25 Anomalies and Diseases of the Fetal Heart

Epidemiology and Indications for Fetal Echocardiography

Epidemiologic Aspects

It is generally known that approximately 15–20% of pregnancies in the second trimester end in spontaneous abortion and that some of these pregnancies are associated with anomalies, particularly involving the heart. Thus, the prenatal examiner will encounter a higher rate of heart defects in second-trimester fetuses than in newborns, for which the incidence of heart defects is five in 1000 births (12).

Perinatal mortality. Even with the improved treatment options that are now available, every fifth child with a congenital heart defect dies during the first year of life (Table 25.**5**). The mortality rate correlates closely with the severity of the heart defect and its early clinical manifestations. Approximately 40% of infants who are symptomatic during the first week of life die before one year of age, compared with just 5% of infants who do not become symptomatic until after 12 weeks of life (20). It is reasonable to assume that the first group includes heart defects that can be readily detected by fetal echocardiography. By diagnosing these conditions prenatally, it may be possible to reduce perinatal morbidity and mortality.

Fetal Echocardiography: Who, Whom, When, and How?

Who?

The main question is how to detect fetal heart disease most effectively. In Germany, approximately 800,000 pregnant women undergo ultrasound screening examinations each year. In most cases the obstetrician is still the primary examiner who evaluates the overall anatomy of the fetus, including cardiac anatomy (22). It is only by intensive training that examiner experience can be increased, improving the detection rate of cardiac anomalies in the 20-week screening at a secondary center. In fetal echocardiography, the examiner should work closely with a pediatric cardiologist (21). When a cardiac abnormality is detected, this specialist can be called in to help make a precise diagnosis and assess the prognosis.

Whom?

Low-risk and high-risk groups. It is important in prenatal ultrasound to distinguish between groups that have a low risk or a high risk for congenital heart disease. While the risk of finding a heart defect in the low-risk group is less than 0.5%, it is approximately 10% (!) in the high-risk group. For this reason, cases that are at high risk for congenital heart disease should be referred directly to an examiner who is experienced in fetal echocardiography.

Indications for fetal echocardiography. The indications for fetal echocardiography are listed in Table 25.**2**. Although recurrence in cases with a positive history is rare (caution: hypoplastic left heart!), fetal echocardiography is still of major value in providing reassurance and relieving parental concerns. The cases that offer the highest "yield" of heart defects consist of ultrasound indications such as an abnormal four-chamber view at screening, the presence of extracardiac anomalies, nonimmune fetal hydrops, and AV block (11).

Improved screening. Since congenital heart defects usually have multifactorial causes, the majority are not found in the high-risk group. Consequently, detection rates can be increased only by improving the screening process (22). Recent studies have shown that increased nuchal translucency thickness in early pregnancy not only suggests a chromosomal abnormality but also suggests the presence of a heart

Table 25.**1** Abbreviations used in the text, tables, and figures

Ao	=	Aorta
AoV	=	Aortic valve
AS	=	Aortic stenosis
ASD I	=	Atrial septal defect type I = incomplete AV canal
ASD II	=	Atrial septal defect type II
AV block III°	=	Third degree atrioventricular block
AVSD	=	AV canal = atrioventricular canal or septal defect
CCHB	=	Congenital complete heart block (= third degree AV block)
CMP	=	Cardiomyopathy
CoA	=	Coarctation of the aorta
D-TGA	=	Complete transposition of the great arteries
DA	=	Ductus arteriosus
DAP	=	Ductus arteriosus persistens (persistent ductus arteriosus)
DOLV	=	Double-outlet left ventricle
DORV	=	Double-outlet right ventricle
EFE	=	Endocardial fibroelastosis
FO	=	Foramen ovale
Heterotaxia	=	left and right isomerism, polysplenia and asplenia syndrome
HLHS	=	Hypoplastic left heart syndrome
IAS	=	Interatrial septum
IUGR	=	Intrauterine growth retardation
IVS	=	Interventricular septum
L-TGA	=	Corrected transposition of the great arteries
LA	=	Left atrium
LV	=	Left ventricle
LVOT	=	Left ventricular outflow tract
MV	=	Mitral valve
PA/IVS	=	Pulmonary atresia with intact ventricular septum
PAPVR	=	Partial anomalous pulmonary venous return
PLSVC	=	Persistent left superior vena cava
PS	=	Pulmonary stenosis
PSVT	=	Paroxysmal supraventricular tachycardia
PT	=	Pulmonary trunk
PV	=	Pulmonary valve
RA	=	Right atrium
RV	=	Right ventricle
RVOT	=	Right ventricular outflow tract
Sp	=	Spinal column
SVES	=	Supraventricular extrasystole
TA	=	Tricuspid atresia
TAC	=	Truncus arteriosus (communis)
TAPVR	=	Total anomalous pulmonary venous return
TGA	=	Transposition of great arteries
TOF	=	Tetralogy of Fallot
TV	=	Tricuspid valve
VCI	=	Inferior vena cava
VCS	=	Superior vena cava
VSD	=	Ventricular septal defect

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defect. According to a 1999 study, this feature has a sensitivity of 60% in the detection of congenital heart defects (26).

When?

The optimum time to perform a screening examination is the period from 20 to 22 weeks. The period of 16–18 weeks was preferred in the past, but recent findings indicate that 20–22 weeks is better because at that time the fetal cardiac structures can be defined more clearly with screening ultrasound in more than 90% of cases (30). A 5.0-MHz transducer should be used for adequate resolution.

How?

Systematic examination. It is important to explore the somewhat difficult path from noting a cardiac abnormality to making a diagnosis. Only by following a systematic approach (see Chapter 11) can the examiner identify specific fetal cardiac structures, describe any abnormalities that are found, and make a presumptive diagnosis. In most cases this can be done without the use of color Doppler. Color imaging can then be used to define the details of the abnormality.

From symptom to diagnosis. This section of the chapter, presented below, covers the most important suggestive signs in the systematic analysis of fetal heart structures. It is intended to help the reader recognize what is normal and formulate a differential diagnosis for any abnormalities that are found.

Specific cardiac anomalies and diseases. In this part of the chapter, specific heart defects are described and placed in diagnostic groups so that when a fetal heart defect is suspected, the examiner can look up the typical B-mode and color Doppler findings and use them in formulating a differential diagnosis. The tables divide the principal heart defects into right-sided (Table 25.**9**) and left-sided defects (Table 25.**10**). Major vascular anomalies, septal defects, malrotation anomalies, and fetal arrhythmias are reviewed in Tables 25.**11**–25.**19**.

Abbreviations. The abbreviations used in the text and tables are explained in Table 25.**1**.

Prognosis of Cardiac Anomalies

Relatively little attention is given to the prognosis of congenital heart defects in this chapter, because every case must be considered individually. The neonatal data available in the literature often indicate much better prognoses than are found in cases that are detected prenatally. This is mainly because there is a tendency to detect more severe anomalies prenatally and because the association with extracardiac anomalies is higher in cases diagnosed prenatally than postnatally (50% versus 28%). Reference data from the Baltimore-Washington Infant Study (20) on survival rates and associations with extracardiac anomalies are presented in Tables 25.**3**–25.**5**.

Table 25.**2** Indications for fetal echocardiography

Positive history

- Family history:
  - Congenital heart defects
  - Other malformations or syndromes commonly associated with heart defects
- Exposure to various insults during pregnancy:
  - Chemical substances (e.g., antiepileptic drugs, lithium, alcohol)
  - Maternal diseases (e.g., diabetes mellitus, phenylketonuria)
  - Infections (e.g., rubella, cytomegalovirus, coxsackie)
  - High doses of ionizing radiation

Detection of fetal abnormalities

- Ultrasound suspicion of a heart defect (e.g., suspicious four-chamber view)
- Cardiovascular symptoms:
  - Arrhythmias
  - Nonimmune hydrops (NIHF)
  - Early increase in nuchal translucency thickness or cystic hygroma
- Early (before 32 weeks) and/or more symmetrical growth retardation
- Anomalies commonly associated with heart defects:
  - Abnormal cardiac position
  - CNS anomalies (hydrocephalus, microcephalus, agenesis of the corpus callosum, encephalocele)
  - Mediastinum (esophageal atresia, diaphragmatic hernia)
  - Gastrointestinal tract (duodenal atresia, visceral transposition)
  - Abdominal wall (omphalocele, ectopia cordis)
  - Kidneys (renal dysplasia)
  - Syndromes associated with cardiac defects
  - Single umbilical artery
- Detected chromosomal abnormality (e.g., Turner syndrome)
- Twin pregnancies:
  - Monozygotic twins
  - Conjoined twins

Invasive test for karyotyping has been omitted due to:

- High risk based on advanced maternal age
- Suspicious biochemical parameters in maternal blood (AFP, HCG, uE3)
- Familial risks

Table 25.**3** Percentage distribution of heart defects in 4390 infants (Baltimore–Washington Infant Study 1981–1989) (adapted from [20])

Diagnostic group	%	Diagnostic group	%
VSD	32.1	CMP	1.9
PS	9.0	PA/IVS	1.7
ASD II	7.7	Peripheral PS	1.5
AVSD	7.4	TAPVD	1.4
TOF	6.8	TAC	1.2
D-TGA	4.7	L-TGA	1.1
CoA	4.6	Ebstein anomaly	1.0
HLHS	3.8	TA	0.7
AS	2.9	Interruption of the aortic arch	0.7
DAP	2.4	Other “left-sided” defects	0.6
Heterotaxia	2.3	Double inlet ventricle	0.4
DORV	2.0	Other “right-sided” defects	0.2
Bicuspid aortic valve	1.9	Cor triatriatum	0.1

From Symptom to Diagnosis

The systematic examiner will conduct a step-by-step analysis of the individual cardiac structures, as described under “Cardiac Examination” in Chapter 11. An accurate diagnosis can be made, however, only if an abnormal finding is correctly interpreted and proper consideration is given to associated findings and differential diagnoses.

Systematic interpretation of abnormal findings. Since this chapter deals with the typical features of specific heart defects, Tables 25.**6**–25.**12** are designed to make it easier to get from an abnormal finding to an initial working diagnosis. Possible abnormalities are presented in the same order that is followed when conducting a systematic examination.

Table 25.4 Distribution of the association of noncardiac anomalies by diagnostic groups (Baltimore–Washington Infant Study 1981–1989) (adapted from [20])

Diagnostic group	n	Association with syndromes, major organ anomalies and deformations (%)
L-TGA	47	32
Heterotaxia	99	80
D-TGA	208	11
TAC	51	37
DORV	86	40
TOF	297	35
Double inlet ventricle	18	11
AVSD	326	80
TAPVD	60	23
TA	32	12
PA/IVS	73	10
Cor triatriatum	5	0
HLHS	167	17
Interruption of aortic arch	31	48
Ebstein anomaly	43	23
PS	395	13
AS	128	19
CoA	203	26
Bicuspid aortic valve	84	21
Peripheral PS	65	35
VSD	1411	18
ASD II	340	30
DAP	104	32
CMP	82	37
Other	35	74
All cases	4390	28

Table 25.6 Principal findings in the fetal upper abdomen

Normal	Suspicious
Stomach on left side, filled	➢ Stomach small or not visualized: esophageal atresia, diaphragmatic defect, or stomach on right side ➢ Stomach on right side or centered: rotation anomaly such as isomerism (situs ambiguus) or situs inversus abdominalis ➢ Stomach in chest cavity: diaphragmatic hernia
Liver on right side	➢ Liver on left side or centered: rotation anomalies Liver protruding: omphalocele
Aorta on left side	➢ Aorta on right side or centered: rotation anom alies or heart defects with right-sided aortic arch
Inferior vena cava	➢ No confluence of inferior vena cava and hepatic veins: azygos continuation in left isomerism ➢ Inferior vena cava and aorta on the same side: right isomerism ➢ Inferior vena cava dilated: severe heart failure or severe hypoxia in IUGR

Table 25.8 Differential diagnosis of suspected abnormalities of cardiac position

Normal	Suspicious
Heart occupies approximately one-third of the chest cavity (see curves for cardiac dimensions)	➢ Pseudocardiomegaly: normal heart in intrauterine growth retardation (CT ratio abnormal with a normal cardiac width or area) ➢ Extreme cardiomegaly: dilated cardiomyopathy (all chambers dilated and hypokinetic), Ebstein anomaly or tricuspid valve dysplasia (marked dilatation of right atrium) ➢ Large heart due to a cardiac defect, usually with tricuspid insufficiency; defect may be AV canal, pulmonary atresia, pulmonary stenosis, etc. ➢ Volume overload (see under Tricuspid Insufficiency)

Table 25.5 Survival rates of congenital heart defects: survivors with and without surgical treatment during the first year of life; n = 4390 infants (Baltimore–Washington Infant Study 1981–1989) (adapted from [20])

Diagnostic group	Survivors with and without surgery (%)
L-TGA	64
Heterotaxia	48
D-TGA	72
TAC	35
DORV	56
TOF	78
Double inlet ventricle	61
AVSD	71
TAPVD	60
TA	69
PA/IVS	57
Cor triatriatum	25
HLHS	15
Interruption of aortic arch	35
Ebstein anomaly	70
PS	98
AS	82
CoA	82
Bicuspid aortic valve	95
Peripheral PS	92
VSD	95
ASD II	94
DAP	94
CMP	77
Other	91
All cases	82

Table 25.7 Differential diagnosis of suspected abnormalities of cardiac position

Normal	Suspicious
➢ Two-thirds of the heart is in the left hemithorax ➢ Cardiac axis points to the left	➢ Heart is partially or completely outside the chest: ectopia cordis ➢ Heart is shifted to the right, with its apex toward the left: dextroposition of the heart (diaphragmatic defect, intrathoracic mass, unilateral agenesis of the right lung, unilateral pleural effusion) ➢ Heart is shifted far to the left within the chest: levocardia due to an intrathoracic mass on the right side (right-sided diaphragmatic defect, right lung cysts, etc.) or due to abdominal displacements, as in gastroschisis ➢ Heart on the left, stomach on the right: situs inversus with levocardia ➢ Heart on the midline: mesocardia ➢ Mirror-image inversion of the heart: mirror dextrocardia in situs inversus; right ventricle is anterior ➢ Heart is rotated toward the right: cardiac dextroversion; the left ventricle is anterior

Table 25.9 Differential diagnosis of principal right-heart findings in the four-chamber view

