ORIGINAL ARTICLE

Clinically-relevant morphometric parameters and anatomical variations of the aortic arch branching pattern

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Abstract

Introduction The ever expanding advances in various domains of cardiac and endovascular interventions has drawn tremendous attention toward the importance of the anatomical variability and morphometric parameters of the aortic arch (AA) and its branches.

Methods The current study delineates the morphometry and anatomical variations of the AA branches by evaluating coronal, axial and sagittal CT multiplanar reformatted three-dimensional angiograms. Correlations between morphometric data as well as the distribution of morphometric data in relation to the anatomical variations were also illustrated.

Results 35% of the examined AA showed abnormal branching patterns, the most common of which was the "bovine arch" (24%), followed by common ostium variant (6%) and aberrant left vertebral artery arising directly from AA (5%). The outer diameter of AA at its origin and its end was 33.83 and 22.06 mm, respectively. The distance between the origin of AA and the origin of brachiocephalic trunk (BCT), left common carotid artery (LCCA) and left subclavian artery (LSA) was 19.59, 23.01 and 26.01 mm, respectively. The outer diameter of BCT, LCCA and LSA was 15.7, 11.42 and 14.02 mm, respectively. The angles between the AA and the BCT, LCCA and LSA were 59.01°, 68.59° and 59.92°, respectively. The mean distance between the BCT and LCCA was 19.59 mm and the distance between the LCCA and the LSA was 23.01 mm. Significant positive and negative correlations between morphometric data as well as the distribution of morphometric parameters in relation to the anatomical variations have been identified.

Conclusion The illustrated anatomical variations and morphometric data provide cardinal information especially for patients undergoing aortic endovascular intervention, principally for choosing the size, shape and type of the angiographic catheters and devices to be delivered.

Keywords Aortic arch · Anatomical variations · Morphometry · Endovascular therapy · Aortic aneurysm · Aortic dissection

Introduction

In modern surgical and radiological procedures, the recognition of morphometric data and anatomic vascular variations of the branching pattern of the aortic arch (AA) has become of paramount importance. The knowledge of the anatomical variants is fundamental for correct pre-operative vascular planning in surgical and/or radiological procedures [22, 27].

The radiological techniques employed to study aortic arch variations (such as MRI, trans-esophageal echocardiography, digital subtraction angiography and CT angiography) have their limitations and disadvantages [2].

The great advent in the medical imaging techniques enabling fusion and extraction of three-dimensional (3D) quantitative information has now rendered the multi-detector 3D computed tomography the imaging modality of choice, as it provides high-quality 3D-reconstructed images and allows non-invasive assessment of normal anatomy and anatomic variants of the aortic arch. Thus, the current 3D-angiography study has been designed for acquisition of anatomical variability and morphometric parameters of the AA and its branches using distinct parameters including the external diameter of the AA at its beginning and termination, the distance between the aortic arch branches, the distance between

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the origin of the aortic arch and the origin of brachiocephalic trunk (BCT), left common carotid artery (LCCA) and left subclavian artery (LSA) as well as the diameter and angulation of those branches.

Knowledge of such characterization of the AA is beneficial for standardizing arch morphometry, improving endovascular arch treatment and optimizing the design of various types of diagnostic and/or therapeutic interventional surgical maneuvers encompassing the AA, especially with the advent of endovascular aortic stenting and catheterization.

To the best of the authors' knowledge, no studies have focused on aortic arch branches' morphometry in terms of surgical relevance, nor have they correlated those variables to each other and to factors such as sex. Such quantitative information defining the AA morphology could be substantially beneficial for endovascular arch therapy.

Materials and methods

Radiological study

The radiological study was carried out on randomly chosen contrast-enhanced CT angiographic scans of 100 patients referred to the Radiology Department of Cairo University hospital (Kasr Al-Ainy) for cardiothoracic dynamic-enhanced multidetector-computed tomography (MDCT). The study was conducted in the time period between May 2017 and August 2018. All patients with previous history of neck or thoracic surgery or a pathological mass compressing the aortic arch or any of its branches were excluded from the study. The study was approved by the Ethical Committee of Faculty of Medicine, Cairo University.

The contrast-enhanced CT angiography scans were obtained through a 64 channel MDCT system (Siemens Somatom Sensation, Siemens AG, Munich, Germany) at 2-mm intervals (0.764-mm slice thickness). MDCT coverage extended from the tenth thoracic vertebra to the base of the skull. All images were obtained at window levels appropriate for the mediastinum (window width, 200–350 HU; window level, 45–50 HU) and were reconstructed with a high-resolution algorithm.

Data retrieval and analysis were performed using a picture archive and communication system (PACS) workstation (Centricity RA 1000; GE Healthcare, Milwaukee, WI, USA). The morphometry and anatomical variations of the AA and its branches were evaluated using coronal, axial and sagittal CT multiplanar reformatted three-dimensional (3D) images by two independent radiologists.

Images were reformatted, analyzed and assessed with respect to site of origin and the anatomy of the AA and its branches.

In cases with discrepancy, the images were reviewed again, with careful correlation among the radiologists. The anatomy was thereby determined by majority opinion.

The main trunk of the aortic arch and its three main branches were subjected to the following measurements (Fig. 1):

- The external diameter of the AA at its beginning (at the level of the 2nd right chondrosternal junction, at the aortic root) and at the end (at the level of 4th thoracic vertebra).
- The external diameter of BCT, LCCA and LSA at their origin.
- The distance between the beginning of the AA and the midpoint of origin of its three main branches.
- The angles between the AA and each of its main branches. The angles were measured between the left sides of these branches at their origin from the AA in 3D reformatted images and then reconfirmed in sagittal and coronal views.
- The distance between BCT and LCCA and the distance between LCCA and LSA.

