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Anatomic variations of the aortic arch depicted on 444 CT angiographies

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SUMMARY

With a view to describing the different anatomic variations of aortic arch branching, their prevalence, the demographic characteristics of the sample, and to propose a new classification for aortic arch branching patterns, 460 thoracic computed tomography angiographies (CTA) with 3D reconstruction were reviewed from January 2012 to December 2014. A total of 444 subjects were included in the study. Of those, 153 (34.4%) were male. Anatomic variations were found in 178 (40.1%) subjects. Prevalence by type of aortic arch (AA) branching pattern were found as follows: Type 1 or "Normal branching": Brachiocephalic trunk (BT), left common carotid artery (LCC), left subclavian artery (LS), in this order, was 59.9% (266/444 subjects); Type 2 or "Bovine arch": BT and LCC arising from the AA in a common trunk, was 27.9% (124/444 subjects); Type 3: LCC originating separately from the BT, was 9.9% (44/444 subjects); Type 4, left vertebral artery arising from the AA, was 2.2% (10/444 subjects). The prevalence of anatomic variations was higher in females than in males (42.3% versus 35.9%). This is the largest study of aortic arch anatomic variations in a South American population. These anatomic variants are not rare and should be addressed before a surgical or interventional procedure that involves the head, neck, thorax and/or upper limbs.

Key words: Aorta – Aortic arch – Aortic morphology – Anatomic variation – Multidetector computed tomography

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INTRODUCTION

The anatomy of the aortic arch (AA) branching is challenging as a result of the multiple variations that have been described. The normal or standard anatomic configuration is described as branches arising from the AA, from proximal to distal with respect to the heart, in this order: brachiocephalic trunk (BT), left common carotid artery (LCC) and left subclavian artery (LS). However, currently there is no consensus about the classification and clinical implications of the various anatomic variations, which, added to the increasing activity in the fields of interventional and surgical procedures in the head, neck and upper limbs, sets a clinical context of uncertainty needing research (Adachi, 1928; Bhatia et al., 2005).

Anatomic variations of the AA are not uncommon. A prevalence around 20% have been found in significant subjects' samples evaluated in various studies (Jakanani and Adair, 2010; Shakeri et al., 2013). Karacan et al. (2014) and Ergun et al. (2013) published the two largest studies: they examined 1000 and 1001 *in-vivo* patients using CTA and found a prevalence of variations of 20.8% and 14.7%, respectively. Type 2 branching pattern was the most frequent in both studies, but its anatomic description was different. For Karacan et al. (2014), it was BT and LCC arising from the AA in a common trunk; and for Ergun et al. (2013), LCC originating separately from the BT. This discrepancy in describing the type 2 AA branching pattern have been seen in other studies as well.

Thus, in order to clarify this confusion, which could generate erroneous epidemiologic data and negative clinical impact, as explained by Layton et al., we describe the type 2 AA branching and sep-

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arate it from other different anatomic patterns. Type 2 AA branching, also named "Bovine arch", is seen when both BT and LCC arise from the AA in a common trunk, and not that in which the LCC originates separately from the BT (Layton et al., 2006). In order to simplify the classification, we proposed a new one: Type 1 or "Normal branching": BT, LCC, LS, in this order; Type 2 or "Bovine arch": BT and LCC arising from the AA in a common trunk; Type 3: LCC originating separately from the BT; Type 4: left vertebral artery originating separately from the AA.

Spiral and multidetector-row computed tomography angiography (CTA) with 3D reconstruction is accepted as a non-invasive diagnostic procedure to assess anatomical variations of AA prior to surgery or interventional procedures. The CTA offers a wide outlook of vessels and the spatial relationship of adjacent organ. The purpose of this study is to describe the different anatomic variations of aortic arch branching, their prevalence, the demographic characteristics of the sample, and to propose a new classification for AA branching patterns.

MATERIALS AND METHODS

Subjects

The Institutional Ethics Committee approved this study. The radiology information system (PACS) of a reference hospital was used to review all thoracic CTA with 3D reconstruction from January 2012 to December 2014. We excluded subjects with an unclear image evaluation, vascular malformations of the AA, vascular injuries of the AA, those born out of Colombia and those younger than 18 years old. Vascular malformations of the AA were intended as congenital anomalies, which included the following examples: the left AA, the aberrant right subclavian artery, the double AA, the cervical AA and the interrupted AA (Flowchart 1). The clinical record of subjects that presented anatomic variations of the AA was used in order to specify documented diagnosis, classifying them into two groups: those with diagnosis of acquired aorta pathologies, and those without.

