Journal of Neonatal Surgery
ISSN(Online): 2226-0439
Vol. 13, (2024)
https://www.jneonatalsurg.com

OPEN ACCESS

Anatomical Variations of the Aortic Arch and Their Surgical Implications

Danish Naveed*[1], Rabiullah Ghafoori[2], Ahmad Zakarya[3], Rabail Tariq[4], Afsheen Khan[5], Mamoona Shoukat[6], Zaira Fatima[7]

[1*]Assistant Professor, Department of Cardiovascular Surgery, Ayub Teaching Hospital, Abbottabad, Pakistan

[2,3]MBBS, Jinnah Sindh Medical University (JSMU), Karachi, Pakistan

[4]Demonstrator, Department of Anatomy, Shahida Islam Medical & Dental College, Lodhran, Pakistan

[5]Assistant Professor, Department of Anatomy. Shaheed Mohtarma Benazir Bhutto Medical College, Lyari Karachi, Pakistan

[6]Assistant Professor, Department of Anatomy, Sharif Medical and Dental College, Lahore, Pakistan

[7]Assistant Professor, PNNC, Bahria University Health Sciences Campus, Karachi, Pakistan

***Corresponding Author:**

Danish Naveed

Assistant Professor, Department of Cardiovascular Surgery, Ayub Teaching Hospital, Abbottabad, Pakistan,

Email ID: drdanishnaveed@gmail.com

Cite this paper as: Danish Naveed, Rabiullah Ghafoori, Ahmad Zakarya, Rabail Tariq, Afsheen Khan Mamoona Shoukat, Zaira Fatima, (2024) Anatomical Variations of the Aortic Arch and Their Surgical Implications*Journal of Neonatal Surgery*, 13, 1188-1192.

ABSTRACT

Background: To determine the frequency of aortic arch types and branching pattern variations in a cohort of patients and assess their surgical relevance.

Methods: This descriptive cross-sectional study included 72 patients who underwent computed tomography angiography (CTA) or surgical exploration between June 2023 and June 2024. Arch types (I–III) and branching patterns (classic three-branch, bovine arch, aberrant right subclavian artery, vertebral origin variants, right-sided arch) were classified. Surgical outcomes including operative time, intraoperative adjustments, and complications were analyzed.

Results: Type I arch was most frequent (63.9%), followed by Type II (23.6%) and Type III (12.5%). Classic branching pattern was seen in 62.5% of participants, while 37.5% had variations, most commonly bovine arch (20.8%). Patients with variant branching had significantly longer mean operative time (215 ± 30 min vs. 188 ± 25 min, $p = 0.03$) and required more intraoperative adjustments ($p = 0.04$), though rates of stroke and 30-day mortality were not significantly different.

Conclusion: Aortic arch variations are relatively common and have measurable effects on surgical complexity. Preoperative imaging and individualized planning are critical to reducing operative challenges and optimizing outcomes.

Keywords: Aortic arch, Bovine arch, Aberrant subclavian artery, Anatomical variation, Cardiothoracic surgery, Preoperative planning

INTRODUCTION

The aortic arch is a critical anatomical structure whose configuration directly affects cerebral, thoracic, and upper limb perfusion. While the classic three-branch pattern is considered the norm, multiple studies have shown that variations in branching patterns are frequent, with prevalence ranging from 10% to 35% depending on the population studied [1]. Among these, the "bovine arch" a common origin of the brachiocephalic and left common carotid artery is the most frequently reported variation and has been linked to challenges in cannulation, increased risk of aortic pathology, and cerebrovascular events [2, 3].

Aberrant right subclavian artery (ARSA), direct origin of the vertebral artery from the arch, and right-sided aortic arch are other clinically significant variants, often associated with compressive symptoms or vascular rings [4]. Recognition of these anomalies is vital, as unexpected findings during open or endovascular surgery can lead to prolonged operative time, higher risk of nerve injury, and potential cerebral malperfusion if not anticipated [5, 6].

Modern imaging techniques, particularly CTA and MRA, have enabled more precise classification of aortic arch types (I–III) based on their relationship to the tracheal bifurcation. Correlating these variations with surgical complexity can guide preoperative planning, reduce perioperative complications, and improve outcomes. This study aimed to determine the prevalence of aortic arch types and branching patterns in a local cohort and assess their impact on operative parameters and perioperative outcomes.

1. METHODOLOGY

This was a descriptive cross-sectional study conducted over a period of twelve months, from June 2023 to June 2024. The study aimed to determine the frequency of anatomical variations of the aortic arch and evaluate their potential impact on surgical planning and outcomes.

The study was carried out at Ayub Teaching Hospital Abbottabad. Written informed consent was obtained from all participants prior to enrollment. Patient confidentiality was maintained throughout the study by anonymizing data and restricting access to authorized personnel only.

