ORIGINAL RESEARCH

Anatomical variations of the Aortic Arch branching pattern: A computerised tomography-based study

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Abstract

Objective: The aortic arch develops from multiple components during embryonic development, i.e. aortic sac, branchial arch artery and dorsal aorta. The pattern of fusion of these components results in anatomical variations in adults. The variations of the anatomy of the aortic arch may lead to problems during open vascular and endovascular interventions. The purpose of the study was to identify anatomical variations in the Sri Lankan patients who underwent contrast-enhanced computerised tomography (CECT) of the chest.

Methods: The patients who underwent CECT chest scans for various medical problems in the radiology department in National Hospital, Sri Lanka, Colombo (NHSL) were analysed retrospectively in relation to the variations of the aortic arch and its branches.

Results: A total of 50 (Male: Female = 30:20) were analysed. 20 (40%) had variations in branching patterns. The commonest variation was bovine arch (BA) (common origin of both common carotid arteries from the brachiocephalic trunk or common origin of brachiocephalic trunk and the left common carotid artery from the aortic arch) 28% (n=14). But the association between BA and gender is not statistically significant (p= 0.69). Four (8%) had a left vertebral artery arising from the arch. One (2%) had a right-sided aortic arch and one (2%) had an aberrant right subclavian artery. One (2%) had both BA and left vertebral artery arising from the arch. The difference between variations and gender was also not statistically significant (p= 0.81)

Conclusion: The variations of the aortic arch are common (40%). Knowledge about these variations is essential, especially during thoracic interventions and surgeries. Therefore, prior to any vascular surgical interventions, proper imaging is recommended to delineate the anatomy to prevent unwanted complications.

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Introduction

The aortic arch (AA) develops from multiple primitive arteries during embryonic development, i.e., the aortic sac, the branchial arch arteries and the dorsal aorta. Patterns of fusion of these components result in anatomical variations in the thoracic aorta and its branches in adults. In adults, the AA begins from the ascending aorta at the level of the manubriosternal joint and arches backwards and to the left over the left main bronchus and ends at the level of the 4th thoracic vertebra and continues as the descending thoracic aorta. Typically, the branches of the AA include the brachiocephalic (Innominate artery) trunk (BCT), left common carotid artery (LCCA) and the left subclavian artery (LSCA).

The variations of the anatomy of the aortic arch may lead to problems during open and endovascular interventions on the AA and its branches (1). In addition, studies have also shown that the variations in the branching pattern of the AA are associated with increased haemorrhagic and ischemic cerebral complications during other thoracic surgical procedures (2).

This study reports the anatomical variations of the aortic arch and its branching pattern among patients undergoing contrast-enhanced computerised tomographic scan (CECT) of the chest at the National Hospital, Sri Lanka, Colombo (NHSL).

Methods

This is a retrospective study done from June 2023 to August 2023. The patients who underwent CECT of the chest at the radiology department at the NHSL were included. Imaging was done with a multi-detector Toshiba Aquilian 16-slice CT scanner with 3-dimensional (3D) reconstructions. Omnipaque 300 (Iohexol injection) was used as a contrast agent (volume about 80ml, i.e. 1ml/kg). The timing was done automatically by selecting the region of interest (ROI) at the arch of the aorta (about 20 sec).

The images were analysed in the arterial phase (the axial, coronal, sagittal and 3D images were analysed) by the radiologist and the vascular surgeon at the console room (using Vitrea software). Data on patient demography, variations in the aortic arch (e.g. right-sided arch), and variations in branching pattern were collected. Non-clear images (due to wrong timing of the contrast), inadequate exposure and images with artefacts (due to Central Venous lines, previous surgeries, and mediastinal pathology) were excluded.

Results

A total of 50 images were included in the analysis. There were 30 (60%) males and 20 (40%) females. 20 (40%) had variations in the branching patterns of the arch of the aorta. The commonest variation was bovine arch (BA) (common origin of both common carotid arteries from the brachiocephalic trunk or the common origin of the BCT and the LCCA from the arch of the aorta) (Figure 1). BA was present in 14 (28%) individuals. Four (8%) had a left vertebral artery directly arising from the aortic arch (VAA) (Figure 2). One of these patients (2%) with VAA, had BA. One (2%) had a right-sided aortic arch (RAA) (Figure 3) and one (2%) had an aberrant right subclavian artery (ARSCA) (Figure 4) (Table 1).

