Computed Tomographic Analysis of Aortic Arch Branching Patterns - Revisited

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Abstract

Background /Objectives

Branching pattern of aortic arch (AA) has a direct impact on the outcome of thoracic surgical and angiographic procedures. Geographical variations in the branching pattern of AA has been described. Hence, this descriptive cross sectional study describes the AA variations in a Sri Lankan population compared to the available global statistics.

Methods

Contrast-enhanced computed tomographic studies (CTC) of thorax (n=219) performed in males (49.3%) and females (50.7%); aged 59±17 years (range: 4 to 96 years), were evaluated. Branching patterns of AA were categorized into seven types as described by Popieluszko et al.

Results

Four AA types were identified in the study population: Type 1 (90%; n=197), Type 2 (n=10, 4.6%), Type 3 (n=8, 3.7%) and Type 6 AA (n=4; 1.8%). The prevalence of AA variations was 10%.

Type 1 was the most prevalent pattern in both genders: female-91%; males-88.9%. The most prevalent AA variant in females was Type 2 (n=6; 5.4%); males Type 3 (n=5; 4.6%). However, the branching pattern of AA has not demonstrated a significant gender influence (Odds: 0.792; 95% CI: 0.327 - 1.917; p=0.605).

Conclusion

Variations in branching pattern of AA is as high as 10% among Sri Lankans. Thus, an in-depth knowledge on population specific prevalence of AA variants would influence the modifications surgical approaches and the choice of angiographic catheters to be utilized, which in turn, would minimize inadvertent vascular injuries during thoracic surgical and angiographic interventions.

Introduction

The aortic arch (AA) is an arcuate shaped vascular segment that connects the ascending and descending aortic segments. It has unique anatomical and functional significance due to its perfusion territory in the head, neck, and upper limbs. The typical branches of AA include the brachiocephalic trunk, left common carotid, and left subclavian arteries. Nevertheless, numerous developmental aberrations in the branching pattern of AA have been described [1]. Malformations or normal variations of AA are typically developmental in origin in the first trimester of intrauterine life due to abnormalities in the involution of fetal aortic arches. Out of six pairs of aortic arches developed from the ventral and dorsal aortae, the fifth pair completely disappears in the foetal life. The remaining arches differentiate into different arteries that supply the head, neck, upper limbs and lungs after birth. Typically, the left fourth aortic arch differentiates into the adult AA [2, 3].

Although many AA variations are asymptomatic, they have the potential to create a devastating outcome during thoracic, vascular angiographic procedures [1]. These minimally invasive diagnostic and therapeutic angiographic procedures are performed using an angiographic catheter introduced through a peripheral artery by avoiding invasive thoracotomy. This catheter is manipulated into the indexed artery (selective arterial catheterization) under fluoroscopy. The outcome of selective arterial catheterization and interventional procedure depends on the operator skills and the branching pattern of indexed arterial territory. It has been shown that the branching pattern of AA has a strong association with the complication rate of an angiographic procedure. Therefore, to reduce the complications and improve the outcome, many angiographic catheter types have been introduced to suit different AA branching patterns. Moreover, a suitable catheter has to be selected considering the vascular anatomy of the index region [4].

Similarly, the AA anatomy is crucial for a successful thoracic surgical outcome. Inadvertent vascular injuries that happened during thoracic surgeries have been reported among patients with undiagnosed anatomical variations of AA. In patients with AA anatomical variants, vascular complications have been prevented by modified surgical techniques, such as hemiarch replacement surgery [1, 4–7]. All these factors emphasize the significance of knowing AA anatomy and its variations in a population.

Computed tomographic angiography is a less invasive technique than digital subtraction angiography (DSA) while retaining excellent anatomical data. Apart from showing exquisite anatomical details on aortic branches and their variants, pathologies can also be accurately studied with computed tomography [8]. Computed tomographic images provide better vascular morphometric evaluation than DSA. The main disadvantage of computed tomography over DSA is the inability to perform real-time angiographic interventions [9, 10]. Thus, using contrast-enhanced thoracic computed tomography (CT) to evaluate AA vascular anatomy is fully justified.

