18

Left heart malformations

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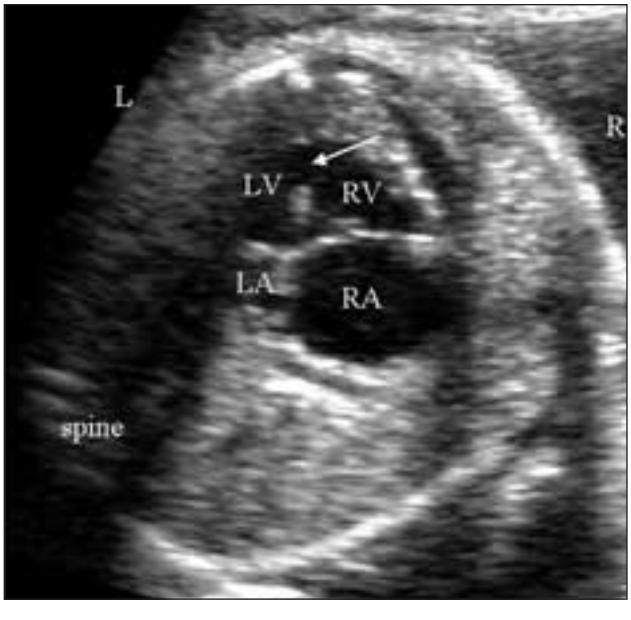
Left heart malformations are commonly detected in fetal life. They comprised 32% of a total series of 2136 malformations reported by Allan.[1] Anomalies affecting the left heart include mitral and aortic valve disorders, subaortic stenosis, aortic interruption and coarctation.

Mitral valve anomalies

Lesions that affect the mitral valve include mitral atresia, stenosis or incompetence. Mitral atresia most commonly occurs in association with aortic atresia in the setting of the hypoplastic left heart syndrome, but can also occur with a ventricular septal defect and concordant great arteries or with double outlet right ventricle. Mitral atresia is the most common mitral valve anomaly seen prenatally. Mitral stenosis as an isolated lesion is uncommon in fetal life and is usually associated with aortic stenosis or atresia. Mitral incompetence can occur in a dysplastic mitral valve, which is uncommon, or in aortic stenosis. It can also be seen in association with fetal cardiac dilatation and heart failure.



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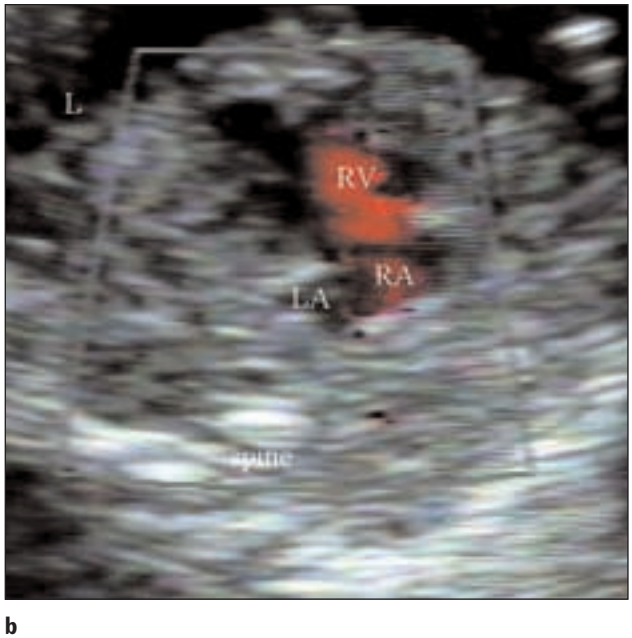

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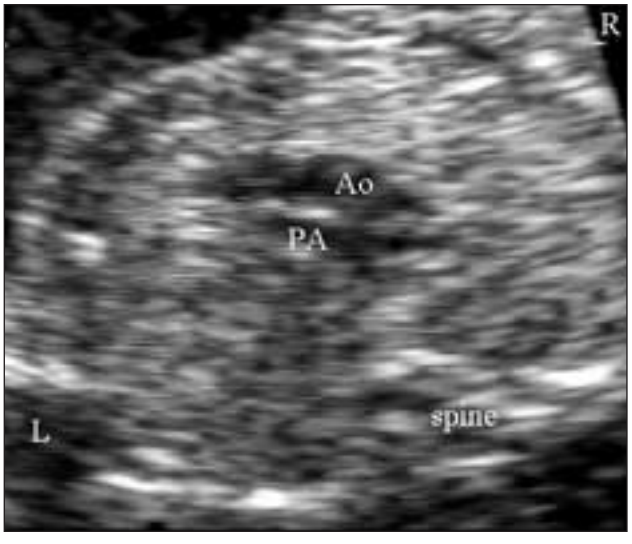
Figure 18.1
(a) The heart is seen in a four-chamber view. The left atrium and ventricle are smaller than normal but the left ventricle reaches the apex. In the moving image, the mitral valve was not opening in diastole. There is a large ventricular septal defect (arrow).
(b) On color flow mapping, there is forward flow through the tricuspid but not through the mitral valve.