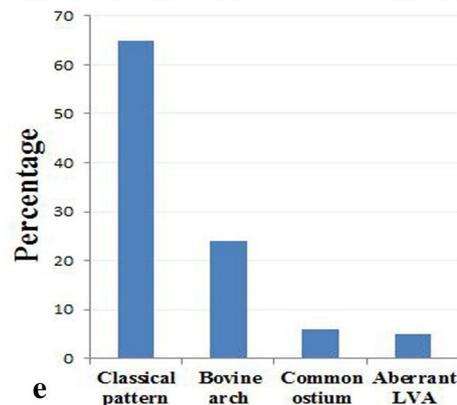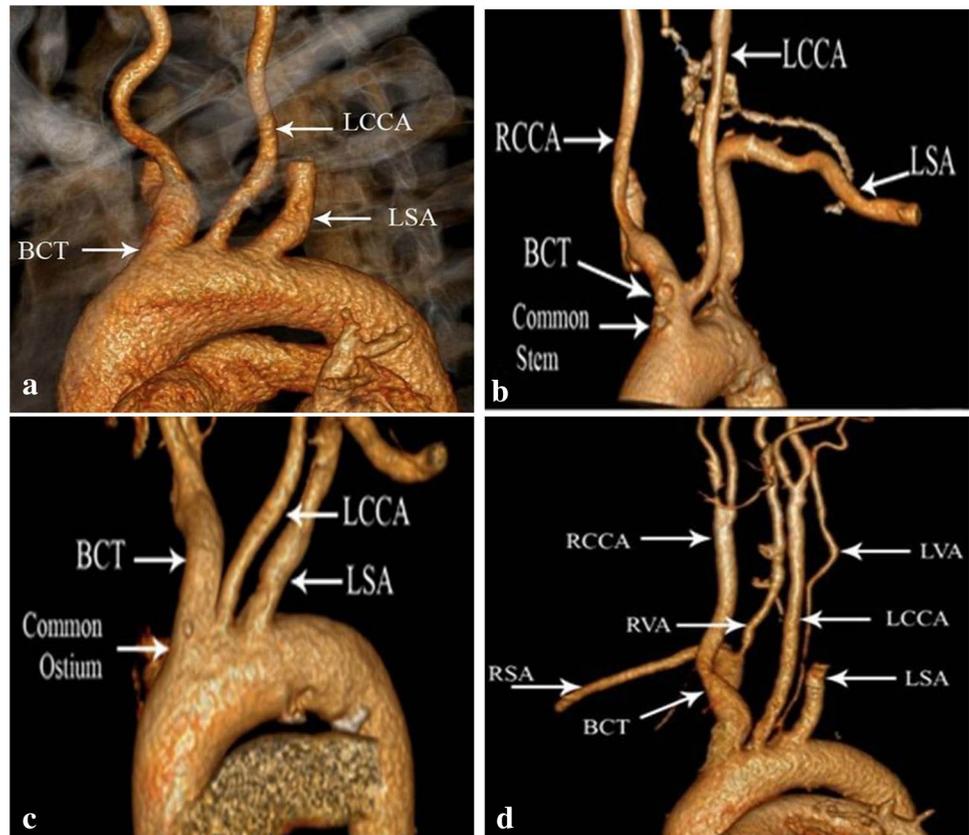Each measurement was taken three times and the mean was calculated to avoid error bias.

Statistical analysis was performed using SPSS statistical software version 16.0. The obtained numerical data were expressed as mean ± standard deviation. Statistical significance of the differences between mean values of males and females was tested using paired Student's "t" test. P value < 0.05 was considered statistically significant. Qualitative data were tabulated and summarized by frequencies and percentages.

Anatomical study

Ten human adult Egyptian cadavers, preserved in 10% formalin solution, were obtained from the Department of Anatomy, Faculty of Medicine, Cairo University. Cadavers with obvious gross pathology or torn damaged aortic arches were excluded from this study. After careful dissection, the AA and its three main branches were subjected to the following measurements using Vernier caliper as previously described [30].

- The external diameter of BCT, LCCA and LSA at their point of origin from the aortic arch.
- The external diameter of the AA at its beginning (at the level of the 2nd right chondrosternal junction) and at the end (at the level of 4th thoracic vertebra).
- The distance between the mid vertebral line and the aortic origin of the BCT, the LCCA and LSA.

Fig. 1 Anatomical variations of the AA branching pattern. **a** Classical pattern, **b** Bovine arch, **c** common ostium, **d** aberrant left vertebral artery arising directly from AA, **e** incidence of the different variants. *BCT* brachiocephalic trunk, *LCCA* left common carotid artery, *LSA* left subclavian artery, *RCCA* right common carotid artery, *RSA* right subclavian artery, *LVA* left vertebral artery, *RVA* right vertebral artery

Every measurement was taken three times and the mean was calculated to avoid measurement bias. Photographs were taken using Canon Digital Camera.

Results

Radiological results

#### Branching pattern of the aortic arch

The aortic arch in the current study exhibited different forms of branching patterns (Fig. 1). Sixty-five out of 100 aortic arches (65%) had a common typical branching pattern in which the aortic arch gave off three main branches: the BCT, LCCA and LSA (Fig. 2).

Thirty-five out of 100 aortic arches (35%) showed abnormal branching patterns. These patterns included:

- Twenty-four aortic arches (24%) had a bovine configuration "v-shaped origin for BCT and LCCA diverging from the outer surface of the AA" (Fig. 3).
- Six aortic arches (6%) had a common ostium "v-shaped origin for BCT and LCCA at the outer surface of the AA" (Fig. 4).