Normal	Suspicious
➢ Lumen of right ventricle (RV) is slightly shorter than that of the left ventricle ➢ RV shows trabeculation ➢ Moderator band is visualized ➢ Normal contractility	➢ Suspicious ➢ Low insertion of the tricuspid valve in the RV, right atrium is strongly dilated: Ebstein anomaly (often with cardiomegaly due to severe tricuspid insufficiency) ➢ Tricuspid valve has normal insertion but dysplastic leaflets, right atrium is strongly dilated: tricuspid valve dysplasia (often with cardiomegaly due to severe tricuspid insufficiency) ➢ Right atrium is visualized but RV is not visualized, single ventricle is perfused from the left atrium: tricuspid atresia with a single ventricle ➢ RV is very small with an echogenic wall, tricuspid valve shows ineffective movements, hypertrophic myocardium with interventricular septum shifted slightly to the left: pulmonary atresia with an intact septum (PA/IVS) ("hypoplastic right heart") ➢ RV is very small, tricuspid valve is not defined, but a VSD is present: tricuspid valve atresia with VSD ➢ Lumen of RV is small with hypertrophic myocardium and hypokinesia: severe pulmonary stenosis ➢ RV is extremely dilated with a very thin wall: Uhl anomaly (prenatal cases extremely rare)

Table 25.**10** Differential diagnosis of principal left-heart findings in the four-chamber view

Normal	Suspicious
➢ Lumen of left ventricle (LV) is slightly longer than that of the RV ➢ Normal contractility	➢ LV is not visualized and left atrium is difficult to define, only one ventricle is perfused from the right atrium: mitral atresia and aortic atresia in HLHS ➢ LV lumen is visible but extremely small with an echogenic wall, mitral valve shows ineffectual movements, myocardium frequently hypertrophic: aortic atresia with mitral valve dysplasia in HLHS ➢ LV is very small, small mitral valve, presence of VSD: mitral valve atresia with VSD ➢ LV is dilated with hypokinetic wall and often with echogenic myocardium: endocardial fibroelastosis due to critical aortic stenosis ➢ LV is considerably smaller than RV, but its contractility is preserved (sometimes with VSD): coarctation of the aorta, hypoplasia of the aortic arch, tubular hypoplasia or interruption of the aortic arch ➢ LV is dilated, left atrium is extremely dilated: isolated aortic atresia with patent (but incompetent) mitral valve

Table 25.**11** Differential diagnosis of an overriding aorta

Normal	Suspicious
➢ Aorta and septum present continuity	➢ Aorta is overriding, pulmonary artery is patent with a normal caliber: malalignment VSD ➢ Aorta is overriding, pulmonary artery is narrow with patent (separate) valve: tetralogy of Fallot ➢ Aorta is overriding, pulmonary artery is narrow and difficult to define, atretic pulmonary valve: pulmonary atresia with VSD (formerly: extreme tetralogy of Fallot) ➢ Pulmonary arteries arise from the aorta: truncus arteriosus ➢ Aorta arises mostly (> 50%) from the RV, with variable interrelationship of the vessels (normal or with D or L malposition): double-outlet right ventricle

Table 25.**12** Differential diagnosis of tricuspid insufficiency

Slight tricuspid valve regurgitation	➢ Normal due to immaturity of fetal lung (often with pulmonary valve regurgitation) or to myocardial immaturity
Heart defects with primary dysplasia of the tricuspid valve, heart defects with "optional" tricuspid insufficiency	➢ Ebstein anomaly ➢ Tricuspid valve dysplasia ➢ AV canal ➢ Hypoplastic left heart ➢ Mitral atresia with DORV ➢ Coarctation of the aorta
Heart defects and diseases with right ventricular obstruction	➢ Pulmonary atresia ➢ Pulmonary stenosis ➢ Constriction of ductus arteriosus (moderate to severe tricuspid insufficiency)
Volume overload (frequent tricuspid insufficiency with mitral insufficiency)	➢ Fetal anemia: Rh isoimmunization, parvovirus ➢ Peripheral arteriovenous fistula: veins of Galen, sacrococcygeal teratoma, chorangioma ➢ Acceptor in twin–twin transfusion syndrome ➢ Cardiac recirculation defect ➢ Severe arrhythmia: tachycardia, bradycardia
Myocardial dysfunction (frequent tricuspid insufficiency with mitral insufficiency)	➢ Myocarditis: infection, connective tissue disease ➢ Cardiomyopathy: dilated CMP, following a severe arrhythmia or volume overload ➢ Myocardial damage due to hypoxia: severe IUGR with abnormal Doppler findings in the periphery

Specific Cardiac Anomalies and Diseases

Tricuspid Atresia (TA)

Definition. In this anomaly, the normal connection between the right atrium and right ventricle is absent. If there is an accompanying ventricular septal defect (VSD), a right (hypoplastic) ventricle can be identified (TA with VSD) (Fig. 25.**1**). Otherwise the heart has only a single (left) ventricle. TA is divided into two types according to the position of the great vessels:

- Type I: ventriculoarterial concordance (70% of cases)
- Type II: discordance (30% of cases)

In turn, types I and II are each subdivided into a patent, stenotic, and atretic form depending on the morphology of the pulmonary valve (18).

Incidence. TA occurs in 0.7% of all live births with a congenital heart defect.

Associated anomalies and chromosomal abnormalities. Besides the cardiac anomalies associated with the different types, TA is frequently accompanied by an atrial septal defect. Typical extracardiac anomalies are not known and are rather uncommon. It is most important to exclude malrotation anomalies (left and right isomerism).

Ultrasound Diagnosis

B-mode image. The four-chamber view shows an absent or hypoplastic right ventricle. Only the AV valve on the left side (mitral valve) opens during diastole, connecting the left atrium to the ventricle. If the right ventricle has a demonstrable lumen, then a VSD (of variable size) can always be detected (Fig. 25.**2**). By defining the great vessels (e.g., in a short-axis view), the examiner can distinguish normal vascular origins from a malposition of the great vessels. When pulmonary atresia is present, a hypoplastic pulmonary trunk is often found.

Color and spectral Doppler. Color Doppler (Fig. 25.**3**) confirms an absence of blood flow from the right atrium to the "right" ventricle. Blood flows from the right atrium through the foramen ovale to the left atrium, from which it enters the left ventricle during diastole (Fig. 25.**3**). If a VSD is also present, the unidirectional left-to-right shunt can be optimally visualized with color Doppler (Fig. 25.**4**). In evaluations of the great vessels, color Doppler also helps differentiate the aorta and pulmonary trunk, and it can help in defining a right ventricular obstruction (see above). Color flow can demonstrate antegrade perfusion through the open pulmonary valve or retrograde perfusion through the ductus arteriosus in pulmonary atresia.

Differential diagnosis. When a single ventricle is found, other anomalies with a univentricular heart should be considered. With a hypoplastic right ventricle, the differential diagnosis should include pulmonary atresia with an intact ventricular septum and severe pulmonary stenosis. If isomerism is found (see below), it can be difficult to make a precise differential diagnosis (mitral valve atresia with VSD?).

Intrauterine course and prognosis. Tricuspid atresia can lead to intrauterine heart failure. For this reason, pregnancies that are carried to term should be examined at regular intervals, giving particular attention to the single AV valve (mitral valve) to look for signs of valvular insufficiency. Doppler examinations of the hepatic veins, vena cava, and

Tricuspid atresia

Fig. 25.**1** Diagram of tricuspid atresia with a VSD (modified from [30]).

Fig. 25.**2** Apical four-chamber view of tricuspid atresia with VSD, 25 weeks. The atretic tricuspid valve appears as an echogenic tissue band, and the lumen of the right ventricle (RV) is hypoplastic, as it receives flow only from the left ventricle (LV) through the VSD (left-to-right shunt) (compare with Figs. 25.**3** and 25.**4**). The small right ventricle shows good contractility.

Fig. 25.**3** TA + VSD (compare with Figs. 25.**1** and 25.**2**). Color Doppler demonstrates how blood flows from the left atrium (LA) through the LV (red) and VSD (blue) to the RV.

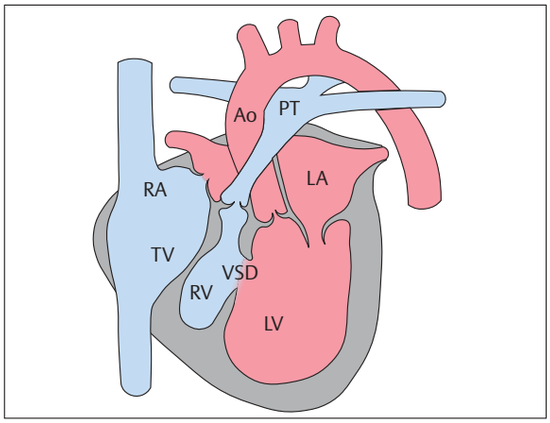
Fig. 25.**4** Doppler spectrum recorded over the ventricular septal defect in a fetus with TA + VSD (compare with Figs. 25.**1**–25.**3**). Because the tricuspid valve is atretic, blood enters the right ventricle only through the VSD in late diastole, creating a unidirectional left-to-right shunt.

Pulmonary atresia

Fig. 25.**5** Hypoplasia of the right ventricle in pulmonary atresia with an intact ventricular septum (PA/IVS). The lumen of the right ventricle is hypoplastic compared with the left ventricle, its wall is hypertrophic, and the ventricle appears hypokinetic in the real-time image. The tricuspid valve is dysplastic. Visualization of the pulmonary trunk would confirm the diagnosis of pulmonary atresia.

Fig. 25.**6** Pulmonary atresia, 25 weeks. Tangential view of the aortic arch (blue) and pulmonary trunk in a longitudinal scan. While blood normally flows in the same direction through both vessels (encoded in blue), pulmonary atresia leads to retrograde perfusion of the pulmonary trunk through the patent ductus arteriosus (DA) (encoded in red).

Fig. 25.**7** In a 35-week fetus with pulmonary atresia, the right and left pulmonary arteries (Rpa, Lpa) and pulmonary trunk (PT) are hypoplastic. By contrast, the ascending aorta (Aoa) appears dilated. Aod = descending aorta.



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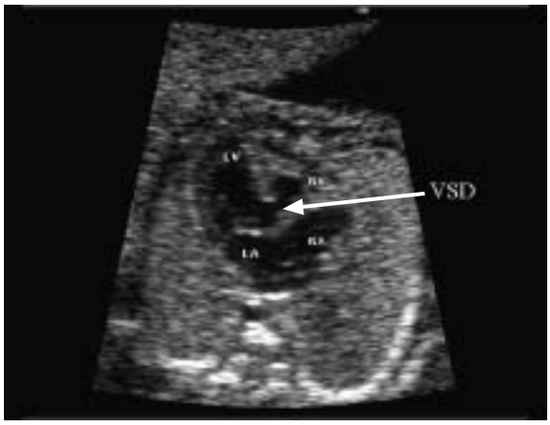

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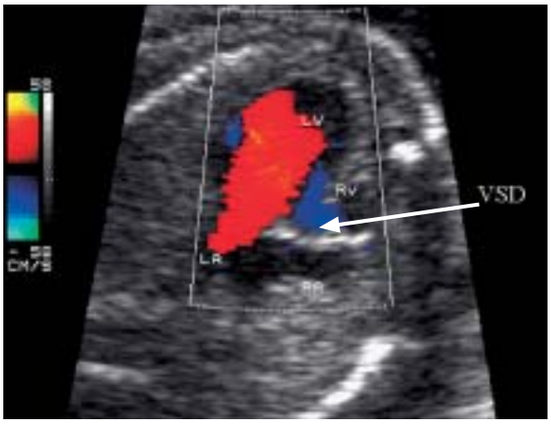

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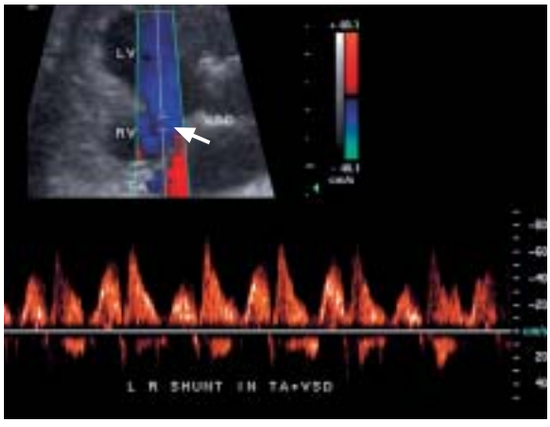

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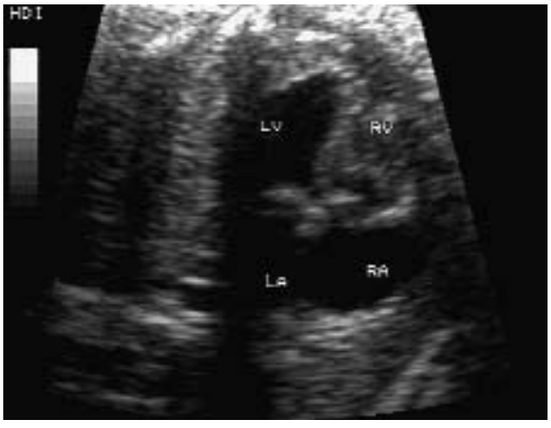

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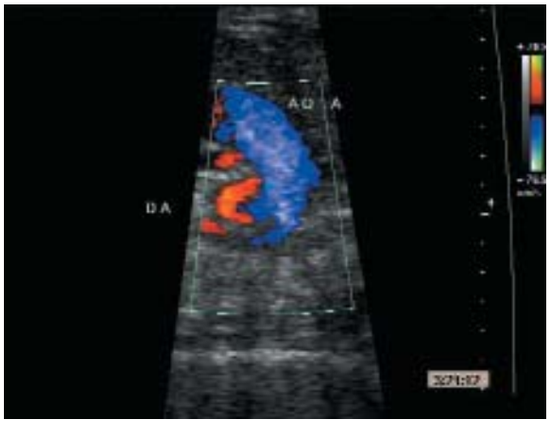

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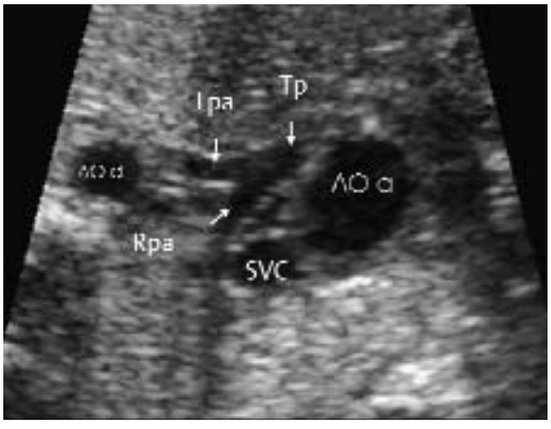

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ductus venosus (24, 26) are also helpful in assessing an atrial volume overload.

Pulmonary Atresia with an Intact Ventricular Septum (PA/IVS)

Definition. This term includes various defects in which the pulmonary valve is atretic and the interventricular septum is intact. Pulmonary atresia also occurs in several complex cardiac anomalies (double-outlet right ventricle [DORV], "extreme" tetralogy of Fallot). Atresia of the pulmonary valve leads to hypoplasia of the right ventricle with pronounced myocardial hypertrophy and secondary dysplasia of the tricuspid valve (Fig. 25.**5**). There are also less common forms marked by a normal-size or even enlarged right ventricle with a dysplastic tricuspid valve. Today, this latter group is increasingly classified as a form of primary tricuspid dysplasia (see below).

