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A Cadaveric Study of Variations in Branching Pattern of the Arch of Aorta and its Clinical Significance

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Abstract

Background: The arch of aorta is a major arterial structure supplying the head, neck, and upper limbs. Although the classical branching pattern consists of the brachiocephalic trunk, left common carotid artery, and left subclavian artery, several anatomical variations are frequently encountered. Knowledge of these variations is essential for anatomists, radiologists, cardiothoracic surgeons, and vascular interventionists.

Aim: To study the variations in the branching pattern of the arch of aorta and evaluate their anatomical and clinical significance in adult human cadavers.

Materials and Methods: A descriptive cross-sectional cadaveric study was conducted in the Department of Anatomy, Pacific Institute of Medical Sciences (PIMS), Umarda, Udaipur, Rajasthan, during 2022–2023. Eighty formalin-embalmed adult human cadavers were examined following standard dissection techniques described in Cunningham's Manual of Practical Anatomy. The branching pattern of the aortic arch, origin and arrangement of branches, and morphometric parameters including branch diameter and inter-branch distances were recorded. Data were analyzed using SPSS software. Descriptive statistics were calculated, and the Chi-square test and Student's t-test were applied where appropriate. A p-value <0.05 was considered statistically significant.

Results: The classical three-branch pattern was observed in 66 (82.5%) specimens. Variations were identified in 14 (17.5%) specimens. The most common variation was the bovine arch pattern in 10 (12.5%) cases, followed by direct origin of the left vertebral artery from the aortic arch in 2 (2.5%) cases and a common trunk associated with the left vertebral artery in 2 (2.5%) cases. Male cadavers constituted 51.25% and female cadavers 48.75% of the study population. The observed frequency of branching patterns was comparable with previous anatomical studies.

Conclusion: The classical three-branch pattern was the predominant configuration of the aortic arch; however, clinically significant variations were present in nearly one-fifth of specimens. Awareness of these anatomical variations is essential for accurate radiological interpretation and safe performance of cardiothoracic, vascular, and endovascular procedures. The findings provide valuable regional anatomical data that may improve surgical planning and reduce procedural complications.

Keywords: Arch of aorta, Branching pattern, Cadaveric study, Bovine arch, Left vertebral artery, Anatomical variation, Clinical significance.

Introduction

The aorta is the principal arterial trunk of the systemic circulation and serves as the main conduit for oxygenated blood from the left ventricle to the entire body. The arch of aorta represents the transitional segment between the ascending and descending thoracic aorta. It is anatomically located in the superior mediastinum, extending from the level of the second right sternocostal joint to the lower border of the fourth thoracic vertebra. Classically, the arch of aorta gives rise to three branches in a right-to-left sequence: the brachiocephalic trunk, the left common carotid artery, and the left subclavian artery[1].

These supra-aortic branches supply the head, neck, brain, and upper limbs, making the arch of aorta a structure of profound anatomical and clinical importance.

Although the classical three-branch configuration is considered the normal anatomical pattern, multiple anatomical and radiological studies have demonstrated considerable variation in the branching pattern of the arch of aorta[2]. These variations may involve changes in the number of branches, the origin of vessels, common trunks, aberrant vessels, or altered spatial relationships. The prevalence of the classical branching pattern varies across populations, ranging from 61% to 92% according to systematic reviews[2].

Such wide variation indicates strong ethnic, genetic, and possibly environmental influences on vascular development.

Cadaveric studies conducted in different regions of India have reported the classical three-branch pattern in approximately 73–76% of specimens[3,4].

This implies that nearly one-fourth of individuals may exhibit some form of variation. Naik et al.[3], in their cadaveric study on the South Indian population, documented variations in about 27% of cases, with the most common being a common trunk for the brachiocephalic trunk and left common carotid artery. Similarly, studies from central India[4] reported variant branching patterns in approximately 24% of cadavers.

One of the most frequently encountered variations is the so-called “bovine arch” configuration. In this variation, the brachiocephalic trunk and the left common carotid artery share a common origin from the arch of aorta. Despite the term “bovine arch,” this configuration differs from the true bovine anatomy and is simply a descriptive term used in human vascular anatomy[2]. The prevalence of this configuration ranges from 4% to 31% depending on the population studied[2,5].

