11

The examination of the normal fetal heart using two-dimensional echocardiography

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Ultrasound techniques used in fetal cardiology are numerous. They include different approaches such as two-dimensional examination by the transabdominal or transvaginal route (in early pregnancy), the M-mode examination and the different methods based on Doppler (e.g. pulsed Doppler, color Doppler, power Doppler, tissue Doppler). However, the accuracy of the screening for heart defects in the fetus did not increase in pace with this technical development. The basis of every fetal echocardiographic examination is still the precise assessment of heart structures using real-time ultrasound. In recent years a huge improvement has been observed in image resolution, not only at centers with high-level ultrasound machines but also at primary and secondary institutions with equipment available for performing antenatal screening. Therefore, a detailed evaluation of the different cardiac structures is no longer the monopoly of a few centers but is available at the screening level. In this chapter, the basics of a complete cardiac examination using different planes in two-dimensional ultrasound is reviewed.

Different approaches for such an examination were proposed in the past, either slightly modifying the pediatric cardiologic planes or creating "new" fetal planes with more flexibility.[1–4] The advantage of the latter is that they are easier to learn in obstetric ultrasound. This chapter concentrates on planes we proposed some years ago[3] (Figure 11.1).

Examination of the upper abdomen

The assessment of the upper abdomen is an integral part of the fetal echocardiographic examination (Table 11.1). Heart malformations associated with abnormalities of the situs are known to be more severe and complex. Furthermore, a careful analysis of the upper abdomen provides a better orientation when examining the fetal heart. The examiner begins with the assessment of the fetal position in utero, in order to distinguish the right and left sides of the fetus. The upper abdomen should then be visualized

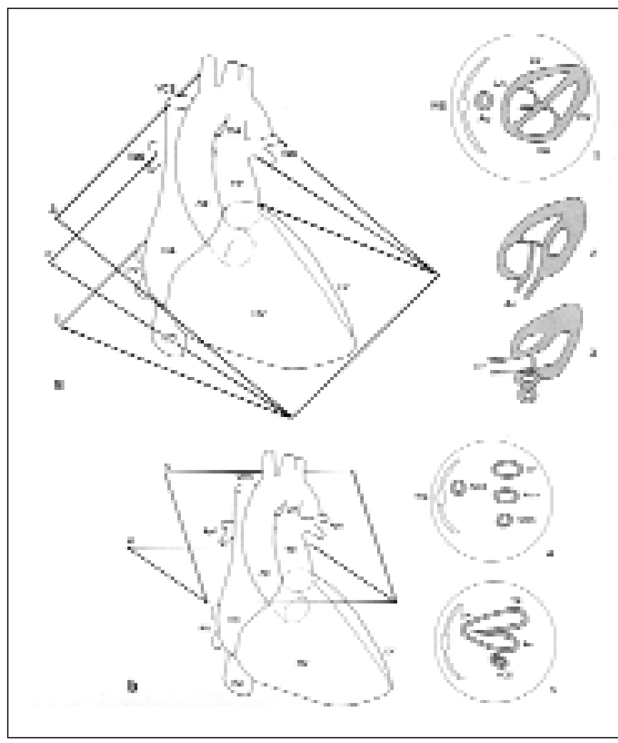

Figure 11.1
(a) The different cross-sections from the four-chamber view to the five-chamber and pulmonary views (compare with Figures 11.2, 11.3 and 11.9). (b) A cross-section of the upper thorax to obtain the three-vessel view (compare with Figures 11.13 and 11.14). From reference 3. Ao, aorta; Aoa, ascending aorta; Aod, descending aorta; Apd, right pulmonary artery; Aps, left pulmonary artery; DA, ductus arteriosus; LV, left ventricle; PV, pulmonary vein; RA, right atrium; RV, right ventricle; TP, pulmonary trunk; VCI, inferior vena cava; VCS, superior vena cava; WS, spine.

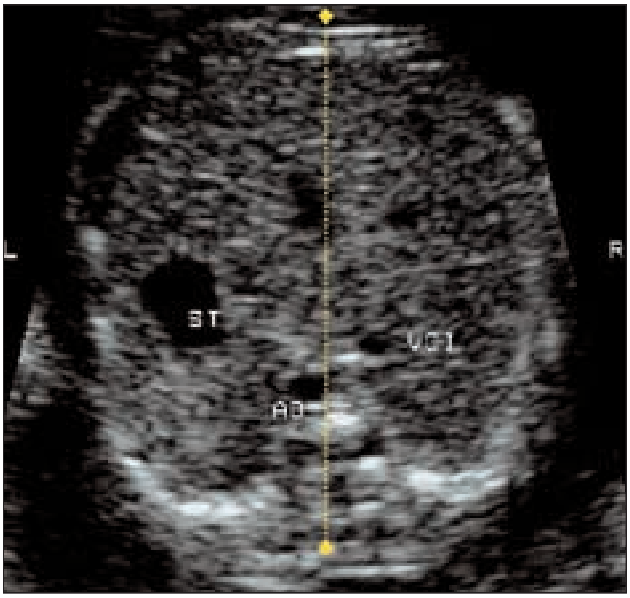

Figure 11.2
Cross-section of the upper abdomen. The line divides the left and right sides. Visualized are the stomach (ST) and the descending aorta (AO) on the left (L) and the liver and the inferior vena cava (VCI) on the right (R).

