Fetal Aortic Arch Anomalies

Key Sonographic Views for Their Differential Diagnosis and Clinical Implications Using the Cardiovascular System Sonographic Evaluation Protocol

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Aortic arch anomalies are present in 1% to 2% of the general population and are commonly associated with congenital heart disease, chromosomal defects, and trachea-esophageal compression in postnatal life. The sonographically based detection of aortic arch anomalies lies in the 3-vessel and trachea view. Although highly sensitive, this view alone does not allow identification of the aortic arch branching pattern, which prevents an accurate diagnosis. The systematic addition of a subclavian artery view as part of a standardized procedure may be useful in the differential diagnosis of these conditions. We describe the sonographic assessment of fetal aortic arch anomalies by combining 2 fetal transverse views: the 3-vessel and trachea view and the subclavian artery view, which are included in the cardiovascular system sonographic evaluation protocol. We also review the sonographic findings and the clinical implications of fetal aortic arch anomalies.

Key Words—aberrant subclavian artery; aortic arch anomalies; double aortic arch; echocardiography; prenatal diagnosis; right aortic arch; subclavian artery view; 3-vessel and trachea view

Aortic arch anomalies refer to a variety of congenital abnormalities that are related to the position or branching of the aortic arch, which occur in 1% to 2% of the general population.[1,2] Most of these anomalies (up to 50%) have been reported to be associated with congenital heart disease, which means that isolated vascular rings are uncommon (1–1.6 per 1000 pregnancies).[3–5] The most common type of aortic arch anomaly is a left aortic arch with an aberrant right subclavian artery, followed by a right aortic arch anomaly with an aberrant left subclavian artery, a right aortic arch anomaly with mirror image branching, and a double aortic arch anomaly.[5–8]

Although most aortic arch anomalies are clinically unimportant in the neonate, during fetal life, they serve as markers for fetal congenital heart disease and chromosomal defects, including 22q11 microdeletion.[9] The presence of an aberrant subclavian artery, either right or left, regardless the laterality of the aortic arch, has been associated with an increased incidence of chromosomal abnormalities, mainly when other associated anomalies are detected. Thus, its prenatal detection is particularly relevant.[10]

Over the last 30 years, we have witnessed an evolution in the prenatal assessment of the fetal heart and great vessels using various methods, with a common trend being the progressive addition of complementary views, starting with the basic 4-chamber view up to the 5 axial views, which can provide a wider image and can give us a

greater understanding of the anomalies in this area.[11–14] Although at the beginning, sonographers were reticent about the addition of further views, they have been gradually incorporating these improvements based on the better results obtained in terms of diagnosis.[15] In this progressive development, the axial view has been the most representative in every systematic approach. Prenatal evaluation of aortic arch anatomy and its branching has been classically performed by using the axial 3-vessel and trachea view.[13,16] Nevertheless, and on the basis of previous statements, we are on the verge of extending our cardiovascular exploration area by also including the cranial area to improve our diagnostic capability by implementing the cardiovascular system sonographic evaluation protocol.[17] Furthermore, we have already reported that the addition of a subclavian artery axial view to the usual 3-vessel and trachea view as part of a standardized procedure may substantially contribute to the characterization of aortic arch anomalies in fetuses, using a simple method that can be easily added to the conventional scanning procedure.[17]

The aim of this article is to describe an improvement made to the systematic method used for the sonographic assessment of fetal aortic arch anomalies by combining the findings of 2 fetal transverse views: the 3-vessel and trachea view and the subclavian artery view (cardiovascular system sonographic evaluation protocol)[17] and to review the sonographic findings and clinical implications of fetal aortic arch anomalies.

Embryonic Development of the Aortic Arch and Fetal Anatomy

In 1948, the pathologist Jesse E. Edwards introduced a hypothetical model, which allowed the understanding of normal and abnormal development of the aortic arch.[18,19] According to this model, most aortic arch anomalies can be explained as disruptions of aortic arch formation.[20]

Development of the aorta occurs during the third week of gestation.[21] Each primitive aorta consists of a ventral part and a dorsal part, connected by an arch. The 2 ventral aortas fuse to form the aortic sac, whereas the dorsal aortas fuse to form the midline descending aorta. Between both, there are 6 pairs of aortic arches (Figure 1).[22]

To simplify, 2 symmetric aortic arches form a vascular ring around the trachea and esophagus, connecting the ascending and descending aortas. Each aortic arch gives rise to a common carotid artery and a subclavian artery. On each side, right- and left-sided ducti arteriosi connect the pulmonary arteries to the distal part of each aortic arch, forming an additional vascular ring.

In normal development, the left aortic arch and left-sided ductus arteriosus persist, whereas the right aortic arch, distal to the origin of the right subclavian artery, and the right-sided ductus arteriosus regress (Figure 2). As a result, the proximal part of the embryologic right aortic arch remains as the brachiocephalic artery, which bifurcates into the right common carotid artery and the right subclavian artery. The left-sided aortic arch, in turn, gives rise to the brachiocephalic artery, left common carotid artery, and left subclavian artery (Figure 2).[20]

Aortic arch anomalies are usually caused by an abnormal position of the arch or abnormal branching, due to the persistence of areas that should have adequately regressed or have regressed at an abnormal point (Figure 3). The assessment and description of the anomalies, therefore, should include the following: (1) the position of the aortic arch relative to the trachea; (2) the location of the most proximal part of the descending aorta in relation to the spine; (3) the presence or absence of an aberrant branch; and (4) the origin and insertion of the ductus arteriosus.[20]

Usefulness of Combining the 3-Vessel and Trachea and Subclavian Artery Views Included in the Cardiovascular System Sonographic Evaluation Protocol

The fetal upper mediastinum is the area that should be assessed in a sonographic study of fetal aortic arch anomalies. This area has been classically explored by using the 3-vessel and trachea view.[13] In this cross-sectional view, the pulmonary artery communicating with the ductus arteriosus is identified, and to its right, a transverse section of the aortic arch, the superior vena cava, and a transverse section of the trachea are shown (Figure 4). The aortic arch and the ductus arteriosus are arranged in a V shape, which opens toward the anterior chest wall and has its vertex to the left of the trachea. On the right of the trachea, the azygos vein can be observed in its posteroanterior course to the superior vena cava. This view is useful for assessment of the great vessels; however, it can be easily complemented to better establish the branching pattern of the aortic arch and to characterize various anomalies. To achieve this purpose, assessment of the anatomic position of the subclavian arteries is essential.