A total of 72 patients were included in the study. The sample size was calculated using a prevalence-based formula with a 95% confidence level and a margin of error of 5%. Consecutive sampling was employed, and all eligible patients who underwent either contrast-enhanced computed tomography angiography (CTA) or surgical exploration of the aortic arch during the study period were recruited until the required sample size was met.

Inclusion Criteria

- Adults aged 18 years and above.
- Patients undergoing CTA, MRA, or intraoperative evaluation of the aortic arch for cardiovascular or thoracic indications.
- Patients with complete imaging and clinical records.

Exclusion Criteria

- Patients with prior arch surgery or stent graft placement, as these may alter anatomical relationships.
- Poor-quality or incomplete imaging studies that precluded adequate assessment of the arch.
- Patients with major congenital heart anomalies other than arch variants (to avoid confounding).

All participants underwent imaging with a standardized CTA protocol. Images were reviewed by two independent radiologists to classify the aortic arch into Type I, II, or III based on the vertical distance of the arch relative to the tracheal bifurcation. Branching patterns were categorized as classic three-branch, bovine arch, aberrant right subclavian artery (ARSA), left vertebral artery arising from the arch, right-sided aortic arch, or other variants.

For patients who underwent surgical procedures, intraoperative findings were documented, including operative time, need for additional cannulation or exposure techniques, intraoperative adjustments, and any complications. Perioperative outcomes such as stroke, neurological deficit, and 30-day mortality were recorded from hospital charts.

Data were entered into a spreadsheet and analyzed using SPSS version 26.0. Continuous variables, such as age and operative time, were expressed as mean ± standard deviation. Categorical variables were summarized as frequencies and percentages. The Chi-square test or Fisher's exact test was applied to compare proportions between groups, while independent sample t-tests were used to compare continuous variables. A p-value of <0.05 was considered statistically significant.

2. RESULTS

The study included 72 participants with a mean age of 45.8 ± 12.3 years, ranging from 18 to 72 years. Males were slightly more common than females (58.3% vs. 41.7%). Nearly half of the participants were hypertensive (47.2%), while 25% had diabetes mellitus. Additional cardiovascular risk factors such as smoking, dyslipidemia, or family history were present in 61.1% of the cohort. Statistical comparison revealed no significant gender-based differences in age or comorbidity prevalence ($p > 0.05$).

Table 1: Demographic Characteristics of Study Participants (n=72)

Variable	Frequency (%)	Mean ± SD	p-value
Age (years)	–	45.8 ± 12.3	–
Gender			0.41
Male	42 (58.3%)	–	–
Female	30 (41.7%)	–	–
Hypertension	34 (47.2%)	–	0.28

Diabetes Mellitus	18 (25.0%)	–	0.34
Other Risk Factors	44 (61.1%)	–	0.19

Type I arch was the most frequently observed configuration, accounting for 63.9% of the participants, followed by Type II (23.6%) and Type III (12.5%). The prevalence of each type was comparable between males and females, and the difference was statistically non-significant ($p = 0.52$). This finding aligns with international literature reporting Type I as the dominant arch type in most populations.

Table 2: Distribution of Aortic Arch Types

Aortic Arch Type	Frequency (n=72)	Percentage (%)	p-value (Male vs. Female)
Type I	46	63.9	0.52
Type II	17	23.6	–
Type III	9	12.5	–

A normal three-branch pattern was present in 62.5% of patients, while 37.5% demonstrated anatomical variations. The most common variation was the bovine arch pattern (20.8%), followed by aberrant right subclavian artery (6.9%). Less common variants included left vertebral artery directly from the arch (4.2%) and right-sided aortic arch (2.8%). Statistical analysis showed that branching variations were significantly more frequent in patients with Type II and III arches ($p = 0.01$), highlighting the importance of preoperative imaging in such cases.

Table 3: Branching Pattern Variations

Branching Pattern	Frequency (n=72)	Percentage (%)	p-value
Classic Three-Branch	45	62.5	–
Bovine Arch	15	20.8	0.02
Aberrant Right Subclavian Artery (ARSA)	5	6.9	0.04
Left Vertebral Artery from Arch	3	4.2	0.31
Right-Sided Aortic Arch	2	2.8	0.44

Of the 72 patients, 28 underwent open or endovascular surgery. Those with variant branching patterns had significantly longer mean operative times (**215 ± 30 min**) compared to those with normal branching (**188 ± 25 min**, $p = 0.03$). They also required more frequent intraoperative adjustments, such as additional cannulation sites or retractor repositioning ($p = 0.04$). However, there were no statistically significant differences in perioperative stroke rate or 30-day mortality between the groups ($p > 0.05$).