Incidence. PA/IVS occurs in approximately 1–2% of all live births with a congenital heart defect.

Associated anomalies and chromosomal abnormalities. Extracardiac anomalies are somewhat rare in PA/IVS. An atrial septal defect is often present as an associated cardiac anomaly. Also, connections are occasionally found between the lumen of the right ventricle and the coronary vessels (ventriculocoronary fistulae), which we have been able to detect in utero (14). The presence of these connections is a poor prognostic sign.

Ultrasound Diagnosis

B-mode image. The four-chamber view demonstrates hypoplasia, myocardial hypertrophy, and hypokinesia of the right ventricle. Not infrequently, slight endocardial fibrosis is noted in the form of an echogenic rim, and the right ventricle bulges to the left. The motion of the tricuspid valve appears restricted. The pulmonary trunk is underdeveloped compared with the aorta (Fig. 25.**7**) (pulmonary trunk biometry or Ao/PT ratio; see Chapter 12), and typical opening movements of the pulmonary valve are not observed. The origins of the pulmonary arteries should be visible, but the arteries themselves are often hypoplastic (Fig. 25.**7**).

Color and spectral Doppler. In the four-chamber view, flow through the tricuspid valve in diastole is absent or greatly diminished, depending on the degree of right ventricular hypoplasia. Regurgitation through the tricuspid valve may be noted during systole. Evaluation of the pulmonary trunk demonstrates retrograde flow through the ductus arteriosus (Fig. 25.**6**). Color Doppler can also detect any ventriculocoronary fistulae that are present. In fetuses with other forms of pulmonary atresia, such as PA with a VSD or in cases of DORV, the examiner should consider that atypical pulmonary arteries may arise directly from the aorta. This type of pattern can be detected only with color Doppler.

Differential diagnosis. With hypoplasia of the right ventricle, differentiation is first required from tricuspid atresia with a VSD (see above). Since the hypoplasia may be mild, the differential diagnosis should also include pulmonary stenosis (Doppler scanning of the pulmonary artery). Hypokinesia of the ventricle should also raise the possibility of cardiomyopathies or hemodynamic changes (e.g., acceptor in twin–twin transfusion). It should be noted that a less experienced examiner may confuse the sides and mistake the finding for a hypoplastic left heart syndrome. Finally, PA/IVS requires differentiation from pulmonary atresia with a VSD. In the latter condition, it is rare to find an extremely small, hypokinetic right ventricle.

Intrauterine course and prognosis. Intrauterine follow-up examinations are done mainly for the early recognition of heart failure, giving particular attention to retrograde flow in the systemic veins. It is also important to follow the development of the right ventricular lumen, for if the chamber is well developed, chances are good that a catheter procedure can be performed in the neonatal period to open up the valves.

Ductus arteriosus. Since cyanosis occurs in the early neonatal period as the ductus arteriosus begins to close, it is important to assess the size, course, and perfusion of the ductus arteriosus when PA/IVS is present. The pediatric cardiologist may need this information if neonatal stent insertion into the ductus is planned or if prostaglandin therapy is required. Under no circumstances should indomethacin be administered during the pregnancy to inhibit labor.

Tricuspid Dysplasia, Ebstein Anomaly

Definition. Both of these tricuspid valve anomalies have clinical and hemodynamic features that often cause them to be erroneously grouped together as "Ebstein anomaly." In tricuspid dysplasia, the valve is markedly thickened and flaccid but has a normal site of insertion (Fig. 25.**8**). In Ebstein anomaly, however, the valve inserts considerably lower in the right ventricle and has decreased mobility (Fig. 25.**11**). A common feature of the both anomalies is that the dysplastic valve is usually incompetent (Figs. 25.**9**–25.**11**), often leading to dilatation of the right atrium and fetal cardiomegaly.

Incidence. These rare anomalies occur in 1% of all live births with a congenital heart defect.

Associated anomalies and chromosomal abnormalities. Associated cardiac anomalies include right ventricular outflow tract obstruction (pulmonary stenosis or atresia), which occurs in 30% of fetuses with Ebstein anomaly and in 80% with tricuspid dysplasia. Extracardiac anomalies are somewhat rare, but several authors have observed associated skeletal deformities and chromosomal abnormalities (e.g., trisomy 13). Fetal hydrops may develop as a complication of cardiomegaly, and the chronically elevated intrathoracic pressure in pronounced cases can lead to pulmonary hypoplasia. Diagnosis is aided in these cases by determining the CTA ratio (ratio of cardiac and thoracic areas) (9). A value > 0.6 is strongly suspicious for pulmonary hypoplasia (10).

Ultrasound Diagnosis

B-mode image. In both anomalies, the four-chamber view demonstrates cardiomegaly and dilatation of the right atrium. As a result, these anomalies are relatively easy to detect at ultrasound screening. On subsequent planes, particular attention should be given to the right ventricular outflow tract, the opening movements of the pulmonary valve, and the caliber of the pulmonary trunk.

Color and spectral Doppler. Color Doppler can vividly demonstrate the incompetence of the tricuspid valve. Color flow is also helpful in assessing the perfusion of the pulmonary trunk to detect right ventricular obstruction. Doppler is of limited value, however, in correctly identifying a RVOT obstruction in cases with severe tricuspid insufficiency (10). Even if the pulmonary valve appears closed in the B-mode image and color Doppler shows only retrograde flow through the pulmonary trunk, the pulmonary valve may still be "open" since the incompetent tricuspid valve allows blood to reflux into the atrium during systole, and no pressure is generated to open the pulmonary valve, simulating atresia (10). The detection of pulmonary insufficiency is evidence for an open pulmonary valve.

Tricuspid dysplasia

Fig. 25.**8** Tricuspid valve dysplasia with extreme cardiomegaly, 32 weeks. Left: the tricuspid valve (TV) is at the correct location (differential diagnosis: Ebstein anomaly), but it is thickened and dysplastic (right arrow). The severe tricuspid insufficiency has led to cardiomegaly. Right: spectral features of severe tricuspid insufficiency, with a peak velocity of 3 m/s.

Fig. 25.**9** In a color Doppler view of the fetus in Fig. 25.**8**, the severe valvular insufficiency produces retrograde flow with a mosaic pattern. The newborn infant was also found to have pulmonary hypoplasia and died on the 2nd day of life.

Fig. 25.**10** Same fetus as in Figs. 15.**8** and 15.**9**. Color Doppler M-mode image shows the diastolic and systolic perfusion of the valve, indicating holosystolic tricuspid insufficiency.

Fig. 25.**11** Color Doppler view of an Ebstein anomaly, 32 weeks. In this condition the tricuspid valve insertion is lower in the right ventricle (long arrow) compared with the mitral valve insertion (two short arrows). Color Doppler indicates severe tricuspid insufficiency (turbulent flow with a mosaic pattern).

Pulmonary stenosis

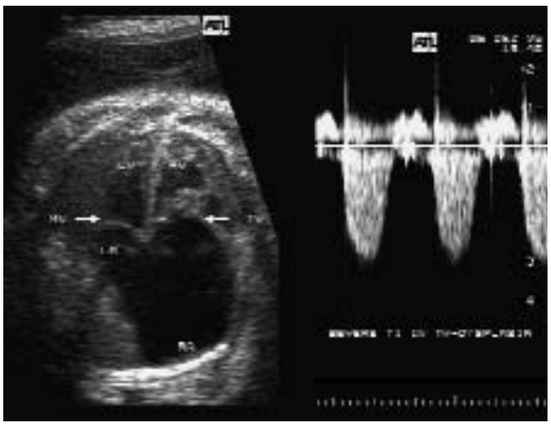
Fig. 25.**12** Isolated pulmonary stenosis, 31 weeks. In a longitudinal scan over the pulmonary trunk, color Doppler indicates turbulence over the pulmonary valve.

Fig. 25.**13** Isolated pulmonary stenosis as in Fig. 25.**12**. CW Doppler shows peak velocities as high as 3.5 m/s!

Hypoplastic left heart syndrome

Fig. 25.**14** Diagram of HLHS with aortic atresia and mitral valve dysplasia. In this case the left ventricle is demonstrable and hypoplastic (after [30]).

Fig. 25.**15** Specimen of a fetal heart with left ventricular hypoplasia following pregnancy termination at 19 weeks. Note the hypoplastic ascending aorta (Ao).



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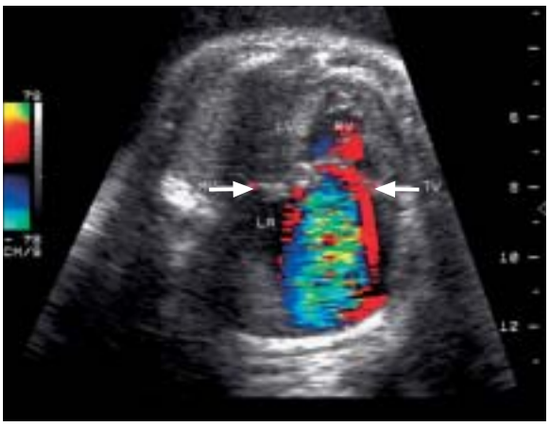

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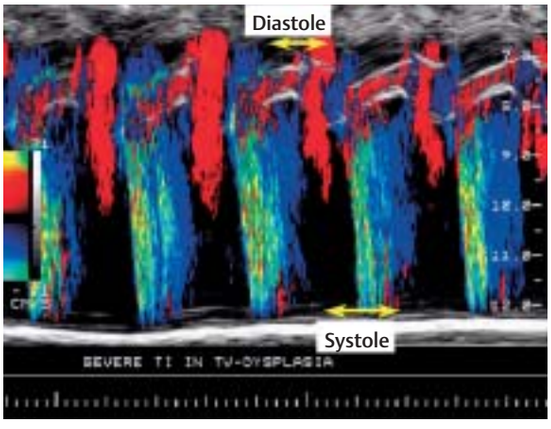

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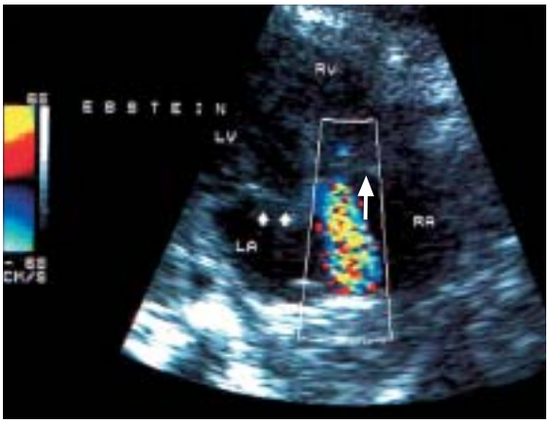

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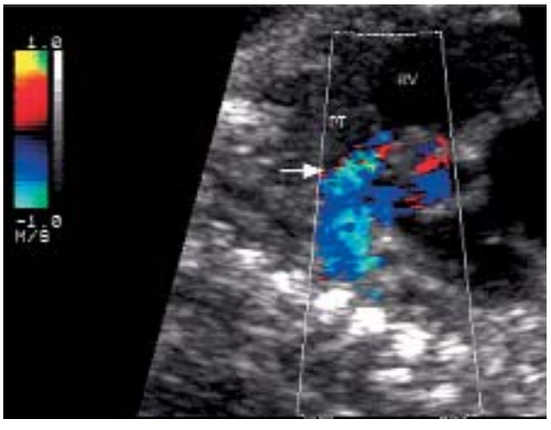

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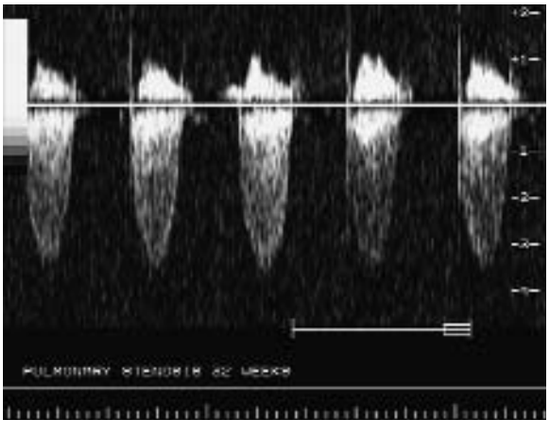

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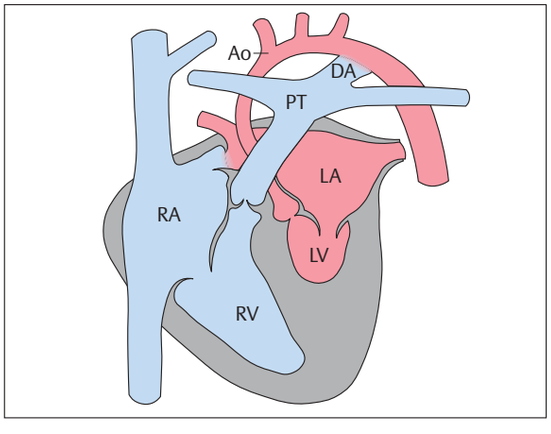

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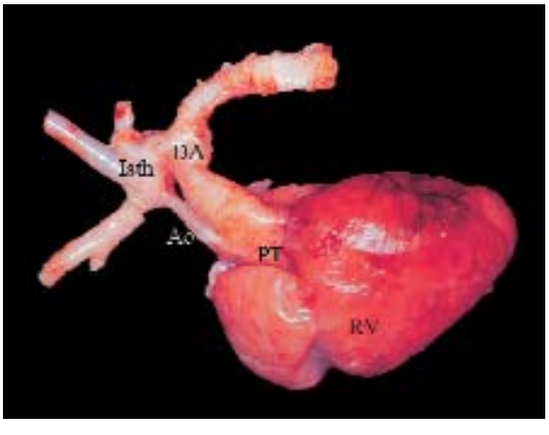

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Differential diagnosis. Table 25.**8** lists the numerous conditions that should be considered in the differential diagnosis of cardiomegaly. The differential diagnosis of tricuspid insufficiency is also extensive, ranging from functional and hemodynamic disturbances to complex cardiac anomalies (Table 25.**12**). A logical, systematic approach is needed to make an accurate differential diagnosis, and subsequent follow-ups during the pregnancy often permit an accurate diagnosis to be made.

Intrauterine course and prognosis. These heart defects tend to take an unfavorable course. Serial examinations during pregnancy are done mainly for the purpose of detecting progression of tricuspid insufficiency. The examiner should also assess the quality of blood flow into the venous system (hepatic veins, ductus venosus, and inferior vena cava). The development of NIHF implies a considerably worse prognosis, with intrauterine fetal death occurring in more than 50% of cases (10).