Fig. 2 Classical branching pattern of the aortic arch in **a** conventional angiography, **b** 3D MDCT angiography, **c** axial CT scan and **d** coronal CT section image. *BCT* brachiocephalic trunk, *LCCA* left common carotid artery, *LSA* left subclavian artery, *RCCA* right common carotid artery, *RSA* right subclavian artery, *LVA* left vertebral artery, *RVA* right vertebral artery
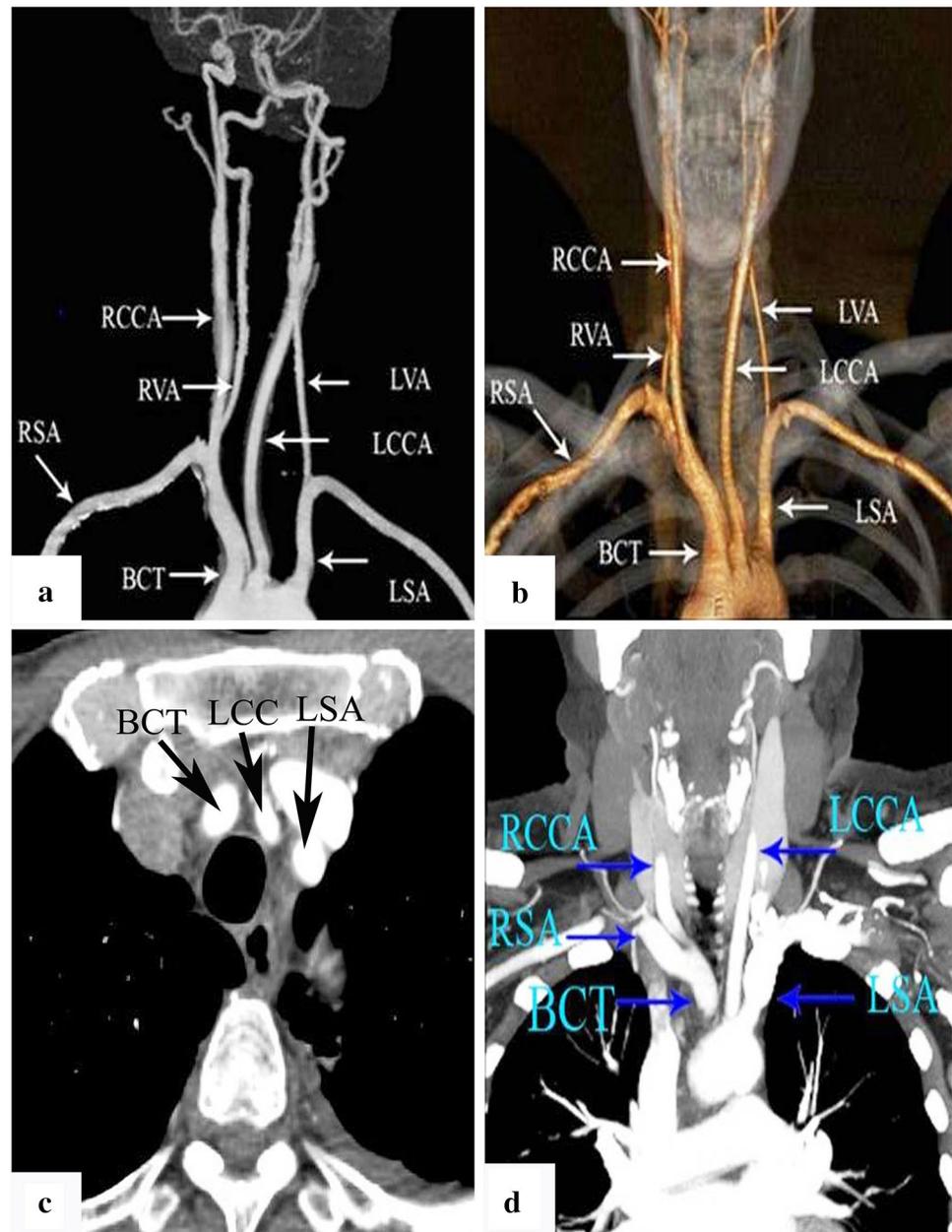
- The remaining five aortic arches (5%) had aberrant left vertebral artery (LVA) arising directly from the aortic arch. The aberrant LVA was noted between LCCA and LSA in four cases and more distally in only one case (Fig. 5).

These abnormal patterns were encountered more in males (37.3%) than in females (26.1%) as represented in Table 1.

Regarding the association between the variations, there have been two cases in which the aberrant LVA was accompanied by bovine aortic arch, and one case in which the aberrant LVA was accompanied by a common ostium for BCT and LCCA (Fig. 6).

Morphometric measurements applied to the aortic arch

While the distance between the origin of the aortic arch and the LSA was recorded in 100 aortic arches, the distance between the origin of the aortic arch and midpoint of aortic origin of the BCT and the LCCA was recorded only in 76 aortic arches after exclusion of the 24 bovine aortic arches from this analysis as represented in Table 2.

Fig. 3 Bovine aortic arch (common stem for BCT and LCCA) in **a** conventional angiography, **b** 3D MDCT angiography, **c** coronal CT section image, **d** sagittal and **e** axial CT scan. *BCT* brachiocephalic trunk, *LCCA* left common carotid artery, *LSA* left subclavian artery, *RCCA* right common carotid artery, *RSA* right subclavian artery, *LVA* left vertebral artery, *RVA* right vertebral artery
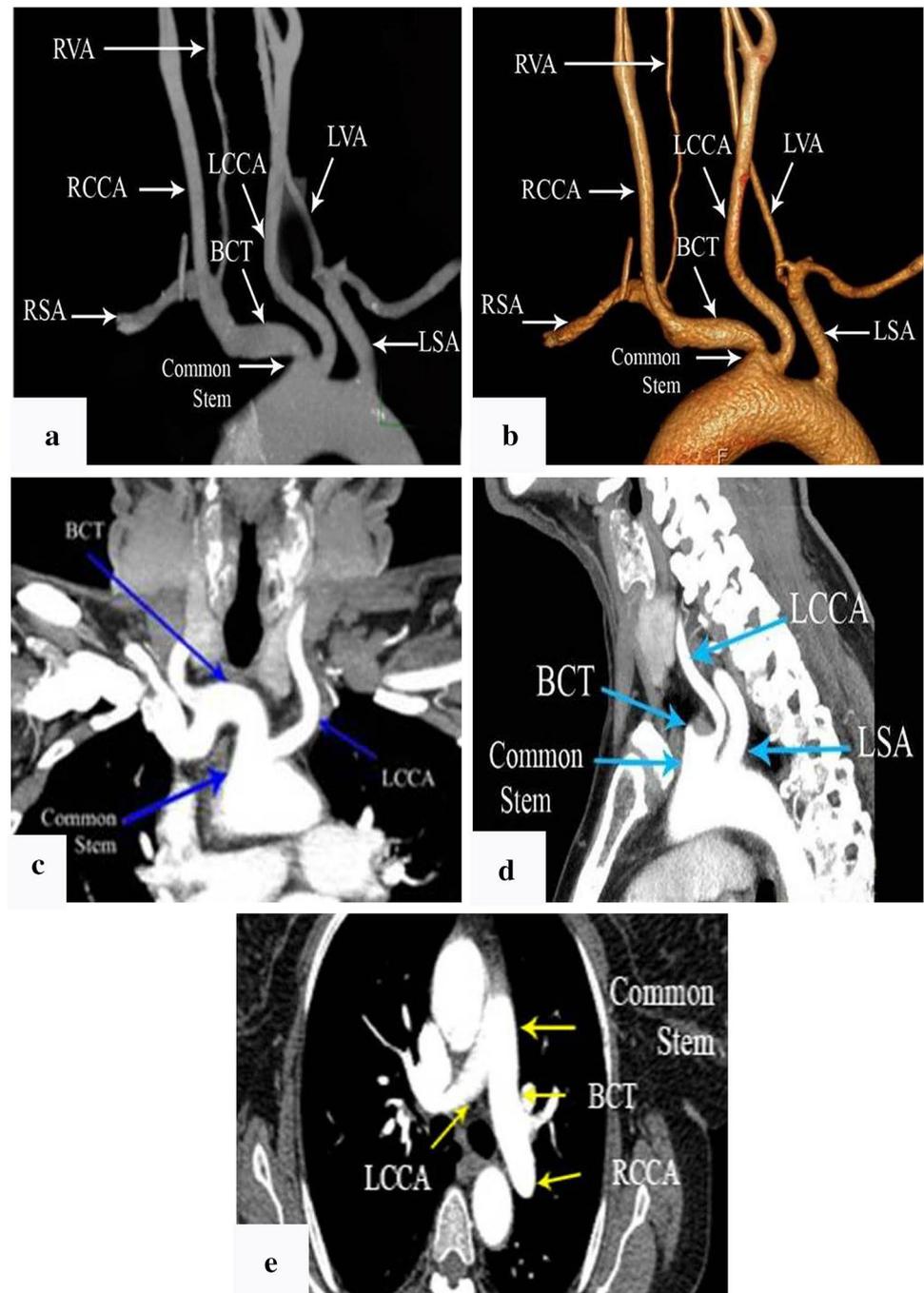
Morphometric measurements applied to the three main branches of the aortic arch

The morphometric parameters of the three main branches of the aortic arch including their diameters, angulation, distances from the beginning of the aortic arch and inter-branch distances are represented in Table 2.

