Pictorial Review

Frequency of variations in aortic arch anatomy depicted on multidetector CT

G.C. Jakanani*, W. Adair

Department of Clinical Radiology, Leicester Royal Infirmary, University Hospitals of Leicester NHS Trust, Leicester, UK

AIM: To investigate the prevalence and imaging appearances of anatomical variations of the common aortic arch, as depicted on multidetector computed tomography (CT).

METHODS AND MATERIALS: A retrospective study of 861 chest and thoracic aorta examinations in consecutive patients who underwent CT imaging over a 4 year period was undertaken.

RESULTS: The branching of the aortic arch had a conventional configuration in 643 (74%) patients. The most frequent anatomical variant was a common origin to the brachiocephalic and left common carotid artery (bovine arch), which occurred in 20% of participants.

CONCLUSION: To the authors’ knowledge this is the largest study of aortic arch variant anatomy in a living patient population. With the ever increasing complex endovascular interventions in the aorta and head and neck regions, recognition and appreciation of these entities is of importance to the interventional and diagnostic radiologist alike.

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Introduction

The aorta, aortic arch, and its branches develop through a complex process in the foetus during the first few weeks of development. The standard anatomical configuration described in anatomy texts is present in approximately 80% of individuals. This figure, and the prevalence of anatomical variations of arch anatomy, has previously been gleaned from post-mortem studies. Whilst having little physiological consequence in the vast majority of patients, these anatomical variations have significant implications for planning interventional vascular radiology and surgical procedures in the head and neck and the upper limbs. With the increase in recent years of thoracic aortic stenting and hybrid aortic reconstructive procedures, recognition of these variations has assumed greater importance, to ensure safer and more accurate endovascular and surgical planning.

In this paper the prevalence of anatomical variations of the common aortic arch as depicted on multidetector computed tomography (MDCT) imaging of the chest and thoracic aorta, were investigated over a 4 year period in vivo within our referral population.

Embryology of the aortic arch

The development of the definitive aortic arch and its branches takes place within the first few weeks of foetal life. A common arterial trunk, the truncus arteriosus, arises from the primitive heart and divides into six paired arches. In fish these arches provide blood supply to the gills for oxygenation. However, in humans these arteries fuse on either side of the pharynx to form bilateral dorsal aortae (Fig. 1). During the third week, these dorsal aortae fuse caudally into a single descending aorta at the fourth thoracic vertebral level. The first, second, and fifth arches then regress. The third arches
form the carotid arteries. The fourth arch on the right forms the brachiocephalic and right subclavian artery, whilst on the left this forms the left subclavian artery, and the aortic arch proper, which subsequently joins the descending aorta beyond. In reptiles both these fourth branches persist as a double aortic arch. The truncus arteriosus divides into the ascending aorta and pulmonary trunk, and the latter fuses with the sixth arches to become the pulmonary arteries. Persistence or obliteration of these various arches, due to unforeseen events in utero, may lead to anatomical variation.

Method and materials

The hospital radiology information system was interrogated to identify all patients undergoing CT of the thorax over the preceding 4 years. The period covered was from January 2004 to January 2008. Search terms included "CT aorta," "CT thoracic aorta," "chest CT," and "CT pulmonary angiography." All consecutive patients were included irrespective of, and without knowledge of, the indication. Hence unenhanced and intravenous contrast medium-enhanced examinations were included.

The vast majority of studies over this time period were performed on a 16 channel MDCT system (Siemens Somatom Sensation, Siemens AG, Munich, Germany) or a 64 channel MDCT system (Aquilion, Toshiba, Tokyo, Japan). Image analysis was performed on a patient archive and communication system (PACS) workstation (AGFA Impax 5.1, Morstel, Belgium) by two radiologists (G.C.J. and W.A.) in consensus.

The anatomy of the arch and its branch vessels was determined on the axial images. Where uncertainty existed on axial images, multiplanar reconstruction was performed on a workstation. Examinations were excluded when clear identification of the arch anatomy was not possible due to technical reasons (e.g., motion artefact), or in cases of prior arch reconstructive surgery.

The data were initially collected as part of an audit study, and so in compliance with our local policy, ethics committee approval was not required.

Results

Nine hundred and forty-five patients were initially identified, of which images were irretrievable in 78. Five patients were excluded as they had undergone previous
aortic arch surgery. One patient was also excluded due to marked motion artefact in the region of interest. This left a total of 861 images suitable for analysis.