Table 11.1. Checklist of the upper abdominal plane

- Filled stomach is on the left side
- Aorta is on the left side of the spine
- Liver is on the right side
- Inferior vena cava is on the right side of the spine, ventral and lateral to the aorta
- Inferior vena cava receives the hepatic veins and is connected to the right atrium

Table 11.2. Checklist of the four-chamber-view plane

- Position of the heart in the thorax
- Cardiac axis
- Size of the heart
- Rhythm
- Contractility
- Size of the left and right atria
- Size of the left and right ventricles
- Size relationship of the left and right sides
- Position and function of the tricuspid and mitral valves
- Continuity of the interventricular septum
- Position and form of the interatrial septum and of the valve of the foramen ovale
- Connections of the pulmonary veins to the left atrium

in a cross-sectional plane (Figure 11.2). A fictitious anterior-posterior line is drawn dividing a left and a right side. On the left side is the stomach, the descending aorta, and the spleen, which is located between the stomach and diaphragm. On the right side, the liver and the inferior vena cava are found, the inferior vena cava lying anterior to the aorta. By tilting the transducer slightly, the confluence of the three liver veins toward the inferior vena cava are seen. The umbilical vein enters the liver and continues to the right side into the portal sinus. The transducer is then moved slightly cranially to visualize the next plane, i.e. the four-chamber view (Figure 11.3). During this movement the connection of the inferior vena cava with the right atrium is checked (venoatrial connection).

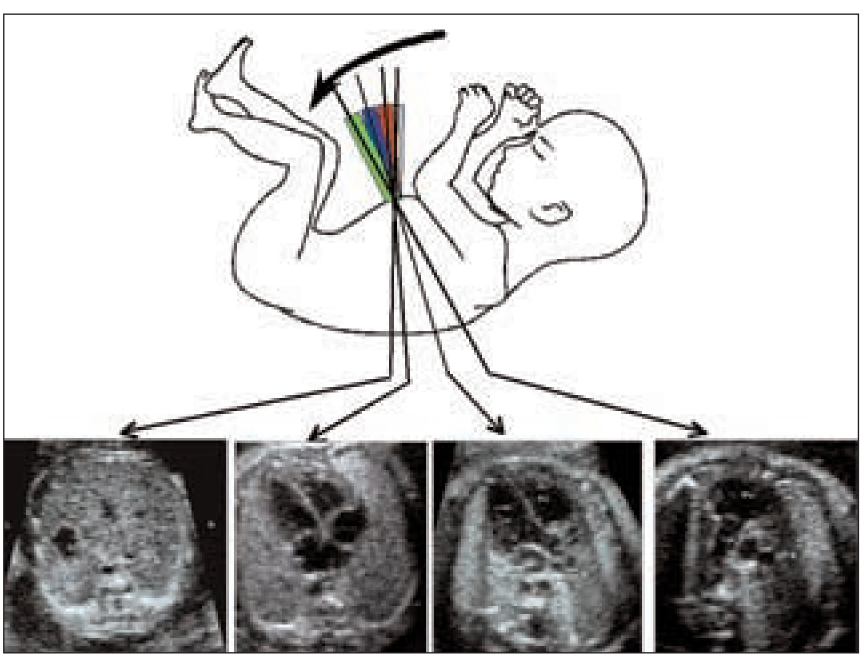

Figure 11.3
The approach to obtain the different planes from the abdominal plane to the four- and five-chamber views toward the pulmonary view.

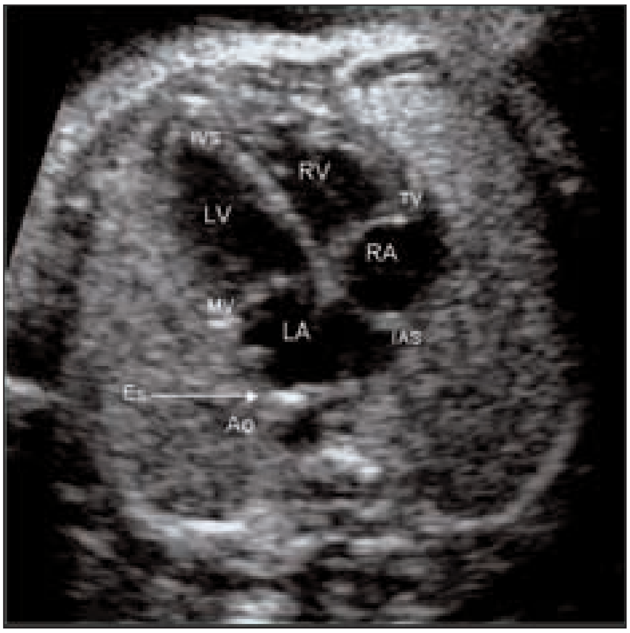

Figure 11.4
Cross-section of the thorax visualizing the apical four-chamber view. In front of the spine the descending aorta (Ao) is seen and in front of it the esophagus (Es, arrow). In this plane, the following structures can be seen: right and left ventricles (RV, LV), right and left atria (RA, LA), interventricular and interatrial septa (IVS, IAS), foramen ovale, mitral (MV) and tricuspid valves (TV).