Gender differences observed in the morphometric parameters applied to the AA and its branches revealed statistically significant difference between sexes in the outer diameter of LCCA, the distance between BCT and LCCA and the distance between LCCA and LSA (Table 3). Distribution of the morphometric parameters of the AA and its branches in relation to the anatomical variations is illustrated in Fig. 7.

Correlation between the measurements applied to AA and its branches
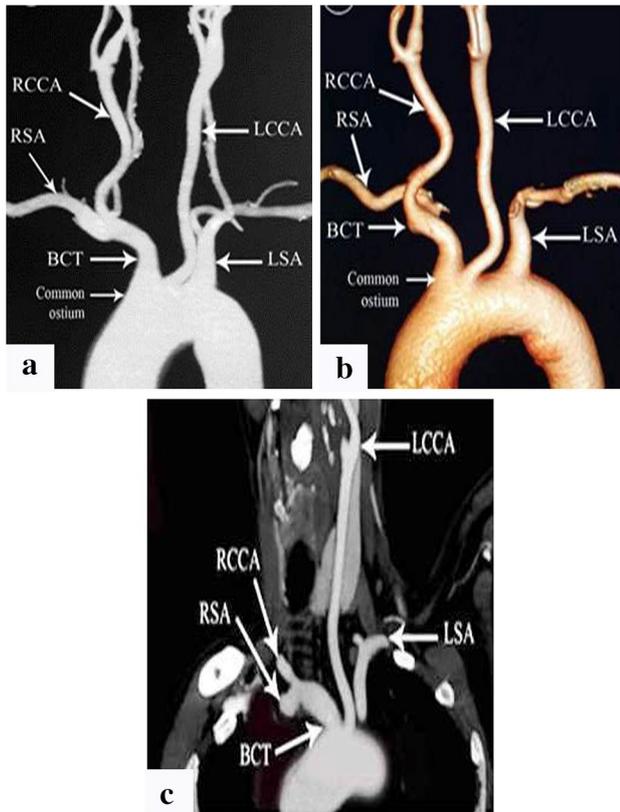
Correlation between diameters

Fig. 4 Common ostium variant (v-shaped origin for BCT and LCCA) in **a** conventional angiography, **b** 3D MDCT angiography and **c** coronal CT scan. *BCT* brachiocephalic trunk, *LCCA* left common carotid artery, *LSA* left subclavian artery, *RCCA* right common carotid artery, *RSA* right subclavian artery

Fig. 5 Aberrant left vertebral artery arising directly from the aortic arch. arising proximal to the origin of RSA in **a** 3D MDCT angiography and **b** sagittal CT scan, arising distal to the origin of RSA in **c** 3D MDCT angiography (posterior view) and **d** conventional CT angiography (A branch (red arrow head) is seen originating from the aberrant LVA beneath the RSA). *BCT* brachiocephalic trunk, *LCCA* left common carotid artery, *LSA* left subclavian artery, *RCCA* right common carotid artery, *RSA* right subclavian artery, *LVA* left vertebral artery, *RVA* right vertebral artery

Using Pearson correlation, the current study detected highly statistically significant positive correlation between the diameter of BCT and the diameter of LCCA ($r = -0.474$) (Table 4; Fig. 8a) and between the diameter of BCT and that of LSA ($r = 0.052$) (Table 4; Fig. 8b).

Correlation between angles: There was a highly statistically significant negative correlation ($r = 0.068$) between the BCT angle and the LCCA angle (Table 4; Fig. 8c).

Correlation between distances: There was a highly statistically significant positive correlation ($r = 0.112$) between the distance between BCT and LCCA and the distance between LCCA and LSA (Table 4; Fig. 8d).

Correlation between angles and distances: There was a highly statistically significant positive correlation ($r = 0.052$) between mean BCT angle and the distance between the origin of the aortic arch and midpoint of aortic origin of BCT (Table 4; Fig. 8e).
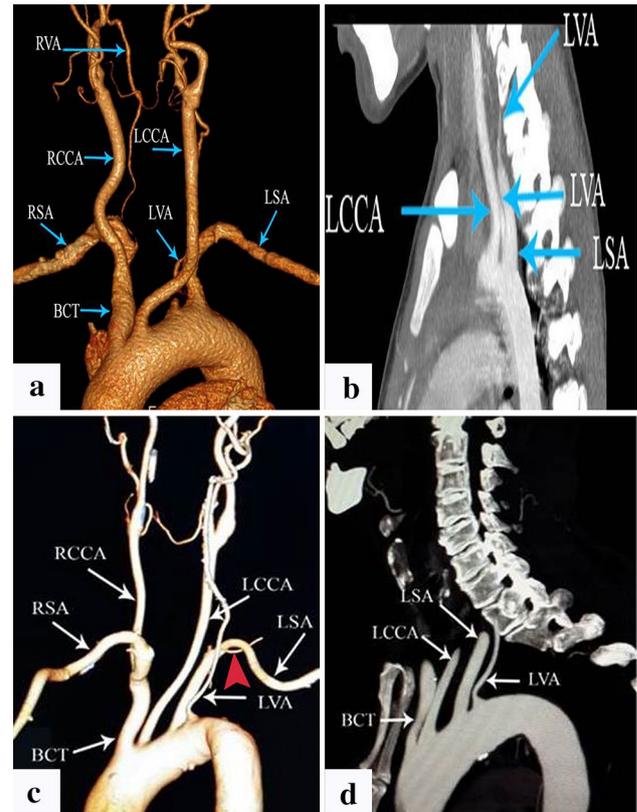
Table 1 Gender difference in the incidence rate of different types of the branching pattern of the aortic arch (males: $n = 77$; females: $n = 23$)