The branching of the aortic arch had a conventional configuration in 643 patients (74%). The most frequent anatomical variant was a common origin to the brachiocephalic and left common carotid artery origin (bovine arch), which occurred in 176 (20%) patients (Fig. 2a and b). In 53 patients (6%) the left vertebral artery arose directly from the aortic arch, with further variations in anatomy also observed in this group: 17 occurred in conjunction with a bovine arch, four (0.5%) occurred in conjunction with both a bovine arch and an aberrant retro-oesophageal right subclavian artery. In the four cases of aberrant right subclavian artery, the right vertebral artery arose from the subclavian artery in the conventional position in two subjects, and in the remaining two it originated from the right common carotid artery just cranial to its origin. Two patients had a right-sided aortic arch (0.2%). An incidental aortic coarctation was observed in one individual (see Figs. 3–7).

Discussion

Isolated variations in anatomy of the aortic arch and its branches are commonly asymptomatic. However, certain anomalies may cause clinically significant symptoms, which often arise from compression or pressure effects on the trachea or oesophagus. An aberrant course of the right subclavian artery compressing the oesophagus is a classic example of this. This “artery lusoria” results in “dysphagia lusoria” (derived from the Greek lusus naturae meaning “trick of nature”) and follows persistence of the right dorsal aorta with obliteration of the fourth arch.3,4

The opportunities for endovascular interventions in the head and neck and intracranial territories, as well as more complex surgical undertakings in the head, neck, and upper limbs continue to expand. The importance of the recognition, and appreciation, of aortic arch anatomy cannot be overestimated as it allows accurate surgical planning and helps avoid potential complications. Clearly, confusing the left common carotid artery for the left subclavian artery at surgery could have disastrous consequences. In interventional radiology, angioplasty of left subclavian artery origin lesions is much less hazardous if the left vertebral artery does not arise directly “downstream.” Prior knowledge of the arch anatomy will facilitate other interventional decisions, such as catheter shape selection, or whether to use embolic protection devices.

Thoracic endovascular aneurysm repair (TEVAR) requires careful planning paying particular regard to arch branches, which may complicate or contraindicate conventional stent placement. Unrecognized or misinterpreted branches may lead to subsequent endoleak, or ischaemic complications in the brain or upper limbs. Revascularization of aberrant arch vessels (or even conventional anatomical branches) may be required in order to achieve an adequate proximal seal for the stent graft, and to preserve limb, brain, or spinal cord perfusion. For the non-endovascular radiologist, an appreciation of variant anatomy is also important in undertaking procedures such as needle biopsy or injections around this territory.

The existing literature on the relative frequency of anatomical variations in the aortic arch has come from relatively small post-mortem series.5,6 To the authors’ knowledge, the present study is the first to specifically investigate the frequency of such variations in a large unselected population in vivo. Seventy-four percent of patients in the present study had a conventional anatomical pattern of aortic arch branching, with 20% having a bovine configuration, and small numbers of other variations. This compares favourably with other generally small studies.5 Bhatia et al.6 studied a series of 81 unrelated donated cadavers in South Australia who had died of natural causes. Similar to the present results, they found a 7% frequency of aberrant left vertebral artery arising from the arch. Interestingly this figure increased to 14% if only those born in South Australia were included. They speculate that this may relate to social or environmental factors during the first half

Figure 2 Left anterior oblique sagittal thickslab MPR (a) and volume rendered (b) MDCT images of the same patient showing the “bovine” arch. Innominate artery (dotted arrow) and right common carotid artery (solid arrow) share a common origin.
of the last century. Their hypothesis that high levels of social deprivation and stress in mothers may lead to delay or failure in angiogenesis is an attractive one.

In the present study there was no attempt to correlate the results with the ethnic origin of the patients as it would have been difficult to collect these data retrospectively. However, the present results reflect a catchment area with an ethnically diverse population as imaging is undertaken of patients located over a wide geographical area. Specifically within Leicester, in the 2001 census, 61% of the population were classified as white British, with Asian or Asian British Indians being the next largest group making up 26%, which is the largest Indian population of any local authority area in England and Wales.

Shin et al. studied the branching pattern in 25 Korean adult cadavers. Twenty-one of the cadavers had conventional branching anatomy, whilst only two (8%) had a bovine configuration. The remaining two had a separate origin of the left vertebral artery from the arch. The aortic arch changes shape with advancing age or longstanding hypertension and this group also undertook morphometric measurements of the arch branches, including angles of origin and distance of origins from each branch. Using such data has led to the description of three types of aortic arch as the angles between branch vessels become more acute, and the origin of the brachiocephalic trunk moves anteriorly.

