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Original Research Article

MDCT Evaluation of Variations in branching patterns of aortic arch: Study of 830 Indian patients

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Abstract

Objectives: The aim was to determine the prevalence of various variations in the branching pattern of the aortic arch.
Material and Methods: 830 Indian patients were included in the study, who had undergone neck and chest CTbetween Dec 2015 and May 2016, with the exclusion of patients with congenital cardiac anomalies.
Results: Of 830 patients, 694 (83.6 %) patients were observed to have the classic three-vesseled branching pattern of the aortic arch, i.e. the brachiocephalic trunk, left common carotid artery and left subclavian artery arising from right to left, with brachiocephalic trunk further dividing into right common carotid and right subclavian arteries. Variations in branching pattern were seen in the remainder 136 (16.3 %) patients. It was also noted that out of the 136 patients with variant branching patterns, 91 (66 %) were females, and the rest were males. The most common variation was the origin of the left common carotid artery from the brachiocephalic trunk, i.e. two-vesseled arch, which was observed in 79 (9.5 %) cases. In 26 (3.1 %) cases, four-vesseled arch was seen, which is direct origin of left vertebral artery from the aorta.5 (0.6 %) patients had aberrant right subclavian artery.
Conclusions: Variations in the branching pattern of the aortic arch are quite common. It is especially important that head and neck surgeons and interventional radiologists should be aware of these aortic arch variations. Contrast-enhanced CT imaging is a reliable method for demonstrating anatomical features and variations of the aortic arch.
Keywords: Arch of aorta, aortic branches, CT

1. Introduction

The classical anatomical configuration consists of left-sided aortic arch, with its three major branches: the brachiocephalic trunk, the left common carotid artery and the left subclavian artery, from right to left. The brachiocephalic trunk further branches into right subclavianand right common carotid artery. This branching pattern, described as “normal”, occurs in 64.9–94.3% of the cases [1-6]. Variations in aortic arch branching pattern range from differences in the origins of its various branches to differences in the number of its branches [2, 4].

The aorta develops during the third week of gestation, with six pairs of aortic arches developing between the ventral and dorsal aorta. The various variations in the branchingpattern of the aortic arch can be explained by persistence of segments of the aortic arches that normally regress or disappearance of segments that normally remain, or both [1, 5, 6].

Anatomical variations in the branching pattern of the aortic archare interesting from anatomical and embryological aspect. They are, however, more important for thoracic operations (especially in vascular, cardiac, esophageal and mediastinal surgeries) and various procedures of interventional radiology.

1.1 Aims and Objectives:

1) To describe the CT appearance of various anatomical variations in branching pattern and position alterations of the aortic arch and to determine their prevalence in 830 Indian patients.
2) To determine gender differences in the distribution of these variations.

2. Material and Methods

830 consecutive patients that underwent CT imaging of the neck and/or chest for different purposes were examined retrospectively. The examinations evaluated belonged to 490 males and 340 females, who had undergone CT imaging during a 6-month period between Dec 2015 and May 2016. The age range was 15 to 65 years. There was nosignificant age difference between male and female patients.

2.1 Exclusion criteria

Patients with congenital cardiac anomalies were excluded from this study.

2.2. CT Protocol:

CT examinations were carried out in the Radiology department of LTMGH, Sion, Mumbai (Maharashtra, India), on a Philips Brilliance 64 –Slice MDCT scanner V.2.6, (Philips Healthcare, Netherlands). The standard CT protocol of neck or chest imaging was followed. During examination, an 18–20 gauge angiocatheter in the antecubital vein was used to inject 50-60 ml of nonionic iodinated contrast media using bolus-tracking method with an automatic injector at a rate of 3 ml/sec. The region of interest was positioned at the aortic arch, and the threshold was set to 130 HU. When the threshold was surpassed, helical scanning was automatically initiated. Scan parameters were 120 kV, 300 mA, and 420 msec rotation time with a slice thickness of 1 mm.