The visualization of both normal fetal subclavian arteries in a transverse section requires an upward swiping motion to a plane slightly cranial to the 3-vessel and trachea view.[23] The subclavian arteries are seen on either side of the thorax as vessels with an origin anterior to the trachea and an S-shaped course toward the fetal arm that resembles a bicycle handlebar (Figure 4). To see these vessels, highly

sensitive color Doppler imaging with a low velocity range (10–15 cm/s) is required, although a pulsed wave Doppler interrogation is also useful for providing a classic arterial waveform.[23] In the second-trimester scan, the frequency with which these fetal structures can be seen in both views reaches 99%.[17]

The combined use of these axial views (3-vessel and trachea and subclavian artery) helps determine the presence of a retrotracheal vessel and, thus, a potential vascular ring or sling. The absence of an aberrant subclavian artery in the 3-vessel and trachea view should be confirmed by the characteristic handlebar shape of these arteries in the upper view. The absence of this typical image should prompt a search for an aberrant vessel in the 3-vessel and trachea view. The subclavian artery view may help diminish false-positive diagnoses given by the azygos vein and false-negative diagnoses given by the innominate vein.[24]

Complementarily, an aberrant subclavian artery, either right or left, can also be confirmed by a coronal view when the transverse images are not clear enough. This view has the advantage of providing an image of the origin and course of the anomalous artery in the same plane.[25]

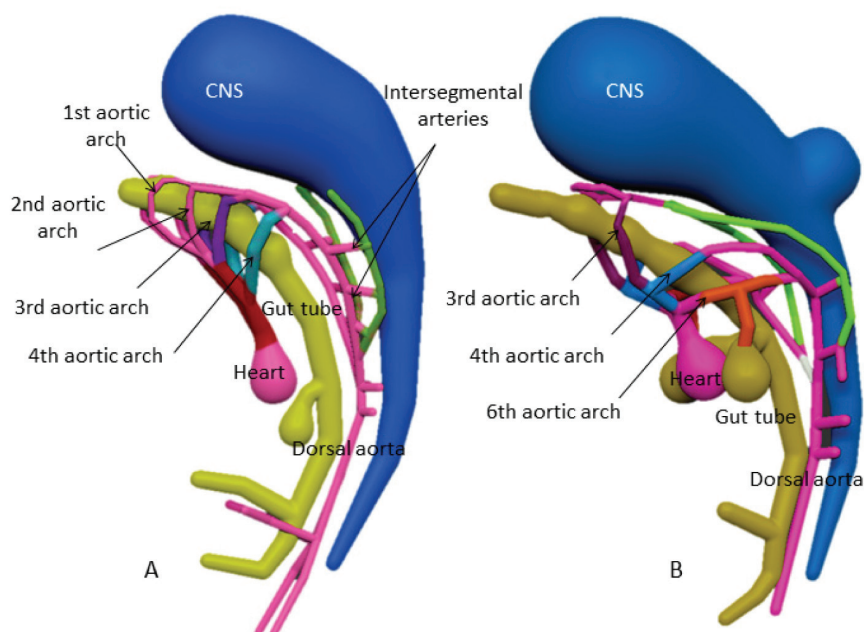## Anomalies of the Aortic Arch: Sonographic Findings and Clinical Relevance

Anomalies of the aortic arch can be characterized on the basis of the number and position of the vessels seen in the 3-vessel and trachea view, in combination with the sonographic findings in the subclavian artery view.

Aortic Arch Anomalies With 3 Vessels in the 3-Vessel and Trachea View

Left Aortic Arch With an Aberrant Right Subclavian Artery
Embryologic Origin
A left aortic arch with an aberrant right subclavian artery is the result of abnormal regression of the right aortic arch between the origins of the right common carotid and right subclavian arteries, leaving the right subclavian artery attached to the distal remnant of the left-sided aortic arch (Figure 3). In most cases, the left-sided ductus arteriosus persists. This combination of vascular elements forms a vascular sling around the left side of the trachea and esophagus (Figure 3).

Figure 1. Embryonic development of the aortic arch and supra-aortic vessels. **A**, Embryo at 26 to 29 days. **B**, Embryo at 35 to 40 days. Between the ventral and dorsal aorta, there are 6 pairs of aortic arches. The first 2 arches regress as the other arches form. The third aortic arch is responsible for the formation of the carotid arteries. The left arch of the fourth pair forms the segment of the normal left aortic arch, which is located between the left common carotid and subclavian arteries. The fourth right arch forms the proximal right subclavian artery. The distal right subclavian artery is derived from a portion of the right dorsal aorta and the seventh right intersegmental artery. The left arch of the sixth pair contributes to the formation of the main and left pulmonary arteries and ductus arteriosus. The sixth right arch contributes to the formation of the right pulmonary artery. The left subclavian artery is derived entirely from the seventh left intersegmental artery, whereas portions of the right artery are derived from the fourth right arch and the right dorsal aorta. CNS indicates central nervous system.

Sonographic Findings

In this case, the 3-vessel and trachea view shows the normal anatomic appearance of the great vessels: the left-sided ductus arteriosus and the transverse portion of the aortic arch forming a V-shaped structure on the left of the trachea and a transverse section of the superior vena cava (Figure 5A). This image is subsequently modified at the level of the aortic isthmus due to the presence of an aberrant vessel, the aberrant right subclavian artery, which crosses the fetal chest posterior to the trachea toward the right upper limb (Figure 5A).

When moving upward to the subclavian artery view, the proximal origin and antetracheal course of the normal right subclavian artery are not visible. The distal portion of the aberrant right subclavian artery might be seen close to the right shoulder. The aberrant course of this vessel should be confirmed by a coronal view (Figure 5B).

Clinical Meaning

This condition is usually an incidental and isolated asymptomatic anomaly, which has been found in 0.5% of large autopsy series and in 0.6% of radiologic findings.[26,27] According to the literature, the prevalence of an aberrant right subclavian artery varies substantially (0.4%–1.9%), being an isolated finding in 46% of cases.[1] Congenital cardiac defects seem to be highly associated (≈20%) with this condition in both euploid and aneuploid fetuses, although these anomalies seem to be more common in the latter.[28–31] The most frequent congenital heart diseases are atrioventricular septal defects and a persistent left superior vena cava.[28–31]

Chromosomal abnormalities, mainly Down syndrome, are also related to an aberrant right subclavian artery in approximately 23.2% of cases, with variations depending on its association with other structural malformations.[1] In fact, when isolated, an aberrant right subclavian artery has not shown any association with Down syndrome, according to a recent meta-analysis.[1] An aberrant right subclavian artery has also been associated with other genetic disorders, especially 22q11 microdeletion, which is found in conotruncal cardiac anomalies.[9,10]

Rare Variants

Cases of complete vascular ring formation have been described when there is a right-sided ductus arteriosus between the aberrant right subclavian artery and the right pulmonary artery.[32] After birth, with the closure of the right-sided ductus arteriosus, the distal part of the right aortic arch persists as the diverticulum of Kommerell. It is theoretically possible for a left aortic arch to be associated with an aberrant origin of the right brachiocephalic artery, but thus far, this association has not been reported.[20]

