Variants and Anomalies of Thoracic Vasculature on Computed Tomographic Angiography in Adults

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Objective: To determine the prevalence and clinical significance of normal, variant, and anomalous branching patterns of the aortic arch and the central veins on computed tomographic (CT) angiography in adults.

Methods: We retrospectively reviewed 1000 consecutive CT angiograms of the chest in 658 women and 342 men with a median age of 53 years.

Results: A total of 65.9% of patients had both normal aortic arch branching patterns and normal venous anatomy. Variants in the aortic arch branching pattern were present in 32.4% and anomalies in 1.5%. Venous anomalies were present in 0.7%. Review of CT reports showed that cardiothoracic radiologists correctly reported the anomaly more frequently than other radiologists (94% vs 20%, *P* = 0.003).

Conclusions: Whereas anomalies of the central thoracic vasculature are uncommon, variants in the aortic arch branching pattern are common. An appreciation of the appearance of these entities on CT angiography allows for precise reporting and is useful in preprocedure planning.

Key Words: CT angiography, aortic arch, central veins, variant, anomaly

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In 1891, the Committee of Collective Investigation of the Anatomical Society of Great Britain and Ireland reviewed 500 cases to describe the various branching patterns of the aortic arch.[1] Large autopsy series by Williams et al[2,3] and De Garis et al[4] in the 1930s focused on the difference in prevalence of branching patterns in various ethnic groups. Some early studies also compared the prevalence of various branching patterns in humans and other mammals.[4,5] Liechty et al,[6] in the largest single study to date, described the aortic arch branching pattern in 1000 adult cadavers. The normal aortic arch branching pattern with separate origins of the brachiocephalic, left common carotid, and left subclavian arteries was present in 65%. A common origin of the brachiocephalic and left common carotid arteries, known as a bovine trunk, was present in 27% of cadavers.[6] Variations in the aortic arch branching pattern have again been described in recent small autopsy studies.[7–10] However, to our knowledge, there has never been a large imaging series addressing this topic.

Anomalies of the central veins are uncommon. These anomalies have been studied in select populations including children with congenital heart disease and in adults as case reports.[11–15] Pulmonary vein anomalies were described in an autopsy series of 251 adult cadavers.[16] The appearance of anomalies of the central veins has been described on imaging, and prevalences have been estimated.[17–19] However, there is a paucity of imaging literature describing the prevalence of central venous anomalies in the general adult population.

Computed tomographic (CT) angiography is currently the most common method of evaluating the thoracic vasculature. We undertook the present study to determine the prevalence and clinical significance of normal, variant, and anomalous branching patterns of the aortic arch and the central veins on CT angiography in the general adult population. To our knowledge, this is the first large imaging series to address this topic.

MATERIALS AND METHODS

We retrospectively reviewed 1005 consecutive CT angiograms (CTAs) of the chest performed in adults for suspected pulmonary embolism or aortic dissection between January 1, 2006, and November 21, 2006, at Montefiore Medical Center, Bronx, NY. Sagittal and coronal reformatted images were available for review in all cases. None of the CTs were electrocardiogram (ECG) gated. Five studies were technically limited and therefore excluded. The study population is composed of the remaining 1000 CTAs of 658 women and 342 men with a median age of 53 (range, 19–97) years. Self-reported data regarding race and ethnicity were available for 727 patients as follows: 368 black, 166 white, 72 Hispanic, 12 Asian, 3 American Indian, 1 Native Hawaiian, and 105 multiracial.

Each case was jointly reviewed by 2 of 4 cardiothoracic radiologists, with differences resolved by consensus. Specific attention was paid to the aortic arch branching pattern and the anatomy of the central veins. Normal variants and anomalies of the aortic arch anatomy were documented, including bovine trunk (common origin of the brachiocephalic and left common carotid arteries), direct origin of the left vertebral artery from the aortic arch, aberrant right subclavian artery, right aortic arch with aberrant left subclavian artery, right aortic arch with mirror image branching, and double aortic arch. If a bovine trunk was present, the common origin was described as short (≤1 cm) or long (>1 cm). If a left vertebral artery arose directly from the aortic arch, we noted if it arose proximal or distal to the origin of the left subclavian artery.