Four-chamber view

The four-chamber view is the most important plane in the examination of the fetal heart. The main cardiac structures—the position, the size, the rhythm and the contractility of the fetal heart—can all be analyzed (Table 11.2). In this slightly oblique plane, the simultaneous visualization of both atria, ventricles, atrioventricular valves and interventricular and interatrial septa is achieved (Figure 11.4). This plane is important since it has an accuracy in detecting a wide range of fetal heart defects, and can be easily learned. Owing to the fluid-filled lungs in prenatal life, as well as to the late calcification of the ribs, different insonation views of the four-chamber plane can be obtained, reducing the disadvantage of the different fetal positions on fetal examination (Figure 11.5). The correct plane should include both patent atrioventricular valves connecting the atria with the corresponding ventricles (Figure 11.6).

Once the four-chamber plane is visualized, an imaginary anteroposterior line is drawn, dividing the thorax into two equal left and right sides. In normal levocardia, one-third of the heart is on the right side and two-thirds are on the left, with the heart axis pointing to the left. In recent years, the assessment of the cardiac axis was added as a new parameter in the analysis of heart position.[5] Compared to the sagittal axis, the cardiac axis is at $45 \pm 15°$ and is abnormal in many heart defects especially those involving the great vessels.

The analysis of the heart size is important in order to distinguish between cardiomegaly, generally due to atrioventricular valve insufficiency associated with right atrium dilatation, and the normal heart in a small thorax in growth-retarded fetuses. In unclear cases, the examiner should use cardiac measurements derived in the four-chamber view, measuring the heart length, width, area and cardiothoracic ratio.[6]

The analysis of heart contractility enables the detection of hypokinesia of the myocardium.

An abnormal heart rhythm is easily detected with real-time sonography, but its classification is effectively performed using M-mode.

After the general examination of the heart, one would continue to inspect the heart structures. After the local-

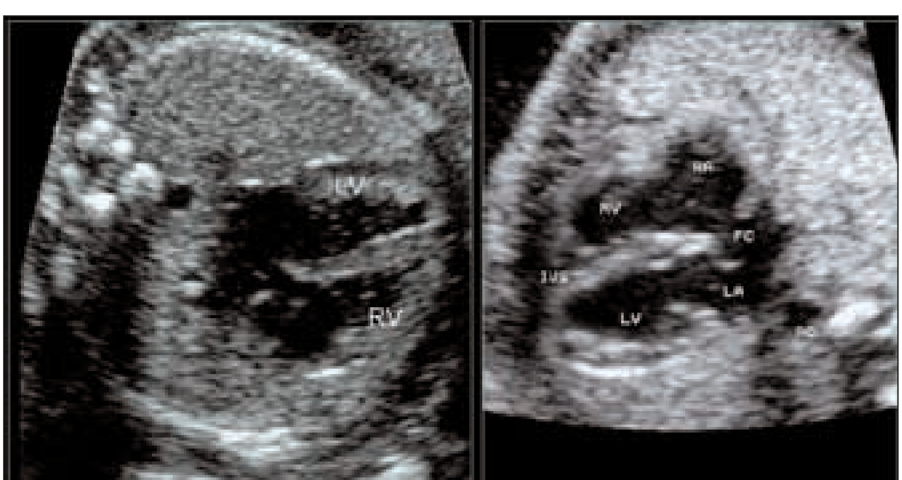

Figure 11.5
Four-chamber view seen from the left side (left) and from the right (right). The advantage of the fetal examination is that the four-chamber view can be visualized in different fetal positions. In the lateral approaches the septum can be better estimated.

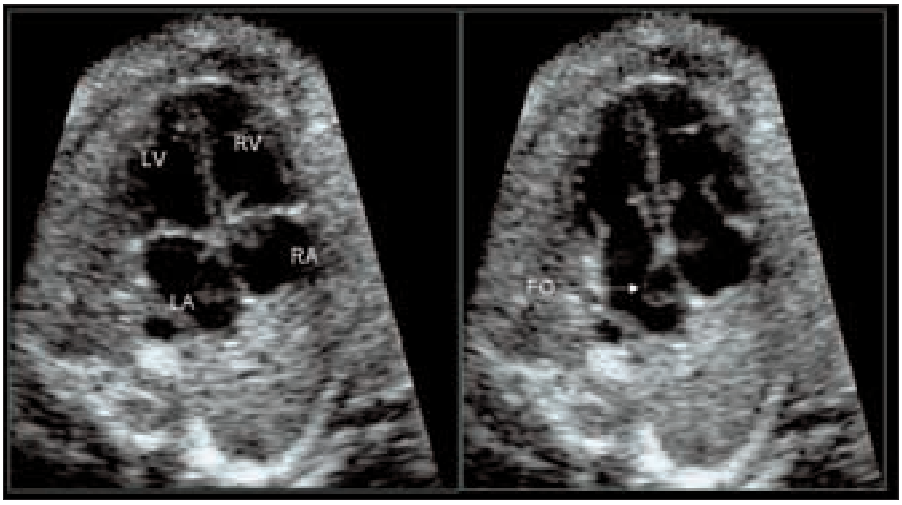

Figure 11.6
Apical four-chamber view in systole (left) and diastole (right). Using a cine-loop, the visualization of different phases of the heart cycle is easier. During diastole the opened valves are well recognized, as well as the bulging of the flap of the foramen ovale (FO) (septum primum).

ization of the heart's left and right sides, as well as the atria and ventricles, the cavities are then compared to each other. Important landmarks to remember are that the lumen of the right ventricle is slightly smaller than the left, and the foramen ovale flap bulges into the left atrium.