Variations of the branching pattern were present in 20% of the males and 20% of the females. BA was present in 30% (9/30) of the males and 25% (5/30) of the females. However, this difference was not statistically significant (p = 0.7). Similarly, the other types of variations of the branching pattern also did not show a statistically significant difference between males and females (Table 1).

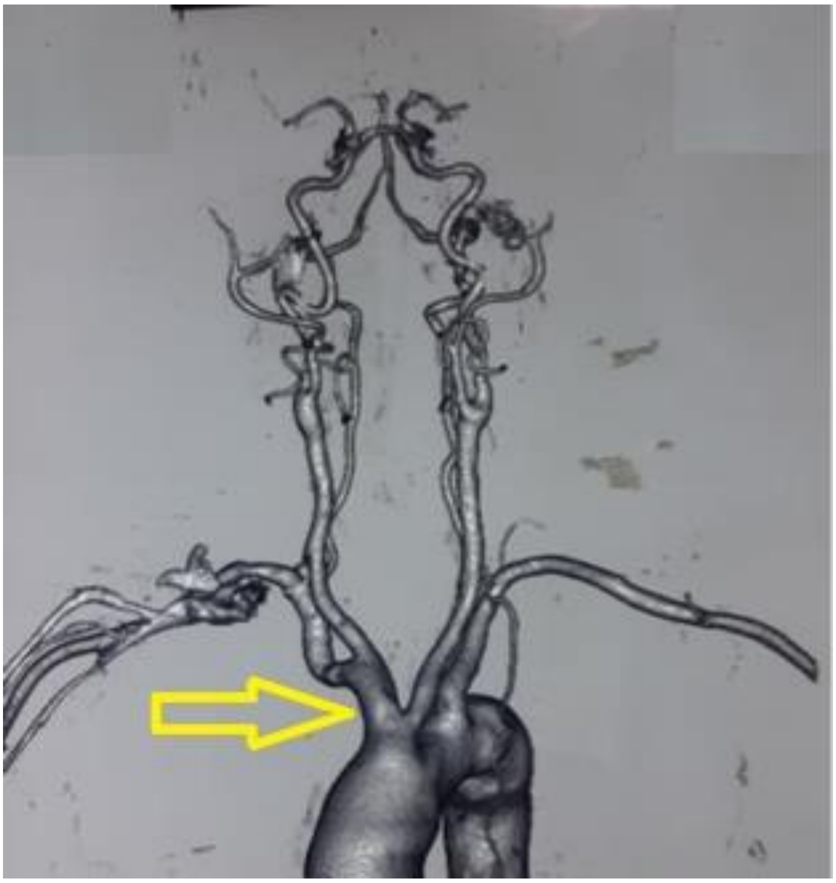

Figure 1: Bovine arch (BA), both common carotid arteries arising from a common trunk