2.3. Image Analysis

The obtained axial images from CT examinations were transferred to the work station (Philips Brilliance Workspace Portal 2.6.1.5) for analysis. Axial source data images, multiplanar reformat images, and post-processed (maximum intensity projection and 3D volume rendered) images were also evaluated in Aquarius iNutrition viewer Ver. 4.4.11 (Terarecon. Inc). Image analysis was performed by a radiologist experienced in CT analysis.

3. Results

Eight hundred and thirtypatients without any congenital cardiac anomalies (490 males and 340 females, age range 10 - 65 years) were included in this study.

Of 830 patients, 694 (83.6 %) patients (445 males and 249 females) were observed to have the *classic three-vesseled branching pattern* of the aortic arch, i.e. the brachiocephalic trunk, left common carotid artery and left subclavian artery arising from right to left, with brachiocephalic trunk further dividing into right common carotid and right subclavian arteries. (Figure 1)

Fig. 1 (a)

Fig. 1 (b)

Figure 1: Coronal MIP (a) and 3-D volume rendered (b) images show the "classical three-vesseled arch", with the brachiocephalic trunk (white arrow head), left common carotid artery (white arrow) and left subclavian artery (white curved arrow)

The remainder 136 (16.3 %) patients (45 males, 91 females) showed various variations in branching pattern of the aortic arch.

The most common variation was the origin of the left common carotid artery from the brachiocephalic trunk, *i.e. two-vesseled arch*, which was observed in 79 (9.5 %) cases. (31 males and 48 females) (Figure 2).

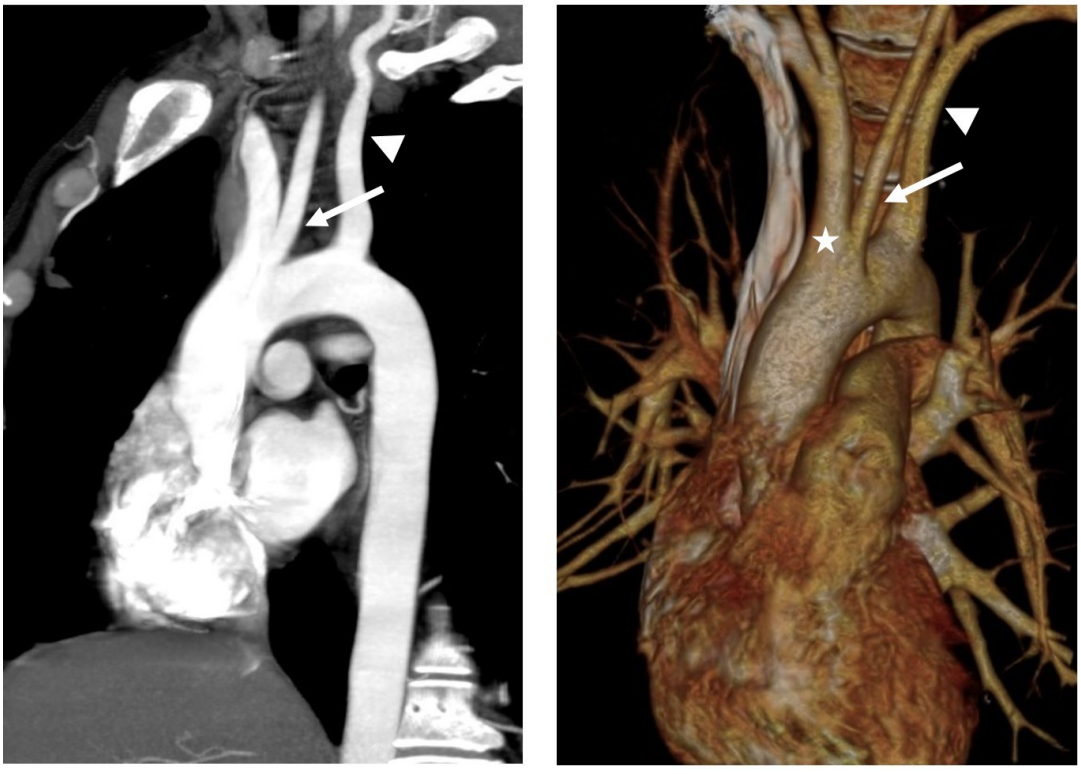

Fig. 2 (a) **Fig. 2 (b)**

Figure 2: Obliquecoronal MIP (a) and 3-D volume rendered (b) images demonstrate "two-vesseled arch", with the left common carotid artery (white arrow) arising from the brachiocephalic trunk (white star) (white arrow head, left subclavian artery).