The typical branching pattern of the AA is observed in the majority, while different anatomical variations in a minority of the population. However, a diverse impact has been described from different AA variants on surgical and angiographic outcome [9–12]. Considering the geographical and ethnic distribution of prevalence of variation in the anatomy of AA, the knowledge on population-specific knowledge would improve the overall outcome of arterial disorders [7, 9–12]. However, to the best of the authors' knowledge, data on the branching pattern of AA is not available for the Sri Lankan population. Therefore, this study was aimed to describe the branching patterns of AA using contrast-enhanced CT scans of the thorax in a group of Sri Lankan population. Furthermore, to compare the local prevalence rates with that of other populations.

Methods

This cross-sectional, observational study was conducted at the Departments of Radiology, Teaching Hospitals Rathnapura and Karapitiya, from July to September 2019. The study retrospectively evaluated the branching pattern of the arch of aorta (AA) using two hundred and nineteen (n = 219) contrast-enhanced computed tomographic (CT) studies of the thorax. As evaluated by previous medical records and CT studies of the subjects with a history of thoracic-vascular surgeries were excluded. The age and gender of the study subjects were recorded.

Computed tomographic (CT) image assessment procedure

Two hundred and nineteen (n = 219) contrast-enhanced CT scans of the thorax, which were performed to investigate suspected lung-pathology, were studied. Sample size was calculated by using Lameshow formula. These CT examinations were performed using Phillips Brilliance 64 scanner, adhering to the standard protocol [20]. CT images were reconstructed three-dimensionally (3D), and in axial, sagittal, coronal planes were evaluated by two experienced Radiologists (DG & SV) to record the vascular anatomy of AA. The assessment quality was maintained by excluding any CT study with considerably low image quality - CT studies with inadequate contrast within the arch of the aorta; motion artefacts; image degradation for any anatomical or technical reasons.

Definition of the type of arch of the aorta according to branching patterns

Anatomy of the arch of the aorta (AA) was classified into seven types according to the branching patterns, as stated by Popieluszko et al. [7] as follows:

Type 1 aortic arch: typical branching pattern with three branches arising from the AA - brachiocephalic trunk (BCT), left common carotid artery (LCCA) and left subclavian artery (LSA).

Type 2 aortic arch (bovine arch): only two branches arise from the AA – a common origin for BCT and LCCA, and LSA.

Type 3 aortic arch: four branches from the AA – BCT, the left vertebral artery (LV) directly originates from the AA in between LCCA and LSA branches.

Type 4 aortic arch: three branches from the AA - common origin for BCT and LCCA, LV and LSA.

Type 5 aortic arch: three branches from the AA - right subclavian artery (RSA), right CCA (no BCT), a common trunk for LCCA and LSA.

Type 6 aortic arch: four branches from the AA – right CCA, LCCA, LSA, aberrant right subclavian artery arises from the AA as the last branch.

Type 7 aortic arch: right-sided AA with three branches – BCT, right CCA, RSA.

The prevalence of AA types in the study population was compared with previously published studies [7,11, 13-,15, 17].

Statistical analysis

Following a preliminary assessment for normality, parametric data analysis was performed. Groups were compared using a single sample T-test; the significant value is considered as $p < 0.05$. Binary logistic regression was performed to analyze the gender influence on AA variations.

Results

This study has evaluated the vascular anatomy of AA using two hundred and nineteen (n = 219) contrast-enhanced CT scans of the thorax of adult males (49.3%; n = 108) and females (50.7%; n = 105), who were aged 59 ± 17 years. The age range of the study group was 4 to 96 years. The mean age of males was 61 ± 15 years, and females were 56 ± 18 years.