Anterolaterally to the spine, the descending aorta is recognized as a circular, pulsating structure. Just anteriorly and close to the aorta, the esophagus can often be recognized as an echogenic circular structure (Figure 11.4). During swallowing, the esophagus dilates and mimicks a second vessel in front of the aorta, but then disappears after swallowing is ended. The first cardiac structure ventrally adjacent to the aorta and esophagus is the left atrium.

The left atrium is thus the cardiac structure situated most posteriorly in the chest and is recognized by the connections of the pulmonary veins and the leaflet of the foramen ovale. The foramen ovale "flap" is the free part of the septum primum, which closes during the embryological development of the septum primum. Owing to the right-to-left shunt at the atrial level, the flap bulges into the left atrium, showing a wide variation in its size and shape (Figure 11.6). This structure is semilunar and is best seen using a left-sided approach to the heart.[7] In hypoplastic left heart syndrome, paradoxical movements of this flap can be seen to the right side.

The right atrium is on the right side of the left atrium and communicates with the latter via the foramen ovale (i.e. the ostium secundum). By slightly angulating the transducer cranially and/or caudally, or by tilting the transducer into a longitudinal plane, the connections of the inferior and superior venae cavae can be identified (Figure 11.7). Both atria are nearly equal in size, and are best recognized by the vein connections. Another feature is the visualization of the appendages: the left atrial appendage is finger-like and has a narrow base, whereas the right atrial appendage is pyramidal in shape with a broad base. The appendages can be visualized in a plane slightly cranial to the four-chamber view, but are not identified reliably under many conditions.

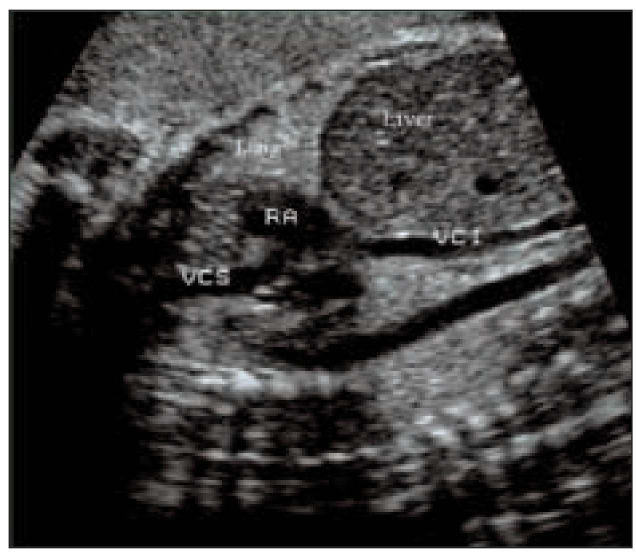

Figure 11.7
Parasagittal right-sided longitudinal view demonstrating the connection of the superior (VCS) and inferior vena cava (IVC) to the right atrium (RA).

Directly behind the sternum, the right ventricle appears as the most anterior cardiac structure. The left ventricle is adjacent and posterior to the right ventricle, and is the most left-sided cardiac structure. Many features can be

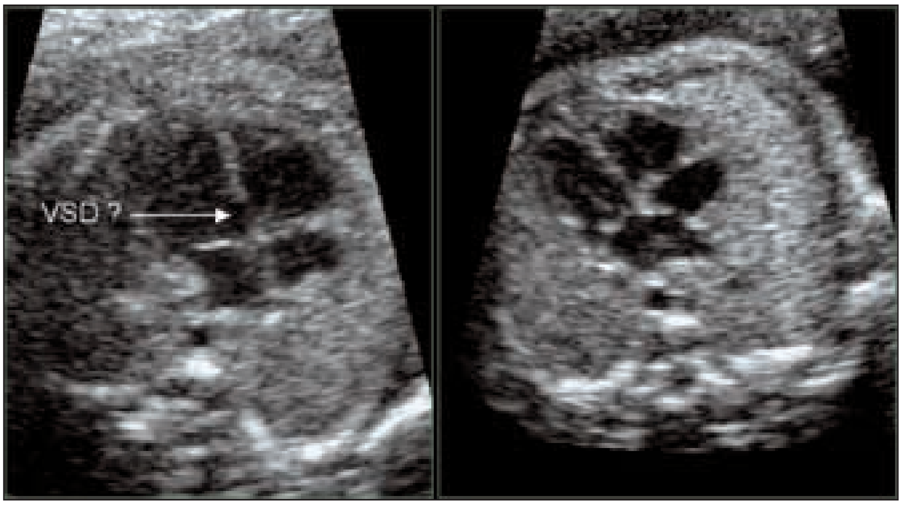

Figure 11.8
Apical four chamber in systole (left) and diastole (right). This "drop-out" effect is due to the insonation angle parallel to the membranous septum. By angulating the transducer more laterally (right), the intact septum is better recognized.

used to differentiate the right from the left ventricle. The right ventricle is trabeculated and the cavity is irregular, whereas the inner shape of the left ventricle is smooth. The lumen of the left ventricle is longer than that of the right ventricle, and reaches the apex of the heart. The right ventricle shows a short lumen, mainly owing to the moderator band (septomarginal trabeculum coursing from the interventricular septum to the lower free wall of the right ventricle). The ventricles can also be recognized by their corresponding atrioventricular valves: the left ventricle receives the mitral valve and the right ventricle the tricuspid valve. The tricuspid valve inserts slightly more apically than the mitral valve on the interventricular septum.