In 26 (3.1 %) cases, it was seen that the left vertebral artery originated directly from the aortic arch between the origin of the left common carotid and left subclavian artery, i.e. *four-vesseled arch*. (Figure 3).

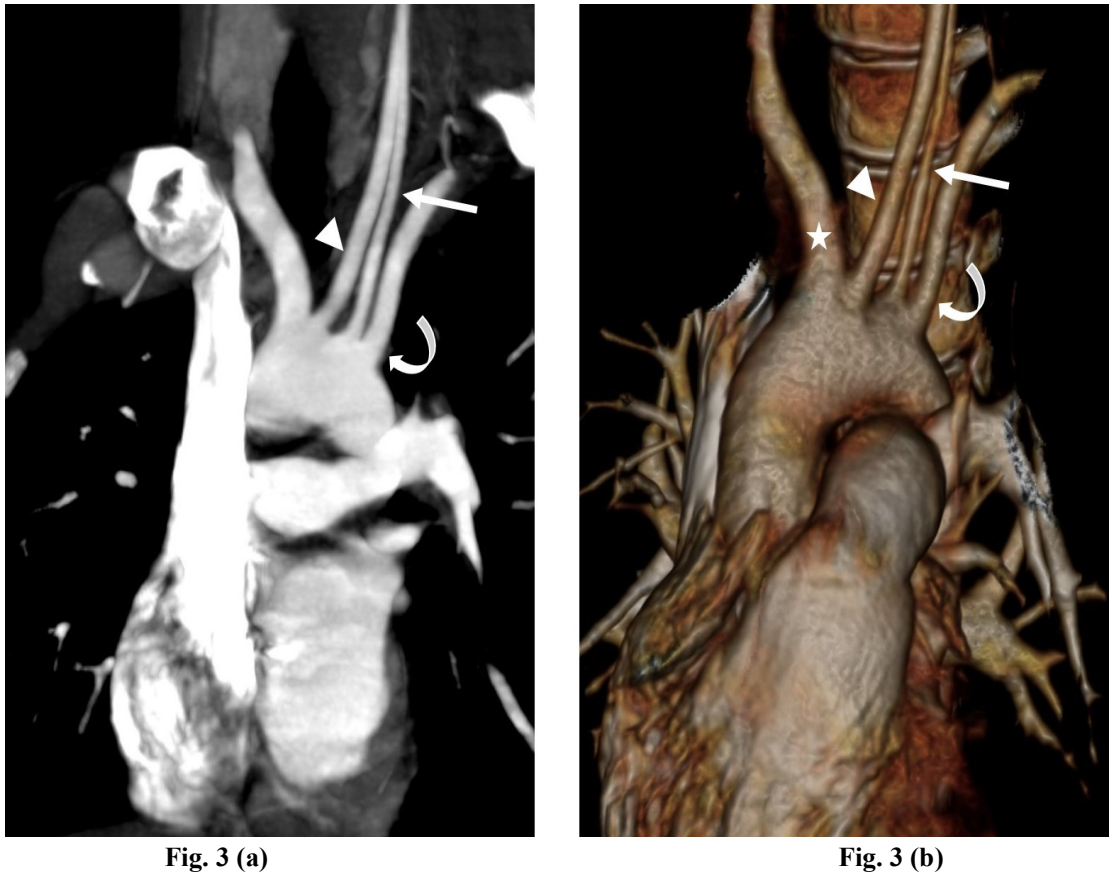

Fig. 3 (a) **Fig. 3 (b)**

Figure 3: Obliquecoronal MIP and 3-D volume rendered images demonstrate "four-vesseled arch", with the left vertebral artery (white arrow) originating from aortic arch between the left common carotid artery (white arrow head) and left subclavian artery (white curved arrow) (white star, brachiocephalic trunk).