Branching pattern	Male		Female		P value
	N	%	N	%	
Classical branching pattern	48	62.3%	17	73.9%	0.52
Bovine configuration	21	27.3%	3	13.2%	
Common ostium for BCT and LCCA A	4	5.2%	2	8.6%	
Aberrant left vertebral artery arising directly from the AA	4	5.2%	1	4.3%	

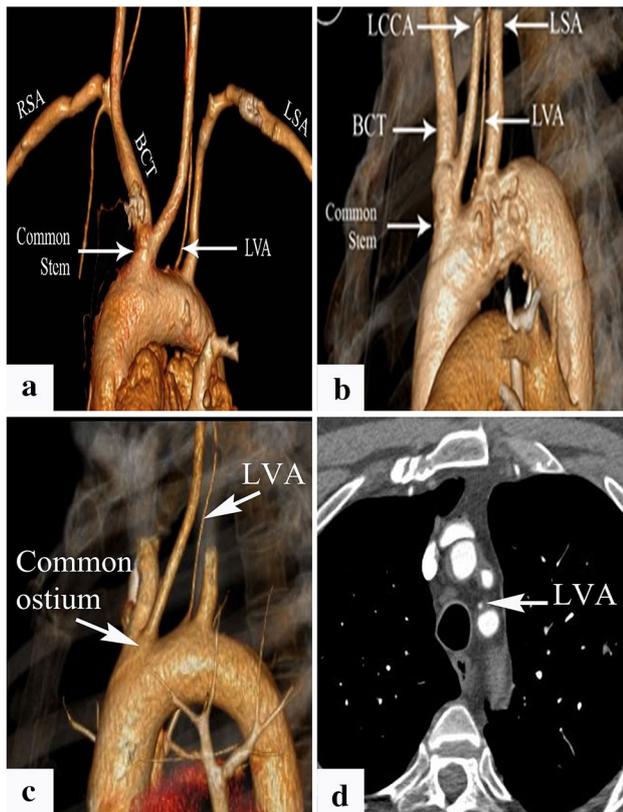*P* value: insignificant using Chi square test

Fig. 6 Association between bovine arch and aberrant left vertebral artery in **a, b** 3D MDCT angiography, association between common ostium and aberrant left vertebral artery in **c** 3D MDCT angiography and **d** axial CT scan. *BCT* brachiocephalic trunk, *LCCA* left common carotid artery, *LSA* left subclavian artery, *RSA* right subclavian artery, *LVA* left vertebral artery

Anatomical results

Measuring the mean diameter of the three main branches of the aortic arch in cadaveric specimens revealed that the BCT displayed the greatest diameter (16.5 ± 2.7), while the LCCA displayed the smallest diameter (10.8 ± 2.1). The average parameters of the aortic arch and its three main branches are represented in Table 5.

Discussion

Comprehensive understanding of the AA branching pattern has very important clinical and surgical implications, especially in arterial embolization and management of certain clinical situations, in addition to its major role as a prerequisite for achieving correct assessment before endovascular treatment of aortic dissection and aneurysms which require hybrid interventional surgical approaches and complex procedures such as selective antegrade cerebral perfusion. In such cases, knowledge of the variability

of the AA branching pattern could enable reconstruction of the AA and restoring its continuity to the aorta with less risk of ischemic and embolic cerebral damage [22]. The abnormal origin and course of aortic arch branches can also favor cerebral disorders by altering the pattern of blood flow in cerebral vessels and explain various patterns of cerebral embolization [27]. Therefore, awareness of abnormal branches originating from the aortic arch is vital in diagnosis of several hemodynamic disorders and intracranial aneurysms [31].

In the current work, the AA displayed the classical branching pattern in 65% of the studied cases. This incidence lies within the range of recent worldwide cadaveric (65–93%) and radiological (61–89%) studies [26].

The most common variant observed in the present study was the "bovine arch", which was noticed in 24% of the cases. In this variant, only two great vessels originated from the AA. The first was a common trunk, which incorporates the BCT and the LCCA, and the second was the LSA, which arose independently distal to the origin of the common trunk. The bovine variant is generally accepted as the most common AA variant in most studies [14, 23]. It is thought that the bovine AA is due to the slower growth of the ventral aortic roots between the third and fourth arches which allows the LCCA to fuse with the BCT [25], or it could be attributed to failure of the left horn of the aortic sac development [24].

Being similar to the vascular pattern of the cattle, this type is known as the bovine aortic arch. However, it is actually a misnomer, since it does not resemble the cattle aortic arch which has only one branch that divides into right subclavian artery and a common trunk for common carotid arteries and LSA. This true bovine arch with a common "bicarotid trunk" is actually very rarely seen in humans. Moreover, the human aortic arch branching pattern ascribed as "bovine" is also not commonly found in cattle. Thus, it would rather be more preferable to use descriptive anatomic criteria supplanting the term "bovine aortic arch" erroneously used in clinical practice to avoid the possibility of miscommunication [3, 16].