Both ventricles are separated by the interventricular septum. The septum begins as a wide thickened structure at the apex of the heart, and becomes thinner as it reaches the level of the atrioventricular valves. This is due to the development and the anatomic structure of the septum, with a muscular part in the lower two-thirds, and a membranous part at the junction with the atrioventricular and semilunar valves. Around 20 weeks of gestation, this thin membranous part is not correctly visualized by an apical approach. This drop-out effect sometimes leads to a false-positive suspicion of septal defects (Figure 11.8). In these conditions, the heart should be examined using a lateral view, allowing better visualization of the septum. Thickness of the septum, ranging between 2 and 4 mm during gestation, should also be measured by the lateral approach.

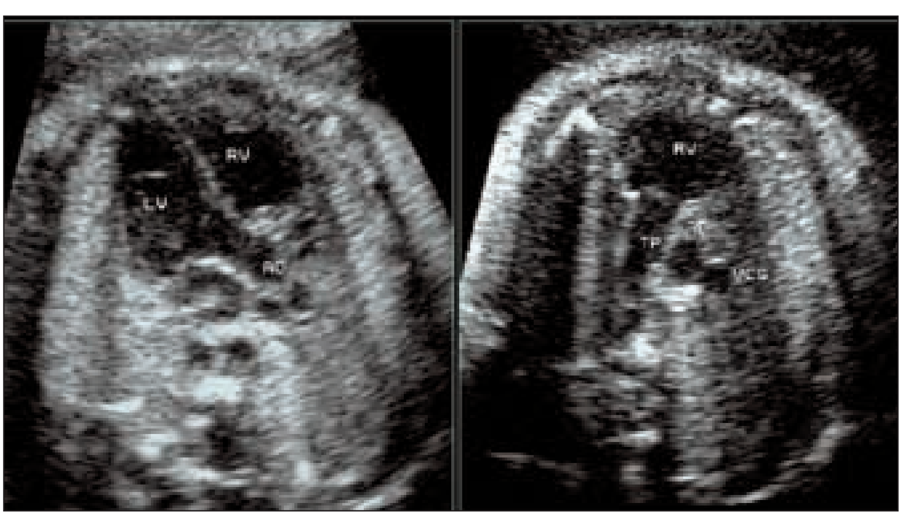

Figure 11.9
"Five-chamber view" (left) with the aorta (AO) arising from the left ventricle (LV) and "pulmonary view" (right) with the pulmonary artery arising from the right ventricle (RV). Compare with Figure 11.1. TP, pulmonary trunk; VCS, superior vena cava.

Table 11.3. Checklist for outflow tract assessment
• Normal connection of the aorta to the left ventricle and pulmonary trunk to the right ventricle
• Both vessels cross over each other
• Compare caliber of pulmonary trunk (PT) and aorta (PT > aorta)
• Assess opening excursion of aortic and pulmonary valves
• Continuity of ventricular septum to the aortic root
• Normal course and caliber of great vessels and of superior vena cava in the upper thorax
• Assess aortic isthmus and ductus arteriosus
• Rule out atypical vessels (e.g. left persisting superior vena cava)

The pericardium of the heart is recognized as a slight double layer around the outer cardiac wall. At the level of the atrioventricular valves, a tiny amount of pericardial fluid can be seen and should not be diagnosed as an abnormal effusion.

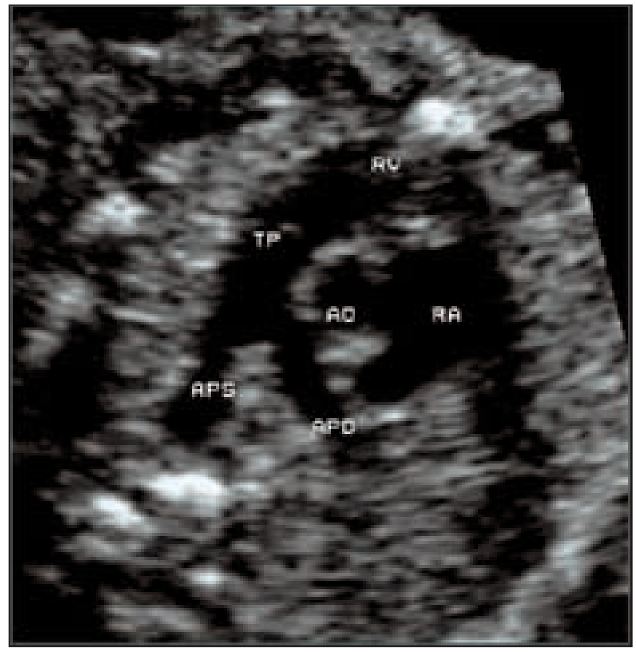

Figure 11.10
Short-axis view visualizing the aorta (AO) in the center and around it the right atrium (RA), the right ventricle (RV), the pulmonary trunk (TP) with its bifurcation into the right (APD) and left (APS) pulmonary arteries.