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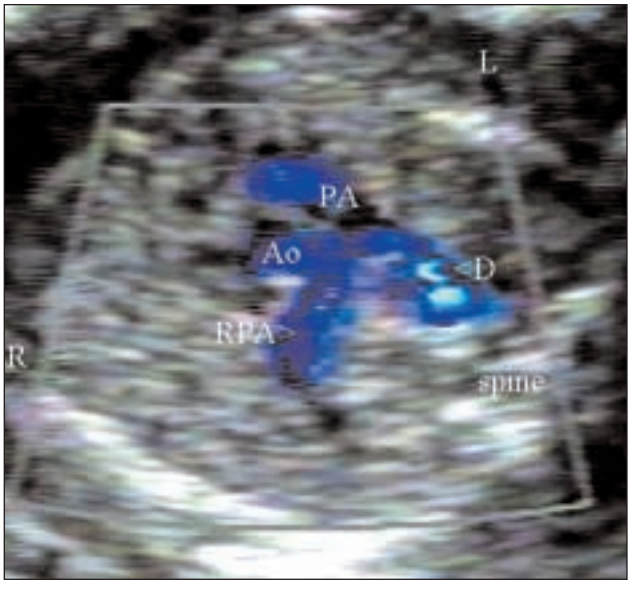

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Figure 18.2
(a) In this fetus with mitral atresia, the great arteries both arose from the right ventricle in parallel orientation with the aorta anterior to the pulmonary artery. The pulmonary artery is smaller than the aorta, indicating pulmonary stenosis. (b) In another fetus with mitral atresia, the great arteries both arose from the right ventricle, but were normally related in position and size.

Fetal diagnosis of mitral valve disease

A normal mitral valve has an annulus of normal size for the gestational age, with two thin leaflets that open in diastole, in addition to two normally spaced papillary muscles in the left ventricle. On the four-chamber view, both atrioventricular valves should have equal excursion in the moving image. If there is any degree of obstruction to or regurgitation across the mitral valve, the four-chamber view will usually be abnormal.

Mitral atresia

Mitral atresia in association with aortic atresia in the hypoplastic left heart syndrome is described below under aortic atresia. It can also occur with a concordant patent aorta and ventricular septal defect or with double outlet right ventricle.[2] Mitral atresia is diagnosed in the four-chamber view by seeing no opening valve into the left ventricle (Figure 18.1a). There is no flow across the mitral valve on color flow mapping (Figure 18.1b). The left atrium is usually small and the interatrial shunt is exclusively left to right. The left ventricle is hypoplastic in association with mitral atresia but the degree of hypoplasia is variable. A ventricular septal defect is nearly always present. If this is sizable, the left ventricle may be of near normal size and apex-forming, particularly with a concordant patent aorta. When the aorta is concordantly connected, the great arteries arise in a normal relationship to each other, although the aorta will usually be significantly smaller than the pulmonary trunk. In contrast, in mitral atresia with double outlet connection, the great arteries either may be normally related or may arise in parallel orientation (Figure 18.2). If there is pulmonary stenosis, which is common, the pulmonary trunk will be smaller than the aorta.

It is important to distinguish between mitral atresia with a ventricular septal defect and mitral atresia with double outlet, as the latter is more frequently associated with extracardiac anomalies. In addition, it is important to distinguish between mitral atresia with ventricular septal defect or double outlet right ventricle and mitral and aortic atresia (the classic form of hypoplastic left heart syndrome), as the postnatal course will be different.

Mitral stenosis

In fetal life, mitral stenosis is associated with a redistribution of flow towards the right atrium through the foramen ovale. This results in increased flow to the right

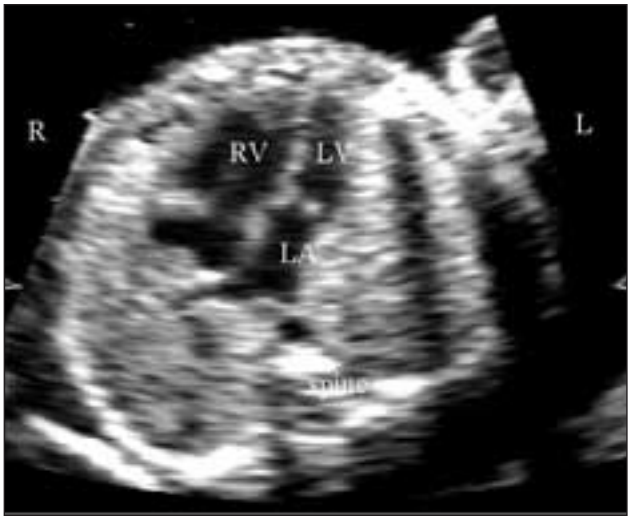

Figure 18.3
In the four-chamber view, the left ventricle is smaller than the right. The mitral orifice is smaller than normal and the valve appears dysplastic. Displacement (which does not occur in the mitral valve) is artefactual and is due to the dysplasia.

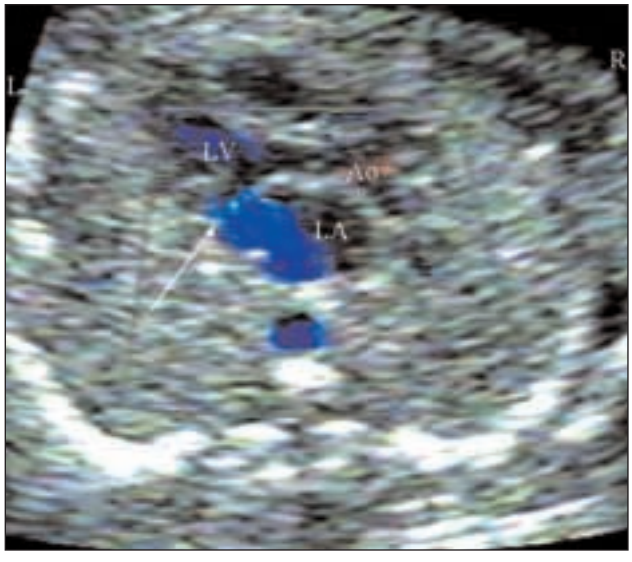

Figure 18.4
A significant degree of regurgitation is seen from a mildly dysplastic mitral valve.

heart and reduced flow to the left heart. The left atrium, mitral valve orifice, left ventricle and aorta may become hypoplastic and the right atrium, right ventricle, and pulmonary artery dilated. There may be a mild increase in the velocity of mitral valve flow, although blood flow redistribution at the foramen often masks this. There may be visible dysplasia of the mitral valve (Figure 18.3) and the interatrial shunt may be reversed.

