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Computed tomography study of bovine arch in patients with coarctation of aorta

A retrospective report analysis

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Abstract

The objective of this study was to define the frequency of the bovine aortic arch in patients with coarctation using the tomographic studies.

This is a descriptive retrospective study involving analysis of reports of computed tomographic angiography done at the Prince Sultan Cardiac center for 700 children with congenital heart diseases over a span of about 10 years from April 1, 2008, to August 1, 2018. Cases with coarctation of aorta were chosen to determine the frequency of the bovine aortic arch using the tomographic studies.

From a total of 700 cases which underwent computed tomographic angiography, 117 (16.71%) were diagnosed with coarctation and 19 (2.71%) had bovine arch. Among the 117 patients with coarctation, the total number of patients with bovine arch was 7 patients representing 5.98%, while in patients without coarctation we found a total number of bovine arches of 12 out of 583 patients representing 2.06%. Patients having coarctation with normal branching pattern were at a slight increased incidence of atrial septal defect, ventricular septal defect and anomalous pulmonary venous return than patients having coarctation with bovine arch.

In the face of increased incidence of bovine aortic arch in patients with coarctation, we recommend multislice computed tomographic angiography as a noninvasive and potentially safe and accurate method to precisely delineate the branching pattern of the arch of aorta in patients with coarctation before the interventional procedures and surgeries.

Abbreviations: AA = aortic arch, ASD = atrial septal defect, CTA = computed tomographic angiography, VSD = ventricular septal defect.

Keywords: bovine arch, coarctation, computed tomography, congenital heart diseases

1. Introduction

Coarctation represents 4% to 6% of all congenital heart defects with a prevalence of 4 per 10,000 live births.[1] Classically the aortic arch is left sided with the following branching pattern from right to left, first the brachiocephalic trunk, then the left common carotid artery, and finally the left subclavian artery. The brachiocephalic trunk branches into right subclavian artery and right common carotid artery. This branching pattern occurs in 64.9% to 94.3% of the cases.[2,3]

Determination of the branching pattern by the conventional catheter angiography, a two-dimensional (2D) imaging modality, may be difficult because of superposition of the other large branches. Recently, multi-detector CTA became the most important imaging modality for the aorta and its branches.[4] It offers high resolution 2D and 3D- images with a short acquisition time.[5]

Bovine aortic arch can be defined as true and false. In the true bovine aortic arch, a single great vessel originates from the aortic arch, while in the false bovine arch the innominate artery and the left common carotid artery have a common origin with a separate origin of the left subclavian artery from the aortic arch.[6,7] The presence of bovine aortic arch may influence the surgical approach during repair as well as the rate of recoarctation after repair.[8,9]

Few studies have assessed the significance of coexistence of bovine aortic arch and coarctation. The current study attempts to analyze this association that might have some impact on the surgical management and prognosis of coarctation. Our study

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The work was done in Prince Sultan Cardiac Center, Riyadh, Saudi Arabia.

The authors declare that they have no competing interests.

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has an anatomical focus rather than clinical, so the clinical features of the patients were not assessed.

The objective of this study was to define the frequency of the bovine aortic arch in patients with coarctation using the tomographic studies.

2. Materials and Methods

2.1. Study design, population

This was a descriptive retrospective study that performed according to STROBE checklist involving analysis of reports of CTA, performed by two experienced pediatric cardiac radiologists in the Prince Sultan Cardiac Center Riyadh, Saudi Arabia.

2.2. Sampling and sample size

Using a convenience sampling method, a total of 700 consecutive CTA scans, carried out over a span of about 10 years from April 1, 2008, to August 1, 2018, were included within this study. Cases with coarctation of aorta were chosen from the database of the Prince Sultan Cardiac Center without previous knowledge of the patient history.

2.3. Inclusion criteria and exclusion criteria

All the CTA reports that described the anatomic distribution of the branches of the aortic arch in patients with coarctation were included to be evaluated for the presence of bovine aortic arch. Only patients who have a left-sided aortic arch were included in this study. We excluded all reports that could have contradictory or incomplete information. Also, 3 patients with a right sided aortic arch, and 1 patient with a double aortic arch were all excluded from the study.