A meta-analysis by Popieluszko et al.[5] confirmed significant geographical differences in the incidence of bovine arch variants. This variation has practical implications during carotid interventions and aortic arch surgeries, as it alters catheter angulation and hemodynamic flow patterns.

Another important variation includes the direct origin of the left vertebral artery from the arch of aorta. Normally, the vertebral arteries arise from the subclavian arteries; however, several cadaveric and imaging studies have reported its direct origin from the arch[4,6].

The incidence of this variation ranges from 0.17% to 15%[2]. Junagade and Mukherjee[6] emphasized that such variations are particularly important in endovascular and neurovascular procedures because unexpected origins may complicate catheter navigation and increase the risk of arterial injury.

Rare but clinically significant variations include aberrant right subclavian artery (arteria lusoria), right-sided aortic arch, double aortic arch, and presence of additional branches such as the thyroidea ima artery[2,7].

Aberrant right subclavian artery occurs when the vessel arises distal to the left subclavian artery and passes posterior to the esophagus, potentially causing dysphagia lusoria[2]. Although rare, such anomalies may be life-threatening if unrecognized during thoracic surgery.

The embryological basis of variations in the branching pattern of the arch of aorta lies in the complex development and remodeling of the pharyngeal (aortic) arch arteries. During the fourth week of embryogenesis, six pairs of aortic arches develop sequentially from the aortic sac and connect to the paired dorsal aortae[8].

The third aortic arches form the common carotid arteries and proximal internal carotid arteries. The left fourth arch contributes to the formation of the definitive aortic arch, whereas the right fourth arch forms part of the right subclavian artery. The sixth arches form the pulmonary arteries, but only the left sixth arch forms the ductus arteriosus, while the distal part of the right sixth arch regresses.[8].

Any abnormal persistence or regression of these arches, or abnormal partitioning of the aortic sac, can result in variant vascular patterns[2,8].

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For example, a common origin of brachiocephalic trunk and left common carotid artery may result from incomplete septation of the aortic sac[2]. Similarly, direct origin of the left vertebral artery may result from persistence of the dorsal intersegmental arteries[6].

Thus, understanding embryological development is essential for interpreting anatomical variations.

From a clinical perspective, knowledge of variations in the branching pattern of the arch of aorta has gained increasing importance due to the rapid advancement of minimally invasive and endovascular procedures. Carotid artery stenting, thoracic endovascular aortic repair (TEVAR), cerebral angiography, and coronary bypass grafting require precise understanding of supra-aortic vessel anatomy[5],[9].

Natsis et al.[9] reported that complex arch anatomy significantly increases procedural difficulty and complication rates during carotid stenting.

Thoracic endovascular aortic repair (TEVAR) has become a widely used procedure for aortic aneurysm and dissection. Li et al.[10] reported that bovine arch configuration may increase operative time and technical challenges during TEVAR. Hemodynamic studies also suggest that altered geometry of the arch may influence wall stress distribution, predisposing to aneurysm formation and dissection[11].

Radiological evaluation using computed tomography angiography (CTA) and magnetic resonance angiography (MRA) has improved detection of vascular variations. Kumar et al.[12] reported that CT angiographic studies revealed variations in approximately 27% of the North Indian population. However, imaging studies may sometimes underestimate small branches or fail to provide precise morphometric measurements. Therefore, cadaveric dissection remains the gold standard for accurate anatomical documentation[3],[6].

Morphometric parameters such as diameter of vessels, inter-branch distance, curvature of the arch, and spatial orientation of branches are important for designing vascular grafts and planning surgical approaches[6],[13]. Shin et al.[13] demonstrated that arch geometry influences hemodynamic stress and may contribute to vascular pathology. Thus, anatomical studies are not merely descriptive but have functional and clinical implications.

In head and neck surgeries, particularly thyroidectomy and tracheostomy, knowledge of vascular variations is essential to avoid catastrophic hemorrhage[7]. Presence of aberrant vessels may complicate surgical exposure. In neurosurgical procedures involving the vertebrobasilar system, anomalous origin of vertebral arteries must be recognized preoperatively[14].

From an academic perspective, cadaveric studies contribute to anatomical education and enrich the understanding of normal and variant anatomy among postgraduate students. Regional studies are particularly valuable because vascular patterns may vary among ethnic groups[2],[5]. Despite numerous global studies, region-specific cadaveric data remain limited in many parts of India.