Venous anomalies and variants sought were persistent left superior vena cava, partial anomalous pulmonary venous return, anomalous left brachiocephalic vein, azygos lobe, and azygos and hemiazygos continuation of the inferior vena cava.

We performed a focused chart review on patients with anomalies, looking for signs and symptoms previously described in the literature to be associated with each specific vascular anomaly (Table 1). The charts of 4 controls were reviewed for each patient with an anomaly. The controls were chosen by selecting the first 4 sex- and age-matched patients with normal CT findings.

The report of each CTA with a vascular anomaly was reviewed to determine whether the anomaly was described. We

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TABLE 1. Signs and Symptoms Sought in Association With Specific Anomalies

Anomaly	Sign/Symptom
Aberrant right subclavian artery	Dysphagia and dyspnea
Right aortic arch	Dysphagia and dyspnea
Bilateral brachiocephalic arteries	Cerebrovascular disease
Partial anomalous pulmonary venous return	Dyspnea on exertion, fatigue, chest pain, palpitations, congestive heart failure; ECG: right ventricular hypertrophy, conduction defects, arrhythmias
Retroaortic left brachiocephalic vein	Dysphagia and dyspnea

noted the subspecialty training of the radiologist who reported the CTA.

This study was approved by our institutional review board and was Health Insurance Portability and Accountability Act compliant. Informed consent was not required for this retrospective review.

Statistics

We determined the prevalence of normal anatomy, variants, and anomalies. We used the Fisher exact test for comparison of proportions and the Mann-Whitney U test for differences in median. A value of $P < 0.05$ was considered statistically significant.

RESULTS

A total of 65.9% (659/1000) of patients had both normal aortic arch branching patterns and normal venous anatomy. Variants in the branching pattern of the aortic arch were present in 32.4%, and anomalous branching patterns were present in 1.5% (Table 2). The most common variants were bovine trunk in 27.4% and direct origin of the left vertebral artery in 6.6%. The most common anomaly was aberrant right subclavian artery in 1.2%.

Venous anomalies were present in 0.7% (Table 3). The most common venous anomalies were partial anomalous pulmonary venous return and azygos lobe, each present in 0.3%. Two of the patients with partial anomalous pulmonary venous return had anomalous venous drainage of the left upper lobe with a vertical vein draining into the left brachiocephalic vein. The third patient had right-sided anomalous venous drainage with 2 anomalous veins (a right upper and a right middle lobe vein) each draining separately into the superior vena cava. None of these patients had pulmonary veins in the corresponding normal location. All 3 patients had enlargement of the superior vena cava, right atrium, and right ventricle on CT. None had an atrial septal defect identified on CT. Two patients were evaluated with echocardiography. Enlargement of the right ventricle was confirmed in both patients, and no atrial septal defect was noted on either echocardiogram.

All 3 patients with partial anomalous pulmonary venous return were symptomatic. Two had dyspnea on exertion, and the third had chronic nonradiating chest pain. The ECG revealed a conduction defect in 1 patient. There was no significant difference between cases and controls with regard to signs and symptoms ($P = 0.23$, Fisher exact test), which were present in 50% (6/12) of controls. Five had chest pain, and one had a conduction defect on ECG. None of the patients with other anomalies had associated signs or symptoms.