The discrepancy in ventricular sizes may be more obvious in the presence of additional left heart obstructive lesions including coarctation of the aorta, aortic valve disease and more severe left ventricular outflow tract obstruction, so the subaortic area, the aortic valve and aortic arch should be examined carefully. On the other hand, in the presence of less severe stenosis, there may be only a subtle discrepancy in the four-chamber view. Assessment of right ventricular and left ventricular size, as well as tricuspid and mitral valve diameters, may be useful, especially when their ratios are compared to the normal range. The chordae of the mitral valve may be fused or shortened, resulting in limited leaflet mobility and valve excursion. In a parachute mitral valve the chordal attachments are to a single papillary muscle which restricts the mobility of the mitral valve leaflets. Although assessment of the mitral valve morphology is important, additional cardiovascular lesions must be excluded, as the outcome may be dictated by the other lesions.

Mitral regurgitation

Mitral regurgitation is diagnosed by recognizing reverse flow from the valve during systole on color flow mapping (Figure 18.4) and by confirming the finding on pulsed Doppler. The left atrium, in particular, but also the left ventricle, may appear dilated in a four-chamber view, depending on the severity of the regurgitation. Mitral regurgitation may occur secondary to dysplasia of the mitral valve leaflets. Mitral valve anomalies may be a clue to underlying aortic valve or arch anomalies. Mitral and tricuspid regurgitation are commonly seen as secondary functional findings in cardiomyopathy (see Figure 18.9) or in tachycardia in valves of normal morphology, but these are usually easily distinguishable as underlying causes.

Aortic valve anomalies

Lesions that affect the aortic valve include atresia, stenosis or incompetence, or an aortic to left ventricular tunnel. Aortic atresia in association with mitral atresia or severe stenosis (the hypoplastic left heart syndrome) is the second most common form of heart disease seen in the fetus. Aortic atresia as an isolated lesion is rare. Aortic

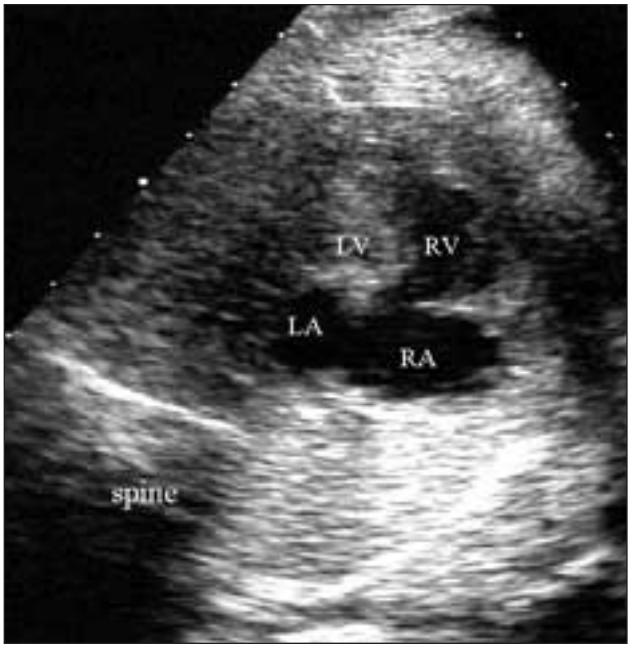

Figure 18.5
In the four-chamber view, the left ventricle is echogenic and thick-walled with almost no cavity. The right ventricle forms the apex. In this fetus, there was mitral and aortic atresia, the typical form of the hypoplastic left heart syndrome.

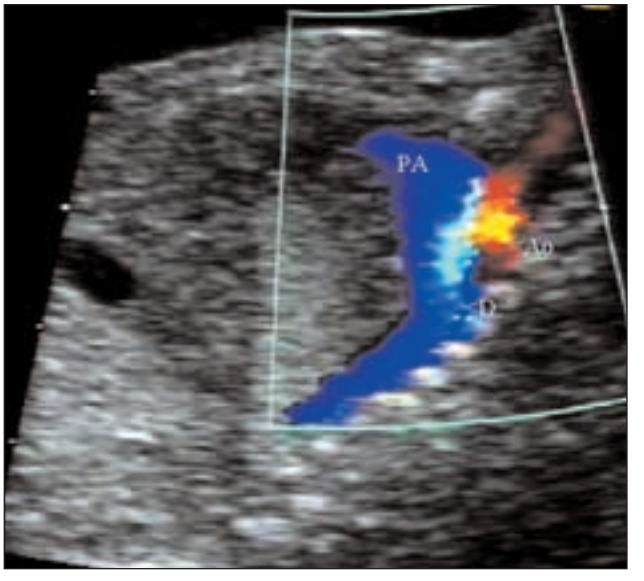

Figure 18.6
The long-axis view of the aortic arch shows a large patent arterial duct (D) and a small transverse aortic arch with reverse flow within it.

stenosis is an important form of heart disease in the fetus. It tends to be critical when detected prenatally, but less severe forms have also been reported. Aortic incompetence is rarely seen in the fetus except in severe myocardial dysfunction. An aortic–left ventricular tunnel is a rare lesion where incompetence occurs around the aortic valve ring through a communication between the ascending aorta and the left ventricle.[3] Subaortic stenosis is unusual prenatally but has been seen in a few cases.