Table 1 describes the branching patterns of the AA for the study population. Type I (standard) AA branching pattern (Fig. 1) was present in 90% (n = 197) of the study population. The prevalence of variations in the branching patterns was 10% (n = 22). Type 2 AA (n = 10, 4.6%), the most common variant identified (Fig. 2), was closely followed by type 3 (Fig. 3) branching pattern (n = 8, 3.7%). Type 6 arch (aberrant right subclavian artery; Fig. 4) was found only in 4 subjects (1.8%), of whom the right subclavian artery has arisen from the AA as the last branch and traversed posterior to the oesophagus (100% retro-oesophagal course) to reach the right side of the body.

Table 1
Aortic arch types and their distribution in the study population

Arch type	Branches arising from the aorta	Number of subjects	Percentage
Type 1	BCT, LCCA, LSA	197	90%
Type 2	Common origin of BCT & LCCA, LSA	10	4.6%
Type 3	BCT, LCCA, LVA, LSA	8	3.7%
Type 4	Common origin for BCT and LCCA, LV and LSA	0	0%
Type 5	RSA, RCCA, common origin for LCCA and LSA	0	0%
Type 6	RCCA, LCCA, LSA, RSA	4	1.8%
Type 7	RAA with or without mirror image branching	0	0%
(BCT-brachicephalic trunk; LCCA- left common carotid artery; LSA-left subclavian artery; LVA- left vertebral artery; RSA-right subclavian artery)			

Table 2 describes the distribution of branching pattern in male and female study populations. Type 1 arch (standard pattern) was identified in 91% (n = 101) of females and 88.9% (n = 96) of males. The female group had type 2 AA as the most common variant, whereas the type 3 arch was the most common among males. However, the absence of gender influence on the branching pattern of AA was confirmed by the binary logistic regression analysis (Odds: 0.792; 95% CI: 0.327–1.917; p = 0.605).

Table 2
Aortic arch types according to the gender

	Male (n = 108)		**Female (n = 111)**	
Arch type	Number	Percentage	Number	Percentage
Type 1	96	88.9%	101	91%
Type 2	4	3.7%	6	5.4%
Type 3	5	4.6%	3	2.7%
Type 4	0	0%	0	0%
Type 5	0	0%	0	0%
Type 6	3	2.8%	1	0.9%

Table 3 compares the variations in the branching pattern of AA among different geographical regions. Geographical variation was evident on AA anatomy since the current study findings were comparable with the prevalence rates of the nearest geographical region - South-East Asia. However, Type 1 AA was the most prevalent arch type irrespective of the geographical region, while Type 2 was the most common variation.

Table 3
Population variations in branching pattern of the aortic arch

Study population		**Type of the aortic arch**						
		Type 1	**Type 2**	**Type 3**	**Type 4**	**Type 5**	**Type 6**	**Type 7**
Present study		90%	4.6%	3.7%			1.8%	-
Global population (7)		80.9%	13.6%	2.9%			0.7%	-
Asia		86.9%	7.4%	3.5%			-	-
Asia: SE	India (13)	91.4%	4.8%	1.6%			-	
	India (14)	92.7%	2.7%	1.8%			-	-
Asia: East	China (11)	83.8%	9.6%	5%			0.9%	-
Asia:West	Iran (15)	84.9%	12.4%	0.9%			1.8%	-
Africa (7)		65.2%	26.8%	2.3%			1.4%	-
Europe (7)		82%	13.6%	2.3%			0.8%	-
North America (7)		87.4%	15.5%	1.9%			1.1%	-
South America (7)		69.5%	24.2%	3.9%			0.2%	-

Discussion

The aortic arch (AA) branches vascularize the vital structures in the head, neck and upper limbs, including the brain [1, 7]. The anatomy of AA has become a well-accepted research topic due to many reasons, such as the significant clinical implications of the perfusion territory and the geographical variation in branching pattern [7, 14, 18, 19]. As a pioneer study, this study has evaluated the branching pattern of AA in a selected Sri Lankan population (using contrast-enhanced CT scans of the thorax) and compared the AA anatomy with available data from other communities. Ninety per cent (90%) of the study population was found to have the standard (Type 1) aortic arch branching pattern with brachiocephalic trunk (BCT), left common carotid (LCCA), and left subclavian (LSA) arteries arising from the AA. Type 2 AA (bovine variant) with a common origin for BCT and LCCA was the most common variant (4.6%) observed. Type 4, 5 or 7 arches were absent in the study group. Despite minor variations among males and females, no gender variation was appreciated in the branching pattern of AA.