Bovine AA has also been linked to congenital abnormalities such as Trisomy and DiGeorge syndrome [18]. Technical access to LCCA during carotid stenting is difficult in the presence of the bovine variant because of the double tight turn from the AA to BCT and from the BCT to LCCA through the femoral approach [6, 29]. Therefore, the brachial or radial approach is a preferred route rather than the femoral approach in cases of bovine arch due to the presence of only one tight turn from BCT to LCCA [9]. A study done by Malone et al. also revealed significant relationship between the bovine AA variant and aortic aneurysm in older patients [17]. Also, there is increased risk of thoracic pathology in the presence of the bovine variant [20]. Stenosis or occlusion
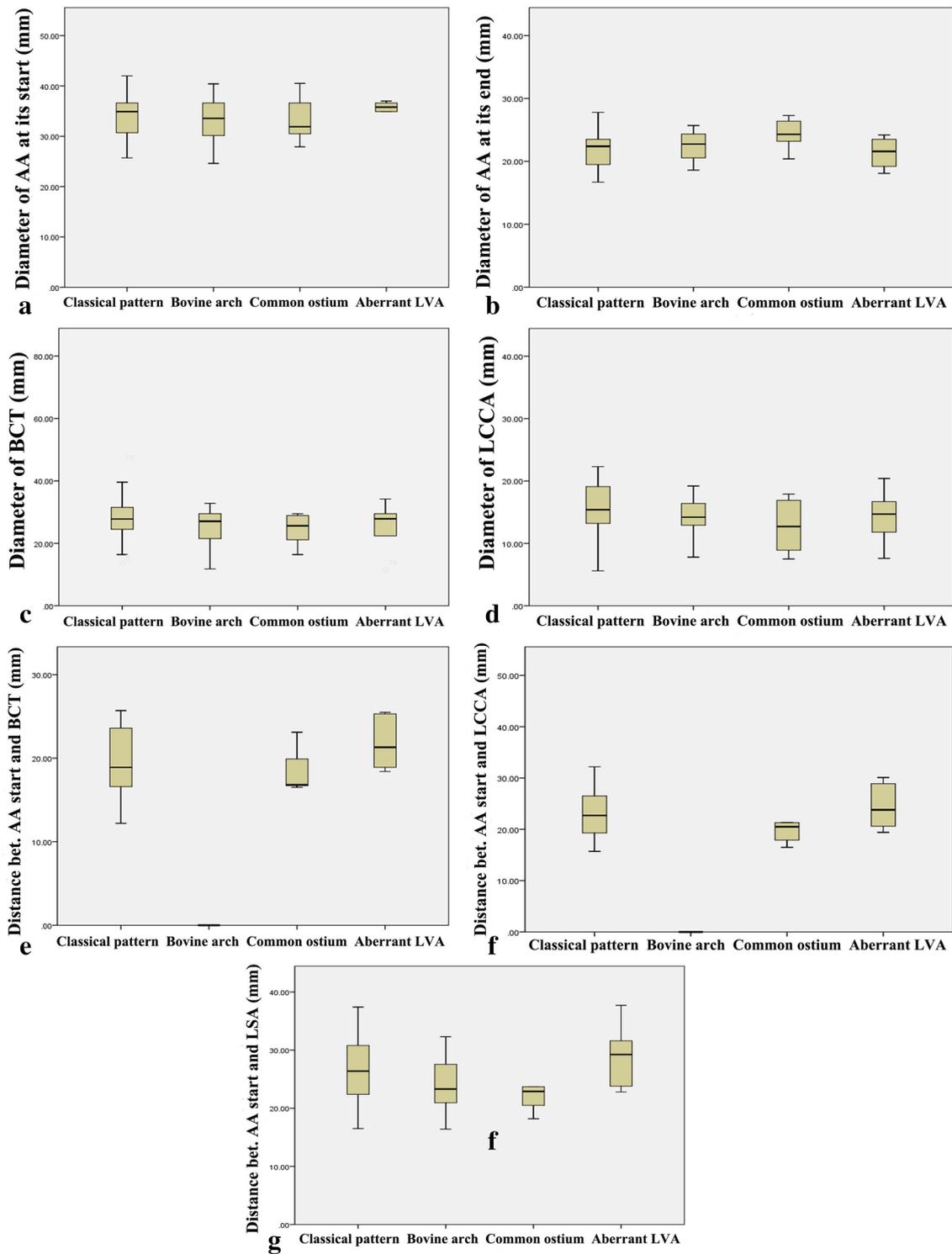
Fig. 7 Distribution of morphometric parameters in relation to the anatomical variations. **a** Diameter of the aortic arch at its start, **b** diameter of the aortic arch at its end, **c** diameter of the brachiocephalic trunk, **d** diameter of the left common carotid, **e** distance between the start of AA and the point of aortic origin of the brachiocephalic trunk, **f** distance between the start of AA and the point of aortic origin of the left common carotid artery, **g** distance between the start of AA and the point of aortic origin of the left subclavian artery

Table 2 Different measurements applied to the AA and its main branches

Parameter	Mean ± SD
Outer diameter of AA at its start (n = 100)	**33.83 ± 4.03**
Outer diameter of AA at its end (n = 100)	**22.06 ± 2.77**
Distance between the start of AA and midpoint of aortic origin of BCT (n = 76)	**19.59 ± 3.81**
Distance between the start of AA and midpoint of aortic origin of LCCA (n = 76)	**23.01 ± 4.96**
Distance between the start of AA and midpoint of aortic origin of LSA (n = 100)	**26.01 ± 4.95**
Outer diameter (in mm) of BCT (n = 100)	**15.7 ± 7.42**
Outer diameter (in mm) of LCCA (n = 100)	**11.42 ± 4.72**
Outer diameter (in mm) of LSA (n = 100)	**14.02 ± 6.8**
Angle between AA and BCT (n = 76)	**59.01° ± 12.91°**
Angle between AA and LCCA (n = 76)	**68.59° ± 14.27°**
Angle between AA and LSA (n = 76)	**59.92° ± 18.42°**
Distance (in mm) between BCT and LCCA (n = 76)	**19.59 ± 3.81**
Distance (in mm) between LCCA and LSA (n = 76)	**23.01 ± 4.96**

Table 3 Gender difference in the measurements applied to the three main branches of the aortic arch

Parameter	Males		Female		P value
	N	Mean ± SD	N	Mean ± SD	
Outer diameter (in mm) of BCT	77	**16.53 ± 7.60**	23	**15.70 ± 6.63**	0.2
Outer diameter (in mm) of LCCA	77	**11.84 ± 4.25**	23	**10.35 ± 5.73**	0.02*
Outer diameter (in mm) of LSA	77	**17.39 ± 21.29**	23	**13.81 ± 4.90**	0.7
Angle between the outer surface of AA and BCT	57	**59.0° ± 12.91°**	19	**55.02° ± 6.18°**	1.3
Angle between the outer surface of AA and LCCA	57	**63.18° ± 16.27°**	19	**68.59° ± 14.27°**	2.8
Angle between the outer surface of AA and LSA	77	**58.03° ± 17.57°**	23	**66.26° ± 20.17°**	0.6
Distance (in mm) between BCT and LCCA	57	**14.07 ± 5.32**	19	**15.89 ± 6.88**	0.007
Distance (in mm) between LCCA and LSA	57	**25.41 ± 11.29**	19	**24.09 ± 7.53**	0.041*

*P value: significant using independent Student's "t" test

Table 4 Correlations applied to morphometric parameters

		Diameter of BCT	Diameter of LCCA
Diameter of BCT	Pearson correlation	1	0.688**
	Sig. (2-tailed)		0.000
		Diameter of BCT	Diameter of LSA
Diameter of BCT	Pearson correlation	1	0.227*
	Sig. (2-tailed)		0.023
		BCT angle	LCCA angle
BCT angle	Pearson correlation	1	0.761**
	Sig. (2-tailed)		0.000
		Distance between BCT and LCCA	Distance between LCCA and LSA
Distance between BCT and LCCA	Pearson Correlation	1	0.351**
	Sig. (2-tailed)		0.002
		BCT angle	Distance between the start of AA and BCT
BCT angle	Pearson Correlation	1	0.227*
	Sig. (2-tailed)		0.023

