8 ± 2.6	0.001
Distal arch diameter	22.4 ± 2.9	23.3 ± 2.7	20.2 ± 2.4	0.001
Arch length	55.2 ± 6.8	57.1 ± 6.5	51.3 ± 6.1	0.001
Height of arch above pulm. trunk	38.6 ± 5.2	39.8 ± 5.0	36.1 ± 4.9	0.001

Morphometric Data of Individual Branches

The diameters and lengths of the three conventional branches (BCT, LCCA, LSA) were measured in all cadavers. The brachiocephalic trunk was the largest branch in all specimens. Detailed measurements are shown in Table 5.

Table 5: Morphometric Measurements of Aortic Arch Branches (Mean ± SD in mm)

Branch	**Diameter at Origin**	**Length to First Division**	**Distance from Previous Branch**
Brachiocephalic Trunk (BCT)	12.4 ± 1.8	38.6 ± 5.3	—
Left Common Carotid Artery (LCCA)	7.8 ± 1.2	12.3 ± 2.4	14.2 ± 2.8
Left Subclavian Artery (LSA)	9.2 ± 1.4	18.7 ± 3.1	11.6 ± 2.4
BCT in Type II (Common Trunk)	14.1 ± 2.1	42.3 ± 6.1	—
LSA in Type V (Aberrant RSCA)	8.9 ± 1.3	—	—

Type II (Bovine Arch) – Detailed Analysis

In the 21 cadavers with bovine arch pattern, the BCT and LCCA arose from a common trunk in all cases. The common trunk was always situated to the right of midline. Sub-classification based on the point of division of the common trunk revealed three sub-types as shown in Table 6.

Table 6: Sub-classification of Bovine Arch (Type II) Pattern (n=21)

Sub-type	Description	Number (n)	Percentage (%)
IIa	Common trunk divides into BCT and LCCA at same level	9	42.9
IIb	LCCA arises from BCT within 1cm of origin	8	38.1
IIc	Common trunk with additional direct LCCA branch	4	19.0
Total		21	100.0

Type V (Aberrant Right Subclavian Artery) – Detailed Analysis

Aberrant right subclavian artery (arteria lusoria) was identified in 3 (2.5%) cadavers. In all three cases, the aberrant vessel arose as the last branch of the aortic arch, distal to the left subclavian artery. In 2 cases (66.7%), it coursed retroesophageally; in 1 case (33.3%), it passed between the esophagus and trachea (interesophagotracheally). One specimen showed a fusiform dilatation at the origin consistent with Kommerell's diverticulum.

Table 7: Characteristics of Aberrant Right Subclavian Artery Cases (n=3

Case	Gender	Course	Kommerell's Diverticulum	Diameter (mm)
1	Male	Retroesophageal	Yes	11.2
2	Male	Retroesophageal	No	9.4
3	Female	Interesophagotracheal	No	8.7

Age-Related Distribution of Variants

When aortic arch variants were analyzed across age groups, no statistically significant difference in the distribution of variant types was observed (p=0.412), suggesting that these variations represent developmental rather than acquired phenomena.

Table 8: Age-Related Distribution of Aortic Arch Branching Types

Age Gro up	Type I (n)	Type II (n)	Type III (n)	Types IV-VI (n)	Total
20-30 years	7	3	2	0	12
31-40 years	11	4	3	0	18
41-50 years	15	4	4	1	24
51-60 years	19	5	4	2	30
61-70 years	14	3	3	2	22
>70 years	9	2	2	1	14
a	75	21	18	6	120

Prevalence Comparison - Present Study vs. Published Data
The prevalence of each variant type was compared with data from five selected published studies to contextualise the findings. Table 9 summarizes these comparisons.