Further re-instating the geographical distribution in AA anatomy, the AA anatomy of the index population was closely followed by that of the nearest geographical region - the Indian population [15–17]. However, few Indian studies have reported much higher prevalence rates in AA variations (36.5%; n = 52 [8]; 36.67% n = 30; [19]. Anyhow, the small sample size of these cadaveric studies needs to be considered seriously upon generalizing the findings [8, 19]. Additionally, the global prevalence of AA variations calculated from pooled data was higher than reported by the current study. Compared to the global prevalence, previous studies have also reported a low prevalence of AA variations for Asian, European and North American populations [7]. In contrast, arch variations have been reported more frequently in African (65.2%) and South American (69.5%) populations [7, 20].

Although seven types of AA have been described previously, only four types were found in the study population [7]; Type 4, 5 and 7 arches were not reported in the study group. The current study agrees with many previous studies by reporting Type 2 AA as the most prevalent arch variant [4, 7, 8, 12, 14, 15, 19–21]. However, Qiu et al. (n = 120) in a cadaveric study have reported type 3 AA (left vertebral artery directly arising from the AA; 7.5%) as the most prevalent anomaly [11]. However, the global prevalence of type 3 arch was as low as 2.9% (95% CI, 1.7–4.3) [7]. Type 7 arch (right side aortic arch) was the least common AA variant reported globally (0.2%) as well as for Asians (0.2%) [7].

As described earlier, type 2 AA was the most prevalent variant for many populations [7, 14–16, 19–21]. The prevalence of type 2 AA for the study population (4.6%) was lower than the global values (13.6%). In some geographical regions, such as Africa and South America, type 2 AA was found in nearly one-fourth of the population [7]. Importantly, type 2 AA has shown a positive association with aortic dilatation and dissection. Also, in aortic dissection, the prognosis of patients with type 2 AA was poor [7, 14]. Increased flow velocity in AA due to fewer branches, as seen in the type 2 arch, is the postulated pathophysiology for increased morbidity and mortality in aortic dissection [7]. Another major clinical significance in the AA variant would be the potential surgical complication during thoracic surgeries, mainly if the variant were not diagnosed previously [7]. Thus, even 4.6% of prevalence rates reported in the study population warrants serious consideration.

Type 6 arch (AA with right aberrant subclavian artery) is also an arch variant with significant clinical implications. The prevalence of type 6 AA reported for the study population (1.8%) was higher than the global prevalence (0.7%. 0.2–1.5) [7]. The lowest prevalence of type 6 AA was reported in South Americans (0.2%; 95% CI. 0.0–4.6) and the highest in the Africans (1.4%; 95% CI. 0.0–6.2). Notably, the prevalence of type 6 AA among the male population of the current study has reached 2.8%. In common with many other AA anomalies, the patients with type 6 AA are often asymptomatic. However, the retro-oesophageal pathway of the right subclavian artery can occasionally produce symptoms such as dyspnea and dysphagia. Dyspnea and dysphagia are respectively due to the tracheal and oesophageal compression by the aberrant artery. These symptoms have been reported approximately in 10% of patients with type 6 AA [7, 22]. The symptomatic incidence of type 6 AA has shown a positive association with a vascular diverticulum called Kommerell diverticulum, a bulbous dilatation at the origin of the right subclavian artery [22]. The Kommerell diverticulum - an embryological remnant of dorsal AA - is reported only in 15% – 30% of type 6 arches [20]. Type 6 arch is also associated with congenital cardiovascular diseases such as coarctation of the aorta, persistent ductus arteriosus, ventricular septal defects, carotid and vertebral artery abnormalities [20]. Anyhow, none of our study participants with type 6 AA was symptomatic, nor with a Kommerell diverticulum or congenital cardiac anomalies.