Figure 2. Normal embryonic development of the aortic arch. **A**, Hypothetical model of the embryonic double aortic arch and double ductus arteriosus. **B**, Fetal stage of the normal aortic arch. Physiologic distal regression of the right aortic arch and right ductus arteriosus has occurred, leading to a single left aortic arch and left ductus arteriosus. Supra-aortic vessels from the right aortic arch have turned into the brachiocephalic artery. BA indicates brachiocephalic artery; DA, ductus arteriosus; LAo, left aortic arch; LCCA, left common carotid artery; LDA, left ductus arteriosus; LPA, left pulmonary artery; LSA, left subclavian artery; PA, pulmonary artery; RAo, right aortic arch; RCCA, right common carotid artery; RDA; right ductus arteriosus; RPA, right pulmonary artery; RSA, right subclavian artery; and T, trachea.
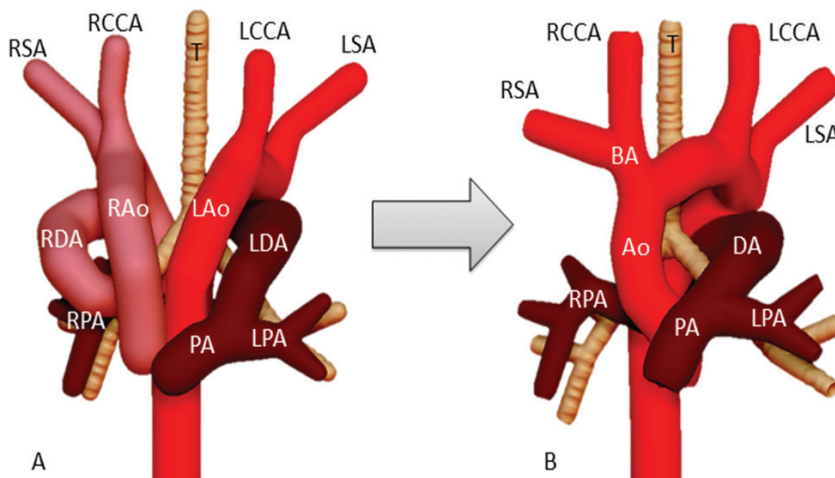
Right Aortic Arch With an Aberrant Left Subclavian Artery

Embryologic Origin

A right aortic arch with an aberrant left subclavian artery results from abnormal persistence of the embryonic right aortic arch and abnormal regression of the left arch between the origins of the left common carotid artery and the left subclavian artery, the latter originating from the distal part of the left aortic arch (Figure 3). The aberrant artery may run either between the trachea and the esophagus (most collateral arteries) or behind the esophagus.[33] The ductus arteriosus is usually left sided, connecting the left pulmonary artery to the distal remnant of the left aortic arch (Figure 6). This combination is the second most common type of ring reported.

Figure 3. Schemes of the anatomic transverse view at the level of the 3-vessel and trachea view. The center image represents the embryonic stage of 2 aortic arches and 2 ducti arteriosi. From this stage and depending on the point and extent of regression (gray area), we may find the following: **A**, normal left aortic arch; the regression occurs in the distal part of the right aortic arch and right ductus arteriosus; **B**, left aortic arch with an aberrant right subclavian artery; **C**, right aortic arch with mirror branching; **D**, double aortic arch; and **E**, right aortic arch with an aberrant left subclavian artery. ALSA indicates aberrant left subclavian artery; and ARSA, aberrant right subclavian artery; other abbreviations are as in Figure 2.
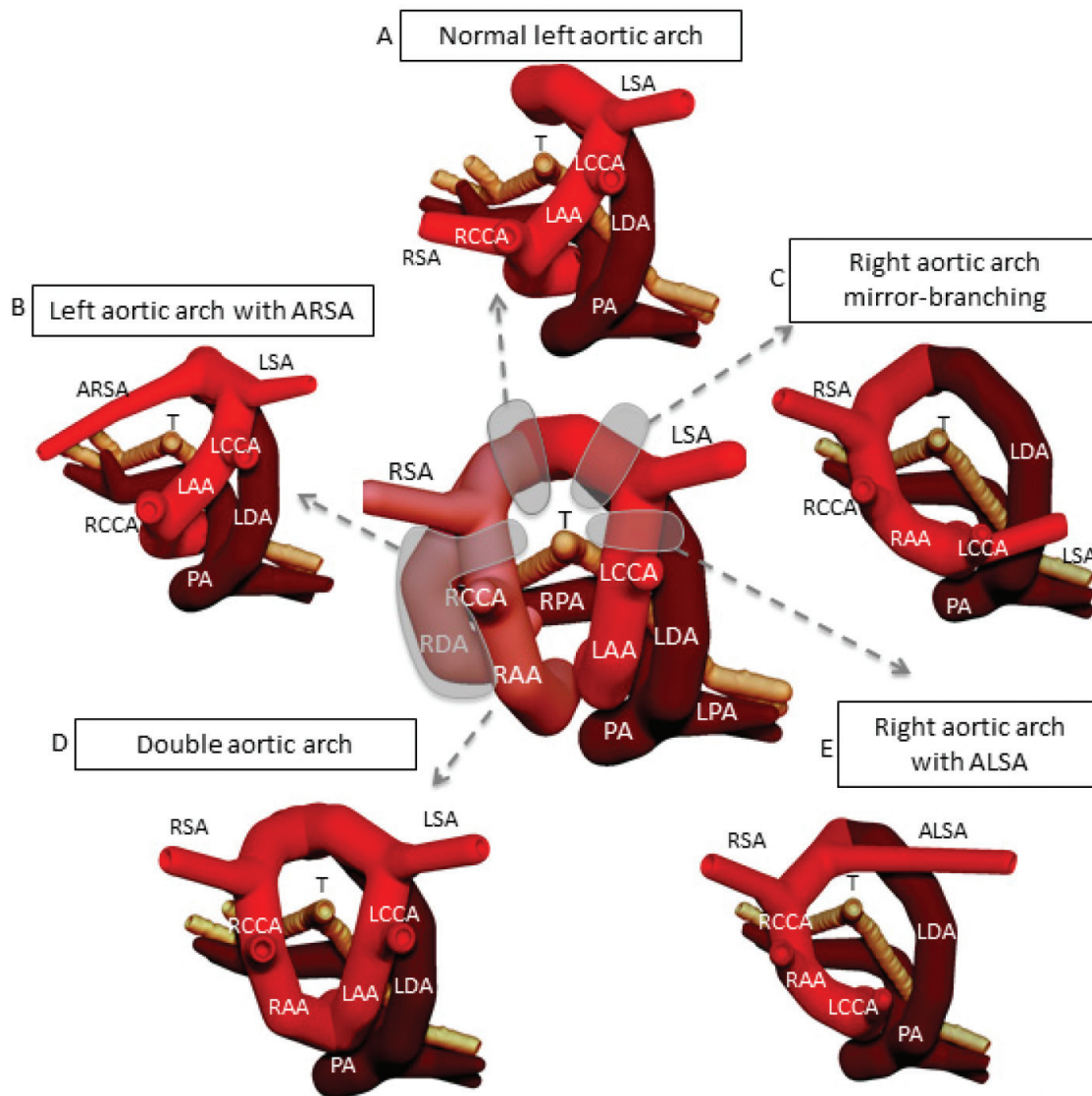
Sonographic Findings

In this case, the 3-vessel and trachea view shows displacement of the aortic arch to the right of the trachea, forming a U shape instead of a V shape. The left-sided ductus arteriosus usually persists and, with the right aortic arch, encircles the trachea and esophagus from behind, resulting in a vascular ring. The transverse section of the superior vena cava remains in its position (Figure 6A). As in the previous section, an aberrant vessel, the aberrant left subclavian artery, can be seen at the level of the aortic isthmus, but this time, its course is posterior to the trachea toward the left upper limb. A coronal view also allows the visualization of this anomaly (Figure 6B).