Five (0.6 %) patients (1 male, 4 females) had *aberrant right subclavian artery*, arising distal to the left subclavian artery as the left-most branch of the aortic arch and traversing to the right, posterior to the esophagus. (Figure 4)

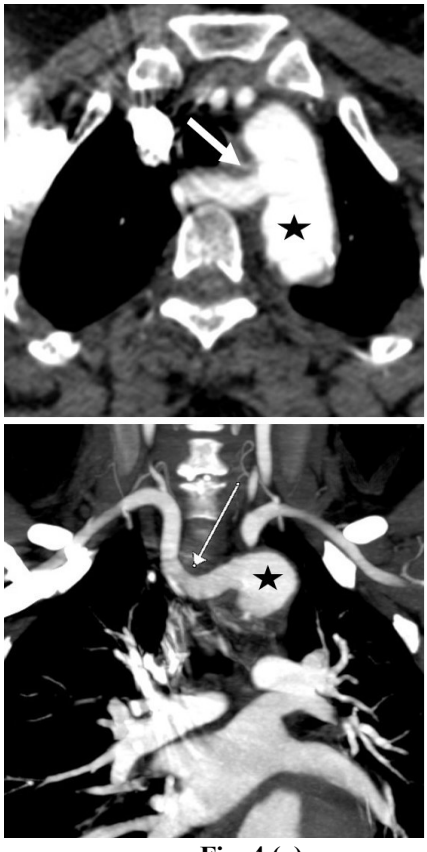

Fig. 4 (a)

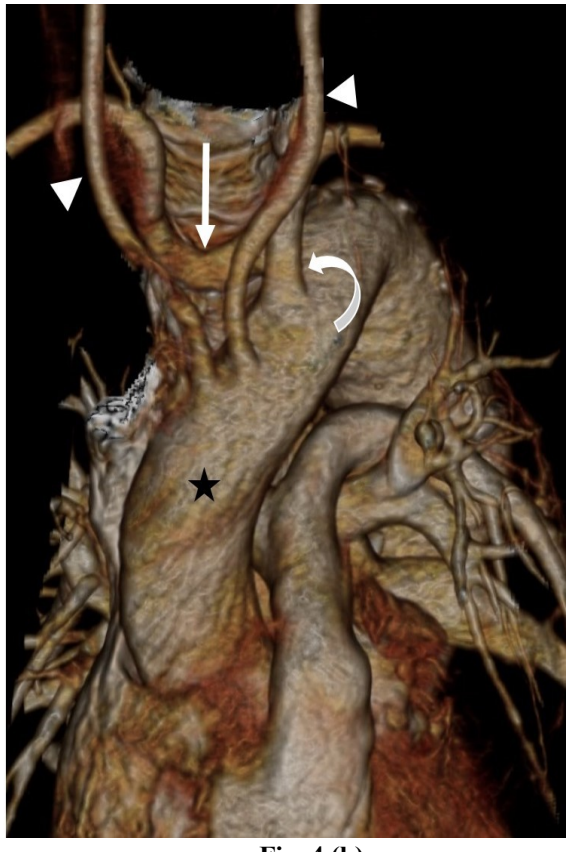

Fig. 4 (b)

Figure 4: Axial and coronal MIP images (a) and 3-D volume rendered images (b) demonstrate the aberrant right subclavian artery (white arrow) originating as the last branch of the aortic arch (black star) and coursing to the right behind the esophagus (white arrow heads, right and left common carotid arteries; white curved arrow, left subclavian artery).