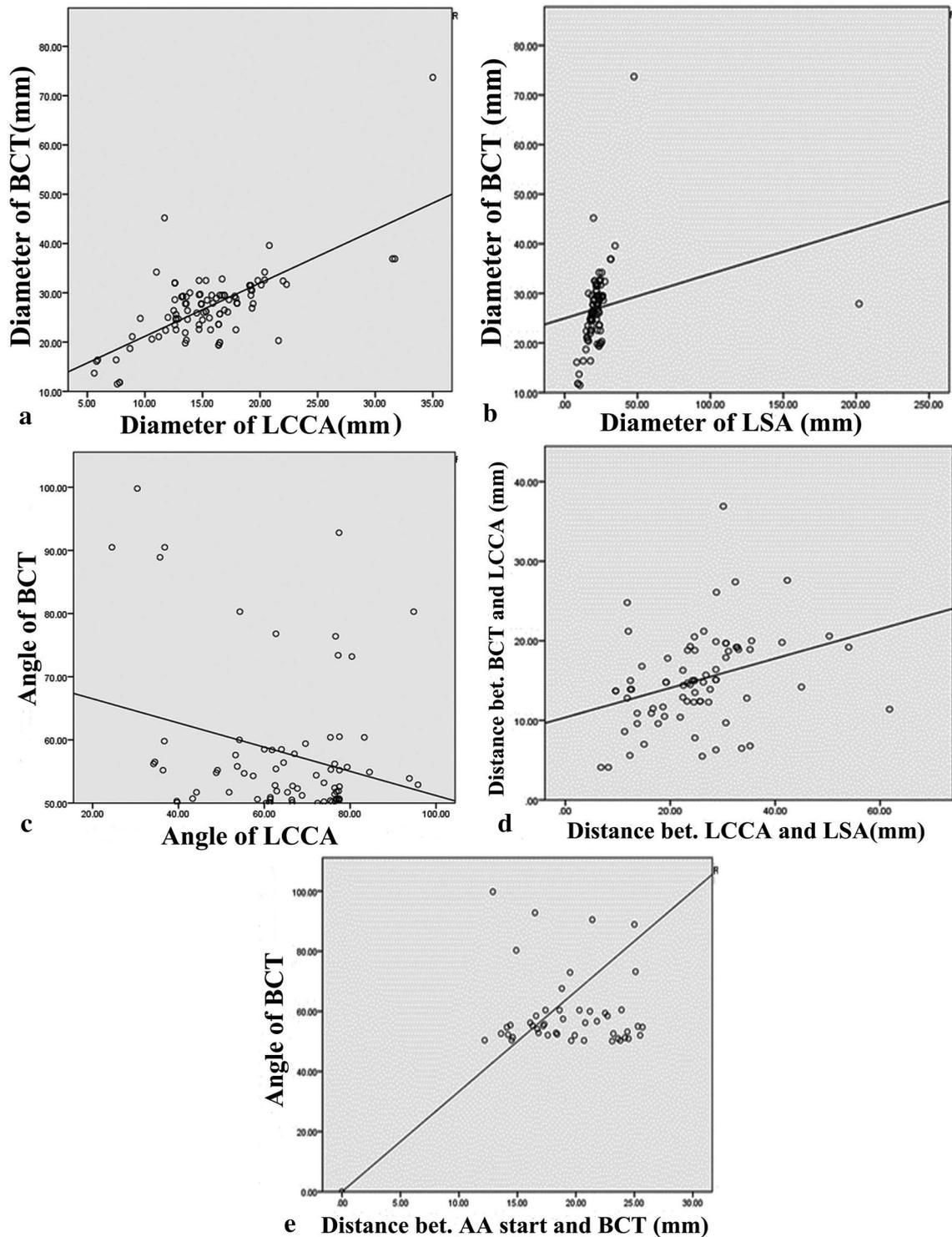**Correlation is highly significant at the 0.01 level (2-tailed)

Fig. 8 Pearson's correlation showing **a** positive correlation between the diameter of BCT and the diameter of LCCA, **b** positive correlation between the diameter of BCT and the diameter of LSA. **c** Negative correlation between the BCT angle and the LCCA angle. **d** Posi-tive correlation between the distance between BCT and LCCA and the distance between LCCA and LSA. **e** Positive correlation between the mean BCT angle and the distance between the origin of the aortic arch and midpoint of aortic origin of BCT

Table 5 Different measurements applied to the aortic arch and its three main branches in cadaveric specimens ($n = 10$)

Measurement	Range	Mean ± SD
Outer diameter of AA at its start	26.6–39.2	**32.77** ± 4.09
Outer diameter of AA at its end	18.7–27.6	**23.38** ± 2.78
Outer diameter of BCT at its origin	11.5–20.4	**16.54** ± 2.77
Outer diameter of LCCA at its origin	7.6–14.3	**10.86** ± 2.16
Outer diameter of LSA at its origin	11.2–17.9	**14.10** ± 2.17
The distance between the mid vertebral line and aortic origin of BCT	1.5–16	**8.38** ± 4.64
The distance between the mid vertebral line and aortic origin of LCCA	3.7–20	**13.64** ± 4.83
The distance between the mid vertebral line and aortic origin of LSA	11–36	**24.47** ± 8.16

of the common trunk of the bovine AA may lead to severe ischemia with neurological deficits [9].

In the current study, the AA had a common ostium "v-shaped origin for BCT and LCCA at the outer surface of the AA" in 6% of cases. This incidence is close to the worldwide reference series [8, 12–14]. On the other hand, a lower prevalence was found by Natsis et al., who reported a prevalence of 0.16% for the common ostium variant [23]. An explanation to this discrepancy could be attributed to different techniques used. Unlike the present study which used high-resolution multi-detector 3D angiography, the authors reported their incidence by studying aortic angiographs using conventional angiography where the angiographic images are often suboptimal and of insufficient accuracy leading to missing and subsequent underestimation of some variations.

The incidence difference between common trunk "bovine arch" and common ostium is evident in the present study (24% versus 6% respectively). A v-shaped origin of the BCT and LCCA at the outer surface of the AA is considered as "common ostium variant". Conversely, a common stem for the BCT and LCCA is regarded a "bovine variant". This categorization gives relevance to the proposed classification and clarifies the description of each type of those branching patterns, thus removing the confusion seen in the literature between the bovine arch and common ostium.

In the remaining 5% of the variant cases in the present study, an aberrant LVA originated directly from the aortic arch. Detection of the aberrant LVA directly originating from the AA is of paramount importance in LVA catheterization during the setting of examination of posterior cerebral circulation by angiographic procedures [4, 10].