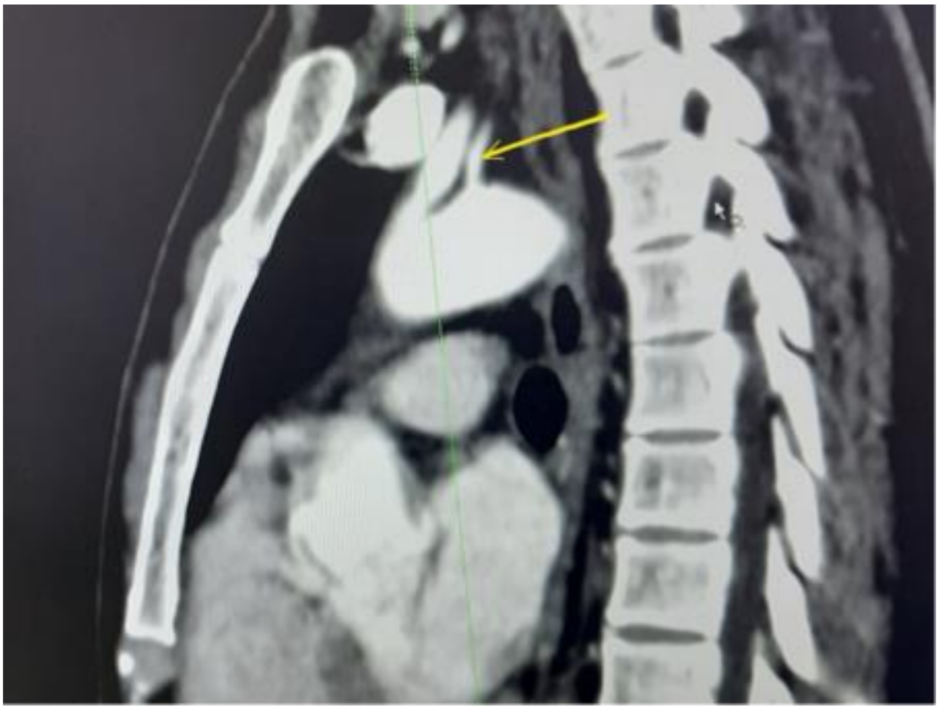

Figure 2: Abnormal origin of the left vertebral artery from the aortic arch.

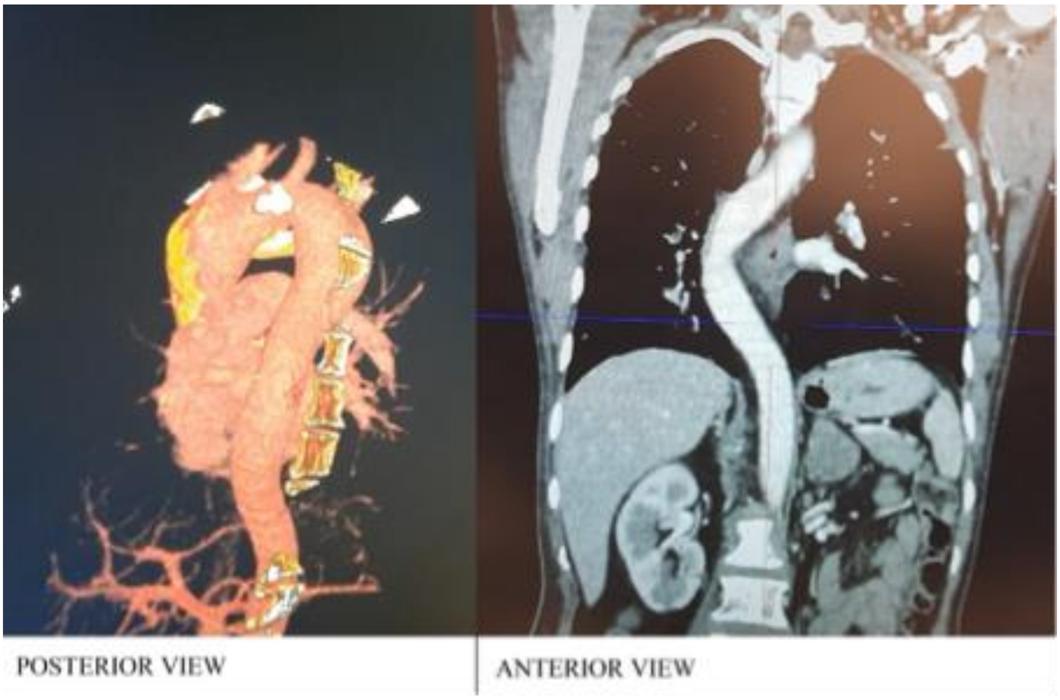

Figure 3: Right-sided aortic arch

Figure 4: Aberrant right subclavian artery (ARSCA)