Fetal diagnosis of aortic valve disease

Aortic atresia

The most common setting for aortic atresia is that of the hypoplastic left heart syndrome. These cases are readily detectable during routine obstetric ultrasound scanning as there will be an abnormal four-chamber view. The size and function of the left ventricle is abnormal. In cases associated with mitral atresia, the left ventricle will appear slit-like and is often not discernible. In some cases of aortic atresia and hypoplastic left heart syndrome, the mitral valve may be miniature but patent. In these instances, the left ventricular cavity is more easily recognized, with an echogenic, globular and dysfunctional chamber (Figure 18.5). The ascending aorta is usually hypoplastic, often thread-like, but the degree of hypoplasia can be variable. No forward flow is detectable across the aortic valve on pulsed Doppler or color flow mapping and retrograde flow from the duct in the transverse arch is an important confirmation of the diagnosis (Figure 18.6). The foramen ovale is usually patent, but in some cases can be restrictive or, more rarely, intact. A clue to the presence of a restrictive atrial septum can be the finding of an abnormal pulmonary venous pulsed Doppler flow pattern, so this should be examined as part of the assessment of this condition. An increase in the reverse flow wave into the pulmonary veins during atrial systole correlates with restriction of the foramen.[4] When the foramen ovale defect is patent, the interatrial shunt is left to right, the reverse of normal. When the diagnosis of the hypoplastic left heart syndrome is made, it is essential to examine the right heart in detail to assess the suitability for Norwood palliative surgery.[5] Tricuspid valve dysplasia is common, but if there is significant tricuspid regurgitation, this can represent a risk factor. Pulmonary stenosis can preclude Norwood repair, as would right ventricular dysfunction. Neonatal heart transplantation may be considered as an alternative form of treatment.[6]

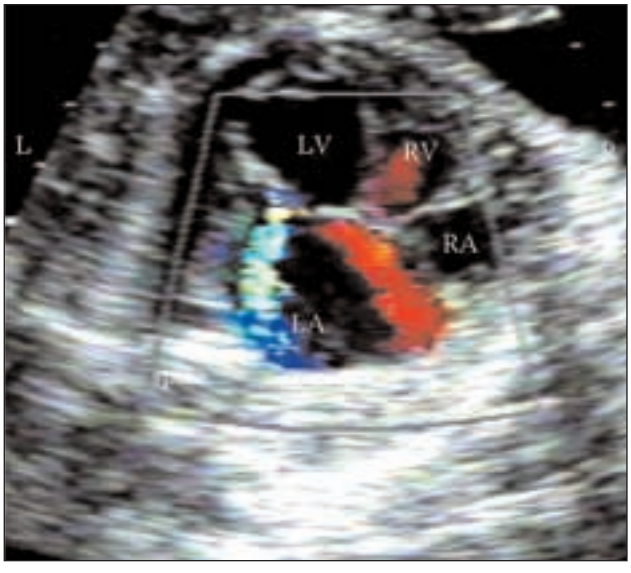

Figure 18.7
The heart is seen in the four-chamber view. The left atrium and ventricle are severely dilated and the ventricle was poorly contracting in the moving image. There is significant mitral regurgitation. This is the typical appearance associated with critical aortic stenosis.

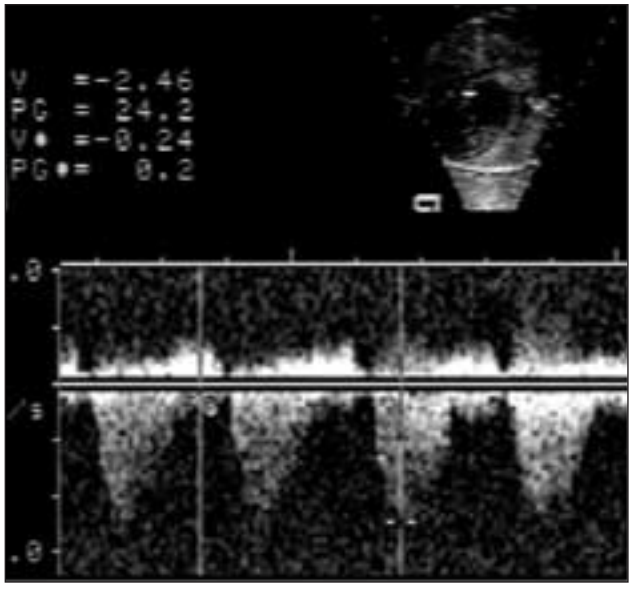

Figure 18.8
The Doppler sample volume is positioned in the ascending aorta just beyond the aortic valve leaflets. The velocity measured was just over 2 m/s. This is abnormally high, but predicts a gradient of only 24 mmHg across the narrowed valve. However, this is typical of critical aortic stenosis, where a high gradient across the obstructed valve is not generated, owing to left ventricular dysfunction.

Aortic stenosis

The appearance of the fetal heart will depend on the degree of obstruction. If aortic stenosis is moderate to severe, the left ventricle may appear normal or only mildly hypertrophied. Color flow mapping may reveal associated mitral regurgitation (Figure 18.7), which may give the first clue to the diagnosis. The aortic valve may appear abnormal with turbulence to flow occurring at the valve orifice. An increased aortic Doppler velocity above the normal range for the gestational age will confirm that the valve is stenotic. If aortic stenosis is critical, typically the left ventricle is dilated and poorly contracting with evidence of increased echogenicity of the ventricular walls and papillary muscles of the mitral valve. This appearance is suggestive of associated endocardial fibroelastosis. The mitral valve may be restricted in opening, owing to increased left ventricular diastolic pressure or to associated mitral stenosis. It may be difficult to demonstrate forward flow across the aortic valve in these cases, particularly flow at a high velocity, because of poor ventricular function. However, the aortic Doppler velocity, in cases with significant left ventricular compromise, may be within the normal range for gestation or only mildly elevated, usually in the range of 1–2 m/s, and often does not reflect the severity of the obstruction in this situation (Figure 18.8). In contrast, in less critical cases, with preservation of left ventricular function, velocities of up to 4 m/s have been obtained. The jet of mitral regurgitation is at high velocity and may help to predict left ventricular pressure. Occasionally there may be evidence of mitral stenosis. The shortening fraction of the left ventricle may be severely reduced.[7] The aortic valve will be thickened and doming. The aortic root and ascending aorta may be within the normal range in the midtrimester, but become smaller than normal for the gestational age in the last trimester of pregnancy.[7–9] If aortic stenosis is critical, there will be reversed flow in the transverse aortic arch. This can be an important discriminating feature between those cases with a poor prognosis for postnatal treatment. There is usually reversal of the interatrial shunt, but in some cases the atrial septum may be intact. In this group, there will be left atrial enlargement with an increased cardiothoracic ratio. Sequential studies have shown a reduced rate of growth of left heart structures in cases of severe left ventricular outflow tract obstruction identified in the midtrimester.[7,9,10] This has also been shown by experimentation in the animal model.[11] Thus, critical aortic stenosis can progress to the hypoplastic left heart syndrome by term, owing to failure of growth of the left ventricle. In some fetuses with aortic stenosis, the apex of the heart may be gradually taken over by the right ventricle as pregnancy advances, as the right ventricle grows normally and the left does not. Therefore, at term,

