Original article

Variations of the aortic arch – a study on the most common branching patterns

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Abstract

Background: Anatomical variants of the aortic arch and its branching patterns often appear as an incidental finding during routine computed tomography (CT) scanning. These variations can be of relevance when performing angiography or endovascular interventions and may cause symptoms such as dysphagia.
Purpose: To analyze common anatomical variations found within the arteries originating from the aortic arch in patients using contrast CT imaging techniques.
Material and Methods: A total of 2033 contrast CT scans were analyzed. To obtain a truly representative sample, cases were chosen from different hospital departments without previous knowledge of the patient history.
Results: The total percentage of variations within the analyzed patients was 13.3%. In 8.0% a truncus bicaroticus was found. 4.2% of the patients showed a left vertebral artery originating directly from the aortic arch, mostly proximal, and in 1 case distal to the left subclavian artery. In 1.0% we found an aberrant right subclavian artery. We also found a single case of a right descending aortic arch.
Conclusion: Variations of the aortic arch and its branching are frequently found, mostly as an incidental finding during routine diagnostic scanning. A contrast-enhanced CT scan is a good method with which to study the aortic arch and its associated branching pattern.

Keywords: Head/neck, vascular, CT angiography

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Anatomical variants of the aortic arch and the arteries originating from it occur on a regular basis. Knowledge of the prevalence of such variants is of interest as they may cause difficulties during conventional angiography and endovascular procedures, especially if such variations are previously unknown (1).

Our aim was therefore to undertake a retrospective, high-powered study, analyzing the structural variations of the aortic arch and the supra-aortic arteries in order to determine the prevalence of such findings.

Material and Methods

Estimation of sample size was performed on the assumption that the prevalence of arterial anomalies was 2%. In order to achieve a 95% confidence interval, it was therefore calculated that 753 cases were required.

A total of 2033 consecutive computed tomography (CT) scans, carried out from April 1, 2008 to March 15, 2009, were included within this retrospective study. Cases were chosen from different hospital departments without previous knowledge of the patient history.

Data acquisition was obtained using a 16-, 64- or 256-slice scanner (Brilliance 16/Brilliance 64/ICT, Philips Medical Systems, Cleveland, OH, USA) following the administration of intravenous contrast agent (1.2 mL/kg body weight, Imeron® 400, Bracco, Konstanz, Germany). In 1224 patients, a CT of the thorax was performed with the following scan parameters: slice thickness 0.9–2 mm, increment 0.5–1 mm, pitch 0.9, rotation time 0.4–0.5 s, 150–200 mAs, 120 kV. In 809 cases, a specific CT angiography of the upper thoracic as well as cervical arteries was applied with the following scan parameters: slice thickness 0.7–0.8 mm, increment 0.3–0.4 mm, pitch 0.4–0.8, rotation time 0.5–0.8 sec, 250–585 mAs, 80–120 kV.

In order to ascertain the correlation between the incidence of certain variations with the age, we undertook separate analyses of patients within the age group 3 months–49 years (group A) and those within the 50–94-year-old age group (group B).

A truncus bicaroticus was defined as the clear origin of the left common carotid artery from the brachiocephalic artery. A V-shaped common trunk of the left common carotid and the brachiocephalic artery was not considered to equate to that of a truncus bicaroticus.

Results

The age range of selected subjects was 3 months–94 years. Mean age was 61 ± 16 years. There were 1200 male patients and 833 female patients.

Of the 2033 patients analyzed, 270 (13.3%) had a variation of the aortic arch or of the supra-aortic arteries. In 163 cases (8.0%) a truncus bicaroticus was detected (Fig. 1c and 1d).

Eighty-six patients (4.2%) had a left vertebral artery originating directly from the aortic arch. In those cases the origin of the vertebral artery was usually proximal to the left subclavian artery (Fig. 2a). In one case a left vertebral artery originating directly from the aortic arch distal to the left subclavian artery was found (Fig. 2b and 2c).

In 20 cases (1.0%) the patient had an aberrant right subclavian artery (Fig. 3). There was a single case of a right descending aortic arch (Fig. 4). Six patients showed two co-existent variations.