Of the patients with anomalies, 32% (7/22) were men and 68% (15/22) were women, similar to the sex distribution in our overall patient population. The median age of patients with anomalies was 49.5 (range, 21–80) years, which was not significantly different from the median age in our overall population ($P = 0.65$, Mann-Whitney U test). There was no

TABLE 2. Aortic Arch Branching Patterns

	n	%
Normal branching pattern	665	66.0
Variant anatomy	324	32.4
Bovine trunk	274	27.4
Short	196	19.6
Long	78	7.8
Direct origin left vertebral	66	6.6
Proximal to subclavian	61	6.1
Coincident with bovine arch	16	1.6
Anomalous branching patterns	15	1.5
Aberrant right subclavian	12	1.2
Coincident with bovine arch	4	0.4
Bilateral brachiocephalics arteries	2	0.2
Right aortic arch	1	0.1

TABLE 3. Venous Anomalies

	n	%
Normal veins	993	99.3
Venous anomalies	7	0.7
PAPVR	3	0.3
Azygos lobe	3	0.3
Retroaortic brachiocephalic vein	1	0.1

PAPVR indicates partial anomalous pulmonary venous return.

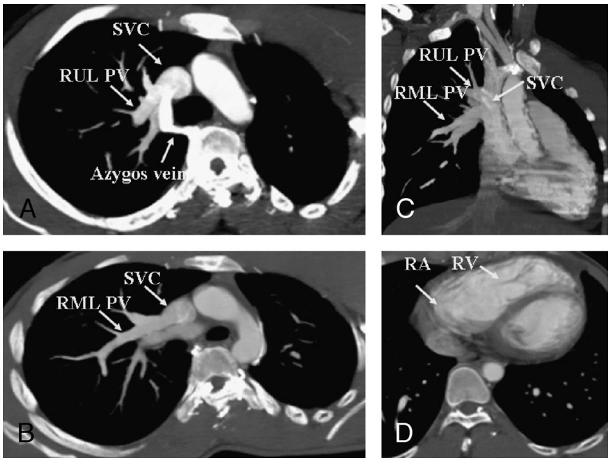

FIGURE 1. A 24-year-old man with partial anomalous pulmonary venous return of the right upper (RUL) and right middle (RML) lobe pulmonary veins (PV). Contrast-enhanced CT angiography demonstrates separate orifices for each vein. Both veins drain into an enlarged superior vena cava (SVC) as demonstrated on axial (A and B) and coronal (C) images. The right atrium (RA) and right ventricle (RV) are dilated (D).

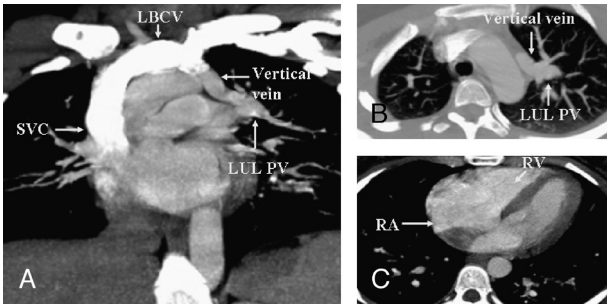

FIGURE 2. A 24-year-old woman with partial anomalous pulmonary venous return of the left upper lobe (LUL). Contrast-enhanced CT angiography demonstrates the LUL pulmonary vein (PV) draining into a vertical vein that drains into the left brachiocephalic vein (LBCV) on coronal (A) and axial (B) images. The patient also has an enlarged superior vena cava (SVC) (A), right atrium (RA), and right ventricle (RV) (C).

association between a bovine trunk and direct origin of the left vertebral artery ($P = 0.55$, Fisher exact test) or between a bovine trunk and an aberrant right subclavian artery ($P = 0.64$, Fisher exact test).

Radiologists with cardiothoracic radiology fellowship training interpreted 78% (780/1000) of all studies and 77% (17/22) of the studies in which an anomaly was present. Of these, the anomaly was correctly reported in 94% (16/17). Radiologists with fellowship training in other subspecialties reported 22% (220/1000) of all studies and 23% (5/22) of examinations in which an anomaly was present. When the interpreting radiologist was trained in another subspecialty, the anomaly was correctly reported in 20% (1/5). There was a significant difference in the correct reporting of vascular anomalies between radiologists with subspecialty training in cardiothoracic radiology and in other subspecialties ($P = 0.003$, Fisher exact test).