Therefore, a detailed cadaveric study focusing on variations in branching pattern of the arch of aorta, along with morphometric analysis and clinical correlation, is justified. Such data will aid anatomists, surgeons, radiologists, and interventional cardiologists in improving procedural planning and patient safety.

2.Materials And Methods

This descriptive cross-sectional cadaveric study was conducted in the Department of Anatomy, Pacific Institute of Medical Sciences (PIMS), Umarda, Udaipur, Rajasthan, during 2022–2023 after obtaining Institutional Ethics Committee (IEC) approval. The study aimed to evaluate the branching patterns of the arch of aorta, identify anatomical variations, and obtain morphometric measurements of its major branches.

A total of 80 formalin-embalmed adult human cadavers were included. The sample size was calculated using the prevalence formula, assuming a 25% prevalence of aortic arch branching variations at a 95% confidence interval and 10% allowable error, yielding a minimum sample size of 72; therefore, 80 cadavers were examined. Adult cadavers with intact thoracic cavities and well-preserved aortic arches were included, while specimens with thoracic trauma, previous thoracic surgery, poor preservation, congenital cardiovascular anomalies, or damaged aortic arches were excluded.

Dissection was performed according to Cunningham's Manual of Practical Anatomy. After opening the thoracic cavity and reflecting the pericardium, the ascending aorta, arch of aorta, and its branches were

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carefully exposed. The branching pattern, number, sequence, and origin of the branches were documented. Variations such as common origin of the brachiocephalic trunk and left common carotid artery (bovine arch), direct origin of the left vertebral artery, aberrant right subclavian artery, four-branch patterns, common trunks, duplication or absence of branches, and other unusual configurations were recorded and photographed where necessary.

Morphometric measurements were obtained using a calibrated digital Vernier caliper (accuracy 0.01 mm). External diameters of the brachiocephalic trunk, left common carotid artery, left subclavian artery, and any additional branches were measured at their origin. Distances between consecutive branches arising from the aortic arch were also measured. Each measurement was taken twice, and the average value was used for analysis to minimize measurement error.

For every cadaver, data including identification number, sex (where identifiable), branching pattern, presence of variations, branch diameters, and inter-branch distances were recorded in a structured proforma and entered into Microsoft Excel. Statistical analysis was performed using SPSS software. Descriptive statistics (mean, standard deviation, frequency, percentage, minimum and maximum values) were calculated. Inferential statistics included the Independent Student's t-test for comparison of morphometric parameters and the Chi-square test for comparison of branching patterns. A p-value < 0.05 was considered statistically significant. All findings were presented in tables, charts, graphs, and percentage distributions while maintaining complete confidentiality and ethical standards regarding cadaveric specimens.

3. Statistical Analysis

Data were entered into Microsoft Excel and analyzed using appropriate statistical software. Continuous variables were expressed as Mean ± SD. Paired Student's t-test was used for within-group comparisons, Unpaired Student's t-test for between-group comparisons, and Pearson's correlation coefficient to assess the relationship between cardiovascular parameters and anxiety scores. A p-value <0.05 was considered statistically significant.

4.Result

The present cadaveric study was conducted on 80 specimens to study the variations in the branching pattern of the arch of aorta and to evaluate their clinical significance. Data were analyzed and presented in tabular and graphical form.

Table 1: Frequency and Percentage Distribution of Aortic Arch Branching Patterns

S.No.	Branching Pattern	Frequency	Percentage	Remarks
1	Type A - Normal	66	82.50%	Commonly observed
2	Type B - Bovine Arch	10	12.50%	Variant pattern
3	Type D - LVA from Arch	2	2.50%	Variant pattern
4	Type E - Common Trunk + LVA	2	2.50%	Variant pattern

Interpretation: The normal branching pattern of the arch of aorta was the most commonly observed pattern. Variant branching patterns were also encountered, indicating anatomical diversity important for surgical planning and angiographic interpretation.