A 15-year old patient had a right aortic arch, with *mirror-image branching* pattern, seen as right subclavian artery, right common carotid artery and left brachiocephalic trunk arising the aortic arch from right to left, with the left brachiocephalic trunk further dividing into the left common carotid and left subclavian arteries. (Figure 5)

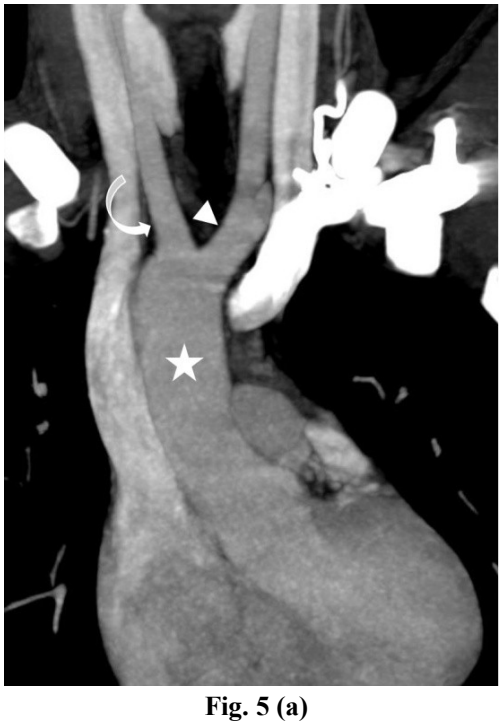

Fig. 5 (a)

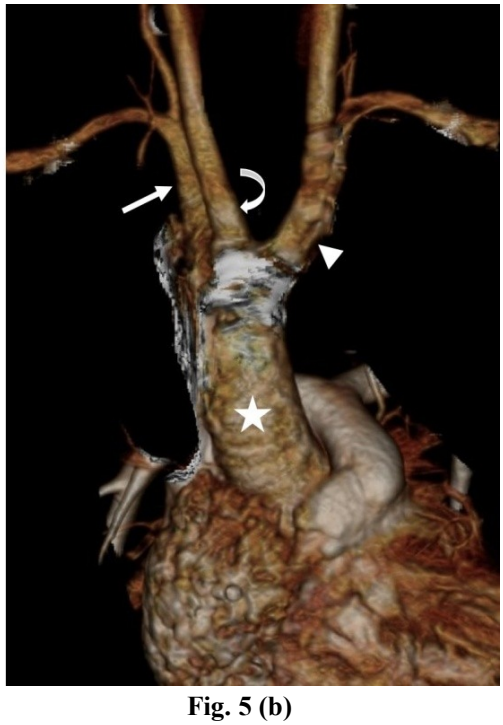

Fig. 5 (b)

Figure 5: Coronal MIP (a) and 3-D volume rendered (b) images demonstrate the right aortic arch (white star) with mirror-image branching (white arrow, right subclavian artery; white curved arrow, right common carotid artery; white arrow head, left brachiocephalic trunk).

One patient was seen to have both, an aberrant right subclavian artery and left vertebral artery originating directly from the aortic arch, which could be called *a 'five-vesseled arch',* with the right common carotid artery, left common carotid artery, left vertebral artery, left subclavian artery and right subclavian artery seen arising from the arch sequentially from right to left.(Figure 6)