DISCUSSION

The present study describes the prevalence of variants and anomalies of the aortic arch branching pattern and central veins in a consecutive series of adults using CT angiography. This topic has received scant attention in the imaging literature, and there have been no large consecutive imaging series describing the prevalence of these variants and anomalies in the general adult population. We found a significant relationship between an anomaly being "missed" on the CT report and interpretation of the examination by a non–cardiothoracic radiologist. Cardiothoracic radiologists generally have a high level of familiarity with the normal, variant, and anomalous branching patterns of the thoracic arteries and veins. Because CT angiography is the most common modality used to image the thoracic vasculature, the present large CT angiographic series serves to elucidate the imaging appearance and significance of these variants and anomalies. Although review of the charts of patients with anomalies compared with controls showed no significant difference in symptoms, recognition of these anomalies may impact planning of surgical or interventional procedures.

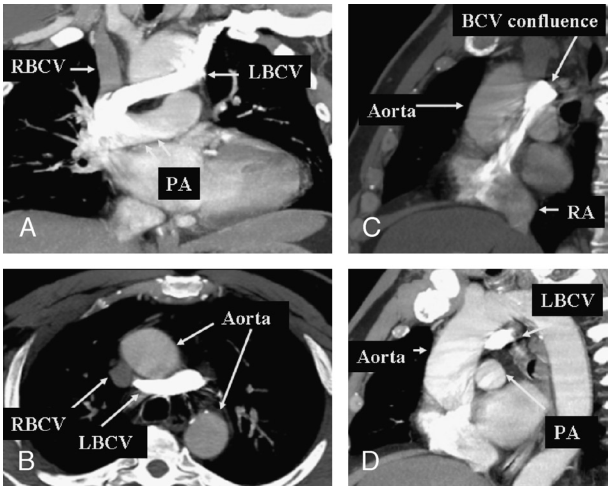

FIGURE 4. A 50-year-old man with a retroaortic left brachiocephalic vein (LBCV). Contrast-enhanced CT angiography demonstrates the retroaortic LBCV in the same plane as the transverse right pulmonary artery (PA) on coronal maximum-intensity projection images (A). Axial (B) and sagittal maximum-intensity projection images (C and D) demonstrate the retroaortic position of the LBCV. The right brachiocephalic vein (RBCV) is in a normal location.

The prevalence of venous anomalies described in the literature is not derived from studies devoted to the determination of the prevalence of these anomalies in the general adult population. The numbers frequently quoted in the literature are extrapolated from cadaver series or are estimates based on series of children with congenital heart disease.[11–16] Our study population, a consecutive series of adults who underwent CT angiography for suspected pulmonary embolism or aortic dissection, represents a different population that would be expected to have a lower prevalence of anomalies. We found a very low prevalence of 0.7% for any venous anomaly in the present series.

In partial anomalous pulmonary venous return, one or more pulmonary veins drain into the right atrium or a systemic vein instead of the left atrium, creating a left-to-right shunt. The

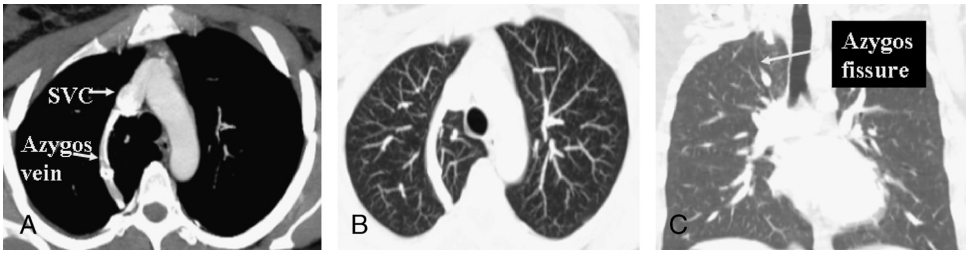

FIGURE 3. A 28-year-old woman with an azygos lobe. Contrast-enhanced CT angiography shows the azygos vein in the azygos fissure and draining into the posterior superior vena cava (SVC) on axial maximum-intensity projection soft tissue (A) and lung (B) windows and coronal maximum-intensity projection lung windows (C).