Pulmonary Stenosis

Definition. Pulmonary stenosis refers to a narrowing of the right ventricular outflow tract in the area of the pulmonary valve. The stenosis is classified by its location as follows:

- Valvular (isolated)
- Subvalvular (infundibular and subinfundibular)
- Supravalvular

This section deals mainly with isolated valvular pulmonary stenosis.

Incidence. Pulmonary stenosis is the second most common heart defect after VSD, occurring in 9% of all live births with a congenital heart defect.

Associated Anomalies and Chromosomal abnormalities

Extracardiac anomalies. These are somewhat rare, occurring in just 12% of cases (20). As part of a genetic syndrome, pulmonary stenosis is a common feature of Noonan syndrome. It is rarely associated with chromosomal abnormalities, although invasive testing is recommended.

Intracardiac anomalies. Pulmonary stenosis is frequently isolated, but it also occurs as an associated cardiac anomaly as in ASD II or anomalous pulmonary venous return. It is also commonly found as part of a complex cardiac anomaly, especially in association with VSD and conotruncal anomalies (e.g., tetralogy of Fallot, DORV, transposition of the great arteries).

Ultrasound Diagnosis

B-mode image. Isolated pulmonary stenosis is rarely diagnosed prenatally with B-mode ultrasound and is difficult to detect. For this reason, pulmonary stenosis is a rare finding in prenatal examinations (6). The four-chamber view can detect only pronounced cases in which the right ventricle is already hypokinetic or third-trimester cases in which right ventricular hypertrophy or tricuspid insufficiency has caused visible dilatation of the right atrium. Proximal dilatation of the pulmonary trunk and a rigid, dome-like opening movement of the pulmonary valve can be important suggestive signs. At screening, however, pulmonary stenosis is usually detected only by the routine use of color Doppler, which can demonstrate the turbulence associated with the stenosis.

Color and spectral Doppler. Color Doppler can demonstrate tricuspid insufficiency in the four-chamber view, but usually this is seen most clearly during the third trimester. In some cases the insufficiency may be so pronounced that the resulting dilatation of the right atrium prompts immediate referral for a fetal echocardiographic examination.

Pulmonary stenosis is then diagnosed by detecting turbulent antegrade flow at the poststenotic level, evidenced by a typical mosaic pattern over the pulmonary valve (Fig. 25.**12**). Spectral Doppler (CW Doppler) can record peak flow velocities in excess of 2 m/s (Fig. 25.**13**).

Differential diagnosis. Isolated forms are not difficult to diagnose with the aid of color Doppler. In our experience, pulmonary stenosis can be difficult to distinguish from pulmonary atresia in cases with severe tricuspid insufficiency and cardiac dilatation (10, 28).

Intrauterine course and prognosis. Pulmonary stenosis is a valvular-obstruction type of heart defect that can develop in utero. Even if the heart appears normal during the second trimester, pulmonary stenosis may be present by the end of the pregnancy. Once pulmonary stenosis has developed, the fetal condition may deteriorate. Sharland et al. (28) investigated the natural history of severe tricuspid insufficiency and cardiomegaly in fetuses. They noted several cases in which pulmonary stenosis in the second trimester had progressed to pulmonary atresia by the end of gestation.

Surveillance. The surveillance of fetuses with pulmonary stenosis includes monitoring the pressure gradient of the stenotic valve along with the detection and possible documentation of increasing tricuspid insufficiency. The examiner should also check for retrograde flow in the systemic veins. When we see a deterioration of these findings, we induce labor no later than 36 weeks' gestation and perform a balloon valvuloplasty on the infant. If the right ventricle appears to be functioning normally, it is safe to take an expectant approach. The prognosis of isolated pulmonary stenosis is very good.

Hypoplastic Left Heart Syndrome (HLHS)

Definition. This is a group of heart defects in which the left ventricle may be nonvisualized or extremely hypoplastic as a result of aortic atresia and mitral valve atresia, dysplasia, or stenosis (Fig. 25.**14**).

Incidence. HLHS is present in 4% of all live-born infants with a congenital heart defect.

Associated anomalies and chromosomal abnormalities. Associated extracardiac anomalies are usually absent. Approximately 10% of fetuses with HLHS have an associated chromosomal abnormality, usually in the form of trisomy 13, trisomy 18, or Turner syndrome.

Ultrasound Diagnosis

B-mode image. HLHS is detectable by B-mode screening. In severe forms, the four-chamber view is already abnormal during the second trimester. The lumen of the left ventricle may be extremely small or nonvisualized (Fig. 25.**16**). The aorta is often extremely hypoplastic, and its origin and course are often difficult to define in the five-chamber view (Fig. 25.**15**). There is compensatory dilatation of the right ventricle and pulmonary trunk.

Color and spectral Doppler. Absent or greatly reduced diastolic filling of the left ventricle is quickly evident in the color flow image (Fig. 25.**17**). The pattern of unilateral perfusion through the right ventricular inflow tract is highly characteristic. Due to the increased perfusion of the right ventricle, a small amount of regurgitation may occur through the tricuspid valve. Another feature of HLHS is retrograde perfusion of the brachiocephalic arteries and coronary arteries through the pulmonary trunk and ductus arteriosus via the aortic isthmus. Color Doppler can demonstrate this retrograde flow in the aortic arch and ascending aorta, directed toward the aortic valve (Fig. 25.**18**).

Differential diagnosis. Differentiation is required from other forms of left ventricular obstruction. If the left ventricle shows good contractility, coarctation of the aorta should not be mistaken for HLHS, as it has a much more favorable prognosis.

Intrauterine course and prognosis. In recent theories on the pathogenesis of heart defects, several anomalies such as aortic stenosis, HLHS, and coarctation of the aorta are placed in the category of heart defects "with impaired intracardiac blood flow." This means that the cardiac defect does not already exist in the embryo in its definitive form, such as an AV canal with a septal defect. Instead, the impairment of intracardiac blood flow leads to decreased perfusion of the left ventricular inflow and outflow tracts, especially in the area of the foramen ovale. In other words, the intrauterine circulatory system, with its natural protective mechanisms, witnesses the increasing "evolution" of this type of obstruction as term approaches. Allan et al. (2) described one fetus in which the left ventricle was still well developed at 20 weeks' gestation, but scans at term revealed a severe form of HLHS. Many other authors have published similar observations. As a result, some cases of HLHS are not detected during the second trimester because the screening four-chamber view still appears normal at this stage of gestation.

Aortic Stenosis

Definition. In aortic stenosis, the narrowing may affect the aortic valve itself (valvular form, approximately 80%) or it may be located below the valve (approximately 15%) or above it (approximately 5%). Two types of aortic stenosis should be distinguished because of their different prognoses:

- "Simple" aortic stenosis
- "Critical" aortic stenosis

The latter is a severe form that causes severe prenatal changes in the wall of the left ventricle, described pathologically as endocardial fibroelastosis (Fig. 25.**19**).

Incidence. Aortic stenosis occurs in 3% of live births with a congenital heart defect.

Associated anomalies and chromosomal abnormalities. Associated extracardiac anomalies are somewhat rare in aortic stenosis. A critical type of stenosis can lead to intrauterine heart failure, and therefore this lesion should be considered when NIHF is present. A chromosome analysis should be performed.

Ultrasound Diagnosis

B-mode image. Mild forms of ***"simple" aortic stenosis*** are very difficult to diagnose prenatally. Left ventricular hypertrophy or dilatation does not develop until the third trimester, if at all. The attentive examiner may be able to recognize a mild form by the restricted opening movements of the valve (dome-like bulge) and by poststenotic dilatation of the ascending aorta. The mild forms are easier to detect when color Doppler is used.

With a ***"critical" aortic stenosis,*** the B-mode four-chamber view often shows a dilated left ventricle with a densely echogenic wall due to (incipient) endocardial fibroelastosis (Fig. 25.**19**). Besides ventricular dilatation and rounding of the cardiac apex, hypokinesia of the ventricle is a typical finding. The aortic root appears normal or narrowed in the five-chamber view and often shows poststenotic dilatation.

Color and spectral Doppler. "Simple" aortic stenosis can be detected with color Doppler. Turbulent, antegrade blood flow with a mosaic pattern is clearly apparent in the five-chamber view (Fig. 25.**20**). Doppler spectral measurement of peak flow velocities (using pulsed-wave or continuous-wave Doppler) shows values higher than 2 m/s (Fig. 25.**21**).

With a ***"critical" aortic stenosis,*** turbulent antegrade flow can be detected over the aortic valve. The turbulence may be less pronounced if severe endocardial fibroelastosis is present. With the increased pressure in the left ventricle, it is common to detect mitral insufficiency in systole, possibly with a left-to-right shunt through the foramen ovale. Retrograde perfusion of the aortic arch is observed in severe cases.

Differential diagnosis. The differential diagnosis of a dilated left ventricle should include dilatative cardiomyopathy, which is distinguished by the fact that it involves all the cardiac chambers. Also, a small aortic valve, with or without associated turbulence, may result from a left ventricular obstruction with involvement of the aortic arch. Aortic stenosis may be associated with hypoplasia of the aortic arch, especially when there is a coexisting VSD (Table 25.**10**).

Intrauterine course and prognosis. In an interesting retrospective analysis, Sharland et al. (29) studied the data from 30 fetuses with a critical aortic stenosis and left ventricular dysfunction. One of their most important observations was that the aortic valve in five cases was definitely open (and stenotic) prenatally but was found to be atretic several weeks later at autopsy. The authors also described five cases with an initially dilated left ventricle that subsequently developed into a hypoplastic left heart syndrome.

Intrauterine development. The authors underscore this observation, which supports the intrauterine development of valvular obstructions. Thus a critical stenosis or hypoplastic left heart may be associated with a normal-appearing four-chamber view at 18 weeks, causing it to be missed at screening. Moreover, a reliable prognosis cannot be offered when left ventricular dysfunction is detected, because the subsequent intrauterine course cannot be predicted.

Serial scans. For this reason, serial examinations should be conducted when this defect is present so that the subsequent development of endocardial fibroelastosis or NIHF can be recognized.

Aortic Arch Anomalies

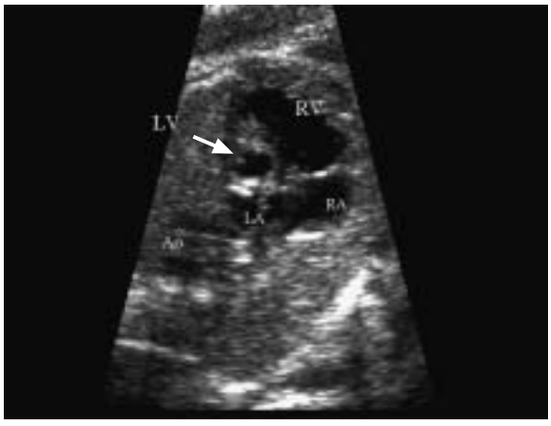
Definition. Aortic arch anomalies basically consist of the following malformations:

- Interruption of the aortic arch
- Tubular hypoplasia of the aortic arch
- Tubular coarctation of the aorta
- "Simple" coarctation of the aorta (Fig. 25.**22**) involving the segment opposite the opening of the ductus arteriosus into the descending aorta ("juxtaductal" form) (13)

Incidence. Coarctation of the aorta occurs in approximately 5% of all live births with congenital heart disease, interruption of the aortic arch in 0.7%.

Associated Anomalies and Chromosomal Abnormalities

Intracardiac anomalies. These mainly include ventricular septal defect, AV canal, double-outlet right ventricle, and a dysplastic aortic valve. It is also very likely that these anomalies have an important pathogenetic role: By equalizing the pressure between the left and right sides of the fetal circulation, these defects give rise to a "chronic" underperfusion of the aortic isthmus, inhibiting its development. This is supported by the fact that defects with greater aortic perfusion, such as tetralogy of Fallot (TOF) and truncus arteriosus communis (TAC), are almost never associated with coarctation of the aorta.



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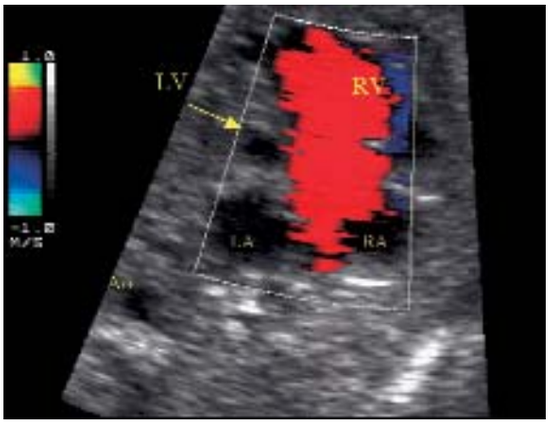

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Fig. 25.**16** Hypoplastic left heart syndrome, 28 weeks. Apical four-chamber B-mode image shows a hypoplastic left ventricle (arrow). Hypokinesia of the left ventricle is evident in the real-time image.

Fig. 25.**17** Color Doppler confirms the finding in Fig. 25.**16** by showing unidirectional perfusion through the right ventricular inflow tract.

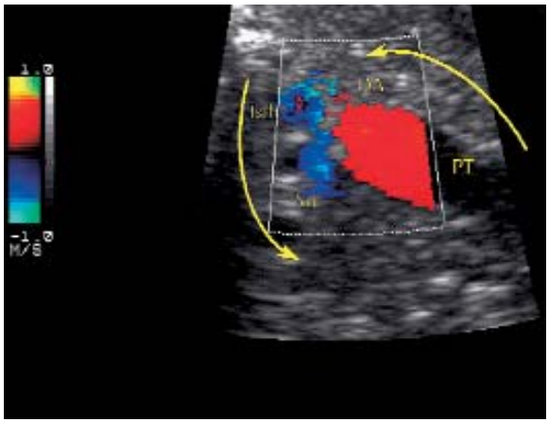

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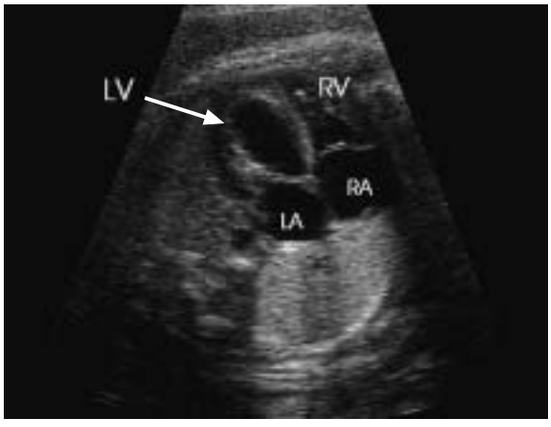
Fig. 25.**18** Color Doppler view of the great vessels in HLHS. Often the aortic arch cannot be seen in the B-mode image, but color Doppler clearly demonstrates retrograde flow through the isthmic portion of the aorta toward the ascending aorta.