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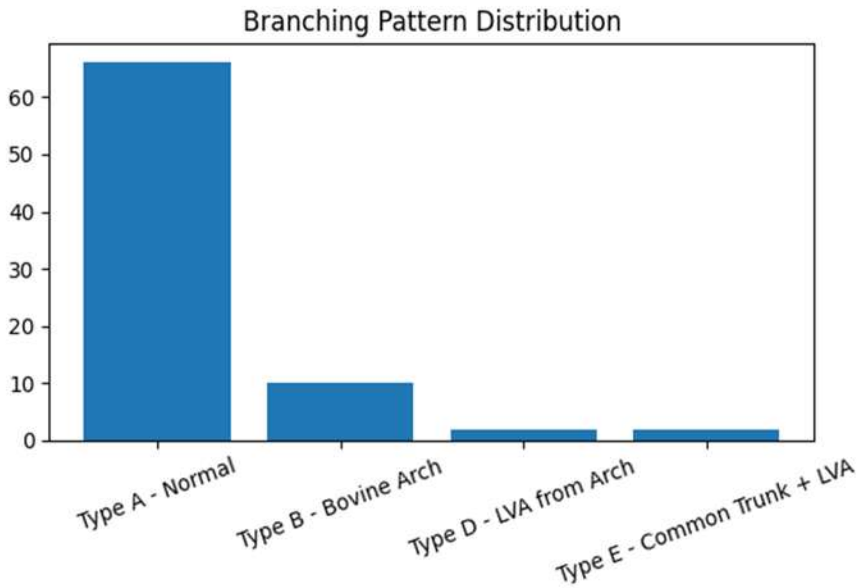

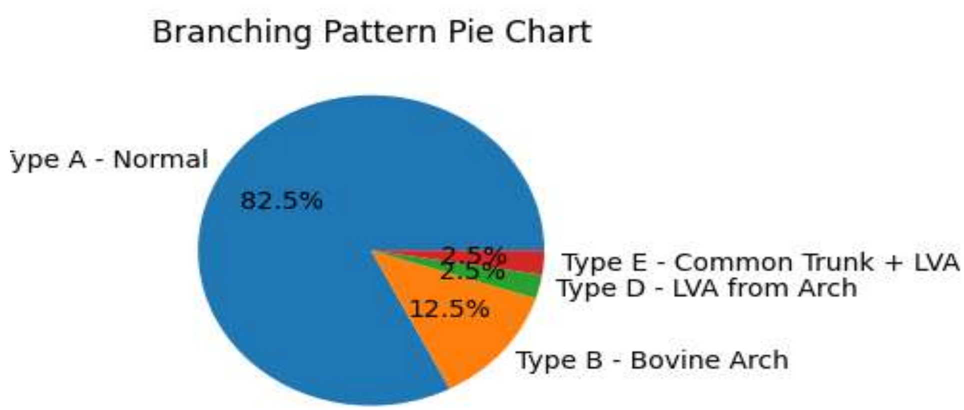

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Table 2: Sex-wise Distribution of Cadaveric Specimens

S.No.	Sex	Frequency	Percentage
1	Male	41	51.25%
2	Female	39	48.75%

Interpretation: Male and female cadaveric specimens were included to observe distribution of aortic arch variations among both sexes.