Table 1: Summary of individuals and variations

	Number	Percentage		P value
Total	50	100%		-
Males	30	60%		-
Females	20	40%		-
Variations	20	40%	M -40% (12/30)	NS
			F – 40% (8/20)	P > 0.05
Bovine arch (BA)	14	28%	M -30%(9/30)	NS
			F – 25%(5/20)	P > 0.05
VAA	04	08%	M -6.7% (2/30)	NS
			F – 10% (2/20)	P > 0.05
BA + VAA	01	02%	M -3.3% (1/30)	NS
			F – 00% (0/20)	P > 0.05
RAA	01	02%	M -3.3% (1/30)	NS
			F – 00% (0/20)	P > 0.05
ARSCA	01	02%	M -00% (0/30)	NS
			F – 05% (1/20)	P > 0.05

Bovine arch (BA), right-sided aortic arch (RAA), left vertebral artery directly arising from the aortic arch (VAA), aberrant right subclavian artery (ARSCA), NS – Not significant

Discussion

The AA begins at the level of the manubriosternal joint anteriorly from the ascending aorta, and arches posteriorly to the left and ends at the level of the 4th thoracic vertebra (T4). From this level, it continues as the descending thoracic aorta. The branches of the AA arise from its outer convexity. The branches are the brachiocephalic trunk (BCT), the left common carotid artery (LCCA) and the left subclavian artery (LSCA).

BCT is the first branch of the aortic arch. It ascends to the level of the right sternoclavicular joint and divides into the right subclavian artery (RSCA) and the right common carotid artery (RCCA). The LCCA arises from the highest point of the outer convexity of the arch and runs upward and outwards towards the left sternoclavicular joint and continues as the cervical part of the LCCA. The LSCA arises from the aortic arch distal to the origin of the LCCA. It runs in a superolateral direction towards the upper thoracic aperture. Both the CCA are divided into external and internal carotid arteries in the neck. The internal carotid artery supplies the eye (via the ophthalmic artery), the frontal and the parietal lobes of the brain. The SCA gives off the vertebral artery (VA) as its first branch. The VA supplies the spinal cord, brainstem, cerebellum and the occipital lobe of the brain. SCA are also the source of blood supply to the upper limbs.

Development of the thoracic aorta and its branches

During the embryonic development of the aorta, two primitive aortas form on the ventral and dorsal sides of the foregut (ventral and dorsal aortas). The two ventral aortas join at the proximal end to form the aortic sac, while the rest of the ventral aorta remains as right and left aortic horns (Figure 5).

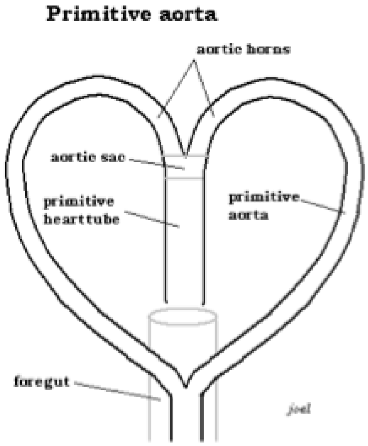

Figure 5: Primitive aorta

During further development, a series of arterial arches develop (in the pharyngeal arches), connecting the aortic horn with the dorsal aorta (Figure 6).

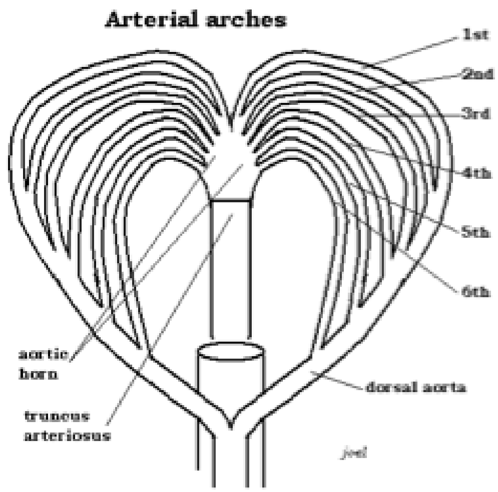

Figure 6: Pharyngeal arterial arches

During further development, some parts of the embryonic aorta and the arch arteries disappear, and the remaining parts unite to form the adult pattern of aorta and its branches in the following manner (Figure 7, Figure 8).