In our study the bovine aortic arch was defined as a common origin of the innominate artery and the left common carotid artery with a separate origin of the left subclavian artery from the aortic arch (Fig. 1).

2.4. Outcome variables

The prevalence of bovine aortic arch was determined by evaluating CTA of patients with coarctation in the axial, coronal, sagittal, and 3-dimensional reconstruction images. In addition to imaging data, morphology of the aortic valves was collected during the chart review. Aside from the age and the sex of the individual, no other sociodemographic data were included in the study.

2.5. CTA data acquisition and post processing

Examination was performed under general anesthesia for small children. Data acquisition was done using a 64-slice scanner (Brilliance 64/ICT, Philips Medical Systems, Cleveland, OH) after fast intravenous injection of the contrast 1.2 mL/kg, (Imeronw 400, Bracco, Konstanz, Germany) into a large vein with 20 ml saline flushing. Scanning delay depends on the injection site and the size of the patient. For infants below one year the injection rate was 1–1.5 ml/second, while for children 1–10 years the rate was 2–3 ml/second and for those over 10 years the rate was 4–5 ml/second.

The slice thickness was 0.6–2 mm, increment 0.5–1 mm, pitch 0.9, and rotation time 0.4–0.5 seconds, 150 to 200 mAs, 120 kV.

Image acquisition was started as soon as the contrast was seen in internal carotid artery at the level of 1–2 cervical vertebrae. Scanning was performed in the cranio-caudal direction, extending from the diaphragm and included the region arcus aorta. The calculated received dose with this protocol was 8 mSv. CT raw data were converted to a remote workstation (Vitrea 2, Vital Images Inc., Minnetonka, Minn.) for further image processing and analysis.

Image analysis was performed by two pediatric cardiologists who are experienced in CTA. Axial images were evaluated first and then sagittal and coronal images, oblique multiplanar reformate (MPR) images, thick and thin slab maximum intensity projection (MIP) images and volume rendering (VRD) images.

2.6. Ethical approval

The study was performed in accordance with ethics declared by Helsinki. An ethical approval (No.# 21-5\1; 15/07/18) was obtained from the Institutional Ethics Committee at Prince Sultan Cardiac Center, Riyadh, Saudi Arabia. All patients' data was not identified and just the researchers had access to the records.