Within group A (a total of 429 patients) 58 patients (13.5%) had an anatomical variation of the arteries originating from the aortic arch. In 31 patients (7.2%) a truncus bicaroticus was found, 20 (4.7%) showed a left vertebral artery originating directly from the aortic arch, and seven patients in this group (1.6%) had an aberrant right subclavian artery.

In group B (1604 patients), 211 (13.2%) patients exhibited anatomical variations of the branches of the aorta. In 132 cases (8.2%) a truncus bicaroticus was found. Sixty-six

Fig. 1 Contrast material assisted multidetector CT shows a fluid transition from (a) a separate (34-year-old woman) or (b) adjacent, V-shaped origin (51-year-old man) of the innominate and the left carotid artery to a true truncus bicaroticus in a 54-year-old man (c) and a 47-year-old man with an even more pronounced truncus bicaroticus (d)

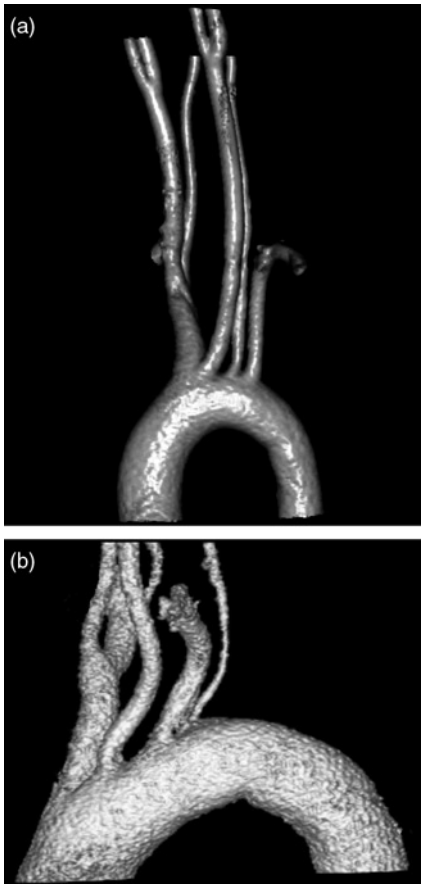

Fig. 2 Left vertebral artery originating directly from the aortic arch. Contrast material assisted multidetector CT with the left vertebral artery originating proximal (a) of the left subclavian artery in a 19-year-old woman. (b) A rare case of the left vertebral artery originating distal of the left subclavian artery

patients (4.1%) showed a left vertebral artery originating directly from the aortic arch and 13 patients (0.8%) had an aberrant right subclavian artery. In one case a right descending aortic arch was found.

Discussion

The embryonic development of the aortic arch takes place during the 4th and 8th week of fetal life. The primary arterial arches arise from the arterial sac and evolve into the final formation of the great arterial vessels, where the left 4th arch forms the anatomical basis of the subsequent, fully-formed aortic arch (2). During angiogenesis two growth factors play a decisive role. Whereas VEGF causes a decrease in cell-to-cell adhesion in newly formed arteries, TGF-ß acts to reinforce the extracellular matrix (3). There are a large number of different anatomical variants of both the aortic arch and the supra-aortic arteries that emerge during this period. The formation of certain variations can be explained somewhat by the embryonic development of the aortic arch, whereas the underlying cause of this is nevertheless unclear (4).

With the exception of the aberrant right subclavian artery, which may cause dysphagia (5) (Fig. 3b), the more commonly-found variations do not usually cause symptoms. They are therefore principally coincidental findings which occur during routine diagnostic procedures. Certain rare variations, however, can potentially lead to severe clinical problems such as compression of the trachea caused by a vascular ring. Such a ring may be formed by a double aortic arch or a right descending arch with an aberrant left subclavian artery (6).

Furthermore, it is hypothesized that anomalous origins of the vertebral arteries lead to altered hemodynamics and predispose the patient to the formation of intracranial aneurysms. Satti *et al.* (4) claim that patients with such anomalies should therefore be screened for co-existing aneurysms. However, within the current literature there is no conclusive evidence to suggest that an anomalous origin of the vertebral arteries predispose an individual to cerebrovascular disorders (7).