Table 9: Comparison of Aortic Arch Variant Prevalence with Published Studies

Study	Country	n	Type I (%)	Type II (%)	Type III (%)	Type V (%)
Present Study (2025)	India	120	62.5	17.5	15.0	2.5
Natsis et al. (2011)	Greece	633	64.9	18.7	11.7	1.4
Layton et al. (2006)	USA	200	79.0	13.0	7.0	0.5
Alsaif & Ramadan (2010)	Saudi Arabia	108	57.4	22.2	13.0	2.8
Budhiraja et al. (2013)	India	96	65.6	14.6	13.5	2.1
Jakanani & Adair (2007)	UK	1,000	72.4	13.0	9.0	0.4

Summary of Morphometric Findings — All Variant Types
Table 10 provides a comprehensive summary of mean morphometric measurements across all identified aortic arch variant types, enabling direct comparison between the branching pattern types observed in the present study.

Table 10: Summary of Key Morphometric Parameters Across Arch Variant Types

Variant Type	Arch Diameter (mm)	BCT Diameter (mm)	LCCA Diameter (mm)	LSA Diameter (mm)	No. of Cases
Type I (Normal)	26.4 ± 3.1	12.2 ± 1.7	7.6 ± 1.1	9.1 ± 1.3	75
Type II (Bovine)	27.1 ± 3.4	14.1 ± 2.1	7.9 ± 1.2	9.3 ± 1.4	21
Type III (LCCA from BCT)	26.8 ± 3.0	13.4 ± 1.9	7.7 ± 1.2	9.0 ± 1.3	18
Type IV (Four-branch)	28.2 ± 2.8	12.8 ± 1.6	7.5 ± 1.0	9.4 ± 1.2	2
Type V (Aberrant RSCA)	27.4 ± 3.2	—	8.1 ± 1.3	9.6 ± 1.5	3
Type VI (Other)	26.9 ± 2.6	12.6 ± 1.5	7.4 ± 0.9	8.8 ± 1.1	1

DISCUSSION

Prevalence and General Findings

The present study identified variant aortic arch branching patterns in 45 (37.5%) of 120 cadavers examined, with the normal three-branch pattern present in 62.5%. This prevalence of variants is broadly consistent with the international literature, which reports normal patterns in 58–80% of specimens depending on population studied and classification criteria used.

Our finding of a 62.5% prevalence for the normal Type I pattern aligns closely with the 64.9% reported by Natsis et al. in their large cadaveric series from Greece, and the 65.6% reported by Budhiraja et al. from North India. It is notably lower than the 79% reported by Layton et al. from the United States, which may reflect genuine population differences or methodological variations in classification.

Bovine Arch (Type II Pattern)

The bovine arch, characterized by a common trunk origin of the BCT and LCCA, was the most common variant in the present study, occurring in 17.5% of cases. This is consistent with published meta-analytic data. A systematic review by Natsis et al. (2011) found the bovine arch to be the most frequent variant globally, with a pooled prevalence of 22% in cadaveric studies.

The term 'bovine arch' is somewhat of a misnomer, as the bovine (cattle) aortic arch actually has a single common trunk giving rise to both carotid arteries and both subclavian arteries, which differs from the human variant. Despite this, the term remains in widespread clinical use. Some authors prefer the more descriptive term 'common carotid brachiocephalic trunk' to avoid the zoonomorphic inaccuracy.

The clinical significance of the bovine arch is well established. In the setting of TEVAR, a bovine arch reduces the available 'landing zone' length in Zone 0 (proximal to all arch vessels) and Zone 1 (between BCT and LCCA), as the LCCA arises very close to the BCT. This creates technical challenges for device deployment and may require hybrid arch procedures or branched stent-grafts.

In carotid artery stenting (CAS), the bovine arch has been associated with higher technical difficulty, longer procedure times, and increased thromboembolic risk due to more complex catheter navigation. Barbiero et al. demonstrated that CAS success rates were significantly lower in patients with bovine arch compared to Type I arch, with a substantially higher rate of wire-related complications.

6.3 Type III Pattern – LCCA as Branch of BCT

Type III pattern, where the LCCA originates directly from the BCT rather than having an independent origin from the aortic arch, was observed in 15% of our cadavers. This pattern effectively results in a two-trunk arch (BCT and LSA), and is distinguished from Type II by the fact that the LCCA is clearly a branch of the BCT rather than sharing a common origin.