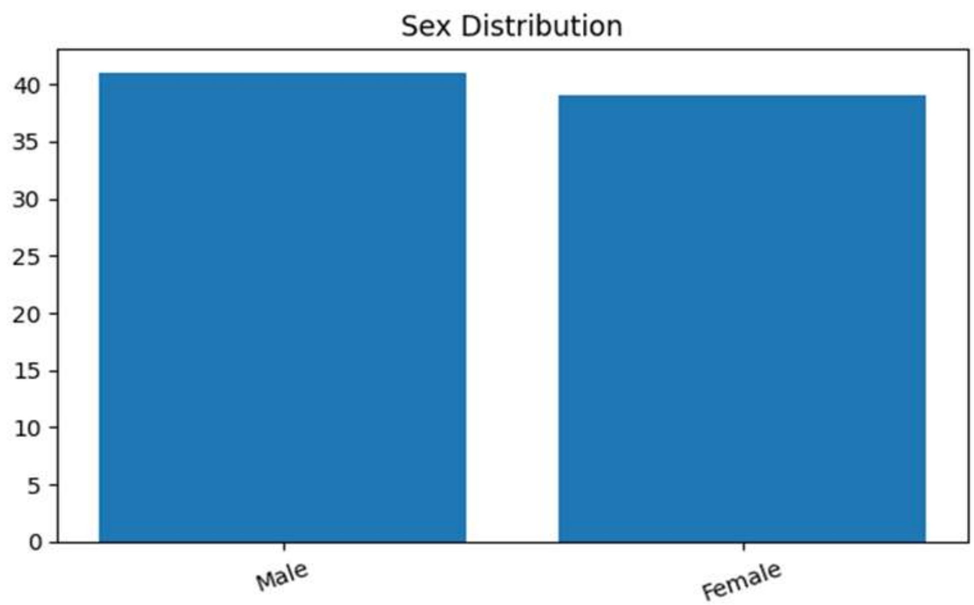

Table 3: Age Group Distribution

S.No.	Age Group	Frequency	Percentage
1	61+ yrs	32	40.00%
2	20-40 yrs	32	40.00%
3	41-60 yrs	16	20.00%

Interpretation: Cadavers from different age groups were studied to understand the distribution of branching patterns.

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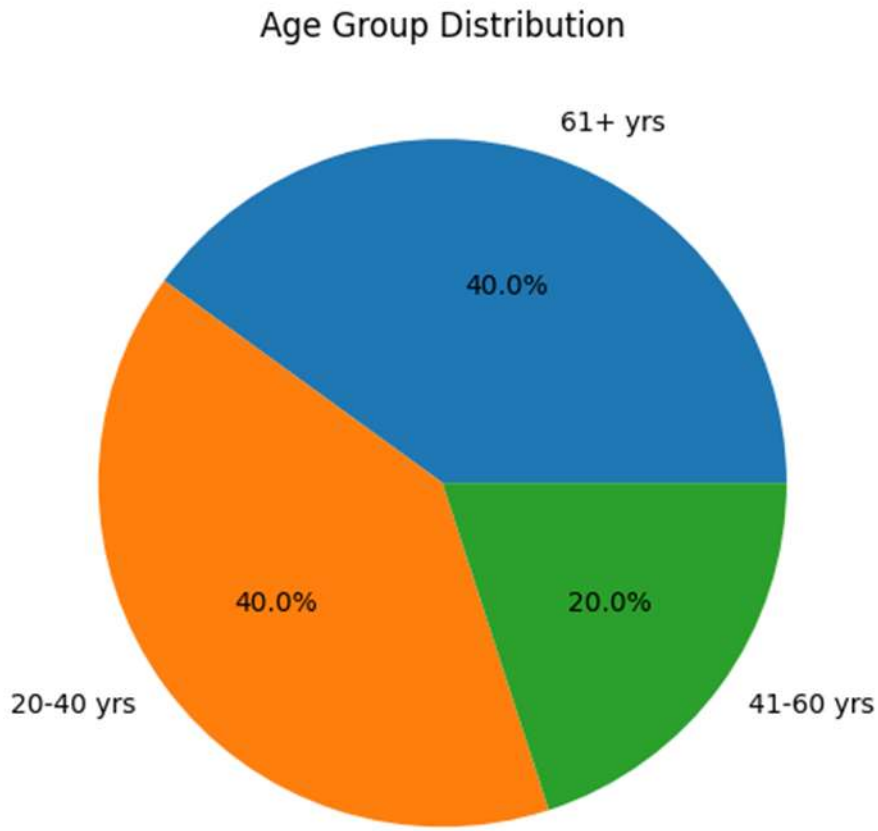

Table 4: Comparison with Previous Studies

Study	Sample Size	Normal Pattern (%)	Variant Pattern (%)
Adachi	516	65–70	30–35
Natsis et al.	633	80–85	15–20
Current Study	80	82.50	17.50

Interpretation: Findings of the present study were broadly comparable with previous cadaveric studies, though slight variations may occur due to ethnic and geographical differences.

Clinical Significance

Knowledge of variations in the branching pattern of the arch of aorta is important during cardiothoracic surgery, angiography, catheterization, carotid stenting and endovascular interventions. Surgeons and radiologists should be aware of these variants to avoid operative and diagnostic complications.

Overall Result Summary

In the present study of 80 cadaveric specimens, the normal branching pattern was most frequently observed, while variant patterns including bovine arch and left vertebral artery origin directly from the aortic arch were also identified. Detailed anatomical understanding of these variations is clinically relevant for successful surgical and radiological interventions.