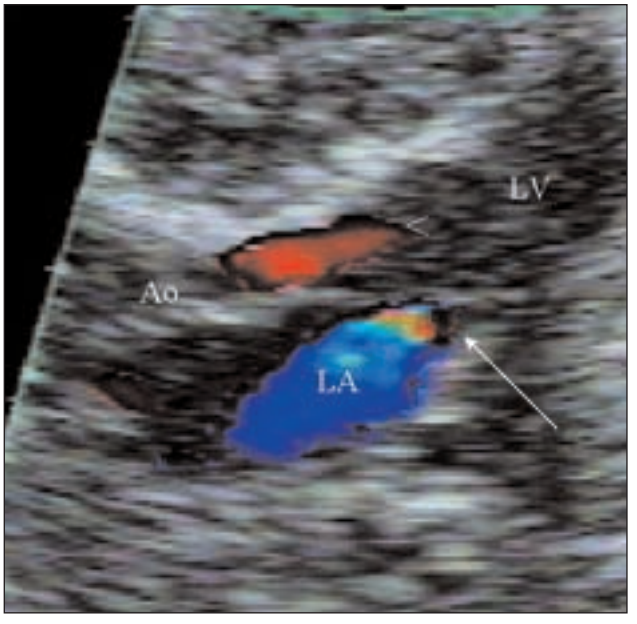

Figure 18.9
In this fetus, there was a jet of mitral (arrow) and aortic (arrowhead) regurgitation in the setting of severe left ventricular dysfunction.

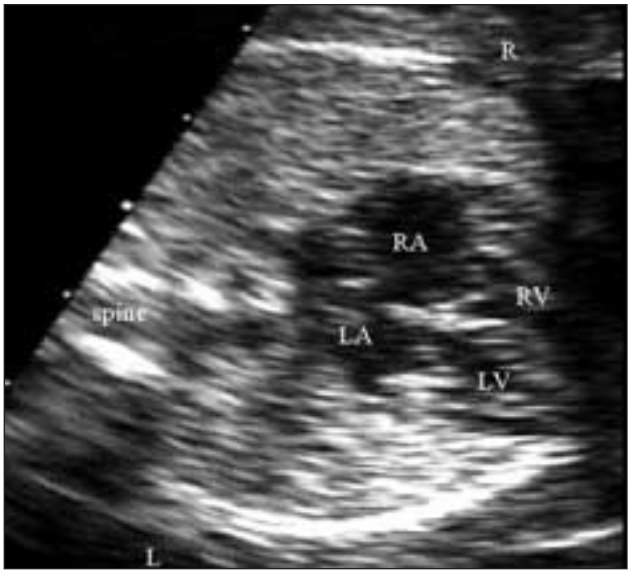

Figure 18.10
There is a difference in ventricular sizes in this fetus with coarctation of the aorta. The right heart is dilated relative to the left.

a biventricular repair may not be considered feasible, even though there is still forward flow through the left heart. Where there is milder aortic stenosis in the midtrimester there may be more normal growth of the left ventricle, although abnormal growth of the aortic valve may result in increasing stenosis by the time of birth.[8]

Aortic–left ventricular tunnel

Aortic–left ventricular tunnel is a very rare congenital heart malformation, which comprises an abnormal communication or channel that originates in the ascending aorta, bypasses the aortic valve and terminates in the left ventricle. The features of the lesion seen during fetal life which give a clue to this rare diagnosis are aortic regurgitation with a dilated ascending aorta, and a dilated left ventricle.[3] This last state is potentially detectable by examining the four-chamber view of the fetal heart, and thus this lesion can be detected during obstetric ultrasound examination. Color flow mapping will demonstrate turbulent regurgitant flow, which may initially appear to be across the aortic valve, but closer inspection will reveal this to be around the valve. The aortic valve can sometimes appear thickened. The dilated aortic root can potentially 'balloon' into the right ventricular outflow tract and cause some obstruction to right heart flow.

Other aortic valve anomalies

Aortic regurgitation can occur secondary to severe left ventricular cardiomyopathy (Figure 18.9) but this is rare. Subaortic stenosis is also rare in the fetus but can be seen especially as part of Schone syndrome, which is the association of coarctation with mitral valve disease and obstruction to the left ventricular outflow tract. Endocardial fibroelastosis as a primary lesion is very rare and is usually echocardiographically indistinguishable from that occurring in association with critical aortic stenosis. This diagnosis is made at autopsy.