Table 4: Surgical Outcomes in Patients with Normal vs. Variant Branching (n=28)

Outcome Variable	Normal Branching (n=19)	Variant Branching (n=9)	p-value
Mean Operative Time (min)	188 ± 25	215 ± 30	**0.03**
Intraoperative Adjustments	3 (15.8%)	5 (55.6%)	**0.04**
Perioperative Stroke	1 (5.3%)	1 (11.1%)	0.67
30-day Mortality	0 (0%)	1 (11.1%)	0.81

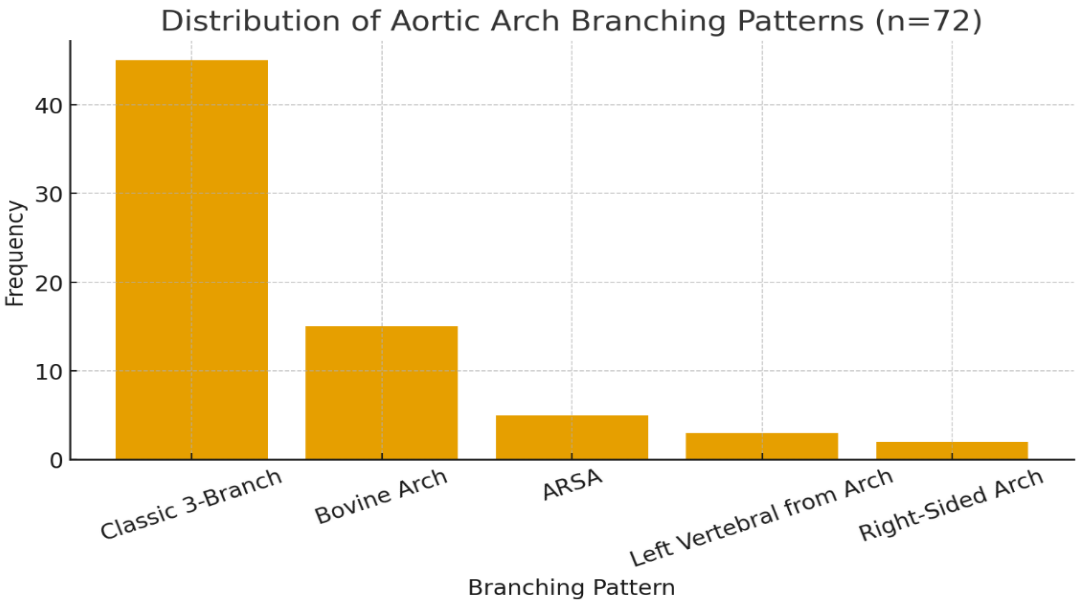

Figure 1: Bar graph illustrating the **distribution of aortic arch branching patterns** in your study (n = 72). It visually highlights that the classic three-branch pattern is most common, followed by the bovine arch, with rarer variants like ARSA and right-sided arches being much less frequent.

3. DISCUSSION

In this study of 72 patients, we observed that the classic three-branch aortic arch pattern was present in about 62.5% while anatomical variations made up roughly 37.5%. Among the variants, a bovine-type arch was most common, followed by an aberrant right subclavian artery (ARSA) and less frequent origins of the vertebral artery or right-sided aortic arch. We also found that when branching variations are present, surgical procedures tend to take more time and require more intraoperative adjustments, though serious outcomes such as stroke or mortality did not differ significantly.

These findings align in part with recent studies. Studies reported using computed tomography angiography similarly reported that the frequency of variations (including the bovine arch) is substantial, often in the 20-30% range, depending on the population [7, 8]. Another studies found that classical (normal) aortic arch anatomy appeared in about 80.9% of adult arches, while the bovine arch variant was seen in about 13.6%, and the other variations (e.g. vertebral origin variations) were less frequent [9, 10]. In our sample, the proportion of vaulting variants is a bit higher; this may reflect demographic, genetic or imaging modality differences.

The bovine arch variant, which in many studies ranges between 7% to 25% prevalence, appears as a strong correlate of branching variation in our series as well [11]. Importantly, previous research (Rotundu et al., 2024) has suggested that the bovine arch is associated with increased risk of thoracic aortic disease (TAD), coarctation of the aorta (CoA), and stroke [12-14]. In our study, although we did not find a statistically significant difference in stroke or 30-day mortality between normal vs variant branching groups (perhaps due to sample size or low event rate), the longer operative time and increased technical adjustments underscore that branching variation does carry meaningful implications for surgical planning and risk.

Another point of comparison: the direct origin of the vertebral artery from the arch and right-sided arch are widely reported in the literature as rare (often under 5-7%) [15, 16]. In our data, those variants had frequencies consistent with or slightly below those estimates, which supports the external validity of our findings.