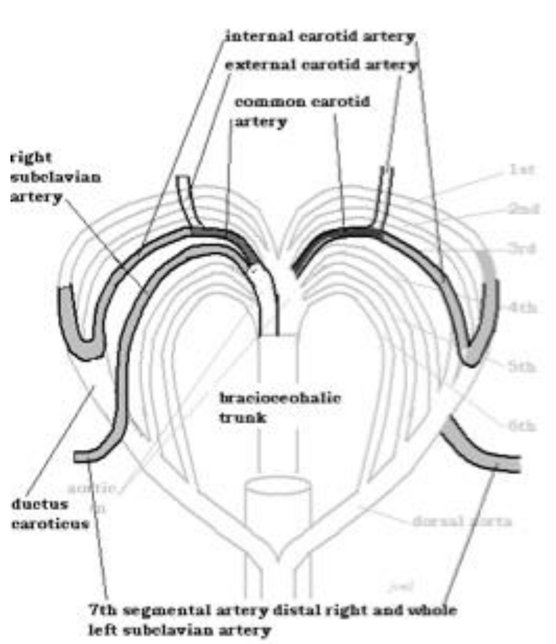

Figure 7: Development of adult pattern 1

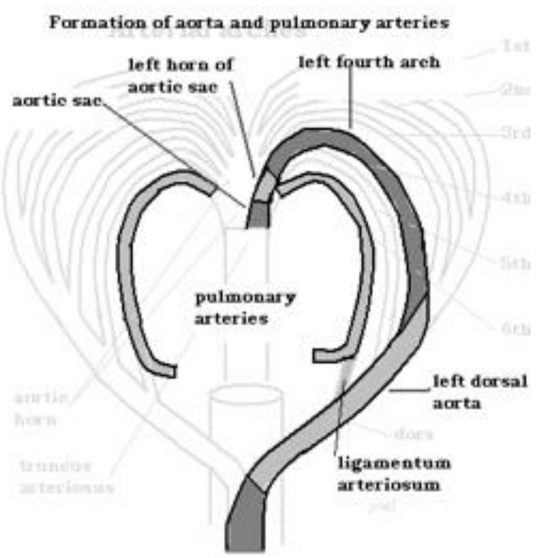

Figure 8: Development of adult pattern 2

1. Most of the 1st arch disappears, other than a small part that remains as the maxillary artery in the adult. Similarly, most of the 2nd arch also disappears, except for the part that forms the stapedial artery in adults.
2. The right aortic sac develops into the brachiocephalic trunk.
3. The proximal right and left 3rd arch arteries form the right and left common carotid arteries, respectively.
4. Both 3rd arches give rise to a bud which forms the external carotid artery.
5. Right 4th arch forms the proximal subclavian artery.
6. The part of the dorsal aorta between the 3rd and 4th arches (ductus caroticus) disappears completely.
7. The 5th arch disappears on both sides.
8. 6th arches form the pulmonary arteries. The remnant between the left 6th arch and the dorsal aorta forms the ductus arteriosus (ligamentum arteriosum) (Figure 8).
9. Formation of the aorta occurs in the following way by fusion of the following parts (Figure 8).
    a. Part of the aortic sac
    b. Left horn.
    c. Left 4th arch.
    d. Left dorsal aorta.

Variations in the disappearance of and the way the arterial components fuse in the embryo result in variations in the aortic arch and its branches in adults.

A meta-analysis has reported that the variations of the aortic arch branching patterns occur in 19.9 % of individuals. In our study population, it occurred in 40% of the individuals. This difference was statistically significant ($p < 0.05$) (2).

Common variations described in the literature include bovine arch (BA), Abnormal origin of the left vertebral artery from the AA, Aberrant right subclavian artery (ARSCA) and the right-sided AA (2).

Bovine arch (BA)

In BA, there is a common origin of the BCT and the LCCA from the aortic arch or both the common carotid arteries (CCA) arise from the BCT (Figure 1). This is the commonest variation described. The reported prevalence varies depending on the race and the country. The reported prevalence of this variation is 8% to 25% (3) (4). However human bovine arch does not exactly represent the true bovine arch present in cattle. In cattle, there is a single trunk that originates from the aortic arch. From this trunk, both subclavian arteries and a bi-carotid artery originate. The bi-carotid artery divides into the CCA (5).