Arch anomalies

These include coarctation and interruption of the aorta. Coarctation of the aorta is a fairly common lesion to be recognized in fetal life, whereas interrupted aortic arch is rare both in fetal and in postnatal life. Aortic arch anomalies accounted for 6.1% of all cardiovascular lesions detected antenatally in the combined series of Allan et al.[12] Coarctation of the aorta can be identified at the time of obstetric scanning by detecting a discrepancy between the size of the left and right ventricles. Arch obstruction when diagnosed antenatally represents a more severe spectrum

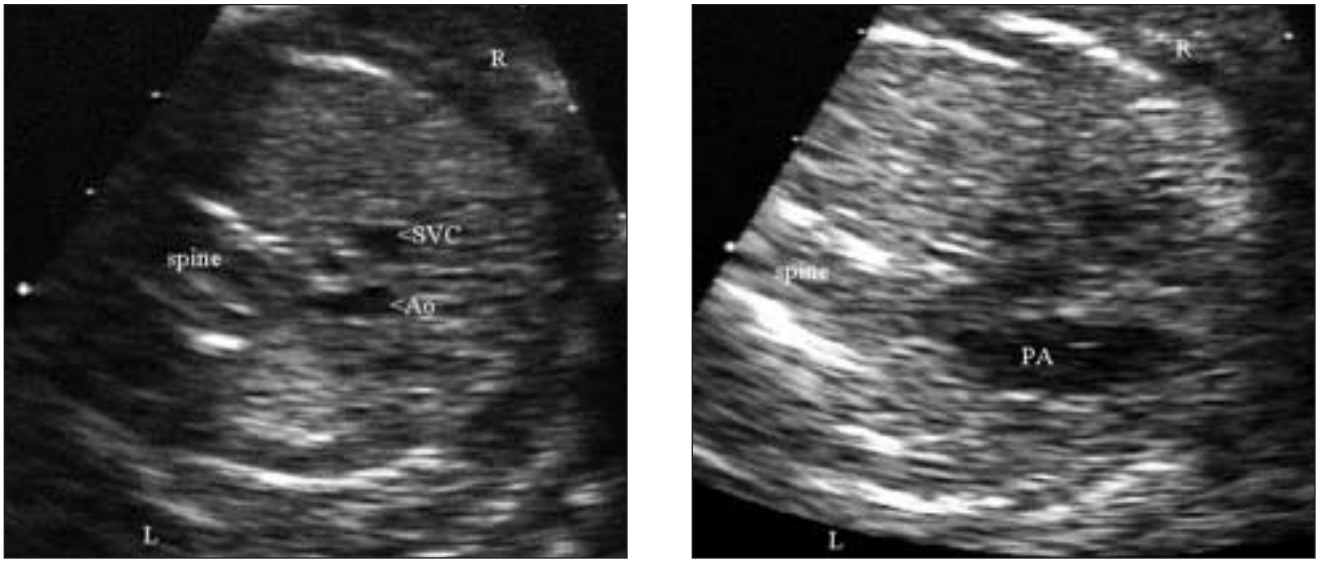

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Figure 18.11
(a) In this section, the ascending aorta and part of the transverse arch are imaged. The aorta is smaller than the superior vena cava which is an abnormal finding. (b) The pulmonary artery is seen in the same fetus at the same magnification, lying immediately below the previous section. The pulmonary artery can be seen to measure almost twice the size of the aorta. This abnormal aorta:pulmonary artery ratio is a reliable guide to the presence of coarctation.

of disease than that seen postnatally, as the lesion is more likely to be associated with significant intracardiac pathology.

Fetal diagnosis of arch anomalies

The antenatal diagnosis of coarctation of the aorta is often suspected initially by the detection of ventricular size discrepancy in the four-chamber view[13] (Figure 18.10). Ventricular size discrepancy, however, is not consistently present in the setting of isolated coarctation of the aorta.[14] Discrepancy of great artery size is more reliable in the diagnosis of fetal coarctation of the aorta (Figure 18.11), present in one study in 75% of affected fetuses, although it is still not a consistent finding. However, the aorta to pulmonary artery ratio is a useful measurement to help discriminate true cases[15,16] and also for sequential evaluation. The most sensitive diagnostic feature of fetal coarctation of the aorta which has been shown so far is the presence of transverse aortic arch and isthmic narrowing. In the series of Hornberger et al, of 20 fetuses with postnatal confirmation of coarctation of the aorta with or without intracardiac lesions, 80% had transverse aortic arch hypoplasia and 100% had isthmus hypoplasia.[14] Comparison of fetal aortic arch dimensions with the normal range is useful in the prenatal detection of aortic coarctation,[17,18] as is direct comparison of the aortic arch size with ductal size. In a cross-sectional view of the upper thorax, to image both the ductal and the aortic arch simultaneously, significant discrepancy in the size of the arches is an important clue to the potential presence of coarctation of the aorta (Figure 18.12). Bronshtein and Zimmer described a long-axis view of the aortic arch to image the junction of the duct and the distal arch, which they called the Y connection.[19] Normally these two vessels are equal in size at this junction. However, a dilated duct and small aorta at this site was found in 13 cases, where coarctation was subsequently confirmed. When coarctation of the aorta is suspected, further investigation for additional intracardiac lesions should be made, such as mitral valve abnormalities, ventricular septal defects, and left ventricular outflow tract obstruction in the form of subvalvular, valvular or supravalvular aortic stenosis. Conversely, where complex intracardiac pathology is detected, if the aorta is significantly smaller than the pulmonary artery, the aortic arch should be imaged for the possibility of coarctation of the aorta as an additional malformation.