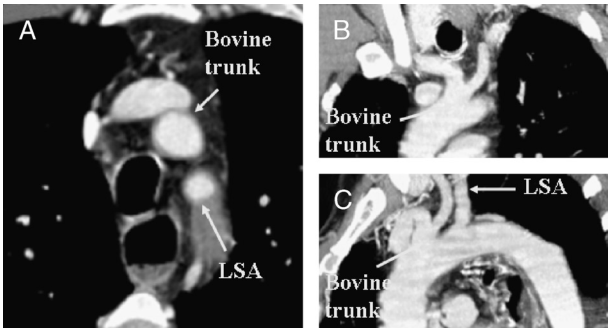

FIGURE 5. A 66-year-old man with a bovine trunk. Contrast-enhanced CT angiography demonstrates a bovine trunk giving rise to the brachiocephalic and left common carotid arteries on axial (A), oblique coronal (B), and sagittal (C) maximum-intensity projection images. LSA indicates left subclavian artery.

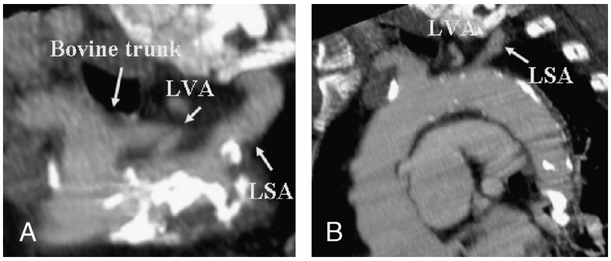

FIGURE 6. An 84-year-old woman with direct origin of the left vertebral artery (LVA) and a bovine trunk. Contrast-enhanced CT angiography demonstrates the LVA arising directly from the aortic arch, proximal to the origin of the left subclavian artery (LSA) on oblique images (A and B). Note the bovine trunk (A).

prevalence of partial anomalous pulmonary venous return was 0.4% to 0.7% in prior autopsy series[16] and was 0.3% in our series (Figs. 1 and 2).

The azygos lobe is an accessory lobe that may be found in the superior portion of the right lung (Fig. 3). It results from failure of migration of the right posterior cardinal vein, a precursor of the azygos vein, over the lung during embryonic development. Instead, this vessel indents the lung and its overlying pleural layers, creating the azygos fissure. It is important to be aware of the location of this vein when planning thoracic surgical procedures. The azygos fissure presents a barrier to the spread of disease, and thus pneumonia or other disease processes of the right upper lobe or of the azygos lobe will often remain contained.[20] An azygos lobe has been described in 1% of anatomical specimens,[18] 0.07% to 2.6% of radiographic studies,[19] and was present in 0.3% of patients in this series.

The normal course of the left brachiocephalic vein is anterior to the aortic arch. Rarely, the left brachiocephalic vein takes an anomalous course, passing below the arch and posterior to the ascending aorta (Fig. 4). A retroaortic left brachiocephalic vein is often associated with congenital heart disease,[21–23] and its prevalence in the general population has not been previously described. In this series, the prevalence was 0.1% and it was not associated with other anomalies.

Persistence of the left superior vena cava is caused by persistence of the left anterior cardinal vein. It is considered a relatively common venous anomaly, previously estimated to occur in 0.3% of the general population.[15] We found no cases of persistent left superior vena cava in the present series, suggesting a prevalence of less than 0.1% in the general adult population. Both the left superior vena cava and the vertical vein of partial anomalous pulmonary venous return have a similar vertically oriented tubular appearance in the left mediastinum. Knowledge of the site of origin and drainage of each venous anomaly is necessary in rendering an accurate diagnosis.[24]

The aortic arch branching patterns that we observed in this CT angiography series are concordant with autopsy series performed in the early half of the last century. A number of these studies examined the prevalence of variants among populations with different racial origins, focusing in particular on the high incidence of bovine aortic arch in African Americans.[2–4] Although racial data obtained in our study were based on self-reporting by patients and were not uniformly available, the study included patients with diverse racial and ethnic backgrounds. Recognition of variants and anomalies of the branching of the aortic arch has diagnostic and therapeutic implications.