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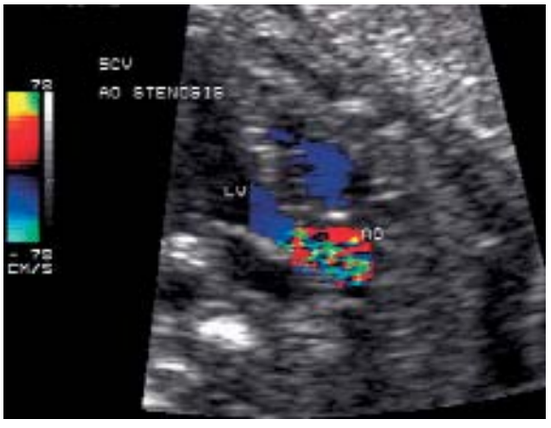

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Aortic stenosis

Fig. 25.**19** Endocardial fibroelastosis in the apical four-chamber view, 31 weeks. The left ventricle (LV) is dilated, its wall is densely echogenic ("porcelain-like"), and its contractility is extremely diminished. Critical aortic stenosis is present.

Fig. 25.**20** Valvular aortic stenosis, 26 weeks. Color Doppler in the apical five-chamber view shows typical turbulence (mosaic pattern) over the aortic valve.

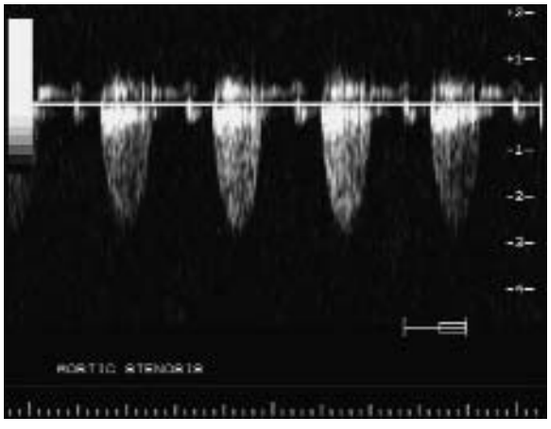

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Fig. 25.**21** Valvular aortic stenosis in CW Doppler, 26 weeks. Continuous-wave Doppler is used to prevent aliasing at the high flow velocities. Vmax is approximately 280 cm/s.

Extracardiac anomalies. Coarctation of the aorta is accompanied by extracardiac anomalies in 26% of cases and by interruption of the aortic arch in 50% of cases. The rate is much higher in prenatal studies, due largely to the fact that most cases are detected based on the presence of extracardiac anomalies. Typical anomalies include those whose embryonic development coincides with the timing and location of aortic arch development, such as upper gastrointestinal tract anomalies (esophageal atresia, diaphragmatic defect).

With an interruption of the aortic arch, the group of velocardiac anomalies should be considered (DiGeorge syndrome, Sphrintzen syndrome, etc.), and chromosome analysis should include a specific search for a deletion on chromosome 22 (CATCH 22: ***c***ardiac defects, ***a***bnormal facies, ***t***hymic hypoplasia, ***c***left palate, ***h***ypocalcemia) using the fluorescence in-situ hybridization (FISH) technique.

Ultrasound Diagnosis

B-mode image. A simple coarctation of the aorta is very difficult to diagnose prenatally (1, 13). Other aortic arch anomalies such as tubular hypoplasia, aortic arch hypoplasia, and interruption of the aortic arch can be detected prenatally, but many of these cases are still difficult to diagnose (25). Visualization of the aortic arch in longitudinal section is of minor importance in prenatal diagnosis. Primary attention should be given to disproportion between the left and right ventricles and between the aortic arch and pulmonary trunk (Fig. 25.**24**) (1, 25). The "small" left ventricle shows normal contractility in these cases — an important sign in the prenatal differentiation of left ventricular hypoplasia (Fig. 25.**23**, Table 25.**10**). Even in a healthy fetus, however, scanning in the third trimester will show a discrepancy between the left and right ventricles, making it more difficult to distinguish between normal and abnormal.

Color and spectral Doppler. Spectral and color Doppler have contributed relatively little to the prenatal diagnosis of coarctation of the aorta. Although the lesion is a "stenosis," turbulence is not observed in the area of the coarctation. Allan et al. (1) found that fetuses with coarctation of the aorta had a low flow volume across the aortic valve and twice as much flow through the tricuspid valve as through the mitral valve. In cases with pronounced findings, such as a coexisting VSD or aortic stenosis, color Doppler may demonstrate retrograde perfusion in the aortic isthmus.

Differential diagnosis. Although several ultrasound signs have been described for coarctation of the aorta, all authors note that the signs are unreliable and stress the possibility of false-positive and false-negative findings (25). The differential diagnosis should include a normal heart, therefore. In some cases even an experienced examiner cannot diagnose the lesion with confidence. HLHS should also be considered when a small left ventricle is found, but that condition is distinguished by a hypoplastic ventricle and a nonpatent aortic valve (Table 25.**10**).

Intrauterine course and prognosis. The main purpose of serial scans is to observe the development of the aortic arch from the aortic valve to the termination of the ductus arteriosus. In cases that are detected early, the discrepancy between the right and left ventricles (RV/LV) and between the pulmonary trunk and ascending aorta (25) (see curves in Chapter 12) during the course of the pregnancy can serve as important parameters in evaluating progression.

Atrial Septal Defect (ASD)

Definition. A defect in the atrial septum is seldom mentioned in prenatal studies, because it can rarely be diagnosed antenatally. Four types of defect are distinguished:

- A sinus venosus defect
- An ostium secundum defect (ASD II)
- A septum primum defect
- A common atrium

Incidence. ASD II occurs as an isolated anomaly in approximately 7–8% of all live births with a congenital heart defect.

Associated anomalies and chromosomal abnormalities. ASD II does occur in isolation but is more often part of a complex cardiac anomaly (TGA, PS, Fallot, TAPVD, PLSVC, etc.). It is also found in association with extracardiac anomalies (right and left isomerism, Holt–Oram syndrome) and chromosomal abnormalities.

Ultrasound Diagnosis

B-mode image. An atrial septal defect is very difficult to diagnose prenatally. ASD I (Fig. 25.**25**) and a common atrium can be diagnosed by an experienced examiner, however, whereas a sinus venosus defect and ASD II usually go undetected.

Color Doppler. Color Doppler is less important than B-mode in evaluating these defects. But if a large ASD II is suspected, it can be confirmed with color Doppler, which demonstrates a left-to-right shunt in addition to the physiologic right-to-left shunt. With a septum primum defect, the examiner can use color flow to confirm his suspicion. Color Doppler will show any communication that exists between the right atrium and left ventricle or between the left atrium and right ventricle.

Differential diagnosis. Differential diagnosis rarely presents a problem with these defects. In fetuses who have a persistent left superior vena cava (PLSVC), that vessel usually opens into a dilated coronary sulcus. When viewed in a plane slightly inferior to the four-chamber view, the site where the vena cava enters the coronary sulcus may be mistaken for an ASD. The septum primum and secundum can be visualized, however, in a plane slightly superior to the four-chamber view.

Intrauterine course and prognosis. ASD is considered to have a very good prognosis when it is not associated with other cardiac or extracardiac anomalies. When present, these anomalies usually take precedence over septal defects. Invasive testing is strongly indicated in cases with ASD I and II to exclude a chromosomal abnormality.

Ventricular Septal Defect (VSD)

Definition. Two types are distinguished by their location:

- Defect in the membranous part of the interventricular septum (80% of VSDs)
- Defect in the muscular part of the septum (20%)

Incidence. VSD is the most common heart defect, occurring in 30% of live births with a congenital heart defect.

Associated Anomalies and Chromosomal Abnormalities

Complex defects. VSD often occurs in isolation but may also be part of numerous complex cardiac defects that involve the ventricles and great vessels (Table 25.**13**), including tricuspid atresia, mitral atresia, pulmonary atresia, tetralogy of Fallot, DORV, TAC, TGA, tubular hypoplasia

of the aortic arch, and interruption of the aortic arch. Thus whenever a VSD is detected prenatally, the patient should be referred for a detailed fetal cardiac scan that includes a precise evaluation of the great vessels.

Extracardiac anomalies. VSD also occurs in association with a number of extracardiac anomalies and in the setting of syndromes. An isolated VSD detected prenatally may be a sign of a chromosomal abnormality such as trisomy 21, 18, or 13 (4). The likelihood of aneuploidy increases significantly when extracardiac anomalies or abnormalities are present.

Ultrasound Diagnosis

B-mode image. Because VSDs vary in size, their accessibility to prenatal diagnosis also varies. They are most reliably detected by scanning from different directions in multiple contiguous planes. Even with optimum examination conditions, however, a VSD cannot be excluded with complete confidence. Whereas larger VSDs can be recognized in the B-mode image as early as 13 weeks' gestation, small muscular defects may be missed and may not be detected until the third trimester, aided if necessary by color Doppler imaging (Fig. 25.**26**).

But most defects are located in the membranous, subaortic portion of the interventricular septum and are best visualized in the five-chamber view (Fig. 25.**27**). So even if the four-chamber view appears normal, a large membranous VSD may still be present.

Color and spectral Doppler. Large VSDs (> 5–6 mm) can quickly be detected in the B-mode image. Color Doppler is mainly of value in the detection or confirmation of small VSDs (< 2 mm) (Fig. 25.**28**). Although VSDs are easier to detect in lateral views, is not uncommon for the shunt flow across small defects to produce high flow velocities and turbulence that can also be seen in an apical view (i.e., at a less favorable angle) (Fig. 25.**26**). While postnatal scans indicate a unidirectional left-to-right shunt that follows the pressure gradient, prenatal scans of an isolated defect show a bidirectional shunt (Fig. 25.**26**). This shunt is directed from right to left in systole and early diastole and is reversed thereafter. But in fetuses with a complex cardiac anomaly causing obstruction of the inflow or outflow tract, a predominantly unidirectional shunt is found. A left-to-right shunt is seen with obstruction of the left ventricular outflow tract, tricuspid atresia, and DORV. A right-to-left shunt is seen with mitral atresia, pulmonary atresia, and pulmonary stenosis.

With a membranous VSD, color Doppler can also demonstrate the shunt flow across the septal defect. This is best accomplished in the five-chamber or short-axis view.

Power Doppler imaging. Our own recent studies suggest that power Doppler imaging may one day be useful in the detection of small muscular VSDs. The problem of optimum equipment settings remains to be solved.

Differential diagnosis. A VSD as small as 2 mm in diameter can be detected with B-mode ultrasound using high-resolution equipment.

Dropout effects. Dropout effects in an apical cardiac scan can mimic a VSD. Typically this occurs up to 20 weeks' gestation or when insonation conditions are poor. The examiner can confirm or refute his presumptive diagnosis by obtaining a lateral view in which the sound waves are directed perpendicular to the septum. The inlet and trabecular portions of the septum can be evaluated in the four-chamber view. The potential for false-positive findings was noted above.

AV canal. Differentiation is mainly required from AV canal, which should be considered whenever a VSD is found.

Table 25.**13** Cardiac anomalies that may be associated with a ventricular septal defect

- Tricuspid atresia
- Mitral atresia
- Pulmonary atresia
- Tetralogy of Fallot
- DORV
- TAC
- TGA
- Tubular hypoplasia of the aortic arch
- Interruption of the aortic arch

Incomplete diagnosis. The main problem in the prenatal diagnosis of VSD is making an incomplete diagnosis that misses associated cardiac anomalies (e.g., involving the great vessels). Tubular hypoplasia or interruption of the aortic arch is often associated with a VSD and can be detected only by specific evaluation of the aortic arch (see above). Another problem is the difficulty of detecting and describing malpositions of the great vessels (ventriculoarterial discordance).

Intrauterine course and prognosis. Small VSDs may close spontaneously in prenatal or postnatal life and usually have a good prognosis when they are not associated with other cardiac or extracardiac anomalies. Larger VSDs can be occluded with a "shield" in an interventional procedure or operatively repaired. Surgery should be done promptly, before the pulmonary vessels have been damaged by the postnatal left-to-right shunt.

Atrioventricular Septal Defect (AVSD, AV Canal)

Definition. These defects involve a combination of atrial and ventricular septal defects. They are divided into two forms:
- Incomplete AV septal defect (ASD I)
- Complete AV septal defect (CAVSD, AV canal)

Incidence. An AV canal occurs in 7.4% of all live births with a congenital heart defect.

Associated Anomalies and Chromosomal Abnormalities

Extracardiac anomalies. An AV canal is usually associated with extracardiac anomalies, which should always be excluded when this defect is found. Most are chromosomal abnormalities such as Down syndrome, which occurs in at least 50% of all cases (4). Also, an AV canal is often found in association with an abnormal cardiac position such as left- or right-sided isomerism. These forms, however, are very rarely associated with Down syndrome or other chromosomal abnormalities.

Intracardiac anomalies. These may occur in any cardiac structures. At the atrial level, the septum secundum may be affected in addition to the septum primum, and a common atrium may be present in extreme cases. At the ventricular level, hypoplasia of the left ventricle is sometimes found (this form, too, is rarely associated with Down syndrome). The following anomalies may involve the great vessels: tetralogy of Fallot, DORV, pulmonary atresia or stenosis, TGA, and TAC or coarctation of the aorta, especially in cases with isomerism. The AV canal may be combined with cardiac arrhythmias (especially AV block) due to possible anatomic impairment of the impulse conduction system (23).

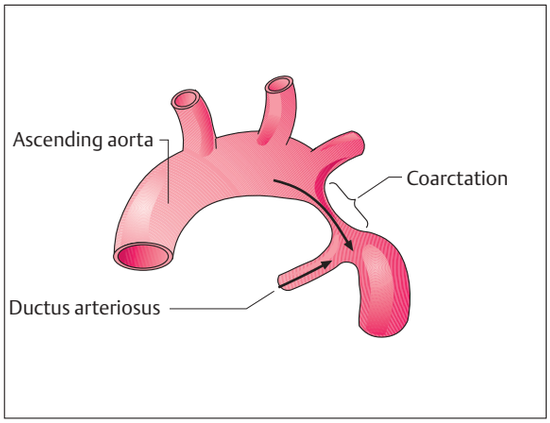
Ultrasound Diagnosis

B-mode image. ASD I is considerably more difficult to diagnose than a complete AV canal. It should be considered whenever a defect is noted

Aortic arch anomalies

Fig. 25.**22** Coarctation of the aorta.

Fig. 25.**23** Coarctation of the aorta in the four-chamber view, 21 weeks. The scan shows a small left ventricle with normal contractility. This is an important suggestive sign of coarctation.