Visualization of left and right ventricular outflow tracts

In the next planes, the five-chamber view and the pulmonary view, the arising of the aorta from the left ventricle and the pulmonary trunk from the right ventricle are visualized. The assessment of the ventriculoarterial concordance is mandatory in analyzing heart anatomy.

Once the four-chamber plane is visualized, the examiner tilts the transducer slightly cranially (Figures 11.3 and 11.9) and focuses the attention on the center of the heart in the left ventricle, where the mitral valve connects with the ventricular septum. The aorta arises as a vessel continuing the ventricular septum but pointing slightly to the right side. The other border of the aortic wall shows a close connection to the mitral valve. Within the aortic root, the aortic valve can be recognized as an echogenic dot. In this plane the examiner checks (Table 11.3) the continuity of the septum and aorta, the angulation of the aorta and septum, the size of the aortic root, the ascending aorta, as well as the opening movements of the aortic valve (most ventricular septal defects can be detected in this plane).

The pulmonary trunk can be visualized by further tilting of the transducer cranially (Figure 11.9), but some authors recommend the short-axis view (Figure 11.10). This plane is easy to obtain by noncardiologists and can be obtained by successive tilting from the four- and five-chamber planes (Figure 11.3). Once the five-chamber view is obtained, the examiner focuses attention during the further tilting of the transducer on the connection of the right ventricle with the descending aorta (vessel toward the spine). The vessel then arising is the pulmonary trunk, continuing as the ductus arteriosus (Figure 11.9). The pulmonary trunk crosses perpendicularly over the ascending aorta and then becomes the vessel on the left. On its right side, two vessels in cross-section can be recognized: the ascending aorta and the superior vena cava. During the tilting movement from the five-chamber view, the examiner checks for the correct connection of the right ventricle and pulmonary trunk, as well as the crossing of the pulmonary trunk (absent in transposition of the great arteries, where both vessels show a parallel course). The size of the pulmonary trunk has a slightly larger caliber compared to that of the aorta,[8] and the valve is seen as a white dot showing opening and closing movements.

In some heart defects involving the great arteries, it is important to identify correctly which vessel is involved. In these conditions, the aorta and pulmonary trunk are differentiated by the arising of the stem vessels for the aorta, and the bifurcation of the right and left pulmonary arteries for the pulmonary trunk. Whereas the three arterial branches are seen by visualizing the aortic arch, the

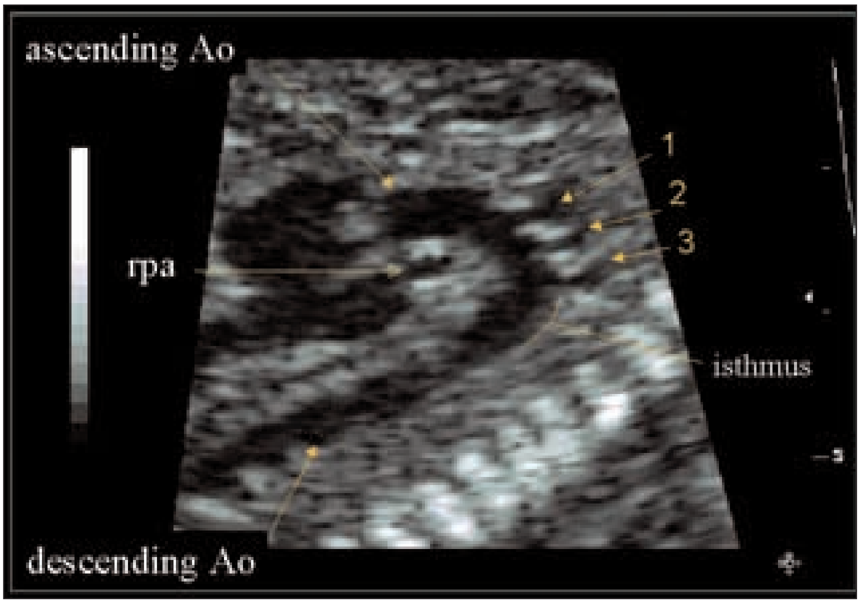

Figure 11.11
Longitudinal view of the aortic arch, resembling a candy cane. One can easily recognize the three vessels to the head and upper limbs. Under the aortic arch the right pulmonary artery is seen in cross-section.

pulmonary arteries are best visualized by obtaining a short-axis view of the heart. This is achieved by visualizing the five-chamber view, and then rotating the transducer in order to obtain a plane from the right hip to the left shoulder, demonstrating the "circle and sausage" sign, with the aorta in the center, and the right atrium, right ventricle, pulmonary trunk and bifurcation around it (Figure 11.10). The right pulmonary artery is seen very easily in its course under the aortic root toward the right lung.