Pulsed Doppler is not useful in the diagnosis of isolated coarctation of the aorta, but color flow mapping can help to delineate the hypoplastic lumen of the distal arch for comparison to the ductal arch, which is usually quite

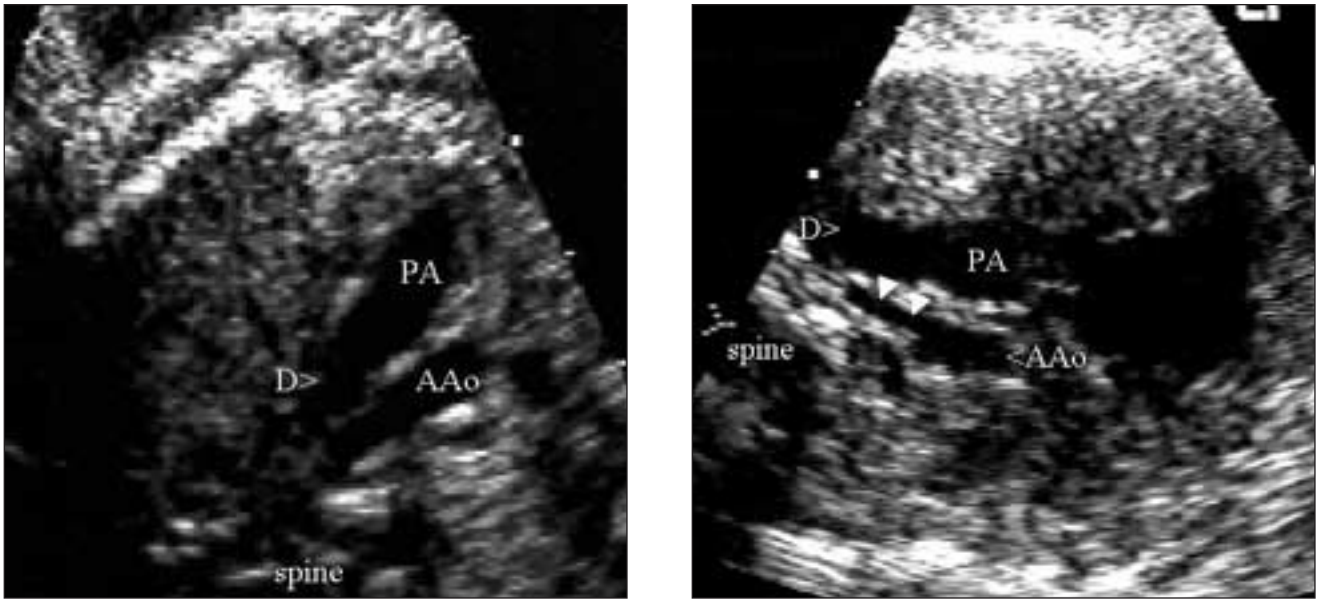

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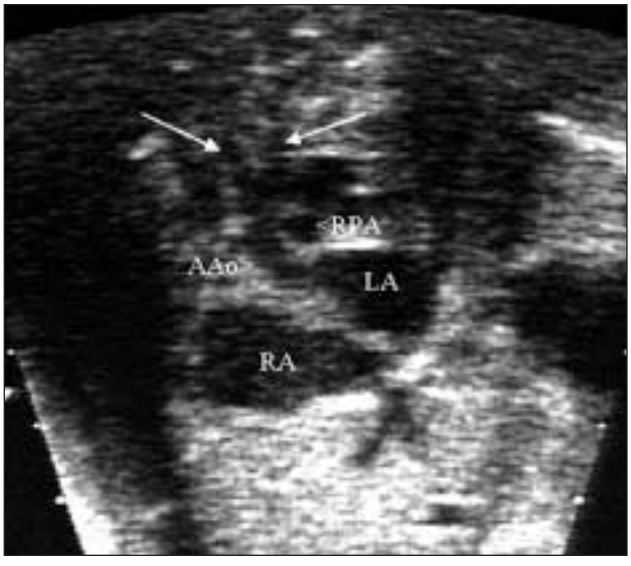
Figure 18.12
(a) The arch and duct are seen in the upper thorax in a normal fetus. At this point, the aorta crosses the midline in front of the spine to join with the duct (D) and turns caudally to continue as the descending aorta. As seen here, the transverse arch and the arterial duct should look similar in size in this projection. (b) In coarctation of the aorta, the transverse arch (arrowheads) is significantly hypoplastic relative to the larger arterial duct (D).

large. Blood flow through the foramen ovale is usually bidirectional in severe cases of coarctation. Color flow mapping can aid in the detection of associated ventricular septal defects. In coarctation, flow in a ventricular septal defect is usually mainly left to right, in contrast to bidirectional shunting which usually occurs in an isolated ventricular septal defect. Coarctation of the aorta may develop prenatally with progression in the degree of distal arch hypoplasia and also of other left heart obstructive lesions, which may be subtle at the initial antenatal examination in the second trimester. Thus, a case of coarctation with a good-sized aortic arch in early fetal life may become one with more extensive arch hypoplasia by the time of delivery, necessitating a more difficult surgical repair. Also, in a case of coarctation with a mildly small left ventricle in early pregnancy, poor growth of the left ventricle during the rest of pregnancy can lead to a ventricle of inadequate size for a two-ventricle repair.

Although discrepancy in ventricular or great artery size may be present in the setting of an interrupted aortic arch, the diagnosis is confirmed by demonstrating the pathology at the level of the aortic arch (Figure 18.13a). A ventricular septal defect is almost invariably associated (Figure 18.13b). When this is large, there is usually no significant discrepancy in ventricular size. A significant discrepancy in great vessel size, however, is observed. The ascending aorta has an unusual orientation and often appears to have a straight course to the head and neck. Interruption may also be associated with progressive left ventricular outflow tract obstruction.

Associated extracardiac abnormalities

Extracardiac abnormalities in fetal left heart disease can occur. Polyvalvular disease with dysplasia and redundancy of both the atrioventricular and the semilunar valves can be detected in utero in the setting of trisomy 18, often in association with a large-inlet ventricular septal defect. In a series of 108 cases of mitral atresia,[20] 17 had associated chromosomal anomalies (16%), most commonly trisomy 18. The hypoplastic left heart syndrome is associated with chromosomal anomalies in about 2–4% of cases,[12] particularly Turner syndrome, but also trisomies 18 and 13. Valvular aortic stenosis is not commonly associated with extracardiac malformations. Coarctation of the aorta in fetal series is commonly associated with chromosomal malformations, nearly 30% in one series.[12] Interrupted aortic arch has a high incidence of microdeletion of chromosome 22.[21]