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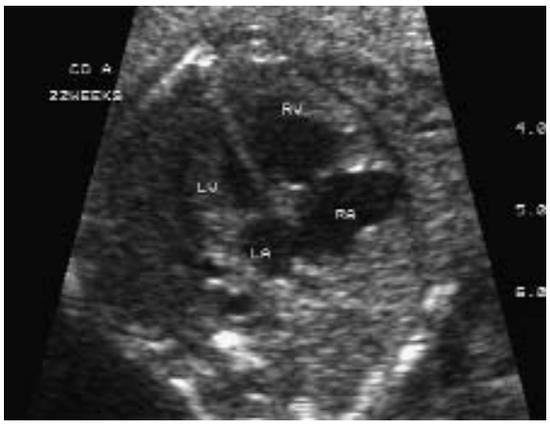

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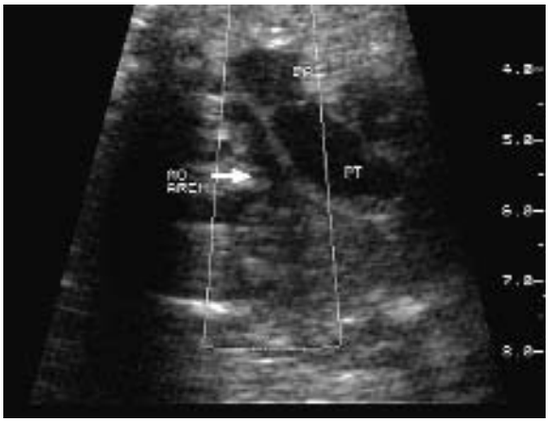
Fig. 25.**24** Tubular hypoplasia of the aortic arch (plane 5). Besides the normally developed pulmonary trunk (PT) and ductus arteriosus (DA), the scan gives a tangential view of the hypoplastic aortic arch.



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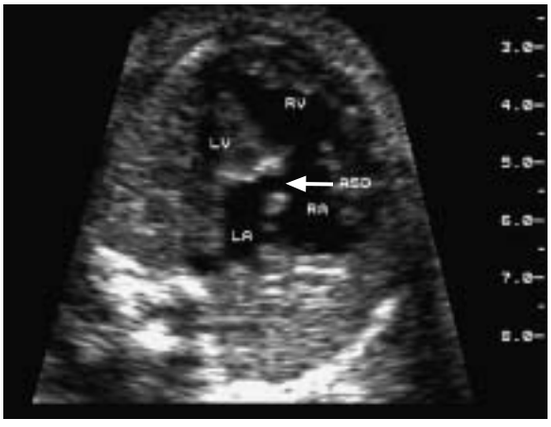
Septal defects

Fig. 25.**25** Atrial septal defect (arrow) in the septum primum area of a fetus with mitral valve atresia and a hypoplastic left ventricle, 33 weeks.

Fig. 25.**26** Ventricular septal defect (VSD), 33 weeks. Color Doppler reveals a bidirectional shunt in the central, muscular part of the interventricular septum. The VSD was not visible in the B-mode image and could be diagnosed only by visualizing the shunt with color Doppler.



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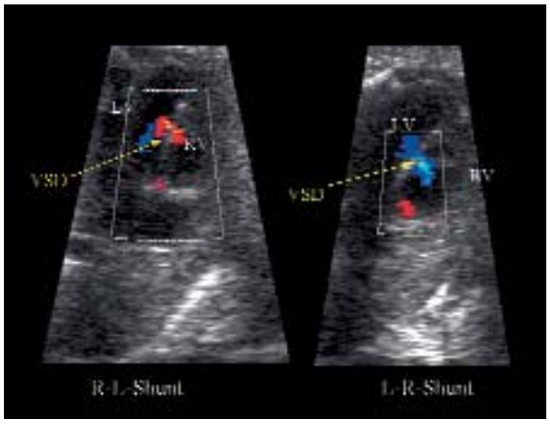

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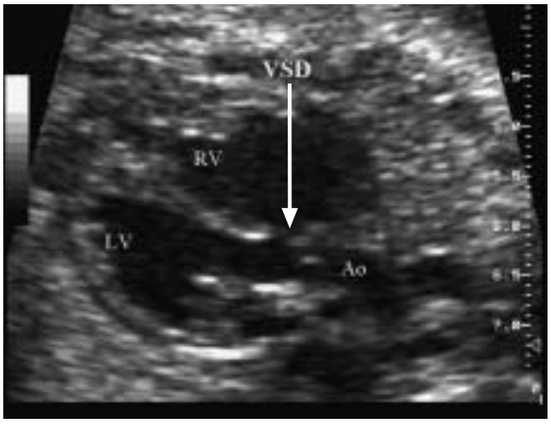
Fig. 25.**27** Small, membranous VSD in a lateral five-chamber view, 28 weeks. Often these VSDs are clearly defined only at the subaortic level. The aorta appears in continuity with the interventricular septum and is not "overriding" (compare with Fig. 25.**33**).

Fig. 25.**28** Color Doppler view of the VSD in Fig. 25.**27**. The right-to-left shunt confirms the finding.



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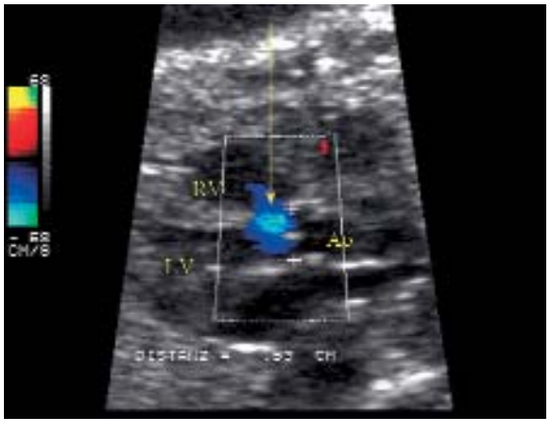

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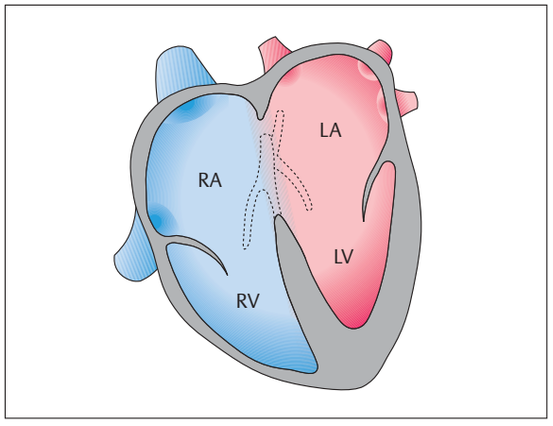

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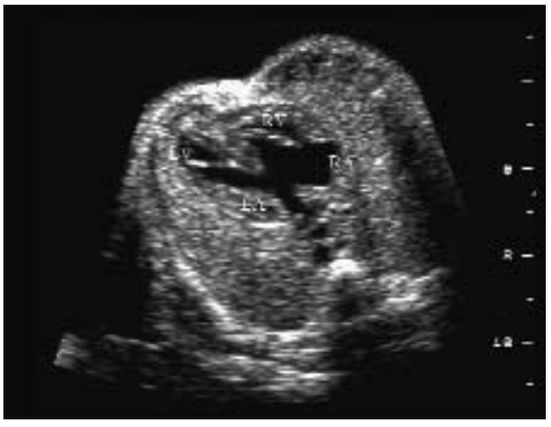

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Fig. 25.**29** Diagram of a complete atrioventricular septal defect ("AV canal"). The dotted outlines indicate the missing structures (modified from [31]).

Fig. 25.**30** Complete AV canal, 31 weeks. The complete absence of the endocardial cushion is evident in the four-chamber view. A combined ventricular and atrial septal defect with only two AV valve leaflets are characteristic. In more than 50% of cases, an AV canal is associated with Down syndrome (as was the case with this fetus).

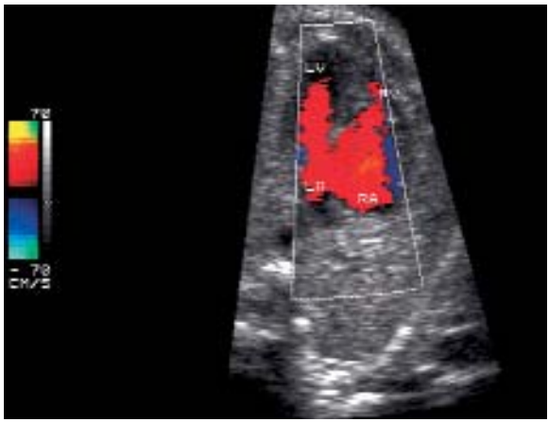

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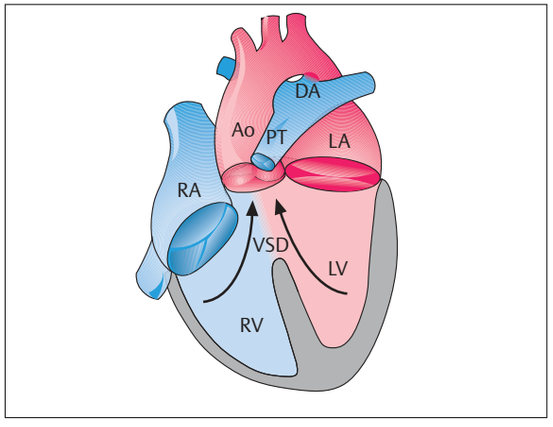
Fig. 25.**31** Complete AV canal at 33 weeks, with mixing of blood from both inflow tracts via the atrial and ventricular septal defects during diastole. Note the typical "H" configuration.



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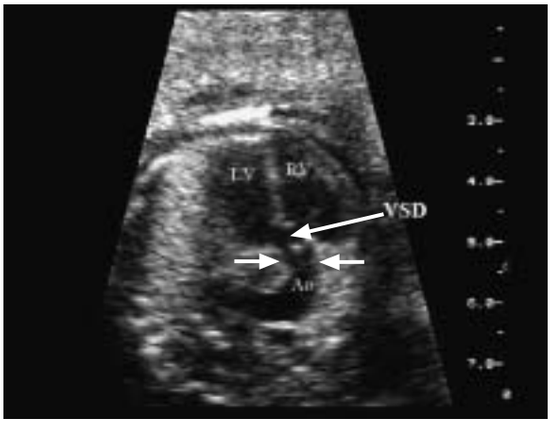

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Tetralogy of Fallot

Fig. 25.**32** The tetralogy of Fallot is characterized by four abnormalities: ventricular septal defect (VSD), overriding aorta, pulmonary stenosis, and right ventricular hypertrophy. Only the first two of these signs can be detected prenatally (modified from [31]).

Fig. 25.**33** Tetralogy of Fallot, 31 weeks. The dilated, overriding aorta (short arrows) is visible above the ventricular septal defect (long arrow) in the apical five-chamber view. Right ventricular enlargement can rarely be detected prenatally.

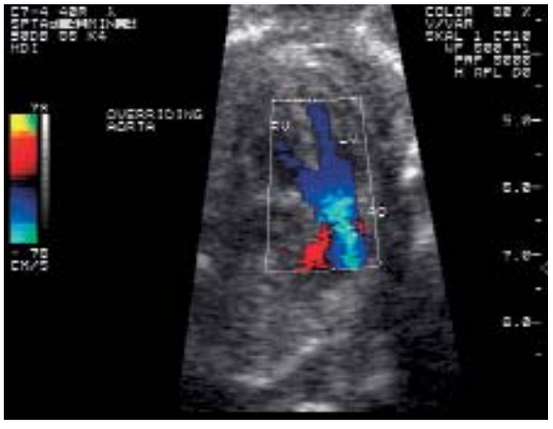

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Fig. 25.**34** Tetralogy of Fallot, apical five-chamber view, 31 weeks. During systole, blood flows from the left and right ventricles across the VSD and then through the aortic valve into the ascending aorta. Note the typical "Y" pattern in the color Doppler image.

in the portion of the atrial septum near the AV valves (septum primum) in the four-chamber view (Fig. 25.**25**).

A large ***complete AV canal*** is most conspicuous in the four-chamber view during diastole when the valve is open. The central portion of the heart appears "punched out" (Fig. 25.**29**). During systole, the atrial and ventricular septal defects can be seen above and below the closed AV valves (Figs. 25.**30**, 25.**44**). An AV canal can be diagnosed as early as the late first trimester, as it is already fully developed in the embryo. Color Doppler is a tremendous aid to prenatal diagnosis.

Since an AV canal may also occur in ***isomerism,*** the detection of the defect warrants a segmental analysis of the upper abdomen (Figs. 25.**43**, 25.**44**), especially when there is a coexisting heart block.

Color Doppler. Color Doppler in the four-chamber view shows a lack of separation between the right and left ventricular inflow tracts in diastole, producing a typical "H" configuration (Fig. 25.**31**). With color flow, blood can be seen mixing in the area of the septum primum defect, the dysplastic AV valves, and the ventricular septal defect. Also, incompetence of the dysplastic AV valve is often evident during systole, and color flow is needed to evaluate the degree of the valvular insufficiency. It may be severe enough to produce fetal heart failure with ascites.

Differential diagnosis. Questions of differential diagnosis mainly arise in distinguishing between a complete and incomplete AV canal. Differentiation is also required from a simple VSD. A hypoplastic left heart or single ventricle may sometimes be confused with an AV canal, particularly due to the moderator band in the right ventricle.

When color Doppler is used, increasing the color gain scale can simulate the atrioventricular mixing of blood (false-positive finding). This can be clarified by scrutinizing the B-mode image and by adding a lateral view of the heart.

Intrauterine course and prognosis. NIHF may develop as a result of valvular insufficiency. Cardiac biometry, valvular insufficiency, and Doppler ultrasound findings in the venous vessels should be evaluated on serial scans. The prognosis of AV canal depends critically on associated extracardiac anomalies.

Tetralogy of Fallot

Definition. Tetralogy of Fallot (TOF, Fig. 25.**32**) is defined by the presence of four abnormalities:

- A large ventricular septal defect (VSD)
- An overriding aorta ("dextroposition" of the aorta)
- Infundibular pulmonary stenosis
- Right ventricular hypertrophy (a secondary condition)

Incidence. TOF occurs in approximately 6–7% of all live births with congenital heart disease.

Associated Anomalies and Chromosomal Abnormalities

Extracardiac anomalies. TOF, as a conotruncal anomaly, has a relatively high association with extracardiac anomalies (approximately 30–50% of cases) (5). Chromosomal abnormalities are found in 10–25% of cases (4). Associated gastrointestinal anomalies are particularly common. Cleft anomalies and associations with syndromes (e.g., VACTERL association) are also common.

Intracardiac anomalies. Associations with intracardiac anomalies often alter the classification of the disorder. For example, if an associated AV canal is present, the anomaly is classified as an atrioventricular septal defect. Another anomaly that has an extremely rare association with TOF is the absence of the pulmonary valve (absent pulmonary valve syndrome), characterized by massive dilatation and insufficiency of the pulmonary trunk. Agenesis of the ductus arteriosus is usually present and contributes to the pathogenesis of the condition.

Ultrasound Diagnosis

B-mode image. Only two of the four abnormalities that characterize TOF—the VSD and overriding aorta—can definitely be detected in the fetus. Pulmonary stenosis usually results from underperfusion of the valve and "develops" during intrauterine and postnatal life. Right ventricular hypertrophy develops as a secondary response to the increased workload on the right ventricle. Generally hypertrophy is diagnosed postnatally, but a few cases are detected in late pregnancy.