6.Discussion

The present cadaveric study was conducted in the Department of Anatomy, Pacific Medical College and

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Hospital, Udaipur, Rajasthan, on 80 embalmed cadaveric specimens to evaluate variations in the branching pattern of the arch of aorta and to assess their clinical significance. The anatomy of the aortic arch is of considerable importance because variations in its branching pattern may influence surgical procedures, angiographic interventions, and endovascular techniques. The findings of the present study were compared with those reported by previous investigators.

Normal Branching Pattern

In the present study, the classical three-branch pattern of the aortic arch was observed in 66 out of 80 specimens (82.5%). This pattern comprises the brachiocephalic trunk, left common carotid artery, and left subclavian artery arising separately from the arch of aorta. Similar observations were reported by Natsis et al.[15] who found the normal branching pattern in approximately 80–85% of cases. Adachi[16] reported the classical pattern in 65–70% of specimens, whereas Nayak et al.[17] observed it in about 89% of the Indian population. The findings of the present study are therefore in close agreement with those reported by Natsis et al. and Nayak et al.[17]

The predominance of the classical branching pattern indicates that normal embryological regression and persistence of the aortic arch system occur in the majority of individuals. However, the occurrence of variant patterns highlights the complexity of embryological development and the possibility of developmental alterations.

Bovine Arch Variation

The bovine arch was identified in 10 specimens (12.5%), making it the most common variant encountered in the present study. This finding corresponds well with the observations of Berko et al.[18] and Natsis et al.who reported incidences ranging between 8% and 27%.

The bovine arch results from a common origin of the brachiocephalic trunk and left common carotid artery and represents an embryological variation arising from altered development of the aortic sac. From a clinical perspective, this variation is important because it may influence catheter manipulation during angiography, carotid artery stenting, and thoracic endovascular procedures. Surgeons should therefore be aware of this anatomical variant to avoid procedural complications.

Left Vertebral Artery Origin Directly from the Aortic Arch

In the present study, direct origin of the left vertebral artery from the aortic arch was observed in 2 specimens (2.5%). Similar incidences have been reported by Komiyama et al.[19] and Natsis et al.[15] who found frequencies ranging from 2% to 8%.

Embryologically, this variation occurs due to persistence of the dorsal division of the seventh cervical intersegmental artery. Clinically, direct aortic origin of the vertebral artery may alter cerebral blood flow dynamics and has been associated with vertebrobasilar insufficiency, arterial dissection, and aneurysm formation. Recognition of this variation is therefore important during neurovascular and endovascular interventions.

Common Trunk with Left Vertebral Artery Variation

A common trunk associated with direct origin of the left vertebral artery from the aortic arch was observed in 2 specimens (2.5%). This rare variation has been reported sporadically in previous anatomical studies and usually accounts for less than 5% of cases. Such complex vascular arrangements may create technical challenges during aortic arch surgeries and interventional radiological procedures.

Comparison with Previous Studies

The findings of the present study were comparable with those of previous investigators. Adachi[2] reported normal branching patterns in 65–70% of cases, whereas Natsis et al.[1] observed normal patterns in approximately 80–85% of specimens. In the present study, the normal branching pattern was observed in 82.5% of cases, while variant patterns accounted for 17.5% of specimens. These findings are therefore closely aligned with those reported by Natsis et al.[15]

Differences in prevalence among studies may be attributed to racial, ethnic, geographical, environmental, and genetic factors, as well as variations in sample size and methodology.

Sex-wise Distribution

Among the 80 cadaveric specimens studied, 41 (51.25%) were male and 39 (48.75%) were female. Although sex-specific statistical comparison of branching patterns was not performed, inclusion of both sexes enhances the representativeness of the

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study population and improves the applicability of the findings to the general population.

Age-wise Distribution

The study included specimens from different age groups, with 40% belonging to the 20–40 years age group, 20% to the 41–60 years age group, and 40% to the 61 years and above age group. Since aortic arch branching patterns are congenital in origin, age does not influence their occurrence; however, inclusion of multiple age groups allows better understanding of their persistence and clinical relevance throughout life.