In a large meta-analysis done in European countries, the BA was present in 13.6%. In the current series, the BA was found in 28% (2). This difference was statistically significant ($p < 0.05$).

BA is generally not associated with any clinical abnormalities. However, during procedures and surgeries on the aortic arch, it can lead to complications. In one meta-analysis, it was reported that BA was associated with increased ischemic and haemorrhagic complications during thoracic surgeries (2). In addition, studies have also shown that individuals with BA have a higher risk of aortic aneurysm formation (6). Some studies have also shown that individuals with BA have a higher risk of embolic stroke, probably due to altered hemodynamic stress caused by the variant anatomy (7). In addition, following stenting and other interventions for stroke the individuals with BA are more likely to develop complications (8).

Abnormal origin of the left vertebral artery from the aortic arch (VAA)

Usually, the left vertebral artery arises from the first part of the left subclavian artery. It joins with the contralateral vertebral artery to form the basilar artery and supplies the brainstem, cerebellum and the posterior part of the cerebrum.

The left vertebral artery develops as a branch of the 7th intersegmental artery that connects with the longitudinal anastomotic artery in the neck to form the adult vertebral artery. However, when there is a failure of regression of the sixth intersegmental artery, the left vertebral artery in adults originates directly from the aortic arch.

Abnormal origin of the left vertebral artery from the AA (VAA) occurred in 10% (5/50) of the individuals in this series (Figure 2). In another series of 266 individuals, the VAA occurred in 5.3% (14/266) (9). This difference is also statistically significant ($p < 0 .05$) in the current series.

Right-sided aortic arch (RAA)

Right-sided AA (RAA) arises as a result of the persistence of the right dorsal aorta and the disappearance of the left dorsal aorta during embryonic development. It occurs in 0.05% to 0.1% of the individuals (10). RAA was found in one male (2%, 1/50) in the current series

(Figure 3). RAA is associated with vascular rings and an abnormal origin of the left subclavian artery. RAA is also associated with various congenital abnormalities, i.e. congenital heart diseases like tetralogy of Fallot and truncus arteriosus. It is also associated with chromosomal abnormalities, i.e. DiGeorge syndrome (22q11). The patients with RAA can be asymptomatic or they can present due to associated congenital heart disease or with features of chromosomal abnormalities. Other patients present due to the effects of a vascular ring, resulting in compression of the airway or the oesophagus, i.e. with stridor and dysphagia (11) (12).

Aberrant right subclavian artery (ARSCA)

The right subclavian artery develops by the fusion of the right 4th branchial arch artery with the right 7th segmental artery. ARSCA develops when the right 4th arch disappears and the right dorsal aorta persists with the right 7th intersegmental artery. Therefore, in adults, ARSCA originates from the proximal part of the descending aorta and runs posterior to the oesophagus to reach the right side (Figure 4). The reported prevalence of ARSCA is 0.1% - 0.5% (13) (14). In the current series, the ARSCA was found in one female (2%, 1/50). ARSCA result in compression of the oesophagus, causing dysphagia (dysphagia lusoria).

Conclusions

This series shows that the variations of the aortic arch branching pattern occur in 40% (20/50) of individuals. Abnormalities in the branching pattern of the aortic arch are reported to result in increased complications during thoracic vascular surgical and interventional procedures. Therefore, the knowledge about the variations in the aortic arch branching pattern is essential for both surgeons and interventional radiologists. Furthermore, prior to any vascular intervention and thoracic surgeries, proper imaging and accurate interpretation are recommended to delineate the anatomy to prevent unwanted complications. The number of subjects included in this study is only 50. This number is not enough and in addition the ethnic variations also was not considered to predict the true prevalence of the AA branching pattern variations in Sri Lanka. Therefore, larger multicenter studies in Sri Lanka are recommended to determine the true prevalence of aortic arch branching variations.

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