The VSD is sometimes detectable in the four-chamber view and is always detectable in the five-chamber view, preferably using a lateral scan direction (see above). A presumptive diagnosis of TOF can be made in the five-chamber view by demonstrating the ***overriding aorta*** (Fig. 25.**33**) above the VSD. The aorta typically shows marked dilatation, which can be confirmed by biometry (16). The diagnosis is completed by evaluating the ***pulmonary trunk,*** which typically shows a smaller caliber than the aorta. An overriding aorta raises several diagnostic possibilities (Table 25.**11**), the most common being the tetralogy of Fallot.

Color and spectral Doppler. Color Doppler is of key importance in the diagnosis and differential diagnosis of TOF. The VSD is clearly visualized with color Doppler, and the typical overriding aorta is displayed in the five-chamber view. Since the ascending aorta receives simultaneous flow from both ventricles, a characteristic "Y" configuration is seen in the apical five-chamber view (Fig. 25.**34**). In the next plane, the perfusion of the pulmonary trunk is evaluated as an aid to differential diagnosis. Pulmonary atresia with VSD or truncus arteriosus can be recognized in this view. Differentiation from a double-outlet right ventricle is still difficult in many cases, even when color Doppler is used.

Differential diagnosis. The five-chamber view is first used to distinguish a simple VSD from an overriding aorta or a double-outlet right ventricle, where the aorta emerges mainly from the right ventricle. When an overriding aorta is found, it can sometimes be difficult to differentiate among the various forms (Table 25.**11**). B-mode biometry and Doppler evaluation of the pulmonary trunk are necessary in order to distinguish a VSD in the setting of TOF from pulmonary atresia with VSD, truncus arteriosus, and absent pulmonary valve syndrome.

Intrauterine course and prognosis. When a tetralogy of Fallot is diagnosed, the intrauterine follow-up focuses on the development of the pulmonary trunk, which will dictate the strategy for neonatal care. Heart failure with fetal hydrops is unlikely to develop in the setting of TOF, but it is possible, especially if the pulmonary valve is absent. Allan and Sharland (5) analyzed the prognoses of 23 fetuses with TOF and found a mortality rate of 75% in the 16 pregnancies that were continued. Thus, on detecting a heart defect with an otherwise "good" prognosis, the examiner should first exclude extracardiac anomalies, especially chromosomal defects.

Double-Outlet Right Ventricle (DORV)

Definition. In this anomaly the aorta and pulmonary trunk both arise from the right ventricle (Fig. 25.**35**). Usually these trunks are parallel to each other, forming an L or D type of malposition. The morphologic forms of DORV are correspondingly diverse.

Incidence. This anomaly occurs in 2% of live births with a congenital heart defect.

Associated Anomalies and Chromosomal abnormalities

Intracardiac anomalies. DORV is often associated with anomalies at the AV level such as AV canal or mitral atresia. Possible anomalies of the great vessels include coarctation of the aorta and pulmonary stenosis or atresia. The VSD in DORV may be very large, creating the appearance of a single ventricle.

Extracardiac anomalies. Associated extracardiac anomalies consist mainly of malrotation anomalies (polysplenia or asplenia syndrome); gastrointestinal tract anomalies such as esophageal atresia, diaphragmatic defect, and omphalocele; and facial malformations (DiGeorge syndrome, Charge syndrome, etc.). DORV is also found in fetuses with chromosomal abnormalities (e.g., trisomy 18) and in the fetuses of diabetic women (11, 19).

Ultrasound Diagnosis

B-mode image. Because of its diverse morphology, DORV does not have a "typical" ultrasound appearance. The four-chamber view may be abnormal in fetuses with a large VSD, a single ventricle, or coexisting mitral valve atresia (Fig. 25.**25**) (small left ventricle!). But a precise evaluation of the great vessels is necessary in order to make a presumptive diagnosis (Fig. 25.**36**). Often there is a conspicuous malposition of the great vessels with a discrepancy in the calibers of the aorta and pulmonary trunk. Occasionally, a tetralogy of Fallot is diagnosed in the initial examination and the diagnosis is revised later. Since DORV may occur in the setting of a heterotaxic syndrome (right or left isomerism), the segmental evaluation of cardiac anatomy is always advised.

Color and spectral Doppler. Usually there is a large VSD that can be visualized with color Doppler. With concomitant mitral atresia, the absence of flow between the left atrium and small left ventricle can be directly visualized, and the VSD displays a right-to-left shunt. Not infrequently, a relative tricuspid insufficiency is present due to the volume overload.

In many cases the origin of the two great vessels from the right ventricle is defined more easily and clearly with color Doppler (Fig. 25.**37**) than with B-mode ultrasound, supporting the presumptive diagnosis. Often, color Doppler can also more easily define the parallel course of the two great arteries in cases where a malposition is present. Especially when vascular anatomy is uncertain, color Doppler can help to differentiate the two vessels by defining the bifurcation of the two pulmonary arteries or the origin of the vascular trunks.

Differential diagnosis. Differential diagnosis can be quite difficult in fetuses with DORV, depending on the findings and the experience of the examiner. But a distinction should be made between "true" difficulties and "academic" problems. The true difficulties consist mainly of determining whether the great vessels are in an L or D relationship to each other and whether the hypoplastic vessel is the aorta or pulmonary trunk. The "academic" problems mainly involve questions of nomenclature and determining whether the anomaly is a tetralogy of Fallot, pulmonary atresia with a VSD, or a form of DORV. The small left ventricle can mimic HLHS, especially when mitral atresia is present. If there is suspicion of L-TGA or D-TGA with a VSD, it is important to exclude a DORV or DOLV.

Intrauterine course and prognosis. Intrauterine follow-up should focus on signs of AV valvular insufficiency so that heart failure can be detected without delay. Checking the hepatic veins for retrograde perfusion is particularly helpful in this respect. The association of this complex heart defect with other anomalies (including chromosomal abnormalities) helps explain the high intrauterine fetal death rate of 60% that we have documented in our own cases. If pulmonary stenosis or atresia is present, indomethacin should not be used during the pregnancy to inhibit labor.

Complete Transposition of the Great Arteries

Definition. In this anomaly (dextro-transposition of the great arteries, D-TGA), the aorta arises from the right ventricle and the pulmonary trunk from the left ventricle (ventriculoarterial discordance), with otherwise normal connections between the atria and ventricles (atrioventricular concordance) (Fig. 25.**41b**).

Incidence. D-TGA is a relatively frequent cardiac anomaly, occurring in approximately 5–7% of all live births with a congenital heart defect.

Associated anomalies and chromosomal abnormalities. Associated intracardiac anomalies are common. Pulmonary stenosis or a ventricular or atrial septal defect is present in 25% of cases.

Associated extracardiac anomalies are somewhat rare, occurring in less than 10% of cases. Trisomies and other chromosomal defects are very rare in D-TGA (4).

Ultrasound Diagnosis

B-mode image. D-TGA cannot be detected in the B-mode four-chamber view. Its detection requires a systematic evaluation of the origin and course of the two great vessels. The four-chamber view appears normal except in cases with a VSD. D-TGA may also be missed in the five-chamber view. The condition is diagnosed by attempting to define the vessel arising from the right ventricle, for that vessel (the aorta) does not cross the other vessel (pulmonary trunk) in the normal way but runs parallel and to the right of it (hence the "D" prefix). Defining the parallel course of both vessels in one plane, along with their valves, is characteristic of D-TGA (Fig. 25.**38**). Examiners who prefer the short-axis plane will find the aorta located anterior to the pulmonary trunk (Fig. 25.**40**) and will not see the typical "circle and sausage" sign.

Color and spectral Doppler. Color Doppler is mainly helpful in quickly defining the parallel course of both vessels (Fig. 25.**39**) and quickly distinguishing between the aorta and pulmonary trunk. Once the diagnosis has been established, color Doppler can help to exclude possible associated cardiac anomalies such as VSD and pulmonary stenosis.

Intrauterine course and prognosis. In most cases D-TGA has no clinical manifestations and first becomes symptomatic postnatally with the reversal of the circulation. In cases where pulmonary stenosis or a VSD is present, attention should be given to the prenatal course. It is also advisable to check for constriction of the foramen ovale during the final weeks of pregnancy, as this could necessitate an acute neonatal intervention (Rashkind balloon atrioseptostomy).

Corrected Transposition of the Great Arteries

Definition. In the "corrected" form of TGA (levo-transposition of the great arteries, L-TGA), the ventriculoarterial discordance is accompanied by atrioventricular discordance. The right atrium is connected to the morphologic left ventricle, which gives rise to the pulmonary trunk. The left atrium is connected to the morphologic right ventricle, which gives rise to the aorta (Fig. 25.**41c**). Although the vessels are anatomically transposed, there is no resulting circulatory impairment in this "corrected" form of the anomaly.

Incidence. L-TGA occurs in 1% of all live births with a congenital heart defect.

Associated anomalies and chromosomal abnormalities. This anomaly is often associated with a third-degree AV block (23). Also, an L malposition of the great vessels with ventriculoarterial discordance is not an uncommon finding in a heterotaxia syndrome or other complex cardiac anomalies (tricuspid atresia, double-outlet right ventricle, single ventricle, etc.). Extracardiac anomalies and chromosomal abnormalities are rare in "classic" L-TGA.

Ultrasound Diagnosis

B-mode image. Aside from cases associated with a third-degree AV block, an "isolated" L-TGA can be diagnosed only by a highly experienced examiner. Even in the four-chamber view, the experienced examiner can recognize that the morphologic left ventricle is on the right side while the right ventricle, with its moderator band and trabeculation, is on the left side. The origin of the great vessels appears suspicious at once, for when the transducer is tilted toward the five-chamber plane, the pulmonary trunk is seen emerging from the ventricle on the right side (the anatomic left ventricle). In the next plane, the aorta is found to be located anterior and to the left of the pulmonary trunk (hence the "L" prefix). The two vessels are parallel to each other. The inability to obtain a typical short-axis view supports the diagnosis.

Color and spectral Doppler. Although L-TGA can be diagnosed in the B-mode image, the use of color flow can confirm the diagnosis. It can differentiate the vessels more clearly and reveal additional defects such as VSD or pulmonary stenosis.

Differential diagnosis. Differentiation from D-TGA can be difficult. Complex defects with an L malposition of the great vessels can be difficult to distinguish from a D malposition.

Intrauterine course and prognosis. Most cases of L-TGA that are detected prenatally are a form of isomerism and/or are associated with a third-degree AV block. Both conditions have a high incidence of intrauterine fetal death. In follow-up, therefore, particular attention should be given to the development of fetal hydrops, which is a poor prognostic sign (23). If hydrops is not present and no significant intracardiac anomalies are found, the prognosis is very good. Some infants will not even require treatment by a pediatric cardiologist in the neonatal period.

Truncus Arteriosus

Definition. In this anomaly a common arterial trunk arises from the base of the heart and gives rise to the systemic (aorta), pulmonary, and coronary arteries (Fig. 25.**42**). Several types are recognized. The classification of Collett and Edwards (15), which identifies four types (I–IV) according to the origin of the pulmonary arteries, is commonly used.

Incidence. Truncus arteriosus occurs in approximately 1–1.5% of all live births with a congenital heart defect.

Associated anomalies and chromosomal abnormalities. Possible associated cardiac anomalies include mitral atresia, aortic arch anomalies, and almost complete absence of the interventricular septum, creating a single ventricle. Truncus arteriosus is more common in the offspring of diabetic women (19). Extracardiac anomalies are found in 30% of cases, often in connection with a syndrome such as DiGeorge syndrome (molecular genetics!) or with midline defects. When a truncus arteriosus is found, therefore, a standard chromosome analysis is not enough and should be supplemented by a search for rare molecular genetic anomalies (CATCH 22) using the FISH technique.

Ultrasound Diagnosis

B-mode image. Truncus arteriosus can be diagnosed in the B-mode image by defining the origin of the great vessels (planes 2 and 3), but this is difficult. Either the VSD or possible associated anomalies are the dominant findings in the four-chamber view. In the five-chamber view, the dilated arterial trunk (first thought to be the aorta) is clearly seen overriding the defect in the ventricular septum (8). A careful search for the pulmonary trunk in plane III or IV will suggest the more common diagnosis of pulmonary atresia with a VSD. But the patient examiner will be able to define the root of a small-caliber pulmonary trunk arising from the truncus arteriosus (in type I). This finding is confirmed with color Doppler.

Color and spectral Doppler. Color Doppler is of major value in this anomaly. Initially the findings resemble those seen in the tetralogy of Fallot ("Y" configuration, see above). But color Doppler in type I cases can demonstrate the origin of the pulmonary trunk from the truncus along with antegrade flow. In the five-chamber view, it is common to observe turbulence over the truncal valve, and valvular insufficiency may already be evident in utero.

Differential diagnosis. Differentiation is mainly required from defects with an overriding aorta such as the tetralogy of Fallot, pulmonary atresia with a VSD, and double-outlet right ventricle with pulmonary atresia (Table 25.**11**).

Intrauterine course and prognosis. Because the valve of the arterial trunk is dysplastic and often shows regurgitant flow, the fetus should be watched for early signs of heart failure during follow-up.

Isomerism, Situs Inversus (Heterotaxia Syndromes)

Definition. This group includes the following conditions:
- Partial situs inversus
- Complete situs inversus
- Left isomerism (formerly known as polysplenia syndrome) (32, 33)
- Right isomerism (formerly known as asplenia syndrome) (32, 33)

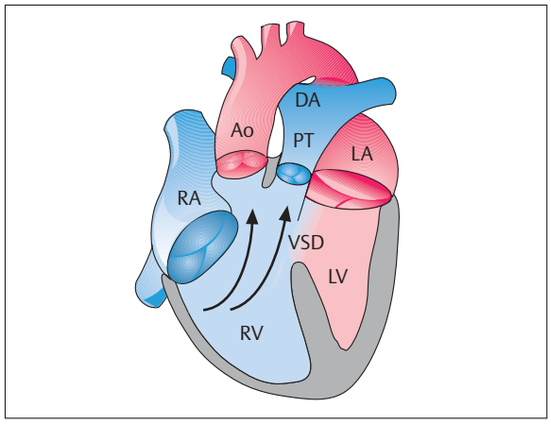
A common feature of these anomalies is a tendency to find a symmetrical arrangement of the asymmetrically formed organs—i.e., a mirror-image arrangement of structures between the two sides of the chest and abdomen.

Incidence. A malrotation anomaly is present in approximately 4% of all live-born infants with a congenital heart defect.