Clinical Meaning

The prevalence of a fetal right aortic arch with an aberrant left subclavian artery has been estimated as 1 to 1.7 per 1000 pregnancies.[3,7,34,35] This aortic arch pattern shows a low association with congenital heart diseases (6.6%–33.3%), with most being ventricular septal defects, tetralogy of Fallot and pulmonary atresia with a ventricular septal defect.[6,7,35,36] However, its association with chromosomal abnormalities, especially 22q11 microdeletion, seems to be higher, occurring in 4.3% to 32% of cases, according to the literature, despite the absence of congenital heart disease.[6-9,37]

The clinical implications of the vascular ring will be observed after birth with the closure of the ductus arteriosus. The left limb of the U-shaped loop disappears, whereas the distal remnant of the left aortic arch persists as the diverticulum of Kommerell. This expansion during fetal life receives blood flow that comes from the left-sided ductus arteriosus. At birth, as the ductus arteriosus closes, the blood flow comes from the descending aorta.[20]

This vascular ring is usually not as tight as that made by a double aortic arch; thus, according to prenatal series, up to 96% of cases are asymptomatic after birth.[8] The severity of the esophageal and tracheal compression varies according to the size of the diverticulum.

Figure 4. Fetal transverse views included in the cardiovascular system sonographic evaluation protocol. **A**, Three-vessel and trachea view with normal anatomy. **B**, Subclavian artery view: handlebar positioning of the subclavian arteries in a healthy fetus. Ao indicates aorta; IV, innominate vein; L, left; R, right; and SVC, superior vena cava; other abbreviations are as in Figure 2.
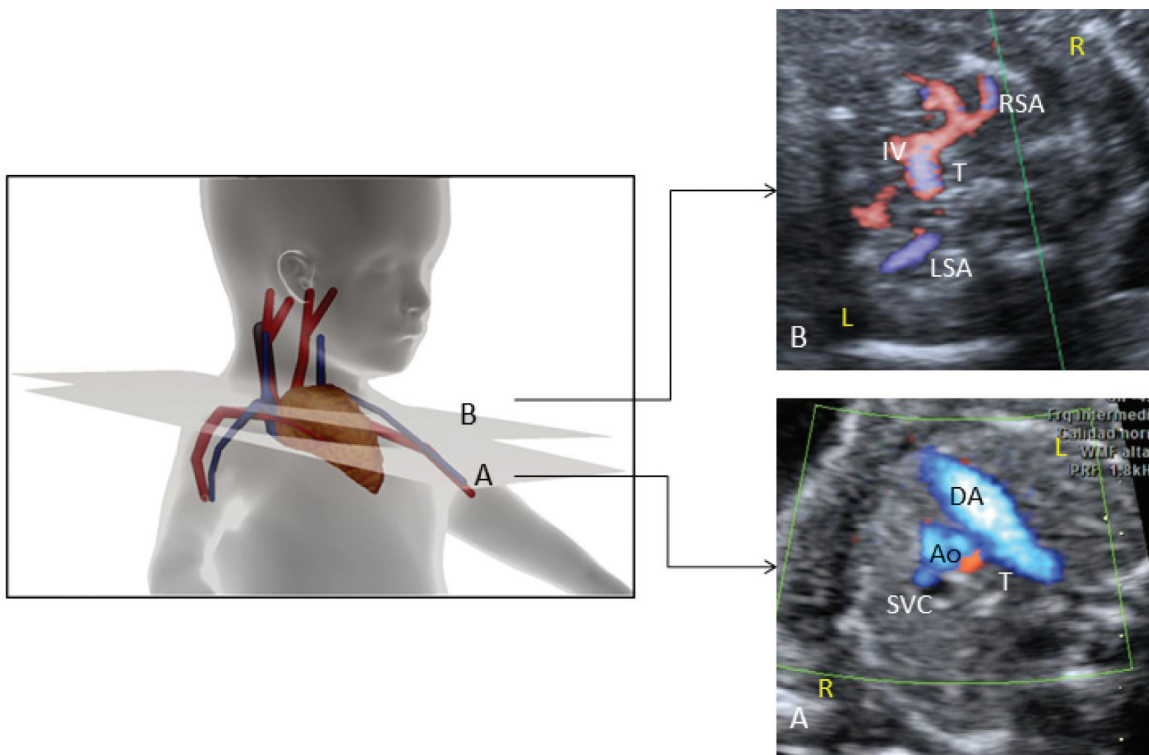
Rare Variants

A possible variation is the rarely occurring right aortic arch with a right-sided ductus arteriosus and an aberrant left subclavian artery. It is secondary to the abnormal regression of the left-sided ductus arteriosus and aortic arch between the left common carotid artery and the left subclavian artery and the persistence of their symmetric arches on the right side. The sonogram would also show a V-shaped vascular structure on the right of the trachea instead of on the left. This V image should not confound observers and make them think of normal anatomy, since the fetal position and the laterality of other organs should also be assessed to ensure the diagnosis. The aberrant left subclavian artery can be seen behind the trachea to the left fetal shoulder, forming a vascular sling.[20] This variant seems to be more associated with cardiac anomalies.[38]

A right aortic arch with an aberrant origin of the left brachiocephalic artery is rare.[39] It results from abnormal regression of the left aortic arch proximal to the origin of the left common carotid artery. The persisting ductus arteriosus is usually left sided, completing a vascular ring.

Right Aortic Arch With Mirror Image Branching
Embryologic Origin

A right aortic arch with mirror image branching is caused by abnormal regression of the left aortic arch distal to the origin of the left subclavian artery (Figure 3). In this pattern, the persisting ductus arteriosus is usually on the left, connecting the base of the left brachiocephalic artery or the descending aorta to the left pulmonary artery.[38]

Sonographic Findings

In a 3-vessel and trachea view, a right aortic arch with mirror image branching depends greatly on the laterality of the ductus arteriosus. Predominant persistence of a left[8,9,20,38] or right ductus arteriosus[3,6] varies according to the literature consulted. As reported by most authors, a left-sided ductus arteriosus is the one that usually persists, either from the left pulmonary artery to the proximal descending aorta (forming a vascular ring) or from the left pulmonary artery to the left brachiocephalic artery (no vascular ring). When a right-sided ductus arteriosus persists, there is no vascular ring. Depending on the laterality of the ductus arteriosus, we