The bovine trunk, a common origin of the brachiocephalic and the left common carotid arteries, is the most common variant in the branching pattern of the aortic arch (Fig. 5). Although this branching pattern is commonly referred to as a "bovine" arch, this classification is inaccurate because this is not the aortic arch branching pattern found in cows.[25] This branching pattern, however, is found in certain other animals, including cats, dogs, and rabbits, leading to the suggestion that this branching pattern should more correctly be known as a "feline," "canine," or "lapine" arch.[26] The reported prevalence of this branching pattern in humans has ranged from 1% to 27%[1–4,6–10] and was 27.4% in this series. A bovine trunk may be associated with an increased rate of technical failure and neurological complications in carotid artery stenting procedures.[27,28]

The prevalence of a direct origin of the left vertebral artery ranged from 3.3% to 7.4% in the literature[1–4,6–10] and was 6.6% in this series (Fig. 6). This variant is important in planning interventional procedures. It is also associated with a higher incidence of spontaneous dissection of the vertebral artery, which may be caused by congenital structural defects in the arterial walls or because of alterations in cerebral vascular

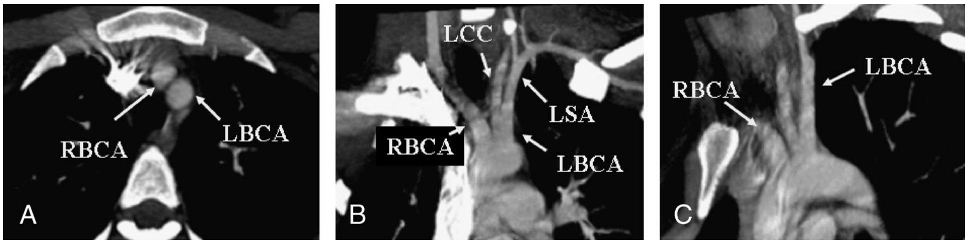

FIGURE 7. A 24-year-old woman with bilateral brachiocephalic arteries. Contrast-enhanced CT angiography demonstrates 2 branches representing the right (RBCA) and left (LBCA) brachiocephalic arteries arising from the aortic arch on axial (A), coronal (B), and oblique (C) maximum-intensity projection images. LCC indicates left common carotid artery; LSA, left subclavian artery.

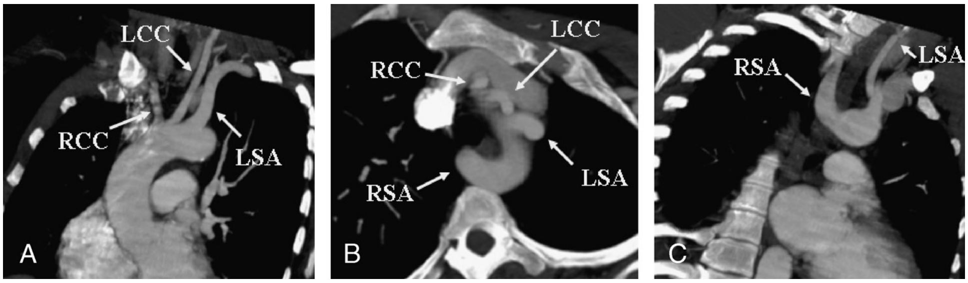

FIGURE 8. A 49-year-old woman with an aberrant right subclavian artery (RSA). Contrast-enhanced CT angiography with oblique maximum-intensity projection images (A–C) demonstrates the aortic arch giving rise to the right common carotid (RCC), left common carotid (LCC), left subclavian (LSA), and finally the right subclavian (RSA) arteries. The RSA crosses the midline from left to right posterior to the esophagus.