Image technique: angiographic computed tomography

All the CTA were indicated by a medical specialist, and were performed on a 64 channel multidetector computed tomography (MDCT) with angiography system, with 100 ml of intravenous contrast at a speed of 5 cc per second for each patient, using *Smartprep* as the contrast detection method. Image 3D reconstruction was made on a radiology workstation with computers equipped with Syngo software (Advanced Syngo version V3A with VRT reconstructions).

Image interpretation

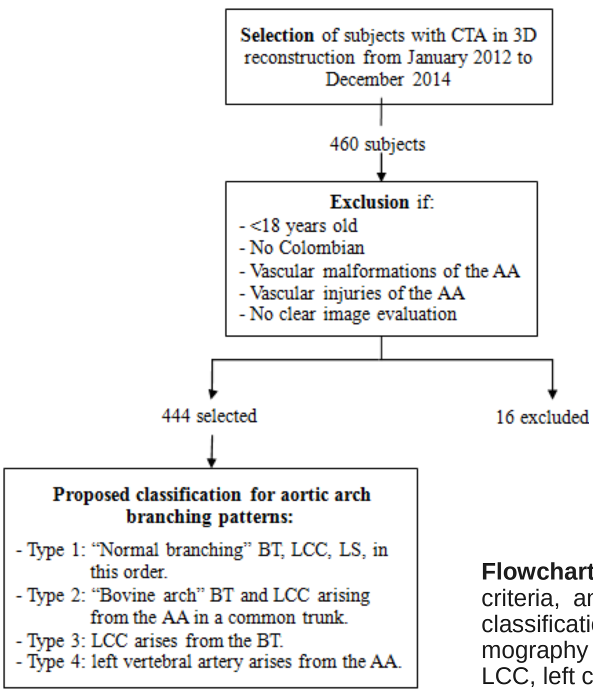
Examinations were conducted by a sixth-year medical student and a radiologist with more of 10 years of experience in CTA. Variations were categorized according to the proposed classification for aortic arch branching patterns: Type 1: BT, LCC, LS, in this order. Type 2 or "Bovine arch": BT and LCC arising from the AA in a common trunk. Type 3: LCC originating separately from the BT. Type 4: left vertebral artery originating separately from the AA.

Statistical analyses

Frequencies and percentages were calculated using Excel®.

RESULTS

This study was performed on 444 subjects; 153 (34.4%) were males and 291 (65.6%) were females, with a mean age of 57 years (18-96 years). Categorization of anatomic variations was made according to proposed classification for aortic arch branching patterns. The prevalence of overall anatomic variations (intended as type 2, 3 and 4 AA branching patterns) was 40.1% (178/444 subjects). Prevalence for each type of branching pattern were found as follows: Type 1 or "Normal": 59.9% (266/444 subjects); Type 2 or "Bovine arch": 27.9% (124/444 subjects); Type 3: 9.9% (44/444 subjects); Type 4: 2.2% (10/444 subjects) (Table



Flowchart 1. Subjects' selection according to inclusion and exclusion criteria, and its posterior categorization according to the proposed classification for aortic arch branching patterns. CTA, Computed tomography angiography. AA, aortic arch. BT, brachiocephalic trunk. LCC, left common carotid artery. LS, left subclavian artery.

Table 1. Demographic characteristics and diagnosis of subjects by type of aortic arch branching pattern.

Characteristic	Type 1 (Normal) (N=266)	Variations Group Types 2, 3, 4 (N=178)*	Type 2 (N=124)	Type 3 (N=44)	Type 4 (N=10)	Total (N=444)
Mean age (range) – yr.	57 (18-96)	57 (18-96)	57 (20-91)	57 (18-96)	59 (18-72)	57 (18-96)
Male sex - no. (%)	98 (36.8)	55 (30.9)	38 (30.6)	11 (25.0)	6 (60.0)	153 (34.4)
Female sex - no. (%)	168 (63.2)	123 (69.1)	86 (69.4)	33 (75.0)	4 (40.0)	291 (65.6)
Diagnosis- no. (%)**						
1	-	25 (14.0)	18 (14.5)	5 (11.4)	2 (20.0)	25 (5.6)
2	-	152 (85.4)	105 (84.7)	39 (88.6)	8 (80.0)	152 (34.2)
3	-	1 (0.6)	1 (0.8)	0 (0.0)	0 (0.0)	267 (60.2)