Figure 5. Fetal transverse views in a case of a left aortic arch with an aberrant right subclavian artery. **A**, Three-vessel and trachea view. The aortic arch appears on the right of the trachea, forming a U shape. **B**, Subclavian artery view. The normal handlebar positioning of the subclavian arteries is absent, and the arteries appear straight. Abbreviations are as in Figures 2–4.
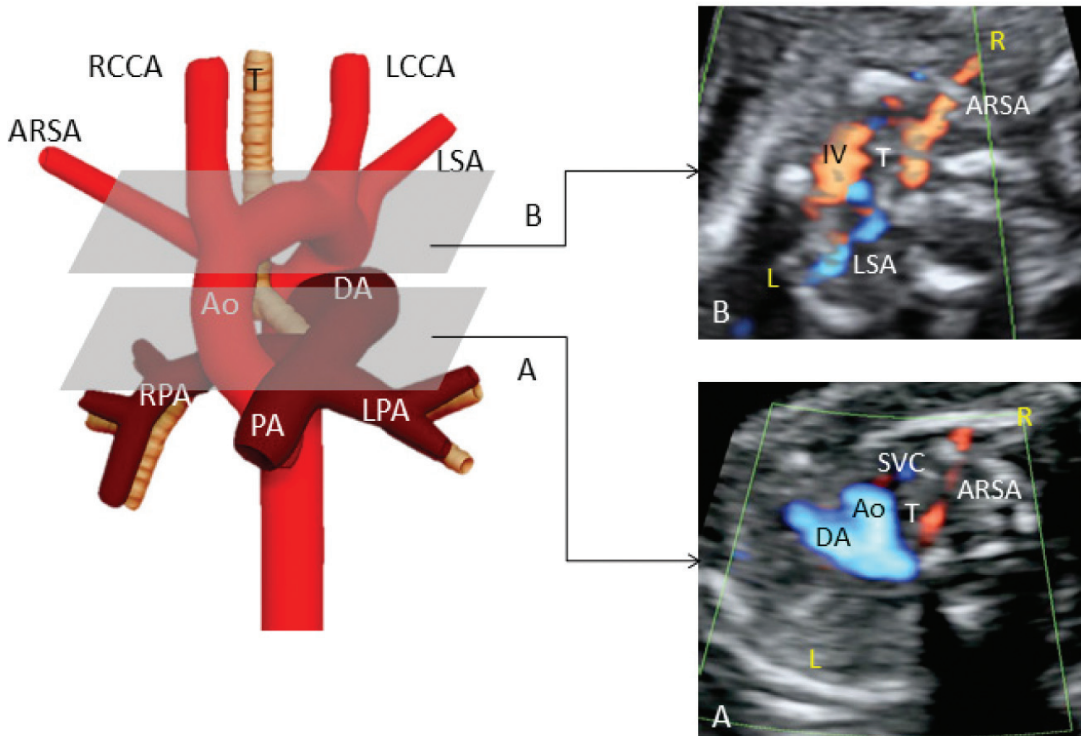
obtain different sonographic findings in the 3-vessel and trachea view. When the ductus arteriosus is connected to the left brachiocephalic artery, it is not visible. However, when it is connected to the descending aorta, a typical U shape instead of a V shape can be observed encircling the trachea, where the right prong of the U is formed by the right aortic arch (Figure 7A). In cases of a persistent right-sided ductus arteriosus a V shape formed by the right aortic arch and the right ductus arteriosus is observed to the right of the trachea.

In the subclavian view, both subclavian arteries maintain their normal positions in an antetracheal location despite the fact that the supra-aortic branching shows a mirror image. The first branch from the right aortic arch is the left brachiocephalic artery, followed by the right common carotid artery and the right subclavian artery (Figure 7B).

In some cases of a right aortic arch, the diagnosis can be suspected in a 4-chamber view when the descending aorta is closer to the right of the spine than it should be. However, this appearance is not a reliable sign, since the descending aorta in a right aortic arch commonly crosses to the left in the mid thorax.[37]

Clinical Meaning

The prevalence of a right aortic arch with mirror image branching is approximately 3.5 per 1000 in high-risk populations,[7] with 13.6% to 47% of cases having aortic arch anomalies[3,9] and 42% to 62% having a right aortic arch.[6] The incidence of congenital heart disease associated with this type of aortic arch ranges from 91.5% to 100%.[3,6,7,35] In one series, the odds ratio of a fetus having congenital heart disease in which a right aortic arch with mirror image branching was detected was 297.4 (95% confidence interval, 40.4–2186.8).[7] The most common associated congenital heart disease is tetralogy of Fallot (41%–57%).[7]

Other frequent associations are pulmonary atresia with a ventricular septal defect (10.3%–36%), a common arterial trunk (13%–36%), and a double-outlet right ventricle (10.3%).[6,7,40,41] Extracardiac anomalies are also common (≈20%–22%).[6,7] The presence of extracardiac anomalies (other than situs anomalies in heterotaxy syndromes) have been significantly associated (60%) with 22q11 microdeletion.[6] In this type of right aortic arch, the incidence of 22q11 microdeletion described ranged from 13.3% to 25%, especially in cases affected by conotruncal

Figure 6. Fetal transverse views in a case of a right aortic arch with an aberrant left subclavian artery. **A**, Three-vessel and trachea view. The aortic arch is located on the right of the trachea, forming a U shape. **B**, Subclavian artery view. The normal handle-bar positioning of the subclavian arteries is absent. Abbreviations are as in Figures 2 and 4.
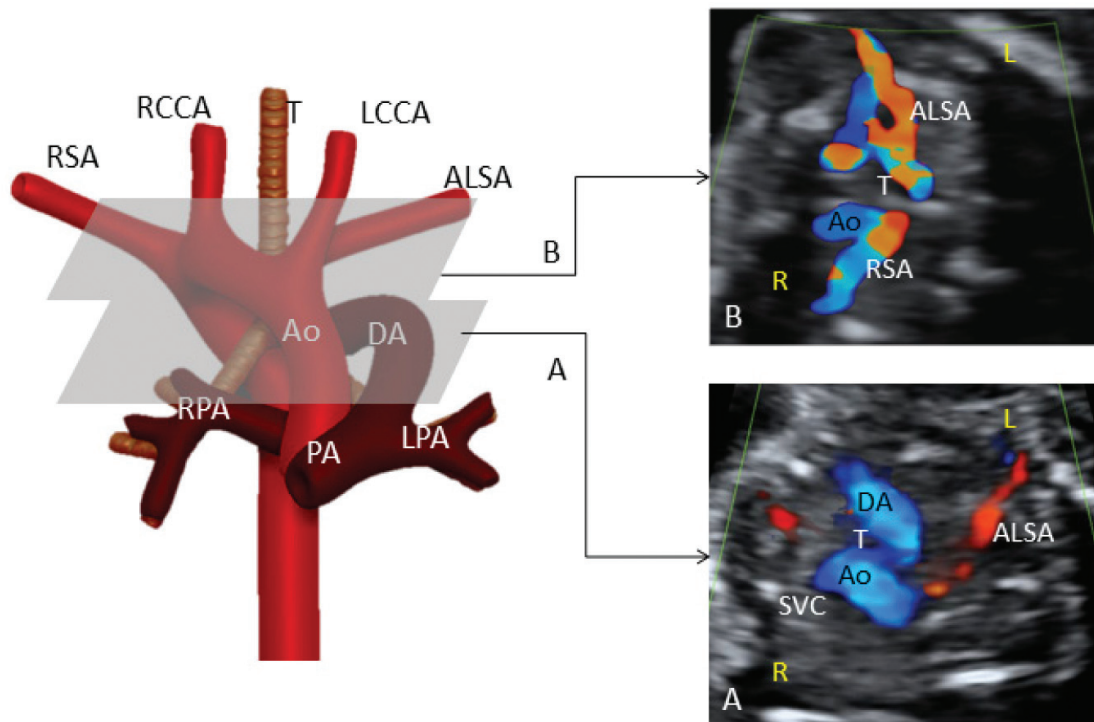
congenital heart disease or extracardiac malformations.[6,8,9] An association of a right aortic arch with mirror image branching with heterotaxy syndromes is also common.[6]