Type 7 arch (right-sided aortic arch), a rare congenital AA abnormality, is frequently associated with many congenital cardiovascular abnormalities such as Tetralogy of Fallot, pulmonary stenosis with septal defects, tricuspid atresia and truncus arteriosus [2, 3, 18]. Both congenital cardiovascular abnormalities and type 7 AA are aberrations of normal development during early fetal development. In this period, six pairs of AA are formed to perfuse the pharyngeal arches. The left fourth arch usually persists to adult life as the AA, while the fourth right arch disappears. Very rarely, vice versa occurs, resulting in right-sided AA [2, 3]. In addition to associated anomalies, the type 7 arch itself is with critical vascular abnormalities such as compression or kinking of the aorta, causing significant vascular stenosis [18]. Therefore, despite being a rare arch anomaly, type 7 AA is of considerable clinical significance.

The male preponderance in AA variations observed in this study agrees with Keet et al. [20]. Keet et al. have described a significant gender variation ($p = 0.025$) in a study with a predominantly male sample (70% males). Anyhow, male predominance identified in this study was not statically significant ($p = 0.605$). Several other studies have also reported insignificant gender influence on AA variations. Interestingly, some have reported a gender influence, particularly on specific AA variants, such as on type 6 AA [20, 23, 24].

In addition to direct clinical implications, the anatomy of AA exerts a substantial impact on angiographic and vascular intervention procedures. The branching pattern of the AA influences the choice of the angiographic catheter. Inappropriate angiographic catheter usage is known to increase the procedural time and the contrast dose used for the procedure [4, 5]. The procedural time is directly proportionate to the patient radiation dose and indirectly related to the carcinogenic risk [25]. Notably, the injected contrast dose is positively related to the incidence of contrast-induced adverse reactions and nephropathy [5]. It has been stated that the carotid stenting procedure is riskier and complicated in patients with type 2 AA, for whom alternative angiographic techniques, such as the brachial artery approach, is more appropriate than a trans-femoral approach [7]. All the above facts highlight the importance of understanding the prevalence of AA's anatomical variations for a better patient outcome in angiographic and surgical procedures.

This study provides a step forward understanding of the prevalence of AA variants for a Sri Lankan population. The internal integrity of the study is assured, considering the reliability of contrast-enhanced CT with multiplanar reformat on delineating vascular anatomy [1, 9]. Since the study sample has obtained from two separate geographical regions from Sri Lanka, the findings can be generalized to the Sri Lankan population to a considerable limit. However, results could be more widely generalized in a study sample representing all geographical regions.

Conclusion

Asymptomatic variations in the branching pattern of the arch of the aorta are not rare among many populations, including Sri Lankans. The predominant branching pattern found in Sri Lankan population is on par with many other communities. Awareness of the prevalence of surgically and angiographically significant arch variations in a community would minimize the adverse outcomes associated with vascular investigations and treatments.

Declarations

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Conflicts of interest/Competing interests: all authors declare no conflict of interest

Ethics approval (include appropriate approvals or waivers): Ethical approval for the study was obtained from the Ethical Review Committee of Kotealawala Defense University of Sri Lanka (RP/2018/13).

Consent to participate (include appropriate statements): Not applicable in this retrospective study

Consent for publication (include appropriate statements): NA

Code availability (software application or custom code): Not applicable

Availability of data and material (data transparency): data will be published in research gate

Author contribution:

I Kodikara- Project development, data management, data analysis, manuscript writing and editing