Clinical Significance

Variations in the branching pattern of the aortic arch have significant implications for cardiothoracic surgery, vascular surgery, angiography, catheterization, carotid artery stenting, and endovascular procedures. Lack of awareness of these anatomical variations may result in operative difficulties, vascular injury, hemorrhage, and misinterpretation of radiological images. Therefore, preoperative evaluation using CT angiography, MR angiography, or digital subtraction angiography is recommended whenever aortic arch interventions are planned.[20]

Summary

The present cadaveric study was carried out in the Department of Anatomy, Pacific Medical College and Hospital, Udaipur, Rajasthan, with the objective of studying the variations in the branching pattern of the arch of aorta and evaluating their clinical significance. A total of 80 cadaveric specimens were examined in detail to identify the pattern of origin and arrangement of the major branches arising from the aortic arch. The aortic arch is one of the most important vascular structures of the body, supplying blood to the head, neck, and upper limbs through its major branches. Variations in its branching pattern are not uncommon and may have significant implications during diagnostic, surgical, and endovascular procedures.

The present study demonstrated that the classical three-branch pattern of the aortic arch was the most common anatomical configuration, being observed in 66 specimens (82.5%). In this pattern, the brachiocephalic trunk, left common carotid artery, and left subclavian artery arise separately from the arch of aorta. This finding is in agreement with the observations of several previous studies reported in the literature and confirms that the normal branching pattern remains the predominant arrangement in the majority of individuals.

Among the variant branching patterns, the bovine arch was the most frequently encountered variation and was observed in 10 specimens (12.5%). In this variation, the left common carotid artery shares a common origin with the brachiocephalic trunk or arises from it. This variation is of considerable clinical importance because it may alter the course of catheterization procedures and influence surgical approaches involving the supra-aortic vessels.

Direct origin of the left vertebral artery from the aortic arch was identified in 2 specimens (2.5%). This variation is embryologically related to persistence of the dorsal division of the cervical intersegmental arteries and may influence cerebral circulation. Another rare variation observed in the present study was the presence of a common trunk associated with direct origin of the left vertebral artery from the aortic arch, which was also seen in 2 specimens (2.5%). Such uncommon vascular arrangements are important to recognize because they may create technical difficulties during angiographic and surgical procedures.

The sex-wise distribution included 41 male specimens (51.25%) and 39 female specimens (48.75%), indicating an almost equal representation of both sexes. Age-wise distribution showed that 40% of specimens belonged to the 20–40 years age group, 20% belonged to the 41–60 years age group, and 40% belonged to the 61 years and above age group. Since these vascular variations are developmental in origin, they are generally independent of age; however, inclusion of different age groups enhanced the representativeness of the study population.

Comparison of the present findings with previous studies revealed close similarity in the prevalence of both normal and variant branching patterns. Minor differences observed between studies may be attributed to racial, ethnic, genetic, geographical, and methodological factors. The overall incidence of variations in the present study was 17.5%, emphasizing that anatomical deviations from the classical pattern are not rare and should always be considered during clinical practice.

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The findings of this study highlight the importance of detailed anatomical knowledge of the aortic arch and its branches. Awareness of these variations is essential for anatomists, radiologists, cardiothoracic surgeons, vascular surgeons, and interventional specialists. Accurate identification of vascular variations before surgical or radiological procedures can help prevent operative complications, reduce procedural risks, improve interpretation of imaging studies, and contribute to successful patient management. Thus, the present study provides valuable anatomical data regarding aortic arch branching patterns and their clinical relevance in the regional population.

Conclusion

The classical three-branch pattern of the aortic arch was found to be the predominant branching pattern in the present study, occurring in the majority of specimens examined. However, a significant proportion of specimens exhibited variations in the branching pattern, demonstrating the existence of considerable anatomical diversity within the population.

The bovine arch was the most common variation encountered, while direct origin of the left vertebral artery from the aortic arch and common trunk with left vertebral artery variation were observed less frequently. The prevalence of these variations was comparable with findings reported in previous anatomical studies, indicating consistency with established literature.

These variations arise due to developmental alterations during embryogenesis and may influence the anatomical relationships of the major arteries arising from the aortic arch. Knowledge of such variations is essential for accurate interpretation of radiological investigations and for planning cardiothoracic, vascular, and endovascular procedures.

Recognition of aortic arch branching variations before surgical or interventional procedures can minimize operative complications, facilitate safer catheterization and angiographic techniques, and improve overall clinical outcomes. The present study contributes valuable anatomical information regarding aortic arch branching patterns and reinforces the importance of thorough anatomical understanding for both academic and clinical practice.

Ithical Issues:

Research project approved by the ethics committee of Pacific Institute of Medical Sciences Udaipur-313005, Rajasthan, INDIA

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