The outcome of these cases depends mainly on the associated cardiac and extracardiac malformations as well as the presence of chromosomal abnormalities. In most cases, the absence of a vascular ring or sling minimizes the presence of compressive symptoms after birth.[2,3,6]

Rare Variants
It is less common for the ductus arteriosus to be either on the right or bilateral.

### Circumflex Retroesophageal Aortic Arch
Embryologic Origin
This condition is a rare anomaly in which the aortic arch and the proximal descending aorta are located on opposite sides of the spine. It occurs more frequently with a right-sided aortic arch, and the branching pattern of the supra-aortic arteries is variable. When it occurs with a right aortic arch, the arch gives rise to the left common carotid, right common carotid, and right subclavian arteries from its segment on the right side of the trachea. Then the arch makes a sharp oblique leftward and downward turn to connect with the left-sided descending aorta. The left subclavian artery arises from the transitional point of the retroesophageal portion of the arch. It may be considered an aberrant artery, since it is the last, instead of the first, branch of the right aortic arch. In most cases, the left subclavian artery arises from the aorta through the diverticulum of Kommerell. The left-sided ductus arteriosus connects the diverticulum to the left pulmonary artery, forming a vascular ring.[20] Hypoplasia of the retroesophageal segment of the aortic arch is common.[42]

Sonographic Findings
The 3-vessel and trachea view shows a D-shaped structure around the trachea, which is formed by the right aortic arch with its retrotracheal segment and the left-sided ductus arteriosus on the opposite side completing the vascular ring.[43]

Figure 7. Fetal transverse views in a case of a right aortic arch with mirror image branching. **A**, Three-vessel and trachea view. The aortic arch is located on the right of the trachea, forming a U shape. **B**, Subclavian artery view: antetracheal course of the subclavian arteries. Abbreviations are as in Figures 2 and 4.
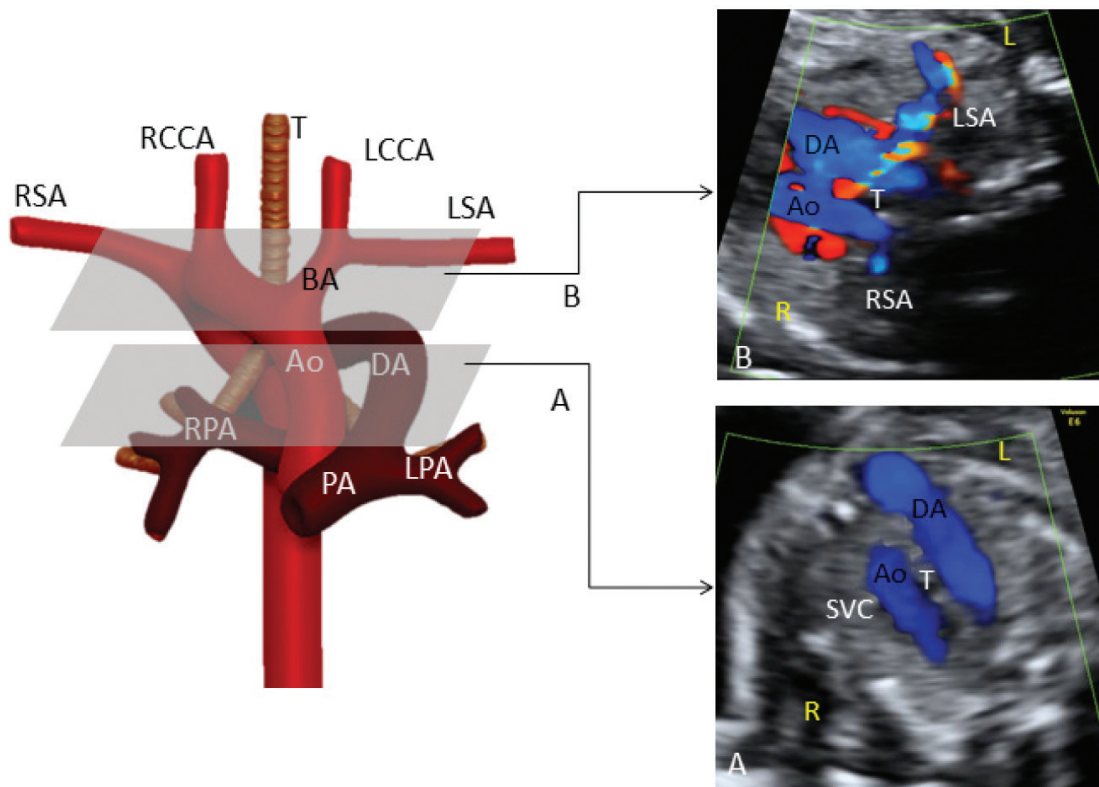
The aberrant left subclavian artery is visible, and its origin is located in the retrotracheal area of the aortic arch. In the subclavian artery view, the left subclavian artery is not in its correct antetracheal position, which suggests an aberration. As in previous cases, a coronal view would allow visualization of the left subclavian artery from its origin.

Clinical Meaning
This anomaly has been scarcely seen in the prenatal setting, mainly because of its rarity and its differential diagnosis with a simple right aortic arch with an aberrant left subclavian artery.[43,44] The association with congenital heart disease is common, and it can be responsible for compressive symptoms.[45]

Anomalies With 4 Vessels in the 3-Vessel and Trachea View

Double Aortic Arch
A double aortic arch is the tightest and most commonly identifiable form of vascular ring.[18]

Embryologic Origin
A double aortic arch is formed by the persistence of both the right and the left embryonic aortic arches, one on each side of the trachea and esophagus, without regression of any segment (Figure 3). An arterial duct, more frequently the left one, persists, although some cases with bilateral ducts have been described.[2,43] Each aortic arch gives rise to common carotid and subclavian arteries. Usually, the right arch is larger than the left arch. In general, the apex of the larger arch is higher than that of the smaller arch. Occasionally, a segment of one arch (usually the left one) may be atretic and almost always distal to the subclavian artery. The proximal descending aorta is left sided in just more than two-thirds of patients a with double aortic arch, is right sided in almost all of the rest, and rarely occupies a neutral midline position.[20]