D Gamage- data collection, data analysis

S de Soyza- data collection, manuscript editing

I Ilayperuma – project supervision, manuscript editing

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Figures

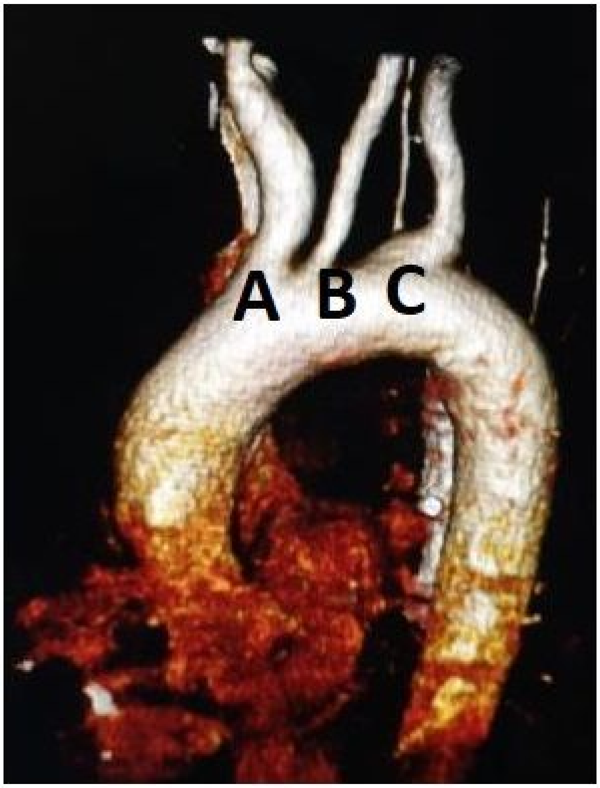

Figure 1

CT image of type 1 aortic arch (A – brachiocephalic trunk; B – left common carotid artery; C – left subclavian artery)