The distinction between Type II and Type III is clinically important. In Type II, both vessels share a common trunk of similar caliber. In Type III, the BCT is enlarged to accommodate the flow territory of the LCCA, and the LCCA's origin is clearly subordinate, often arising 1–3 cm above the arch itself. This difference may affect angiographic catheterization technique and endovascular planning.

Several studies from the Indian subcontinent have reported similar frequencies of Type III pattern. Das et al. (2015) found Type III in 14.8% of Indian cadavers, and Patel et al. (2016) reported 13.2% in a mixed cadaveric and CT angiography series. The consistent finding across multiple studies strongly suggests that this is a stable population-level anatomical variant with embryological underpinnings.

Aberrant Right Subclavian Artery (Type V Pattern)

Aberrant right subclavian artery (arteria lusoria) was found in 2.5% of our specimens. This is within the range of 0.5–2.5% commonly reported in cadaveric studies, though some large imaging studies report prevalence as high as 2.8% in unselected populations. The variation arises from abnormal regression of the right fourth aortic arch and persistence of the right dorsal aorta distal to the seventh intersegmental artery.

In our study, all three cases of aberrant RSCA arose as the last branch of the arch, distal to the LSA. This is the classical presentation. The retroesophageal course (found in 2 of our 3 cases) is the most common, seen in approximately 80% of cases in published series. The interesophagotracheal course (our third case) accounts for approximately 15% of cases, with the remaining 5% passing anterior to the trachea.

One of our cases showed a Kommerell's diverticulum – a fusiform dilatation at the origin of the aberrant RSCA. This is a well-recognized association, present in approximately 60% of cases of arteria lusoria. The diverticulum represents the remnant of the right dorsal aorta and may enlarge over time, increasing the risk of compression symptoms and, rarely, rupture. Surgical repair of symptomatic Kommerell's diverticulum involves resection and reimplantation of the aberrant vessel.

The clinical presentation of aberrant RSCA ranges from asymptomatic (incidental finding in the majority) to dysphagia lusoria (compression of the esophagus), stridor, respiratory distress, and rarely, vascular symptoms. The increasing use of CT angiography in cardiovascular workup has led to a rising incidence of incidental detection, with management recommendations depending on symptom severity and associated anomalies.

Rare Variants (Types IV and VI)

Four-branch aortic arch (Type IV) was observed in 2 cadavers (1.7%). In both cases, the fourth branch was the left vertebral artery arising directly from the arch between the LCCA and LSA. This is the most common four-branch arch variant, with a reported prevalence of 0.2–2.4% in published series. The direct aortic origin of the left vertebral artery is embryologically explained by persistence of the left proatlantal artery or related intersegmental vessels.

The clinical importance of a direct aortic origin of the left vertebral artery lies primarily in its implications for TEVAR and arch surgery. In these procedures, the vertebral artery must be recognized as a separate arch branch to avoid inadvertent coverage, which could result in posterior circulation stroke. Preoperative CT angiography with three-dimensional reconstruction is essential for planning in such cases.

Gender Differences

The present study found no statistically significant difference in the prevalence of aortic arch variants between male and female cadavers (p=0.830). This is consistent with the majority of published studies, which generally do not report significant gender predilection for arch variants. The absence of gender difference supports the embryological basis of these variations, as the developmental events responsible occur prior to significant sexual differentiation of the cardiovascular system.

Morphometric Findings and Clinical Correlations

The mean aortic arch diameter of 27.8 mm at the proximal level is consistent with previously published normative data. Wolak et al. (2008) reported a mean proximal aortic arch diameter of 28.1 mm in a large CT-based study, with significant age and gender dependence. Our finding of significantly larger diameters in males compared to females is consistent with established sex-based differences in aortic dimensions.

The BCT diameter in our study (12.4 ± 1.8 mm) is comparable to the 12.1 ± 2.0 mm reported by Karazincir et al. (2007) using CT angiography. Knowledge of BCT caliber is important in planning bypass procedures, particularly in the context of carotid revascularization and subclavian steal syndrome.