hemodynamics.[29] Although patients with this variant are generally not susceptible to subclavian steal syndrome on the left, variants of the syndrome have been reported in some patients.[30,31]

An aberrant right subclavian artery is the most common aortic arch anomaly (Fig. 7). This anomaly results from interruption of the embryological right fourth aortic arch between the carotid and subclavian arteries. Its prevalence in previous studies has ranged from 0.4% to 2%[1–4,6,32] and was 1.2% in the present series. The course of the aberrant right subclavian artery is usually retroesophageal, as was true in every case in this series. An aberrant right subclavian artery is usually asymptomatic and is discovered as an incidental finding, although in the past, it was thought to cause dysphagia, a clinical entity known as *dysphagia lusoria*.[33] Prior recognition of an aberrant right subclavian artery is important in planning esophageal and vascular surgical and angiographic procedures.

Bilateral brachiocephalic arteries, present in 1.2% to 2% in previous autopsy series,[6,10] was found in only 2 patients (0.2%) in this series (Fig. 8). Recognition of the anomaly may impact on preprocedure planning.

A right aortic arch has been reported to occur in approximately 0.1% of the population.[6] The 2 main types of right aortic arch, classified according to branching patterns include mirror-image branching (left brachiocephalic, right common carotid, and right subclavian arteries) and aberrant left subclavian artery (left common carotid, right common carotid, right subclavian, and left subclavian). A third uncommon type is a right aortic arch with isolation of the left subclavian artery, in which the left subclavian artery arises from the left pulmonary artery (the branches of the aortic arch are left common carotid, right common carotid, and right subclavian arteries). Although a right aortic arch with aberrant left subclavian artery is usually considered the most common type of right aortic arch,[34] none were present in this series, suggesting a prevalence of less than 0.1%. Right aortic arch with mirror-image branching is usually associated with cyanotic congenital heart disease and is present in 20% to 25% of patients with tetralogy of Fallot.[35–37] The patient with right aortic arch with mirror-image branching (0.1% in this series) had a prior diagnosis of tetralogy of Fallot (Fig. 9).

The terms *variant* and *anomaly* are commonly used in the description of anatomy. The definition of these terms may be based on prevalence in the general population, functional significance, or a combination of the two; however, there is no consensus regarding the use of these terms. We accepted the use of the term *anomaly* to describe an aberrant right subclavian artery because it is commonly described as such. We suggest that variations that occur in less than 1% of the population should be considered anomalies regardless of functional significance. Accordingly, an azygos lobe, found to have a prevalence of 0.3% in this study, would be considered an anomaly rather than a normal variant.

In conclusion, anomalies of the central thoracic vasculature are more likely to be reported by radiologists with fellowship training in cardiothoracic radiology who are familiar with the appearance and significance of these entities. Anomalies are uncommon, with a prevalence of 0.7% for venous and 1.5% for arterial anomalies. However, a bovine trunk is very common, and the typical aortic arch branching pattern was present in only two thirds of patients. An appreciation of the appearance of anomalies and common variants of the thoracic vasculature on CT angiography allows for precise reporting and is useful in preprocedure planning.

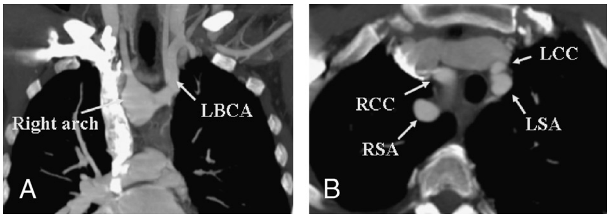

FIGURE 9. A 46-year-old woman with tetralogy of Fallot and right aortic arch with mirror-image branching. Contrast-enhanced CT angiography demonstrates a right aortic arch. The branching pattern is left brachiocephalic (LBCA) artery (giving rise to the left common carotid [LCC] and left subclavian [LSA]), right common carotid (RCC), and right subclavian (RSA) arteries on coronal (A) and axial (B) maximum-intensity projection images.

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