Nevertheless, any variation of the aortic arch and its branching may cause potential difficulties when performing diagnostic or interventional angiography. Indeed, substantial

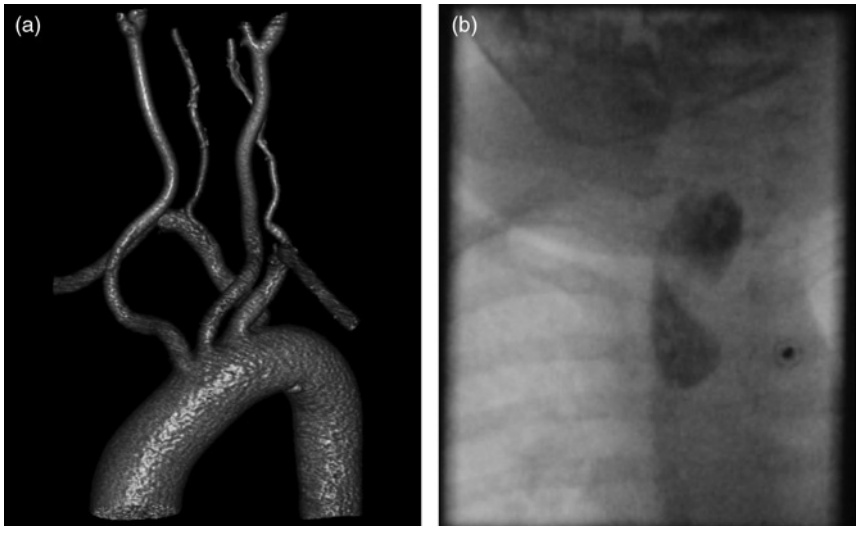

Fig. 3 Contrast material assisted multidetector CT (a) of an arteria lusoria in a 59-year-old man. X-ray examination (b) of the esophagus of a female infant with an arteria lusoria and dysphagia

Fig. 4 Single case of a right descending aortic arch in a 55-year-old woman. 3D reconstruction of a contrast material assisted multidetector CT

deviations in the origin of major arteries may cause severe complications during interventional procedures, for example arterial occlusion during stenting of the aortic arch.

Throughout our analysis, we observed that contrast CT is a good method to detect anatomical arterial variations, and that, furthermore, coronal multiplanar reconstruction (MPR), in addition to scanning in the axial plane, may be helpful in detecting the origin of such a vessel. Before undertaking a scheduled intervention, it is usual for a CT scan to have been previously acquired; if not, it may be obtained with little effort. Information regarding anatomical arterial variations prior to intervention may also be acquired by magnetic resonance imaging (MRI), if such facilities are available.

Due to the large number of cases evaluated within this study, it was indeed possible to produce reliable evidence regarding the prevalence of the most common variations. In our analysis of 2033 scans, we discovered that blood flow occurs from distinct though adjacent origins of the brachiocephalic and left common carotid artery (Fig. 1a and 1b) to a true truncus bicaroticus, where the defined origin of the left common carotid artery from the main trunk is clearly evident (Fig. 1c and 1d). As pointed out by Layton *et al.* (8), the V-shaped pattern of the adjacent origin of the brachiocephalic and the left common carotid artery is often misleadingly termed a 'bovine arch'. This pattern is reported to appear in 13% of the population, whereas there seems to be a disparity in prevalence according to race (8). Likewise, a critical approach must be taken with the use of the term 'truncus bicaroticus', as it consists not only of the two common carotid arteries, but also the right subclavian artery. The pattern of a truncus only consisting of the carotid arteries is however commonly found in elephants and beavers (9).

Apart from common branching patterns, there are various other rare variations of the aortic arch. In our representative sample, we found a single case of a right descending aortic arch as well as one case of a left vertebral artery originating directly from the aortic arch distal to the left subclavian artery. There have been case reports of distinct origins of the left internal and external carotid arteries (10), as well as the vertebral arteries of both sides originating directly from the aortic arch, proximal (7), or distal (11), to the left subclavian artery.