Longitudinal views of the outflow tracts

The longitudinal planes of the outflow tracts are visualized to assess the aortic and the ductus arteriosus arches. In these planes, the continuity and the form of the arches are seen, as well as the brachiocephalic vessels arising from the aorta to the head and upper extremity. The examiner obtains a parasagittal plane slightly to the left, including the aortic valve and the descending aorta, and can thus visualize the aortic arch (Figure 11.11). In this plane the aortic arch appears to emerge from the center of the heart and shows a circular shape ("candy cane"). Under the ascending aorta, a cross-section of the right pulmonary artery can be recognized. In the next adjacent plane to the left, the longitudinal view of the pulmonary trunk with the ductus arteriosus can be recognized (Figure 11.12). The right ventricle and the pulmonary valve are seen anteriorly, and the ductus arteriosus arch courses perpen-

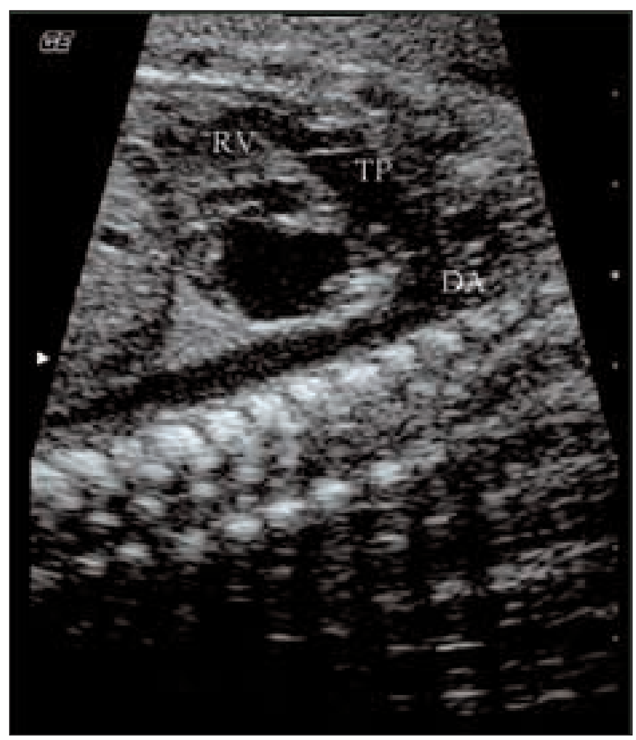

Figure 11.12
Longitudinal view of the ductus arteriosus arch. The pulmonary artery arises from the anteriorly positioned right ventricle and courses toward the descending aorta. This arch has a nearly perpendicular shape and resembles a hockey stick.

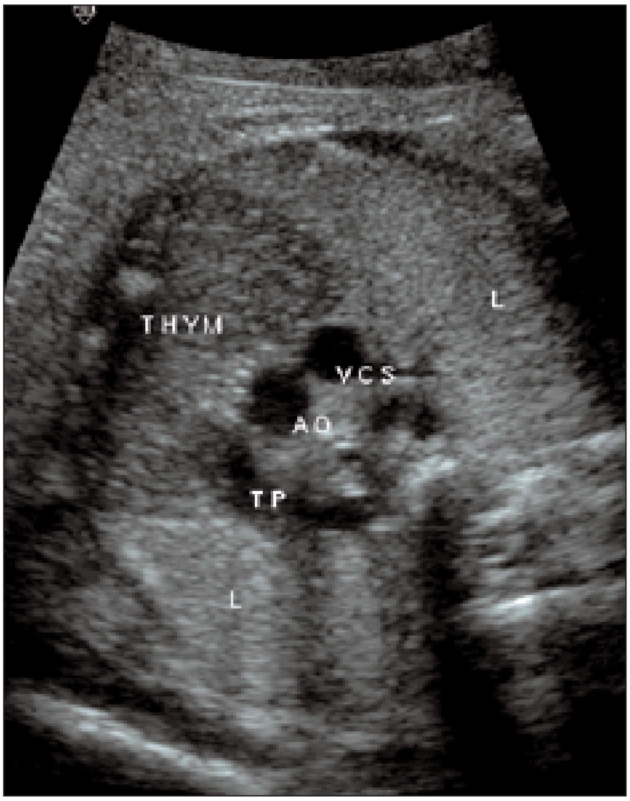

Figure 11.13
Cross-section of the upper thorax demonstrating the three vessels: the superior vena cava (VCS), the aorta (AO) and the pulmonary trunk (TP). In front of these vessels the thymus (THYM) is clearly recognized as an echodense structure compared to the neighboring lungs (L).

dicularly to connect with the descending aorta, recognized as having a more angular shape ("hockey stick"). The examiner can be confronted with two problems while obtaining both of these planes. The first is that these planes can be obtained in only a very few fetal positions: dorsoanterior or dorsoposterior. The second is that both planes are very close to one another, and inexperienced examiners can be easily confused, especially in abnormal cases. Therefore, in teaching fetal echocardiography to the noncardiologist, we proposed an easier plane (Figure 11.1b)[3] which was later called the "three-vessel view", visualizing the above structures in a tangential cross-sectional approach.[9]

Three-vessel view

From the four-chamber plane, the transducer is moved parallel in the direction of the upper thorax. In this sagittal cross-section of the upper thorax, the three vessels of the pulmonary trunk—the ductus arteriosus, aortic arch with aortic isthmus and superior vena cava—can be seen (Figures 11.13 and 11.14). This plane is therefore called the three-vessel view.[3,9] The aortic and the ductus arches are seen in a tangential cross-section and build a V-form pointing to the posterior thorax on the left side of the spine (Figure 11.14). The trachea prior to its bifurcation is recognized as a circular structure with an echogenic wall adjacent to and on the right side of the aortic isthmus and anterior to the spine. In front of the trachea and on the right side of the aortic arch, the superior vena cava is recognized. On the left and right sides of these vessels, lung tissue can be recognized (Figure 11.13). In front of these three vessels, the examiner can also recognize a structure with a less echogenic appearance, which is the thymus (Figure 11.13). The assessment of the three-vessel view has been stressed in the past few years because, with this view, many outflow tract disorders can easily be detected.[9] Furthermore, the position of the trachea in comparison to these vessels can be used as a landmark to distinguish the correct left-sided aortic arch from an abnormal right-sided aortic arch. It was then proposed to call this plane the three-vessel–trachea view.[10] The visual-