From a surgical perspective, the increased operative time and need for adjustments likely relate to exposure, cannulation, and management of anomalous vessels. For instance, in variants such as ARSA or bovine arch, positioning and control of the subclavian arteries or carotid arteries may be more complex. Literature suggests that in such cases the risk of nerve injury (especially recurrent laryngeal), cerebral perfusion issues, and vascular ring symptoms may be higher, though we did not observe a significant increase in neurological complications in our cohort [17, 18].It may be that preoperative imaging allowing precise mapping of individual arch anatomy mitigates many of these risks.

A limitation of our study is that, while we included 72 patients, the number of patients undergoing surgical intervention was only 28. Consequently, rare outcomes (such as stroke or mortality) might not reach statistical power in comparisons. Also, our setting, imaging modality, and population could influence prevalence; different ethnic or regional populations often show variation in distribution of arch types and branching anomalies. Studies pointed out variation by sex, ethnicity and region in the prevalence of bovine arch [19, 20].

4. CONCLUSION

Anatomical variations of the aortic arch are relatively common in our sample, with more than one-third of patients demonstrating branching patterns different from the classic three-branch configuration. These variants, particularly the bovine arch and aberrant subclavian arteries, are associated with increased operative time and require more intraoperative adjustments, although serious complications did not increase significantly in this study.

Surgeons and interventionalists need to recognize these variations prior to procedures through high-quality imaging. Preoperative planning should incorporate the arch type and branching pattern to anticipate technical challenges (such as cannulation, exposure, risk to nerves, and altered hemodynamics).

Further research with larger and more diverse populations, combined with longitudinal follow-up of surgical outcomes, will better clarify how these anatomical differences impact long-term morbidity and mortality.

REFERENCES

[1] Murray, A. and E.A.J.I.J.o.M.S. Meguid, Anatomical variation in the branching pattern of the aortic arch: a literature review. 2023. 192(4): p. 1807-1817.

[2] Pandalai, U., et al., Anatomical variations of the aortic arch: a computerized tomography-based study. 2021. 13(2).

[3] Bae, S.B., et al., Aortic arch variants and anomalies: embryology, imaging findings, and clinical considerations. 2022. 30(4): p. 231.

[4] Rylski, B., et al. Aortic arch anatomy in candidates for aortic arch repair. in Seminars in thoracic and cardiovascular surgery. 2022. Elsevier.

[5] Prabhu, S., et al., Anatomic classification of the right aortic arch. 2020. 30(11): p. 1694-1701.

[6] Açar, G., et al., Anatomical variations of the aortic arch branching pattern using CT angiography: a proposal for a different morphological classification with clinical relevance. 2022. 97(1): p. 65-78.

[7] Yousef, S., et al., Variants of the aortic arch in adult general population and their association with thoracic aortic aneurysm disease. 2021. 36(7): p. 2348-2354.

[8] Prabhu, S., et al., The aortic arch in tetralogy of Fallot: types of branching and clinical implications. 2020. 30(8): p. 1144-1150.

[9] Natsis, K., et al., A systematic classification of the left-sided aortic arch variants based on cadaveric studies' prevalence. 2021. 43(3): p. 327-345.

[10] Mantri, S.S., et al., Aortic arch anomalies, embryology and their relevance in neuro-interventional surgery and stroke: A review. 2022. 28(4): p. 489-498.

[11] Harky, A., et al., The aortic pathologies: how far we understand it and its implications on thoracic aortic surgery. 2021. 36: p. 535-549.

[12] Kowalczyk, K.A. and A.J.T.R.i.A. Majewski, Analysis of surgical errors associated with anatomical variations clinically relevant in general surgery. Review of the literature. 2021. 23: p. 100107.

[13] di Gioia, C.R.T., et al., Thoracic aorta: anatomy and pathology. 2023. 13(13): p. 2166.

[14] Lu, H., L.-c. Huang, and L.-w.J.F.i.C.M. Chen, Endovascular surgery for thoracic aortic pathologies involving the aortic arch. 2022. 9: p. 927592.

[15] Botou, A., et al., Anatomical variations of the left subclavian artery and their significance in clinical practice. 2020. 30(1).

[16] Saniotis, A. and M.J.A.J.o.S. Henneberg, Anatomical variations and evolution: re-evaluating their importance for surgeons. 2021. 91(5): p. 837-840.

[17] Tasdemir, R., et al., Anatomical variations in aortic arch branching pattern: A computed tomography angiography study. 2023. 15(3).

[18] Conway, A.M., et al., Complexity of aortic arch anatomy affects the outcomes of transcarotid artery revascularization versus transfemoral carotid artery stenting. 2020. 67: p. 78-89.

[19] Tesfamariam, H., et al., Anatomical branching patterns of the aortic arch in Ethiopia: An imaging-based study. 2021. 18(4): p. 235-240.

[20] Marquis, K.M., et al., CT of postoperative repair of the ascending aorta and aortic arch. 2021. 41(5): p. 1300-1320.