In a previous study, 1000 CT angiograms of patients suspected to have either pulmonary embolism or aortic dissection were analyzed retrospectively with regard to vascular variants (12). The percentage of cases in which a truncus bicaroticus was found was comparable to our own findings (7.8% vs. 8%), though in the study conducted by Berko *et al.*, a truncus bicaroticus was, however, defined as a 'long bovine arch' (12). There was a slight difference in the occurrence of a direct origin of the left vertebral artery (6.1% vs. 4.2%) within the two studies, however the frequency of an aberrant right subclavian artery was in fact similar (1.2% vs. 1%).

Bhatia *et al.*, in comparing their autopsy results with that of previous studies, suggest an age-related increase of certain anatomical variations (13). Such assumptions could not be confirmed in our study as the prevalence of the analyzed variations within the two age groups was almost alike. The discrepancy between the frequency of an aberrant right subclavian artery between the two age groups (group A: 1.60%; group B: 0.81%) can be taken as being not statistically significant in view of the small sample size of group A and indeed the rare occurrence of an aberrant right subclavian artery.

In conclusion, anatomical variations of the aortic arch and its branching patterns are frequently found, mostly as an incidental finding during routine diagnostic procedures. The main relevance of this study lies within the realm of angiographic or interventional procedures, as anomalies of branching patterns can lead to unexpected difficulties and complications if previously undetected. A contrast CT scan is a good method to survey the aortic arch and its branching patterns, and is therefore helpful in detecting such variants prior to conducting an interventional procedure involving the aortic arch and the supra-aortic arteries.

Conflict of interest: None.

REFERENCES

1 Moran CJ, Cross DT, Derdeyn CP. Techniques of carotid angioplasty stenting. *Neuroimaging Clin N Am* 2007;**17**:337–53
2 Gielecki JS, Wilk R, Syc B *et al.* Digital-image analysis of the aortic arch's development and its variations. *Folia Morphol (Warsz)* 2004;**63**:449–543
3 Gilbert SF. *Developmental Biology*. Sunderland, MA: Sinauer Associates, 2006
4 Satti SR, Cerniglia CA, Koenigsberg RA. Cervical vertebral artery variations: an anatomic study. *Am J Neuroradiol* 2007;**28**:976–80
5 Abraham V, Mathew A, Cherian V *et al.* Aberrant subclavian artery: anatomical curiosity or clinical entity. *Int J Surg* 2009;**7**:106–9
6 Berdon WE. Rings, slings, other things: vascular compression of the infant trachea updated from the midcentury to the millennium – the legacy of Robert E. Gross, MD, and Edward B. D. Neuhauser, MD. *Radiology* 2000;**216**:624–32
7 Albayram S, Gailloud P, Wasserman BA. Bilateral arch origin of the vertebral arteries. *Am J Neuroradiol* 2002;**23**:455–88

8 Layton KF, Kallmes DF, Cloft HJ *et al.* Bovine aortic arch variant in humans: clarification of a common misnomer. *Am J Neuroradiol* 2006;**27**:1541–2
9 Golub DM. Entwicklung der Kiemenbögen bei Kalb und Menschen. Die Entwicklung des Aortenbogens und der von ihm ausgehenden Äste bei Säugetieren. In: Zaborszky L, Zilles K, eds. *Anatomy and Embryology*. Minsk: Springer, 1931:447–72
10 Cakirer S, Karaarslan E, Kayabali M *et al.* Separate origins of the left internal and external carotid arteries from the aortic arch: MR angiographic findings. *Am J Neuroradiol* 2002;**23**:1600–2
11 Goray VB, Joshi AR, Garg A *et al.* Aortic arch variation: a unique case with anomalous origin of both vertebral arteries as additional branches of the aortic arch distal to left subclavian artery. *Am J Neuroradiol* 2005;**26**:93–5
12 Berko NS, Jain VR, Godelman A *et al.* Variants and anomalies of thoracic vasculature on computed tomographic angiography in adults. *J Comput Assist Tomogr* 2009;**33**:523–8
13 Bhatia K, Ghabriel MN, Henneberg M. Anatomical variations in the branches of the human aortic arch: a recent study of a South Australian population. *Folia Morphol (Warsz)* 2005;**64**:217–23