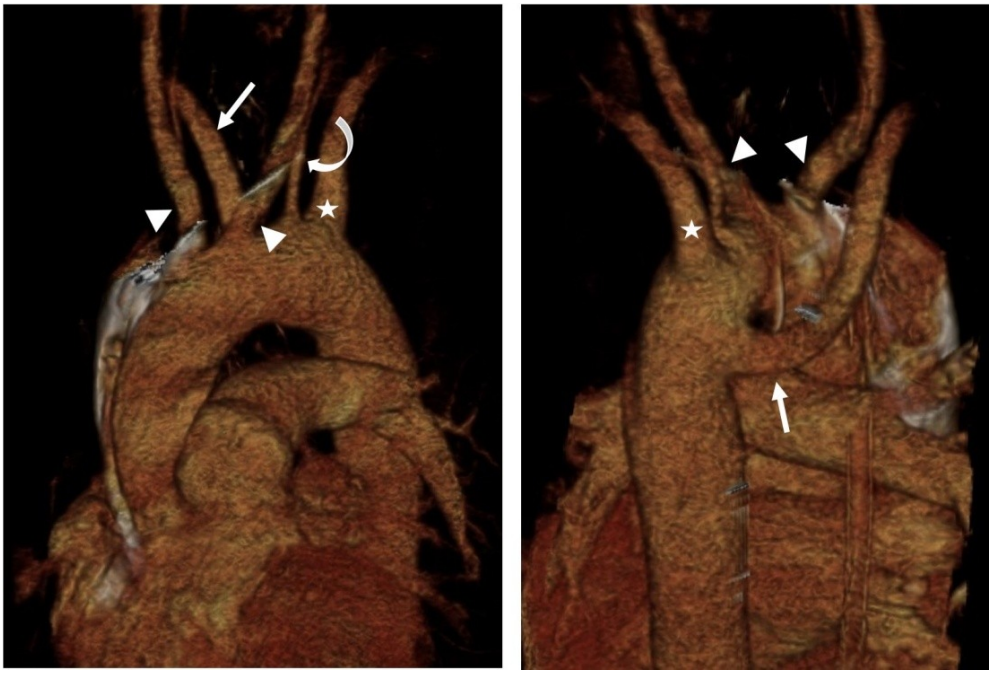

Fig. 6 (a) **Fig. 6 (b)**

Figure 6: 3-D volume rendered images [anterior view (a); posterior view (b)] demonstrate the right and left common carotid arteries (white arrow heads), left vertebral artery (white curved arrow), left subclavian artery (white star) and right aberrant subclavian artery (white arrow) originating sequentially posteriorly from the aortic arch.

Another patient was noted to have a combination of the two-vesseled arch and left vertebral artery arising directly from the arch, *i.e. a variant three-vesseled arch*. (Figure 7)