*Variations group is intended as the total of subjects that presented anatomic variations, regardless of what type. It was obtain by the sum of the subjects with the following types of branching patterns: Type 2, 3 and 4. **The specification of diagnosis was made only in subjects with anatomic variations. 1, aorta pathologies (Aortic aneurysm, Aortic dissection, Coarctation of the aorta, Aortic ingurgitation, Aortic stenosis). 2, others no related to the aorta and its branches (Hypertension, diabetes, hypothyroidism, etc.). 3, No data found.

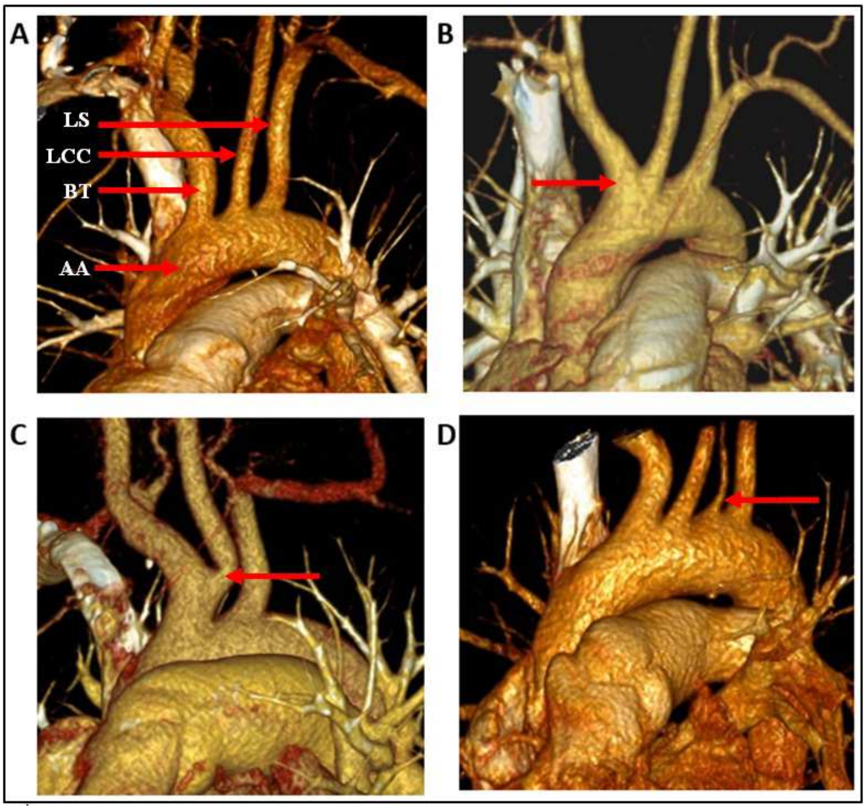


Fig. 1. Aortic arch anatomic variations according to the proposed classification for aortic arch branching patterns. Red arrows show the aortic arch and its branches, and the main characteristic of each type of branching pattern. **(A)** Type 1 or “Normal branching” aortic arch (AA) branching pattern: brachiocephalic trunk (BT), left common carotid artery (LCC) and left subclavian artery (LS). **(B)** Type 2 or “Bovine arch”: BT and LCC arising from the AA in a common trunk. **(C)** Type 3: LCC originating separately from the BT. **(D)** Type 4: left vertebral artery originating sepa-

1, Fig. 1). The prevalence of overall anatomic variations was higher among females compared to males, 42.3% versus 35.9% (123/291 versus 55/153 cases). Also, for Type 2: 29.6% versus 24.8% (86/291 versus 38/153 cases), and for Type 3: 11.3% versus 7.2% (33/291 versus 11/153 cases). Type 4 was the only group with a higher proportion of anatomic variants among males compared with females, 3.9% versus 1.4% (6/153 versus 4/291 cases). Prevalence of diagnosis of aorta pathologies among subjects with anatomic variations was 14% (25/178 cases), and by type of branching pattern was found as follows: Type 2: 14.5% (18/124 cases); Type 3: 11.4% (5/44 cases); Type 4: 20% (2/10 cases). There was no assessment of diagnosis of aortic pathologies for subjects with type 1, or “Normal” AA branching pattern.