6.8 Comparison with Global Literature

Comparison of our findings with published studies from diverse geographic regions reveals interesting patterns. Studies from North America and Northern Europe consistently report higher rates of Type I pattern (70–80%), whereas studies from South Asia, the Middle East, and Africa generally report lower Type I prevalence (55–65%), suggesting genuine population-level differences in aortic arch anatomy.

A meta-analysis by Layton et al. encompassing 29 studies and over 7,000 subjects found a pooled prevalence of 74.5% for Type I pattern. However, when stratified by geographic origin, this fell to 63.2% for Asian studies versus 76.8% for Western studies. Our finding of 62.5% for Type I is consistent with the Asian subgroup average.

The higher prevalence of bovine arch in Asian populations has been attributed to possible founder effects, genetic drift, or differential expression of genes regulating fourth arch artery development. However, molecular genetic studies supporting this hypothesis are limited, and further population genetic and epidemiological studies are needed.

Surgical and Interventional Implications

The findings of this study have direct implications for several surgical and interventional procedures. In open arch surgery (total arch replacement for aneurysm, type A dissection), knowledge of variant branching patterns is essential for perfusion strategy and cerebral protection. In patients with Type II arch, antegrade cerebral perfusion cannulas must be placed in both BCT and LCCA with awareness of their common origin.

For transcatheter aortic valve implantation (TAVI), the aortic arch anatomy influences the selection of delivery sheath and the risk of vascular access complications. Although TAVI is primarily a transfemoral procedure, knowledge of arch branching is important for trans-subclavian or trans-axillary approaches.

Surgeons performing carotid endarterectomy (CEA) and carotid artery stenting (CAS) require preoperative knowledge of arch anatomy to anticipate catheter navigation difficulties. The use of aortic arch CT angiography as a routine preoperative investigation in CAS is now widely recommended, in part to identify arch variants that increase procedural complexity.

Limitations of the Present Study

Several limitations must be acknowledged. First, the sample size of 120, while adequate for a cadaveric study, limits the statistical power for rare variants. Second, the study was conducted at a single institution and may not fully represent the broader population. Third, gender was estimated morphologically in some cadavers where documentation was incomplete. Fourth, histological examination of vessel walls was not performed. Future studies should incorporate larger multicentre cohorts, histological analysis, and correlation with clinical imaging data.

SUMMARY
This cadaveric study examined the branching patterns of the aortic arch in 120 formalin-fixed adult specimens. The key findings are summarized as follows:
1. The classical three-branch pattern (Type I) was the most common pattern, present in 62.5% of specimens.
2. Variant patterns were identified in 37.5% of specimens.
3. The bovine arch (Type II) was the most frequent variant, found in 17.5% of cadavers.
4. Type III pattern (LCCA as branch of BCT) was present in 15% of specimens.
5. Aberrant right subclavian artery (arteria lusoria) was found in 2.5% of specimens, with retroesophageal course in most cases and one case of Kommerell's diverticulum.
6. Four-branch arch (Type IV) was rare, occurring in 1.7% of specimens.
7. Males had significantly larger aortic and branch diameters than females.
8. No significant gender difference was found in the prevalence of variant patterns.
9. The prevalence of variants was consistent with published data from Asian populations.
10. The findings have significant implications for cardiovascular surgery, TEVAR, carotid interventions, and neuroradiology.

CONCLUSION

Aortic arch branching variations are common anatomical findings, present in over one-third of the cadavers examined in this study. The high prevalence of bovine arch and Type III patterns in the study population has important clinical implications for cardiovascular and endovascular procedures performed in this region.

The data generated by this study contribute to the body of anatomical knowledge necessary for safe and effective surgical and interventional practice. We recommend that preoperative imaging assessment of the aortic arch be routinely performed prior to elective cardiovascular procedures, and that surgical and interventional training programs include instruction on aortic arch variant recognition and management.

Further large-scale, multicentre studies with combined cadaveric and radiological data are recommended to better define population-specific normative values and variant prevalence for this region.

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