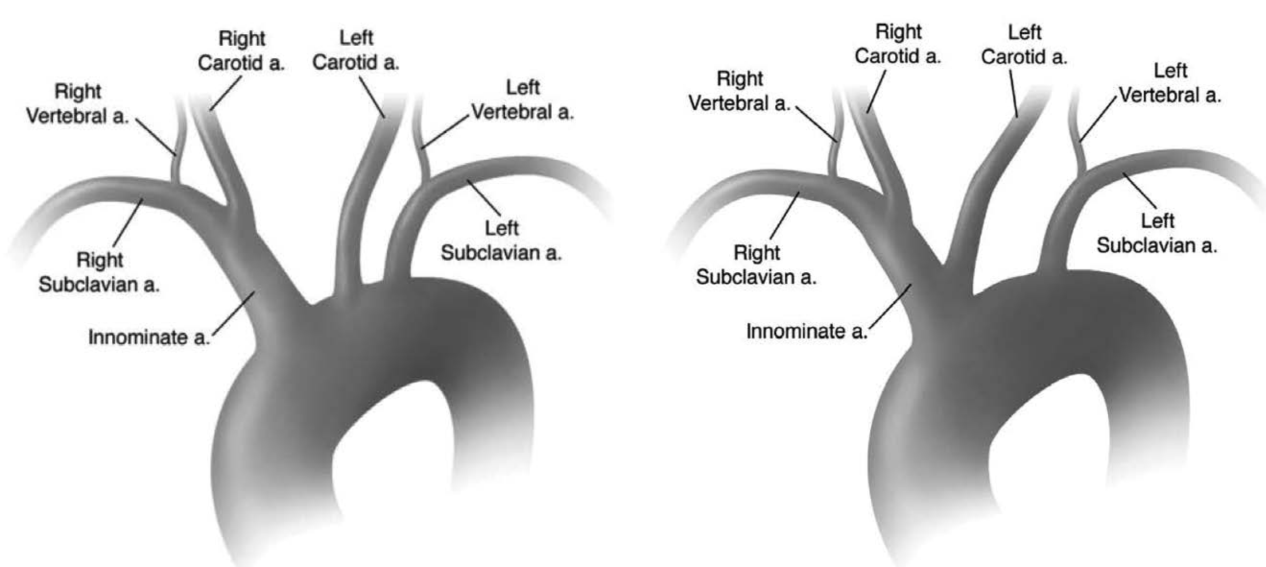

Figure 1. (A) The normal aortic arch branching pattern with separate origins for the innominate, left common carotid, and left subclavian arteries. (B) The "bovine aortic arch." Showing a common origin for the innominate and left common carotid arteries with a separate origin of the left subclavian artery.

2.7. Statistical analysis

It was carried out using the SPSS computer package (IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp., USA). For descriptive statistics: the mean ± SD were used for quantitative variables while frequency and percentage were used for qualitative variables. Fisher exact test was used to assess the differences in frequency of qualitative variables. To highlight the influence of bovine arch, we compared patients with specific anatomic variations to normal aortic arch patterns and the odds ratio with its 95% confidence interval was used to detect the incidence of cardiac anomalies. The statistical methods were verified, assuming a significant level of $P < 0.05$ and a highly significant level of $P < 0.001$.

3. Results

From a total of 700 cases which underwent CTA, 117 (16.71%) patients were diagnosed with coarctation; 63 of them were male (53.85%) and 54 were female (46.15%) with mean age 12.6 ± 7.5 years ranging between 2 days and 18 years. These patients were analyzed for the branching pattern of the aortic arch. The classic branching pattern (Fig. 2) was identified in 100 patients (85.47%) and the total abnormal variants were identified in 17 patients (14.53%) of which, 7 patients (5.98%) showed a bovine aortic arch. The remaining 10 patients (8.55%) had other variations. (Table 1)

The total number of bovine arches (Fig. 3) was 19 patients representing 2.71% of the 700 patients included in the study. Among the 117 patients with coarctation, the total number of patients with bovine arch was 7 patients representing 5.98%, while in patients without coarctation we found a total number of bovine arches of 12 out of 583 patients representing 2.06% with statistically significant difference (Table 2).

Patients having coarctation with normal branching pattern were at a 1.29-fold increased incidence of ASD, a 1.13-fold increased incidence of VSD and a 1.09-fold increased incidence of anomalous pulmonary venous return than patients having coarctation with bovine arch (Table 3).

Regarding association with bicuspid aortic valve in studied patient, we found no patient with bovine arch and coarctation had bicuspid aortic valve but in coarctation without bovine arch there are 6 patients had bicuspid valve.

Figure 2. (A) Volume rendered and (B) contrast computed tomography in a patient with coarctation and normal branching pattern. Note the long distance between the left common carotid and left subclavian artery.

Table 1

The branching pattern of the aortic arch among cases.

Pattern	N = 117	%
Classical pattern	100	85.47
Total abnormal variants	17	14.53
Bovine aortic arch	7	5.98
Other variations	10	8.55

4. Discussion

Embryologically, the arch develops from the aortic sac, the left 4th aortic arch, and a part of the left dorsal aorta. Variation in a branching pattern in the arch of aorta may be attributed to changes in the extent of the fusion or absorption of some of the aortic arches into the aortic sac during embryogenesis.[10]

With increased rates of neck and thoracic surgeries as well as interventional procedures, it is imperative to understand the anatomic variation of the aortic arch. This can help in accurate surgical planning and avoiding the complications that may