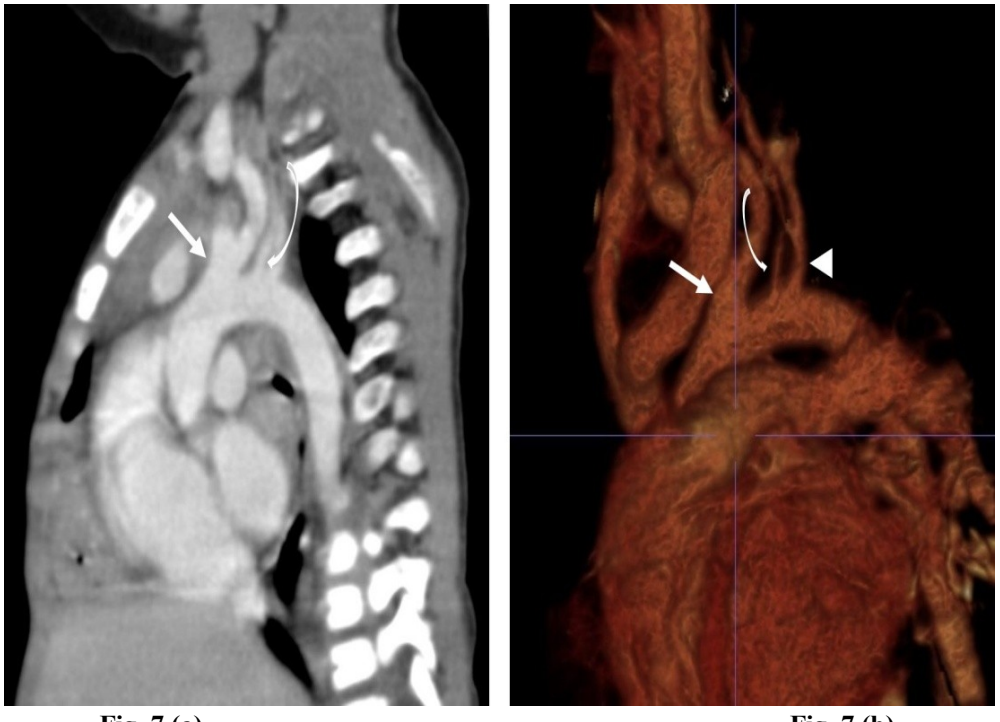

Fig. 7 (a) **Fig. 7 (b)**

Figure 7: Obliquecoronal MIP (a) and 3-D volume rendered (b) images demonstrate combination of left common carotid arising from brachiocephalic trunk (white arrow), with left vertebral artery (white curved arrow) arising directly from aortic arch (white arrow head, left subclavian artery)

It was also noted that out of the 136 patients with variant branching patterns, 91 (66 %) were females, and the rest were males.

4. Discussion

The present study revealed that the "classical three-branch pattern" of the aortic arch was observed in 83.6 % patients, while 16.3 % patients showed various variations.

The various variations of the aortic arch and its branches arise as a result of altered development of primitive aortic arches, and can be explained as occurring due to persistence of segments of the arches that normally regress or disappearance of segments that normally remain, or both [7, 8].

The variations in aortic arch branching pattern that were observed in our study were of 6 types:

1) The most common variant was origin of the left common carotid artery from the brachiocephalic trunk, *i.e. two-vesseled arch*, which was observed in 9.5 % cases.

In this branching pattern, the left common carotid artery arises as the first branch of the brachiocephalic trunk, which further divides into the right common carotid and right subclavian arteries. The left subclavian artery arises as a separate branch of the aortic arch.

This variant has an incidence of 10–22% in the literature and was earlier called 'bovine aortic arch'.

Embryological basis:

Normally, aortic sac bifurcates into right and left limbs. The left limb of the aortic sac forms the part of arch that intervenes between the origins of the brachio-cephalic trunk and left common carotid artery. If the aortic sac fails to bifurcate, the brachio-cephalic trunk and the left common carotid arteries will connect to aortic sac directly, resulting in bifurcated trunk or common trunk giving origin to left common carotid artery [6, 9].

2) Origin of the left vertebral artery directly from the aortic arch, *i.e. four-vesseled arch*, was observed in 3.1 % cases.

In this branching pattern, the brachiocephalic trunk (which further divides into right common carotid and right subclavian arteries), the left common carotid artery, the left vertebral artery and the left subclavian artery arise from the aortic arch, from right to left.

This variant has a reported prevalence of 2.4 to 8% in literature [10, 11].

Embryological basis:

Normally, the first part of vertebral artery develops from the dorsal ramus of the seventh intersegmental artery. The direct origin of the left vertebral artery from the aortic arch can be explained by the fact that vertebral artery develops from the persistent sixth cervical intersegmental artery and intervening segment of dorsal aorta fails to disappear, so blood flows through these persisting routes. It is hypothesized that anomalous origins of the vertebral arteries lead to altered hemodynamics and predispose the patient to the formation of intracranial aneurysms.

3) An *aberrant right subclavian artery* was observed in 0.6 % patients.

In this branching pattern, the brachio-cephalic trunk forms only the right common carotid artery, while the right subclavian artery arises from the aortic arch distal to the origin of the left subclavian artery. It then traverses to the right posterior to the esophagus, where it may be a cause of dysphagia in some patients (dysphagia lusoria).

The percentage range of this variant in the literature is between 0.13% and 25%.

Embryological basis:

Normally, the proximal segment of the right subclavian artery is formed by the fourth aortic arch, while its distal part is formed by a portion of right dorsal aorta and the seventh intersegmental artery [12]. Aberrant right subclavian artery occurs when the right subclavian is developed from the right seventh intersegmental artery and part of right dorsal aorta caudal to intersegmental artery, associated with disappearance of the right fourth arch [13]. In addition, the right vertebral artery in these instances may arise from the right common carotid artery.

All of the cases in our study were asymptomatic and the aberrant right SCA was observed incidentally. In all of the cases, the aberrant right SCA passed behind the esophagus.