Sonographic Findings
During fetal life, when the ductus arteriosus is patent, the arrangement of the 2 arches and a patent arterial duct (usually the left) produces an image of a trident or a number 9 or number 6 configuration in a 3-vessel and trachea view on fetal echocardiography. In a fetal cephalic presentation, a number 6 configuration can be observed when the fetal dorsum lies on the right, but when it lies on the left, a number 9 configuration is shown (Figure 8A). It is, in any case, an image of 4 vessels instead of 3, with these vessels being the right and left aortic arches, the ductus arteriosus (left or right sided), and the superior vena cava. Since one of the arches, typically the left one, is smaller, the sonographic sizes of the arches are expected to be different. Even when an atretic segment is present, it may be difficult to visualize, since an image of arch interruption appears, which is something that makes a differential diagnosis with a right aortic arch a challenge. Thus, proper identification of the branching pattern is essential.[2,7,37]

In the subclavian artery view, both the left and the right subclavian arteries must follow an antetracheal course, as in normal circumstances (Figure 8B). The presence of an aberrant artery in this view or in the 3-vessel and trachea view rules out a double aortic arch, since no other pattern of supra-aortic branching has been described for a double aortic arch. A coronal posterior view shows both aortic arches giving rise to the common carotid and subclavian arteries from their respective sides.[43]

Clinical Meaning
The prevalence of a prenatal double aortic arch is unknown, since it is a less common aortic arch anomaly and it is usually added to series of right aortic arch cases.[3,7,35,46] A double aortic arch is the aortic arch anomaly most frequently associated with the development of airway and esophageal compression after birth.[8,20] Among their series of aortic arch anomalies, most authors have reported that a double aortic arch was responsible for a higher number of cases with compressive symptoms in early childhood and the need for surgery compared to other anomalies causing rings, such as a right aortic arch with an aberrant left subclavian artery[3]: the reason being the tightness of the vascular ring formed by both aortic arches passing over the respective bronchi to join at the thoracic descending aorta. Based on the literature, 74% of double aortic arch cases manifest symptoms in the early years and require surgery to relieve them.[47] Seventy-five percent of the symptoms (stridor, cough, asthma, respiratory distress, apnea, recurrent episodes of pneumonia, and dysphagia) appear early during infancy, ranging from mild-to-severe respiratory obstruction and apnea.[36]

Cardiac and extracardiac anomalies are less common in a double aortic arch than in other aortic arch anomalies. Approximately 17.1% of double aortic arch cases are associated with congenital heart disease: mainly ventricular septal defects and double outlet right ventricles.[47]

There seems to be a low association with 22q11 microdeletion in the absence of congenital heart disease, given that most cases affected by this chromosomal abnormality have congenital heart disease or extracadiac defects. Among patients with a double aortic arch, those with an

atretic minor arch had a significantly higher rate of deletion than those with a patent minor arch, but there was no difference between patients with left and right dominance of the double arch.[9]

Discussion

The objective of this article is to explore fetal aortic arch anomalies in detail, highlighting the relevance of assessing the supra-aortic branching vessels during prenatal sonographic evaluations to help in their differential diagnosis and determine their prognosis.

The utility of the 3-vessel and trachea view for assessment of conotruncal malformations and aortic arch anomalies has been proven, as shown by the growing number of publications reporting its use in the last decade.[8,34,35,46] However, systematic assessment of the supra-aortic vessels, mainly the subclavian arteries, is not a common practice in many units. In this sense, this review tries to focus on the possible improvements this view could offer for diagnostic purposes.

In the last decades, the use of 5 axial sonographic views has been the standardized method for assessment of the fetal heart and great vessels.[48] This method consists of the progressive addition of axial views to the basic 4-chamber view to improve the detection rate of congenital heart disease.[11–14] These axial views have been added to increase the detection rate of cardiac anomalies, progressively changing the way the fetal heart is explored. Hence, the addition of the subclavian artery view to the standard fetal heart exploration means the acquisition of a slightly cranial view beyond the recommended 5 views with a simple swiping movement. This area of the fetal thorax is not included in the systematic exploration of the heart but can be particularly useful when a congenital heart disease or an aortic arch anomaly is suspected and even in cases of apparent normal anatomy.

The addition of the axial views included in the cardiovascular system sonographic evaluation protocol to the recommended 5 axial views for assessment of a more extended fetal cardiovascular system may provide certain advantages. In particular, the addition of the subclavian artery axial view could be a valuable tool for confirming

Figure 8. Fetal transverse views in a case of a double aortic arch. **A**, Three-vessel and trachea view. This view shows 4 vessels instead of 3, confirming a number 6 configuration. There is an aortic arch on each side of the trachea. **B**, Subclavian artery view. Each subclavian artery arises from the ipsilateral aortic arch. Abbreviations are as in Figures 2 and 4.
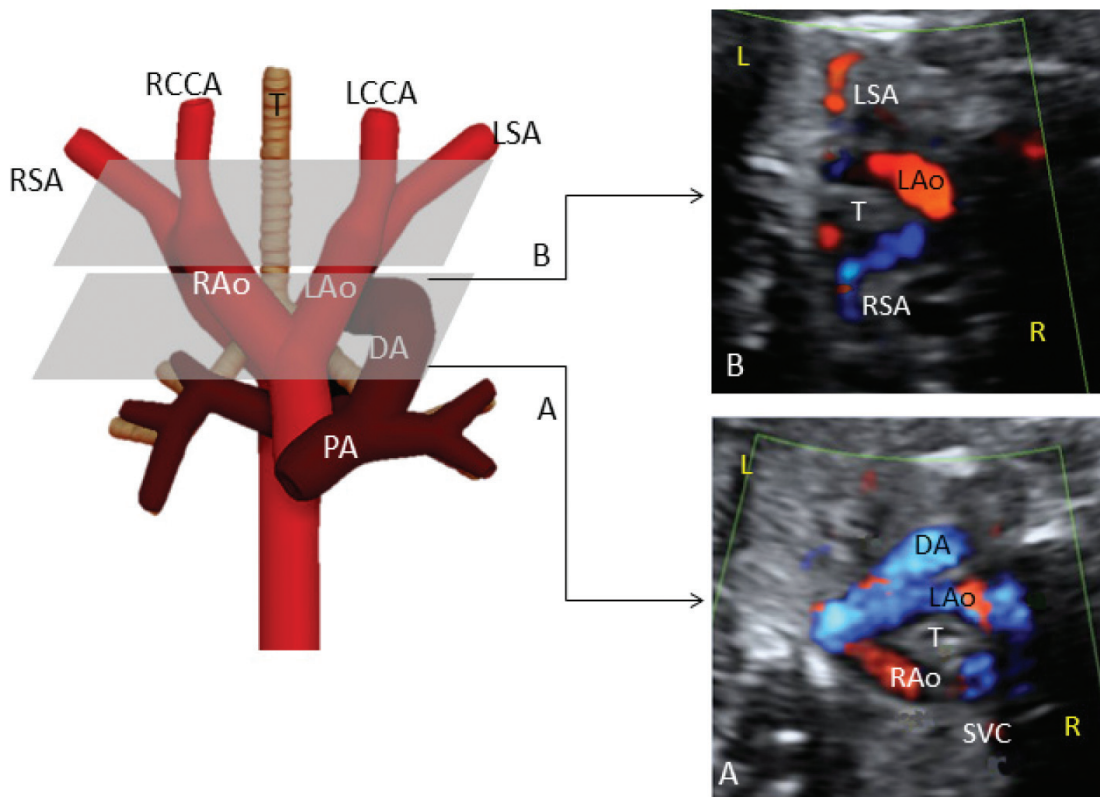
normal or abnormal anatomy[1,24] and to improve the differential diagnosis of aortic arch anomalies: eg, the different types of right aortic arches (with a left subclavian artery versus mirror imaging branching) and differentiation between a double aortic arch and a right aortic arch with a persistent left-sided ductus arteriosus.[6,7,35] Assuming that these entities show different ranges of associated conditions (congenital heart disease and 22q11 microdeletion), this view allows physicians to offer additional testing and a more precise prognosis to parents.