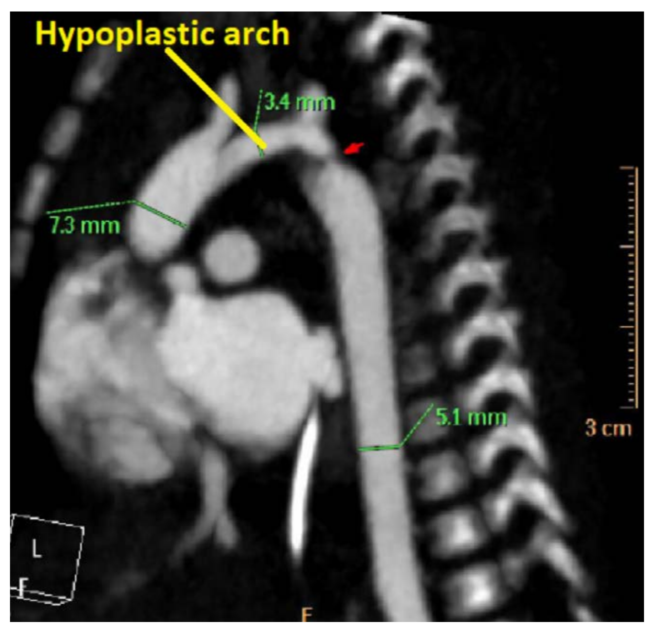

Figure 3. (A) Volume rendered and (B) contrast computed tomography in a patient with coarctation and bovine arch.

Table 2

Prevalence of bovine arch in patients with and without coarctation.

	With coarctation	Without coarctation	
	N = 117 (%)	N = 583 (%)	*P* value
Classic pattern	100 (85.47)	387 (66.38)	<0.001*
Bovine arch	7 (5.98)	12 (2.06)	0.027*
Other variants	10 (8.55)	184 (31.56)	<0.001*

Values present as number and percent were analyzed by Fisher exact test.
*Significant.

Table 3

Cardiac anomalies in patients with different patterns of coarctation.

Cardiac anomalies	Coarctation with normal branching pattern N = 85 (%)	Coarctation with bovine arch n = 7 (%)	*P* value	OR (95% CI)
ASD	15 (17.65)	1 (14.28)	1.000	1.29 (0.14–11.48)
VSD	31 (36.47)	0 (0.0)	0.091	1.13 (1.03–1.24)
Anomalous pulmonary venous return	8 (9.41)	0 (0.0)	1.000	1.09 (1.02–1.16)

ASD = Atrial septal defect, CI = Confidence interval, OR = Odd ratio, VSD = Ventricular septal defect.
Values present as number and percent were analyzed by Fisher exact test.

occur during the procedures. This study aimed to provide an anatomic insight into the prevalence of bovine arch in patients with coarctation of the aorta.

In Classic branching pattern, the arch of the aorta generally gives rise to 3 branches, namely the brachiocephalic trunk, the left common carotid, and the left subclavian arteries. The present study found that the aortic arch gives rise to these 3 branches (classical branching pattern) in 85.47% of patients with coarctation and in only 66.38% of cases without coarctation.

Classic branching pattern was the most frequent aortic arch configuration reported in our study with a prevalence of about 85.47%, which is compatible with other studies worldwide (64.9%–94.3%).[11,12]

The present study showed 5 types of variations with the bovine aortic arch and aberrant right subclavian artery being the most common variations with a prevalence of about 5.98% while symmetric branching pattern (Bi-innominate pattern) being the least common variation with a prevalence of 0.85%.

In bovine arch, the brachiocephalic artery shares a common origin with the left common carotid artery.[6] Its frequency has been described 15%–21.1% in normal population with higher prevalence in Black peoples and those with Turner syndrome.[13–15] In a study by Natsis et al, there is male sex predilection of bovine arch with a higher prevalence in males compared with females (69.8% vs 30.2%).[15]

In a study conducted by Reinshagen et al the incidence of bovine arch in patients with coarctation who underwent cardiac catheterization was 18.5%.[16] In our study it was 7%. The difference may be related to the type of imaging. In our study we use the CTA which may provide more accurate 3-dimensional imaging of the aortic arch branching pattern than the conventional angiography. Another factor which may need further study is racial difference in the prevalence of bovine arch.[5]