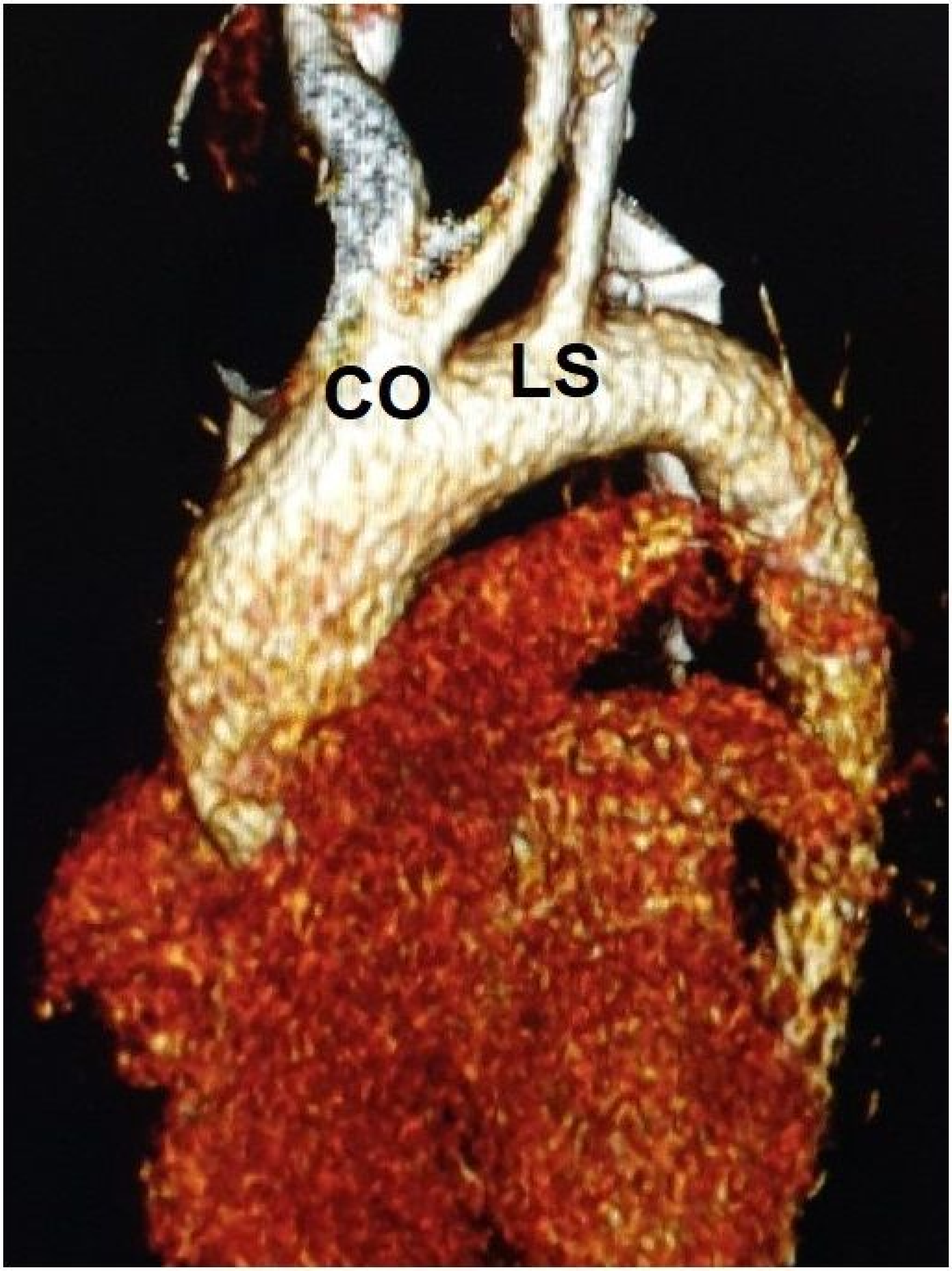

Figure 2

CT image of type 2 aortic arch (CO- common origin for brachiocephalic trunk and left common carotid artery; LS- left subclavian artery)

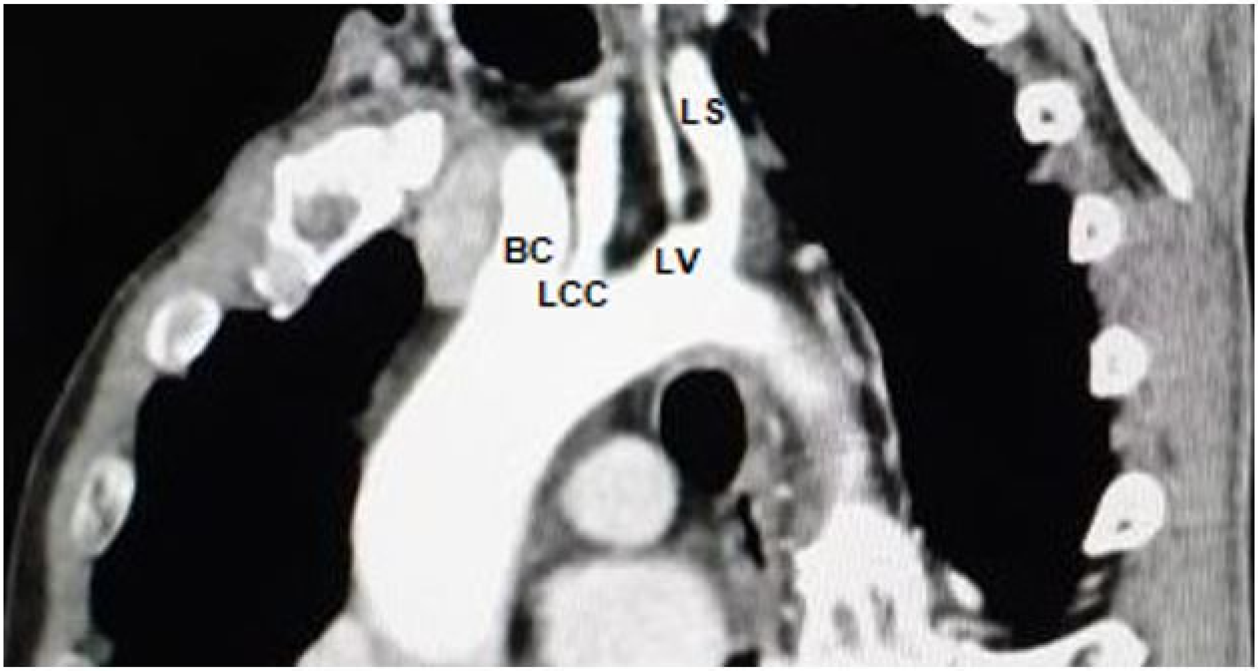

Figure 3

CT image of type 3 aortic arch (BC- brachiocephalic trunk; LCC- left common carotid artery; LV - left vertebral artery directly originating from the aorta; LS - left subclavian artery)