4) *Right aortic arch* is an uncommon anatomical anomaly, which was observed in one patient in our study.

In this aortic arch variation, the arch and the descending thoracic aorta lie on the right of the mediastinum. Its prevalence is noted to be <0.1% in previous literature [14].

All the variations described above could also occur in a right-sided aortic arch.

Embryological basis:

Right-sided aortic arch results from the persistence of the right fourth branchial arch [5]. The most common type is right aortic arch with an aberrant left subclavian artery. This type is rarely associated with congenital heart disease. Right aortic arch with mirror-image type is almost always associated with congenital heart disease, especially the cyanotic type [14].

The patient with right aortic arch in our study had mirror-image branching pattern, however, no known congenital cardiac disease.

5) A combination of any of the above variants could also occur.

In the current study,

- One patient showed both, direct origin of left vertebral artery (variant 2) and right aberrant subclavian artery (variant 3). In this branching variant, right common carotid artery, left common carotid artery, left vertebral artery, left subclavian artery and right subclavian artery were seen arising from the arch of aorta, sequentially from right to left.
- Another patient was noted to have a combination of left common carotid artery arising from brachiocephalic trunk (variant 1) and left vertebral artery as a direct branch of the aorta (variant 2)

Various aortic arch branching variations have great clinical significance --

- A double or a right-sided aortic arch, then a common stem of the right and left common carotid arteries, a left or a double brachiocephalic trunk, or a retro-esophageal aberrant right subclavian artery, may cause a compression of the trachea and/or esophagus, with resultant dyspnea, cough, recurrent respiratory infections, and dysphagia [9, 11].
- An anomalous origin of a common carotid artery and, especially, a common trunk of the bilateral common carotid arteries, or an aberrant vertebral artery, have been found to be associated with a higher incidence of cerebrovascular disorders [15,16].
- Thrombosis of a retro-esophageal aberrant subclavian artery may cause acute ischemia of the upper limb [17]. The arterialusoria is also important in oesophageal surgery.
- The aortic origin of some aberrant vessels, such as the internal thoracic, thyroid, or coronary arteries, may also have certain clinical implications.
- Similarly, a left brachiocephalic trunk or a longer brachiocephalic trunk that also inclines to the left, as well as the common carotid arteries, thyroideaima artery, and similar aberrant vessels, may extend in front of the trachea above the sternum, which may be injured during various procedures like tracheostomy, thyroid resection, laryngeal transplantation, mediastinoscopy, etc. [18].
- An aberrant origin of right vertebral artery arising from the right common carotid artery can be lacerated during thyroid or anterior cervical spine surgery [18, 19].

In general, we noticed the majority of the supra-aortic variations described thus far in various literatures. We did not, however, observe a common stem origin of the right and left common carotid arteries or of the right and left subclavian arteries, some other origin types of the vertebral arteries, nor the aortic origin of some other aberrant vessels, e.g. the internal thoracic, thymic, or left coronary arteries [6, 20]. The mentioned differences can be explained, among others, by some national and racial features or environmental circumstances [4, 20].

In symptomatic patients, various techniques of vascular surgery can be employed for the treatment: division of a vascular aortic ring, transposition and reimplantation of certain arteries, angioplasty, endovascular grafts, stent placement, bypass grafting, etc. Radiologists may have a dual role in diagnosis (by angiography, multi-slice CT imaging) and management (catheterization and trans-catheter coil occlusion), of the aberrant arteries and their associated complications [20].

5. Conclusion

Thus, variations in the branching pattern of the aortic arch are not rare. Most of them are asymptomatic and usually found as an incidental finding during routine diagnostic procedures. However, it is important that head and neck surgeons and interventional radiologists be aware of the various possible aortic arch variations. Identification of these vascular variations before diagnostic interventions is crucial in order to avoid complications. CT imaging using contrast in arterial phase is a reliable imaging method for demonstrating anatomical features and variations of the aortic arch. Non-recognition of certain aberrant aortic arch branches at surgery may have fatal consequences [20].

Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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