The development of the bovine arch is proposed to be due to failure of aortic sac to bifurcate so that left common carotid artery maintain its connection to the sac, resulting in a common trunk that gives origin to brachiocephalic artery and that left common carotid artery.[11]

This variation is usually asymptomatic and incidentally discovered on thoracic imaging or during thoracic surgery.[4,17]

Bovine arch may be isolated or associated with other cardiovascular defects and may be a sign for the aortic arch diseases.[17,18] The mechanism behind that could be an increased velocity of blood flow in the aorta due to a reduced number of branches coming directly from the arch. This increased velocity may provide additional shear force with subsequent aneurysm formation or vessel dissection.[19]

Bovine arch may cause some difficulty during carotid stenting making it riskier. This may be related to the tight turn involving the brachiocephalic artery and left common carotid arteries on stenting through a femoral approach.[14] Therefore, patients with bovine arch may benefit from a brachial approach, a radial one, or a novel transcarotid artery revascularization procedure.[18]

The association of innominate artery injury in blunt trauma and bovine aortic arch was described in reports by Moise and colleagues and Wells and colleagues.[20,21]

A relatively high association bovine arch with aortic coarctation warrants at least a careful preoperative anatomic evaluation of the branching pattern of the arch. Some surgeons recommend a median sternotomy approach instead of left-lateral thoracotomy for coarctation repair in those with bovine arch.[8] The arch, after the take-off of the bovine arch, is often small or even hypoplastic and need reconstruction during the coarctation repair.[16] Some researchers recommend more aggressive approaches to arch reconstruction of coarctation in the presence of bovine arch.[8] A high incidence of recoarctation occurs after extended end-to-end repair of coarctation with bovine arch anatomy. This may be related to a reduced clampable distance of facilitate repair.[22]

An advantage of the bovine arch during aortic surgery is that it allows bilateral carotid perfusion with a single cannula so that a totally free surgical field is obtained to perform an open distal anastomosis in a safe and not time-consuming way.[23]

The major importance of AA anomalies is that potential surgical complications in operating in a thoracic cavity, as most variants are clinically silent and undetected. As such, it is recommended that the AA be evaluated for branching patterns with contrast-enhanced computed tomography before any surgical interventions in the thorax.[24] The aim of this study was to give a comprehensive prevalence of the most prevalent encountered AA variants to help surgeons understand their true prevalence to make procedural and postoperative standards of care for patients presenting with them.

This study can provide adequate information on branching pattern to catheterize the arch and for a safe endovascular surgery. The clinical presentations which these variations give rise to be well known and may present during first days of life or later in adulthood or remain clinically silent. Nonrecognition of the latter situation in the existence of vascular trauma may have fatal sequalae. Nayak et al observed in their study among 56 cadavers that normal branching pattern was about 91.4%, 4.8% presented common origin of the carotid arteries, 1.6% had bi-innominate sequence, and 1.6% presented.[11]

The study was limited by its retrospective nature with no clinical data. Not all cases with coarctation underwent CTA, suggesting a selection bias toward complicated patients with poorer echo windows or unusual anatomy.

Also, follow-up of patients for the type of repair as well as the long- and short-term complications was not done which may provide more information that can help in decision making for the management of these cases.

5. Conclusions

Variations in branching pattern of arcus aorta are common in patients with coarctation. Most of them have no clinical importance; however, knowledge of branching pattern of the arch of aorta is mandatory for vascular surgeons, interventional radiologists, and head and neck surgeons. Multislice CTA describes the arch anatomy accurately and can be a roadmap for the interventional procedures and surgeries of the head and neck area.

6. Recommendations

This study provides a step toward understanding the prevalence of AA variants in patients with coarctation, but additional studies should be conducted to further identify surgical complications and potential risk factors associated with these patterns.

The main strength of the present study is that it includes the largest study population among the studies which investigate aortic arch variations in patients with coarctation by angiography.

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Author contributions

All authors contributed to study conception and design, data collection, analysis and interpretation of results, and draft manuscript preparation. All authors reviewed the results and approved the final version of the manuscript.

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