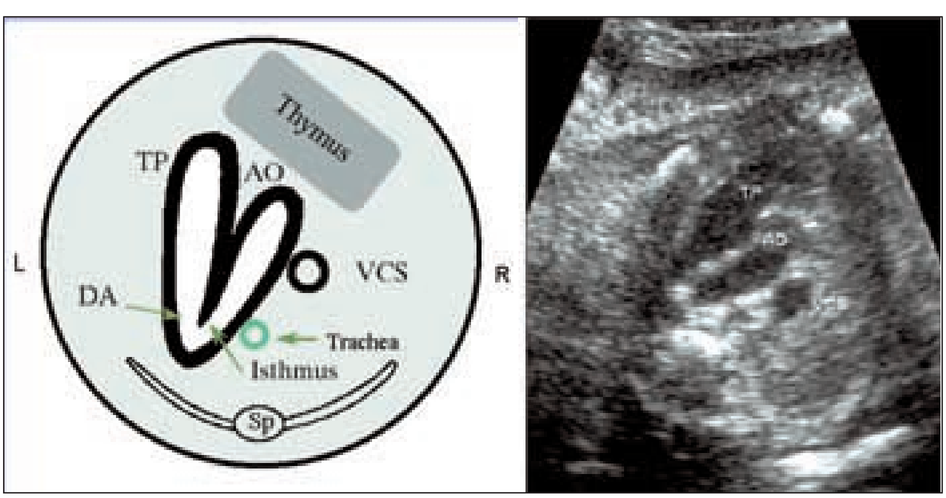

Figure 11.14
Three-vessel view in the upper thorax visualizing the aorta (AO) and isthmus, the pulmonary trunk (TP), ductus arteriosus (DA) and the superior vena cava (VCS). The trachea is recognized as a circle with an echogenic wall on the right side of the two great vessels and behind the vena cava.

ization of the thymus in front of these vessels can also be proposed as a hint to detect defects associated with malformations of the CATCH-22 group.[11]

The advantage of this plane is that it allows the visualization of both arches in most positions of the fetus, allowing an easier detection of possible abnormalities. The slightly larger size of the pulmonary trunk compared to the size of the aorta can be checked, as can the continuity of the aortic arch, or the presence of a fourth vessel on the left of the pulmonary trunk, as a left persisting superior vena cava. Using color Doppler, the visualization of antegrade flow within both outflow tracts under normal conditions can be easily distinguished from the retrograde flow in one outflow tract when severe outflow obstruction on this side is present. It is expected that, in the near future, this plane will be added to the four-chamber view in the routine assessment of the fetal heart.

References

1. Allan LD. Manual of Fetal Echocardiography. Lancaster: MTP Press, 1986.
2. Abuhamad A. A Practical Guide to Fetal Echocardiography. Philadelphia: Lippincott-Raven, 1997.
3. Chaoui R, Bollmann R, Hoffmann H, Heling KS. [Sonoanatomy of the fetal heart. Proposal of simple cross-sectional planes for the non-cardiologists]. Ultraschall Klin Prax 1991;6:59–67.
4. DeVore-GR. The prenatal diagnosis of congenital heart disease—a practical approach for the fetal sonographer. J Clin Ultrasound 1985;13:229–245.
5. Smith RS, Comstock CH, Kirk JS, Lee W. Ultrasonographic left cardiac axis deviation: a marker for fetal anomalies. Obstet Gynecol 1995;85:187–191.
6. Chaoui R, Heling KS, Bollmann R. [Ultrasound measurements of the fetal heart in the 4-chamber image plane]. Geburtshilfe Frauenheilkd 1994;54:92–97.
7. Kachalia P, Bowie JD, Adams DB, Carroll BA. In utero sonographic appearance of the atrial septum primum and septum secundum. J. Ultrasound Med 1991;10:423–426.
8. Chaoui R, Heling KS, Bollmann R. [Ultrasound measurements of the diameter of the aorta and pulmonary trunk of the fetus]. Gynakol Geburtshilfliche Rundsch 1994;34:145–151.
9. Yoo SJ, Lee YH, Kim ES et al. Abnormal three-vessel view on sonography: a clue to the diagnosis of congenital heart disease in the fetus. Ultrasound Obstet Gynecol 1997;9:173–182.
10. Yagel S. The routine use of the three-vessel and trachea view in fetal echocardiography. 9th World Congress of Ultrasound in Obstetrics and Gynaecology, Buenos Aires, November 1999.
11. Chaoui R, Koener H, Bommer C. Prenatal assessment of the thymus in detecting fetuses with del.22q11. Ultrasound Obstetr Gynecol 2000;16(Supp 1):82(abstr.).