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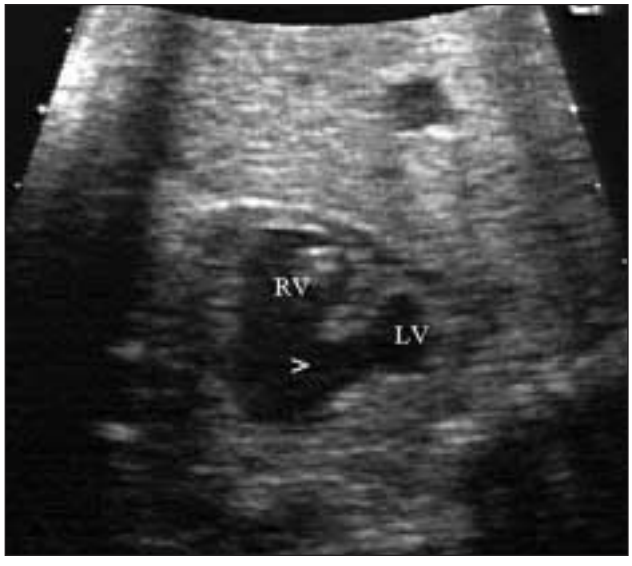

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Figure 18.13
(a) The ascending aorta is seen arising in the center of the heart. It appears to be straighter than normal and to branch into two (arrows), typical of an interrupted aortic arch type B. (b). There is a large muscular ventricular septal defect (arrowhead) seen in this case in association with an interrupted arch.

Prenatal counseling and management

Prenatal counseling regarding the presence of left heart disease is widely variable, depending on the precise anatomical lesion.

In isolation, or in the context of less severe left heart obstructive lesions, the severity of mitral stenosis may be difficult to assess and therefore the postnatal implications difficult to predict. Even if the mitral valve initially appears normal in size, there may be progressive mitral valve hypoplasia throughout the remainder of gestation.[9] Significant mitral regurgitation may result in the development of congestive heart failure.[22] The immediate management of cases of mitral atresia will depend somewhat on the associated lesions but all cases will result in a one-ventricle circulation in the long term.

Aortic atresia lies at the most severe end of the spectrum of cardiac malformations. Surgical options are now available for this group of abnormalities. However, in a recent study of 24 pregnancies which continued with an intention to treat surgically, there were only nine survivors (37.5%), with some patients excluded from surgery because of chromosomal anomalies, extracardiac malformations or additional cardiac malformations.[23] Some risk factors were not predictable prenatally, such as prematurity and evidence of neurological damage. In contrast, 'ideal' patients reaching Norwood stage 1 had a survival rate of over 80%. As yet, there is no information about the long-term survival for these children. It is likely that the single right ventricle will have a shorter lifespan than the single left ventricle, which usually fails after 20–30 years.[24] If this happens, transplantation is all that is currently available for these patients. In addition, there have been reports of neurodevelopmental delay after Norwood palliation.[25]

The management of fetuses with critical aortic stenosis will depend on the severity of the lesion and the gestational age at which the diagnosis is made. Sequential studies have shown that failure of growth of the left ventricle is a frequent occurrence in fetuses with this condition. This has implications for counseling, particularly with regard to the possibility of achieving a biventricular circulation after birth. It appears that fetuses seen in the midtrimester with left ventricular dilatation and global dysfunction are likely to fall in the category of hypoplastic left heart syndrome at term.[7,9] On the other hand, if aortic stenosis in the fetus is associated with a normal or near-normal ejection fraction, then the chances of a biventricular repair are increased. Therefore, when the diagnosis is made in the midtrimester, all the postnatal surgical options should be discussed with

the parents, including the possibility of a Norwood procedure. Prenatal balloon aortic valvuloplasty has been performed with the aim of improving left ventricular growth and function.[26] Although prenatal intervention is an option, the selection of suitable cases poses a difficulty, as does the timing of the procedure. It should be reserved for those with the worst prognosis—for example, those with reversed flow in the arch and an intact atrial septum.

Aortic–left ventricular tunnel can be a severe fetal cardiac malformation if regurgitation produces chronic volume overload and leads to the development of fetal hydrops. It is likely that the cases detected in utero represent the worst end of the spectrum of this abnormality.

Coarctation of the aorta in fetal life can lead to poor left ventricular growth and an 'unusably' small left ventricle by term, such that a biventricular repair is impossible. This condition overlaps the spectrum of a true hypoplastic left heart. If the left heart size is adequate and coarctation of the aorta is symptomatic in the neonate, which occurs in the majority of those cases recognized prenatally, an extended arch repair is usually necessary. This can have a significant mortality especially if there are associated intracardiac lesions, such as a ventricular septal defect or mitral stenosis. Only a relatively small proportion of the cases detected in the fetus will be of the type where elective resection of the coarctation shelf can be performed at low risk in later infancy.

Fetal outcome

The high mortality and morbidity associated with the treatment of most forms of left heart disease that are recognized in fetal life lead to a high incidence of pregnancy interruption. Counseling should be individualized depending on the known natural history of each type of lesion as it occurs in the fetus. Long-term potential morbidity, especially in cases likely to come to a Fontan (or one-ventricle) repair, must be included. Spontaneous intrauterine death can occur in a small proportion of cases, especially in coarctation with Turner syndrome or in aortic stenosis where hydrops develops.

Pregnancies involving nearly all forms of left heart disease recognized prenatally, where the pregnancy continues, should be delivered in a cardiac center in the hope of achieving a successful early intervention. Prostaglandin therapy should be initiated when there is retrograde arch flow or if a coarctation lesion is clearly demonstrated on the postnatal echocardiogram. Prenatal diagnosis results in improved neonatal hemodynamic condition after delivery and this could potentially improve the outcome for all types of left heart disease.[27,28] However, there is a high mortality at the first stage of the Norwood repair. The long-term outlook in children requiring a one-ventricle approach must be guarded.

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