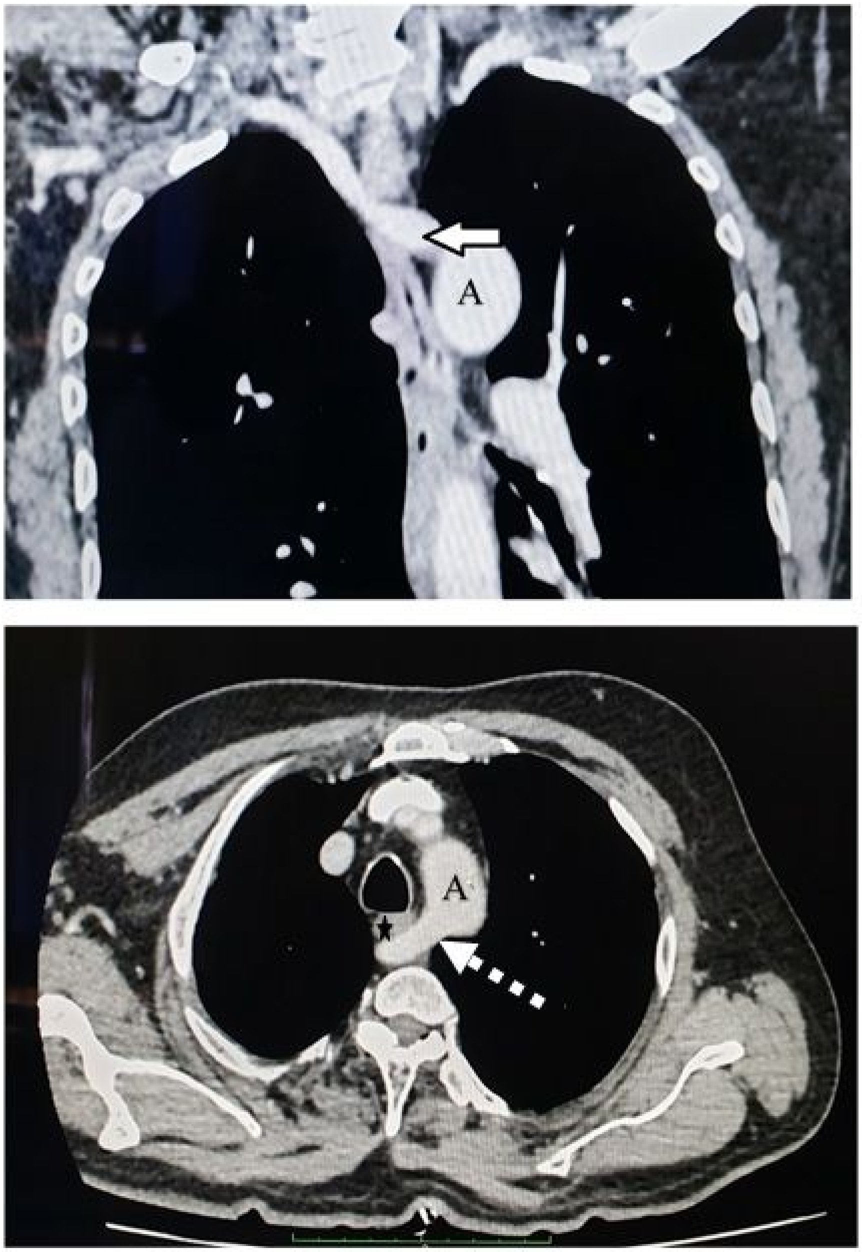

Figure 4

CT image of type 6 aortic arch (white solid arrow indicates the origin of right subclavian artery as the last branch of the aortic arch; white dotted arrow indicates the retro-eosophageal course of right subclavian artery from its origin; black asterix indicates the oesophagus; A – terminal portion of the arch of the aorta)

Supplementary Files

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