The usefulness of the subclavian artery view combined with the 3-vessel and trachea view for detection of an aberrant right or left subclavian artery is substantiated in the clinical implications of these anomalies. Regardless of the laterality of the aortic arch, these anomalies are associated with a higher incidence of 22q11 deletion[10] even without congenital heart disease.[8,9] Both entities have been reported to be associated with congenital heart disease,[6,7,35,36] and specifically, an aberrant right subclavian artery has also been studied as an independent marker for Down syndrome, with a wide range of positive likelihood ratios from 0 to 3.941.[49]

Prenatal detection of an aortic arch anomaly, even when it is isolated, provides several benefits. First, these defects have been related to a wide spectrum of congenital heart disease; thus, there is a consensus that any fetus affected by an aortic arch anomaly should undergo detailed echocardiography performed by specialists in this field, given the high probability of a concurrent congenital heart disease.[1,3,8,43,50] Second, the prenatal awareness of an aortic arch anomaly secondary to vascular rings may help pediatricians in the early diagnosis and management of symptomatic neonates and children.[34,35] Finally, aortic arch anomalies have been frequently associated with chromosomal abnormalities, including 22q11 deletion.[9] Based on this potential association, fetal karyotyping should be considered, although it is a controversial test because of certain conditions with a low risk of aneuploidy. For most investigators, the detection of an aortic arch anomaly together with a congenital heart disease is an indication for invasive testing. However, it is not so clear whether isolated cases should be karyotyped or have fluorescence in situ hybridization to detect 22q11 deletion.[1,3,8,43,50] In cases of an isolated left aortic arch with an aberrant right subclavian artery, the most recent meta-analyses suggest a lack of association with Down syndrome[1,24]; however, controversy is still ongoing, given that isolated cases with prenatal or postnatal identification of trisomy 21 have been described in 8% of cases in the literature.[50,51] In cases of an isolated right aortic arch with an aberrant left subclavian artery, more

studies are required to firmly discard karyotyping, since cases with 22q11 deletion without congenital heart disease have been reported.[9]

In these situations, special attention should be paid to minor markers or risk factors, which may help the physician provide the parents with the proper genetic counseling and help them opt for a conservative approach, invasive testing, or even noninvasive testing (cell-free fetal DNA analysis). In this context, sonographic assessment of the fetal thymus can be useful for predicting 22q11 deletion when the thymus is hypoplastic or absent in association with a cardiac anomaly.[3,51,52] However, there are hardly any studies on thymus assessment and the prevalence of 22q11 deletion in cases of an isolated aortic arch anomaly without congenital heart disease. Although some authors suggest that it could be useful for predicting the deletion,[53] further studies are needed.

Certain aspects about the prognosis of aortic arch anomalies should be taken into consideration. First, when the anomaly is accompanied by a congenital heart disease or a chromosomal abnormality, the nature and severity of these associated anomalies are the factors that may modify the prognosis.[1,7,46] The aortic arch anomaly by itself may be asymptomatic in many cases, with the exception of anomalies forming tight vascular rings. Second, the development of tracheoesophageal symptoms of compression usually occurs early in life, especially in cases of a double aortic arch once the ductus arteriosus regresses and the ligamentum arteriosus appears.[47] However, the occurrence of compressive phenomena could happen as early as in fetal life in the form of a congenital high airway compression syndrome[46,54] or as late as in adulthood. In adults, aortic arch anomalies with an aberrant subclavian artery and the diverticulum of Kommerell (left aortic arch with an aberrant right subclavian artery and right aortic arch with an aberrant left subclavian artery) are the most likely to cause symptoms.[20,36] Symptomatic cases, whenever they occur, are subject to vascular surgery to relieve the pressure.

Postnatal Studies

Most authors convey that postnatal radiologic examinations with computed tomography or magnetic resonance imaging are not necessary in all cases of aortic arch anomalies and should be saved for symptomatic cases or those in which anatomic details remain uncertain after postnatal echocardiography performed by experienced cardiologists.[3,7,35] Fetal sonography provides a more appropriate acoustic window compared to postnatal evaluation, since an air bronchogram produces shadowing that reduces its reliability.[2]

For this reason, an accurate diagnosis in fetal life could help design an adequate follow-up strategy and avoid any unnecessary delay in diagnosis during postnatal life.

The controversy about postnatal symptoms of aortic arch anomalies is still unresolved when comparing prenatal and postnatal series. According to prenatal studies, most of these vascular abnormalities are asymptomatic after birth, with the exception of a double aortic arch and some cases of a right aortic arch with an aberrant left subclavian artery.[8,34] However, pediatricians report that 65% of aortic arch anomalies are symptomatic, most being double aortic arch cases requiring surgery to release the compression.[55,56] Moreover, between 43% and 61% of cases with a right aortic arch and an aberrant left subclavian artery and between 29% to 64% of cases with a left aortic arch and an aberrant right subclavian artery will eventually require vascular surgery secondary to the onset of compressive symptoms.[52,53] This lack of consensus negatively affects the accuracy of the prognosis given to parents. A combined effort between obstetricians and pediatricians specializing in this field is of most importance.

Conclusions

Aortic arch anomalies are uncommon in prenatal life, but when present, they can be either isolated or, more frequently, associated with other anomalies, including chromosomal defects such as 22q11 deletion. Detection of fetal aortic arch anomalies should be performed by using the 3-vessel and trachea view, which can be improved by the addition of the subclavian artery view, according to the cardiovascular system sonographic evaluation protocol,[17] which is essential for establishing the arch branching pattern and can contribute to the differential diagnosis and prognosis of these entities.

After the diagnosis of these anomalies, detailed echocardiography and fetal scanning is recommended to rule out associated malformations. Karyotyping including detection of 22q11 microdeletion should be offered to parents mainly when other related conditions are found. The prognosis of aortic arch anomalies will depend on the associated anomalies and the risk of tracheoesophageal compression.

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