The relative size of branches has also been studied by Grande et al. in a study of 33 Portuguese cadavers where morphometric measurements were also made. Branches that arose from the horizontal aspect of the arch were always wider in calibre than those arising from the ascending part.

Figure 3 Axial (a), left sagittal oblique thickslab MPR (b) and volume rendered (c) MDCT images in the same patient. The left vertebral artery arises directly from the arch (black arrow). Note also bovine configuration (white arrow).
Gluncic et al.\textsuperscript{11} in their case report describe incidental anomalous origins of both vertebral arteries in a cadaver donated for anatomical study. The right arose from a right common carotid artery, whereas the left arose from a short common trunk with the left subclavian artery. In addition both common carotid arteries shared a common origin, and a right aberrant retro-oesophageal subclavian artery arose as the last branch. Cetin et al.,\textsuperscript{12} as an incidental finding at cardiac catheterization, also described aberrant vertebral artery origins, namely each having a shared trunk with each respective subclavian artery bilaterally. In a cadaveric study of 193 Japanese men, Nelson and Sparks\textsuperscript{12} identified an individual with anomalous branches, namely, from right to left: right subclavian; left subclavian, right common carotid, and left common carotid branches, respectively.

In the present study the most common variant of arch anatomy was found to be the so-called “bovine” arch, or shared origin of the innominate and left common carotid arteries, which concurs with other studies. The name is in fact a misnomer having no resemblance to the aortic anatomy of cattle. Instead a single common brachiocephalic

\textbf{Figure 4} Volume rendered MDCT image viewed from posterior (a) showing an aberrant right subclavian artery (open arrow) and a shared origin of the innominate and left common carotid arteries (arrow). Normal left subclavian artery (dotted arrow). Axial image in the same patient (b) shows a short occlusion of the origin of the aberrant right subclavian artery (arrow).

\textbf{Figure 5} Volume rendered MDCT images from the same patient viewed from posterior (a), and from left lateral (b). There is a complex tortuous right sided arch with the left subclavian artery arising from the descending thoracic aorta (solid arrow). The left common carotid artery is the first branch (dotted arrow), the right common carotid artery second branch (dotted open arrow), right vertebral artery third (arrow head), and right subclavian artery fourth (open arrow).
trunk arises from the aortic arch from which branch the right subclavian artery, a common bicarotid trunk, and a left subclavian artery.14 Somewhat confusingly some authors also use the term bovine arch to describe a left common carotid artery arising from the innominate artery proper. By convention the former criterion was used for the present study, and, in fact, no evidence was seen of the latter. It is thought that the slower growth of the ventral aortic roots between the third and fourth arches allows the left common carotid artery to fuse with the brachiocephalic trunk.13

We have already alluded to the clinical aspects of an aberrant right subclavian artery which may rarely cause dysphagia lusoria. Dysphagia lusoria is more likely to occur if the origin of the artery undergoes isolated aneurysmal dilatation. This entity is specifically known as a diverticulum of Kommerell, named after the German radiologist who first recognized the anomaly on barium oesophageal examination. Most frequently, however, it is associated with a right-sided aortic arch where the left subclavian artery arises as the fourth branch passing behind the oesophagus to the arm. The prominent diverticulum develops in the foetus as it shares an origin with the high flow foetal ductus arteriosus.15

The appearances of the various aortic arch anomalies on CT are described in several reports in the literature.16–18 MDCT acquisition allows multiplanar reconstructions that provide accurate delineation of arch anatomy.19 Türkva tener et al.20 recently reviewed anomalies of arch position (side), duplication (mirroring), arch interruption, and aberrant branch anatomy using MDCT in a selected group of patients. Similarly, Weinberg et al.21 described the MRI features of congenital arch abnormalities. Interestingly, neither of these groups describe the bovine arch configuration as a separate entity, and instead quote the commonest vascular anomaly to be an aberrant right subclavian artery occurring in 0.5–2% of individuals, a figure consistent with the literature.

In the present population, aberrant right subclavian artery occurred with a frequency of 0.5%. However the present results show a common origin of the brachiocephalic and left common carotid in 20% of patients, indicating that the bovine arch is, in fact, the commonest variant observed in vivo in an unselected population.

In conclusion, to the best of the authors’ knowledge, this is the largest study to date of the frequency of aortic arch branch variant anatomy in a living patient population. With the ever increasing radiological, endovascular, and complex surgical interventions in the head and neck, recognition and appreciation of these entities is of importance to the interventional and diagnostic radiologist alike.

References