The aberrant LVA in the present study was located between the LCCA and LSA in four cases and distal to the LSA in only one case. In the latter case, the LVA showed an anomalous branch beneath the LSA. We were not able to follow this anomalously arising branch till its destination; however, it is possible that this branch could be an anastomotic branch between the thyrocervical trunk and the aberrant LVA: a connection that has been previously linked to the aberrant origin of the LVA from the aortic arch [33].

It is proposed that the aberrant origin of the LVA is usually due to persistence of the sixth or eighth left intersegmental artery. If the LVA develops from the sixth intersegmental artery, it will be located between the LCCA and LSA in adults. However, if the LVA originates from the eighth intersegmental artery, it will be situated distal to the LSA [19]. Direct origin of the LVA from the upper convex surface of the arch of aorta is usually attributed to increased absorption of embryonic tissue of the LSA between the origin of the aortic arch and the vertebral artery [27].

Normally, the vertebral artery on its course enters the foramen transversarium of the sixth cervical vertebra. The aberrant LVA, on the other hand, is strongly related to an anomalous level of entry in the foramen transversarium (4th or 5th cervical vertebra). This high level of entry can predispose to arterial dissection and/or obstruction during neck rotation [10, 26, 33].

Awareness of the origin of the LVA is also important in preoperative planning of anterior cervical decompression surgery, as laceration of the vertebral artery can lead to catastrophic hemorrhage, arterio-venous fistula or pseudo-aneurysms resulting in vertebro-basilar deficits [4]. The incidence of arterial dissection in the LVA originating directly from the AA is significantly higher compared to that of normal origin of the LVA [15]. The anomalous course of the LVA also significantly increases the risk of iatrogenic permanent neurological damage or death [4].

Aberrant LVA has also been correlated with clinical symptoms when associated with an intracranial aneurysm [30]. Aortic origin of the LVA usually causes rapid cerebral blood flow, leading to alterations in the cerebral hemodynamics and predisposition of cerebral disorders and atherosclerotic changes [11].

Morphometric study of the AA and its main three branches was conducted in the present cadaveric and radiological study. Concerning the external diameter of the AA, the present radiological study reported that the diameter of the AA at its origin and its termination was 33.83 mm and 22.06 mm, respectively, while the mean diameters of the BCT, LCCA and LSA at their origin from the AA were 15.7 mm, 11.42 mm and 14.02 mm, respectively. Cadaveric

assessment of the AA diameters in the present work revealed comparable figures. Several concordant results have been reported [1, 19, 30, 35].

In endovascular surgery that requires the insertion of a guiding catheter within a major branch, the diameter of the AA and its branches should be considered. Therefore, referring to such data would be of great help in selecting the appropriate size of catheter for each blood vessel [5].

The present study recorded a statistically significant positive correlation between the diameter of BCT and LSA. Knowledge about this correlation is vital for accurate vascular surgery [1]. Another association noticed in the current work was a statistically significant positive correlation between the diameter of LCCA and LSA which has also been previously reported [35].

The present radiological study reported that the mean distance between the BCT and LCCA was 19.59 mm and that the distance between the LCCA and LSA was 23.01 mm. Measuring the distances between the three main branches of the AA is of crucial importance in vascular interventions. Suresh et al. stressed that the approximation of the LCCA to the BCT is an important observation during instrumentation of the AA and its branches [32].

Another crucial parameter evaluated in the current thesis was determination of the angles between the AA and the left side of its main branches. The present study reported that the angles between the AA and left side of BCT, LCCA and LSA were 59.01°, 68.59° and 59.92°, respectively. These angle values come in close agreement to the previous reports [30, 19. 34].

Awareness of the angles between the AA and its main branches is mandatory for angiographic catheter selection and for proper choice of the arterial puncture site (brachial, femoral). The choice of the type, size and shape of the cerebral angiographic catheter essentially depends upon the flexion and angles of the AA branches. For example, the Simons type is more applicable when the LCCA has an acute angle [21].

The angle between the AA and its major branches is also of fundamental importance in determining the pattern of moving the angiographic catheter under fluoroscopic imaging during its manipulation within the aortic arch [30].

Difficult catheterization of the AA was reported in cases with a severely curved blood vessel with marked angulation of the AA branches. In these cases, catheterization is catastrophic as it may contribute to an embolism from an atheroma of the aortic arch or its major branches to the intracranial arteries [28]. Consequently, knowledge about angulation of the aortic arch branches especially in elderly patients with cardiovascular diseases can reduce surgical complications [20, 30]. Morphometric measurements of the angles of the AA branches is of particular importance in advanced age or longstanding hypertension where the AA changes its shape

and the angles between its branches become more acute [13]. The fact that the angles evaluated in the present study were measured in volume rendered 3D reconstructed views does not preclude their application in routine daily practice, since the measurements obtained from both coronal and sagittal conventional scans have shown comparable values to those obtained from the 3D reformatted images. Thus, the simple biplanar coronal and sagittal technique can preside over the 3D choice which might not always be the fastest choice in routine practice.

The present study illustrated multiple statistically significant correlations between various morphometric parameters of the AA branches. These correlations included: a positive correlation between the outer diameter of the three main branches of the AA, a positive correlation between the BCT angle and the distance between the AA origin and origin of the BCT and LCCA, a positive correlation between the distances between the main three branches of the AA and a negative correlation between the BCT angle and the LCCA angle.

These correlations are be of a great value for endovascular interventionists and diagnostic radiologists to establish better understanding of the anatomical structure of the AA and the relationship between the angulation, diameters and distances between the aortic arch branches, especially in this rapidly developing and complex era of extensive aortic endovascular surgical maneuvers.

Conclusion

The AA variations in the present study were found in 35% of the studied angiograms. This recorded prevalence signifies that anatomical variations of the AA branching pattern are actually not uncommon and this further highlights the importance of careful preoperative angiographic analysis for accurate surgical planning and avoiding potential complications.

The present study also illustrated a wealth of statistically significant correlations between the angulation, diameters and distances between the branches as well as the pattern of distribution of the different morphometric parameters in relation to the anatomical variations.

Despite the fact that careful measurement of the aortic arch morphometric parameters represents an indispensable preoperative necessity for each patient undergoing aortic endovascular intervention (especially for choosing the size, shape and type of the angiographic catheters), the morphometric data offered by the present study provide a valuable base about the normal values on population basis and call attention to the possibility of arterial stenosis or occlusion in cases of obviously reduced dimensions.

Despite the importance of those morphometric parameters in this era of extensive aortic instrumentation, the majority of the contemporary reported literature usually entails few rough measurements performed on a limited number of cadaveric specimens. The present study, on the other hand, assesses morphometric parameters through 3D MDCT angiography excluding factors related to the method of cadaveric preservation, duration of fixation and degree of tissue shrinkage due to dryness.

Compliance with ethical standards

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