DISCUSSION

The anatomical variations are present since birth, and are taken as benign, but they may represent a challenge on the performance of surgical and radiologist-interventionist procedures, raising the probability of mistakes, adverse effects and even fatal outcomes. There are cases of perioperative ischemia by an incorrect shunt placement due to anatomic variations of the aortic arch during carotid endarterectomy (Koch, 2006; Burzotta, 2015). Hence, the importance of being aware of them and to perform proper assessments of anatomical features of the aortic arch before surgical and interventional procedures involving the head, neck, thorax and/or upper limbs.

The first reports of AA anatomic variations were made in small post-mortem series, and also included cases of congenital anomalies (Thompson, 1893; Williams, 1935; McDonald, 1940; Harley, 1959; Liechty, 1957; Nizankowski, 1975). Then, with the appearance of new diagnostic images tools, there was possible to enlarge the knowledge with bigger series in several regions of the world (Grande, 1995; Natsis et al., 2009). However, in such areas like South America, the literature remains quite behind, and there are not many own or local studies. This issue has forced the South American health care professionals to adopt findings of studies from other continents to their daily practice, a fact that sometimes turns to be not so positive or suitable. This study evaluated 444 *in vivo* subjects in a reference hospital of Cali, Colombia; a sample that because of its demographic features can be extrapolated to the South American population.

The proportion of anatomic variations of the AA is certainly significant given the data of the largest worldwide reference series made by Ergun et al. (2013), who found a prevalence of 26% from a sample of 1001 subjects, and by Karacan et al. (2014), who found a prevalence of 21% from a sample of 1000 subjects. However, in this study the prevalence of AA variations was 40.1%, which is quite higher. This difference could be explained by the fact that in South America this sort of studies had not been conducted before, and, as seen in other general characteristics, the population in this region of the planet displays some precise particularities.

The most frequent anatomic variant, the type 2 or “Bovine arch”, showed a prevalence of 27.9%, which is much higher compared to the series evaluated by Jakanani and Adair (2010), Ergun et al. (2013) and Karacan et al. (2014), that exposed a prevalence of 20%, 7.8% and 14.1%, respectively, but it is still the most frequent type of AA anatomic variation. The second most frequent variant was the type 3, with a prevalence of 9.9%. The epidemiologic difference between type 2 and type 3 is evident (27.9% versus 9.9%), which gives relevance to the proposed classification for aortic arch branching patterns, since it clarifies the description of each type of branching pattern, removes the confusion seen in the literature between Type 2 or “Bovine arch” and Type 3, and simplifies its categorization. The less common variation, type 4, presented a prevalence of 2.2%, which is lower compared to the worldwide reference series given by Jakanani and Adair (2010), Ergun et al. (2013) and Karacan et al. (2014), that reported a prevalence of 6.0%, 5.1% and 4.1%, respectively (Layton et al., 2006).

Another notable finding is that women showed a higher prevalence of overall anatomic variations compared to men (42.3% versus 35.9%), a disparity not seen in other reports, since most of the findings showed similar proportion between both sexes.

Regarding the relationship between AA anatomic variations and the presence of related pathologies, it was found that 14.2% of subjects with variants had diagnosis of aorta pathologies. Although, as it was already explained, the anatomic variations by definition do not have pathological implications, a diagnosis of a pathology of the aorta makes an individual more likely to undergo an invasive procedure involving the aortic arch, its branches and surrounding structures, which could result in a mayor risk of complications and adverse effects if its particular anatomy is not known. This is the point to be reached: it is not only about presenting the information, but also about demonstrating why it is so important to know it and spread it.

Conclusions

As far as the authors know, this is the largest study of aortic arch anatomic variations in a South American population. Anatomic variations of the aortic arch are not rare and should be addressed before a surgical or interventional procedure that involves the head, neck, thorax and/or upper limbs.

The prevalence of aortic arch anatomic variations is higher in the Colombian population compared with other regions worldwide, especially in females, the “Bovine arch” being the most frequent variation. The proposed classification for aortic arch branching patterns sets a simple and useful categorization for the anatomic variations of the aortic arch, and clarifies the description of each type of branching pattern.

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