Associated cardiac and extracardiac anomalies. By definition, isomerism denotes the presence of multiple associated cardiac and extracardiac (e.g., visceral) malformations (Tables 25.**14**, 25.**15**). In fetuses with heterotaxia (right and left isomerism), an association with aneuploidy is very rare (4). Malrotation anomalies have occasionally been found in children with trisomy 13. Some forms are thought to have an autosomal-recessive mode of inheritance (25% recurrence risk), and therefore an aggregation of malrotation anomalies is found in marriages between relatives. Malrotation anomalies are also more common in the fetuses of diabetic mothers.

Ultrasound Diagnosis

B-mode image. A malrotation anomaly is usually easy to detect, for a systematic analysis will quickly disclose the commonly associated anomalous positions of the heart and stomach (Tables 25.**6**, 25.**7**). The



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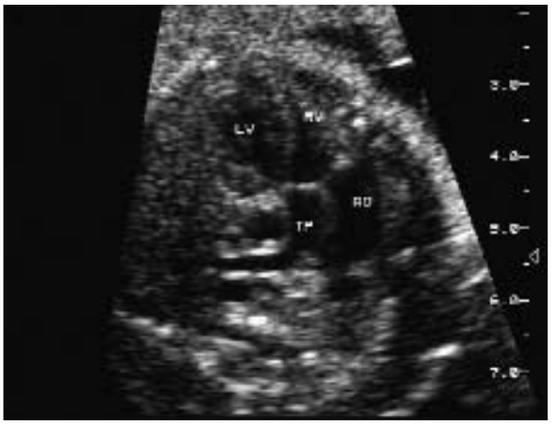

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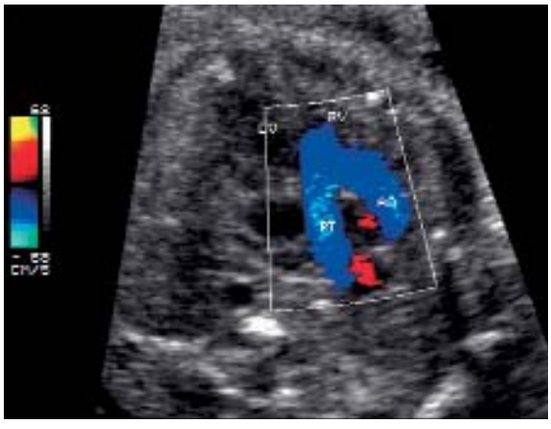

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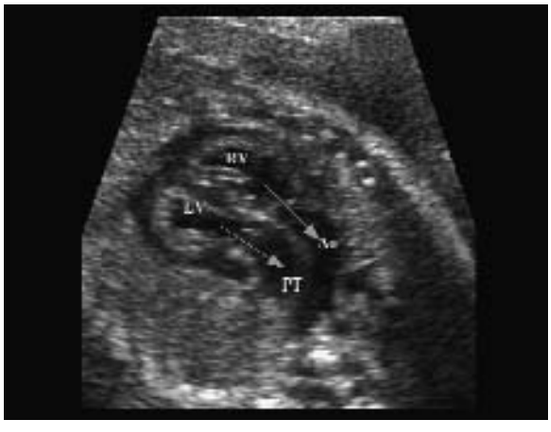

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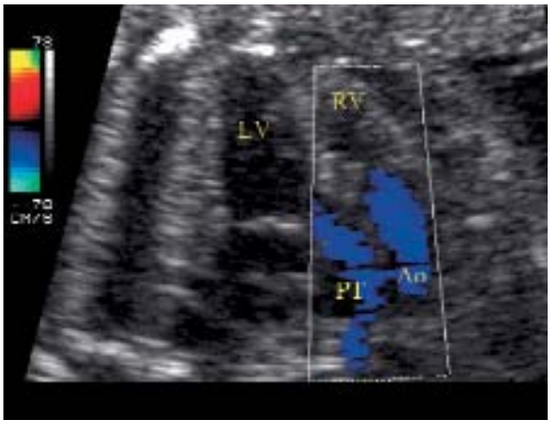

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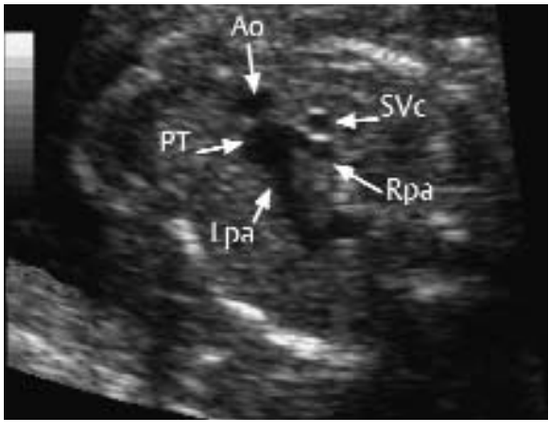

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Double-outlet right ventricle

Fig. 25.**35** With a double-outlet right ventricle, both the aorta and pulmonary trunk arise from the right ventricle. The relative positions of the vessels are highly variable (modified from [31]).

Fig. 25.**36** Double-outlet right ventricle (DORV), 26 weeks. The apical view shows both the pulmonary trunk and aorta arising from the right ventricle and running parallel to each other.

Fig. 25.**37** Double-outlet right ventricle (DORV). Color Doppler shows the parallel origins of both vessels from the right ventricle.

Transposition of the great arteries

Fig. 25.**38** Complete transposition of the great arteries (D-TGA), 25 weeks. When the ventriculoarterial connection is evaluated in a lateral scan, both vessels show a typical parallel course ("double-barreled" pattern). The aorta arises from the right ventricle and the pulmonary trunk from the left ventricle. Both semilunar valves are visualized in one plane.

Fig. 25.**39** Complete transposition of the great arteries (D-TGA), 25 weeks. Color Doppler demonstrates the typical parallel pattern of the two great vessels.

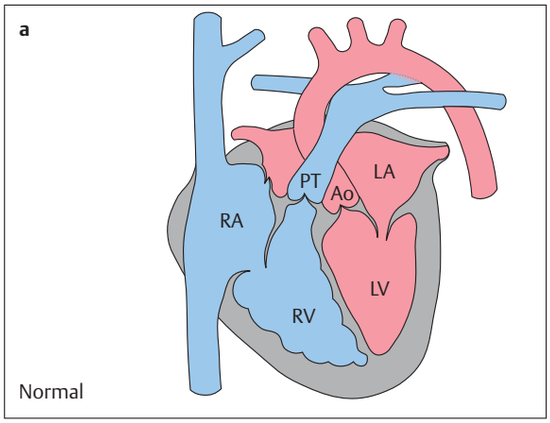
Fig. 25.**40** Origin of the pulmonary arteries in a fetus with D-TGA, 25 weeks. The standard short-axis view cannot be obtained, and the aorta is anterior to the pulmonary trunk. Rpa = right pulmonary artery, Lpa = left pulmonary artery.

Fig. 25.**41** Schematic representation of D-TGA and L-TGA.

a Diagram of a normal fetal heart (patent ductus arteriosus). There are normal connections between the right and left atria and the right and left ventricles, which in turn have normal connections with the pulmonary trunk (PT) and the aorta. "Normal," then, refers to a situation of atrioventricular (AV) and ventriculoarterial concordance. The right-sided anatomic structures of the heart are shown in blue, the left-sided structures in red.

b In D-TGA, the atria connect normally with their ventricles but the great vessels arise from the wrong ventricles (the aorta from the RV, the pulmonary trunk from the LV). This creates a situation of AV concordance and ventriculoarterial discordance.

c In L-TGA, the right atrium connects to the LV and the left atrium to the RV. As in the D form, the LV is connected to the pulmonary trunk and the RV to the aorta. This creates a situation of AV and ventriculoarterial discordance. The aorta and pulmonary trunk are parallel to each other (adapted and modified from [30]).



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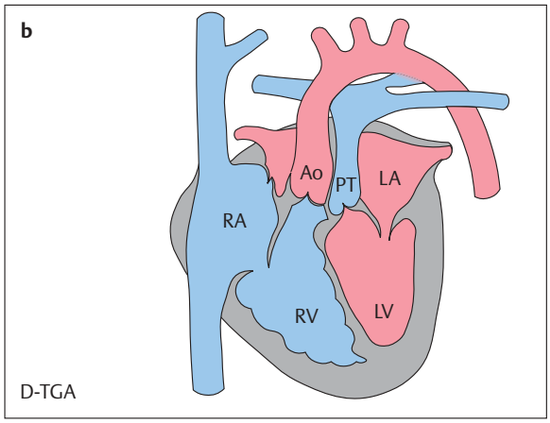

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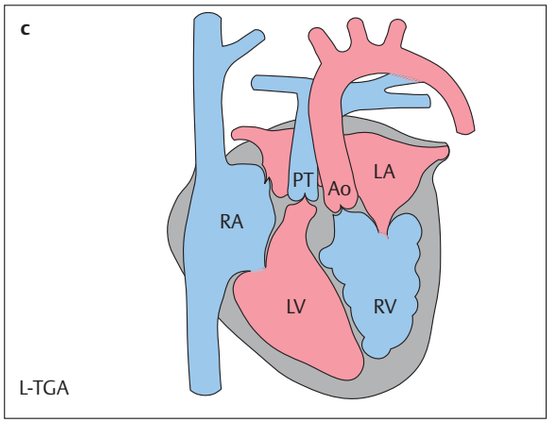

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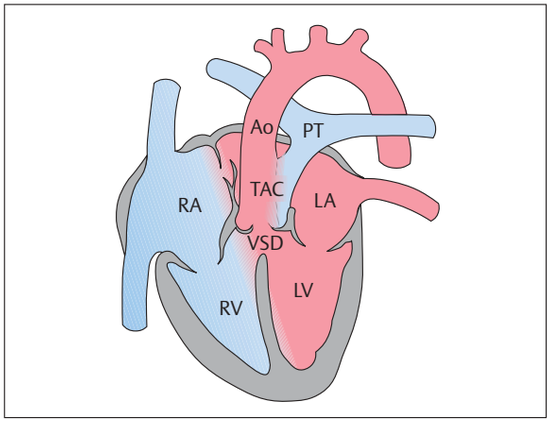
Truncus arteriosus

Fig. 25.**42** Diagram of truncus arteriosus (type I). A large vascular trunk (TAC = truncus arteriosus communis) overrides the VSD. The aorta and pulmonary trunk arise from the common trunk.



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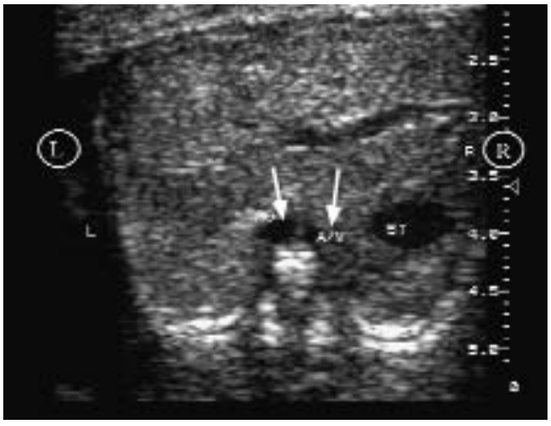
Heterotaxia syndromes

Fig. 25.**43** Heterotaxia syndrome. The stomach (ST) is located on the right side of the upper abdomen in this fetus. The aorta is to the left of the spine. Just to the right of the spine (not anterolateral), the inferior vena cava persists as the azygos vein (AZ). The findings are consistent with a polysplenia syndrome (left isomerism).

Fig. 25.**44** Four-chamber view of the fetus in Fig. 25.**43** demonstrates a complete AV canal (curved arrows). The aorta is visible behind the heart on the left side, and to the right is the dilated azygos vein (see also Fig. 25.**45**).



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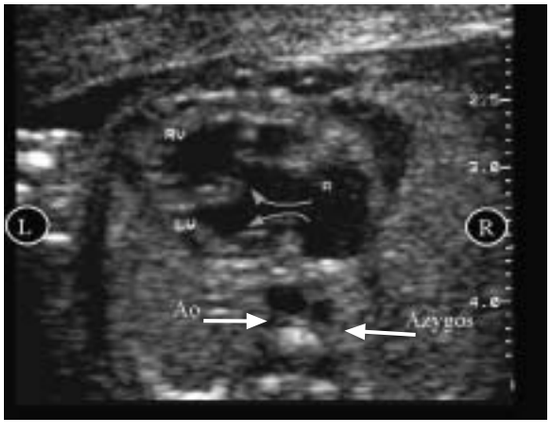

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presence of bradycardia (AV block) may also be a sign of left isomerism.

A scan of the upper abdomen showing the course of the hepatic veins and inferior vena cava is the most important B-mode tool for diagnosing a malrotation anomaly.

- ***In situs solitus,*** the aorta is to the left of the spine and the inferior vena cava (IVC) is to the right of the spine.
- In ***situs inversus,*** there is a mirror-image arrangement of both vessels.
- In ***right isomerism*** (asplenia), the aorta and IVC are always on the same side, and the IVC is usually anterior to the aorta.
- In ***left isomerism*** (polysplenia), the hepatic IVC is frequently absent. Venous blood from the periphery flows through the azygos vein (azygos continuation) or hemiazygos vein on the right or left side of the spine (Figs. 25.**43**, 25.**44**) behind the aorta and enters the superior vena cava, which is on the left or right side (Fig. 25.**45**), or flows directly into the atrium. Often the hepatic veins open directly into the right atrium.

Although these findings are not consistently present in all heterotaxia syndromes or malrotation anomalies, they are still the most reliable suggestive signs in echocardiography. On moving to the next planes, the examiner should adhere strictly to a segmental analysis, for as Tables 25.**14** and 25.**15** indicate, there is no typical heart defect in this group. The precise differentiation of a heart defect in isomerism continues to be one of the greatest challenges in fetal echocardiography.

Color and spectral Doppler. Color Doppler is of major importance in assessing the vascular anatomy of the heart. If the IVC is not visualized, color Doppler can demonstrate a persistent azygos vein running parallel to the aorta to its site of termination (Fig. 25.**45**). The hepatic veins and their connection can also be clearly defined as well as the pulmonary veins. When a malposition is present, color Doppler makes it easier to distinguish the aorta and pulmonary trunk and diagnose stenoses and atresias.

Differential diagnosis. A false-positive diagnosis of situs inversus is most often due to faulty placement of the transducer or confusion of the sides in breech- and vertex-presenting fetuses. Also, the detection of an abnormal organ position should always prompt consideration of an intrathoracic mass (diaphragmatic defect, unilateral pulmonary atresia, lung cysts, etc.) (Tables 25.**6**, 25.**7**).

It can be difficult to distinguish partial situs inversus (Fig. 25.**46**) or complete situs inversus from isomerism, but this distinction is important owing to the better prognosis of situs inversus. The anomalous venoatrial connection is the key feature in differentiating these conditions. Differentiating between the forms of isomerism is described above.

Intrauterine course and prognosis. The course is variable, depending on the nature of the anomaly. With complete situs inversus, no adverse hemodynamic effects can be detected prenatally or postnatally. By contrast, left isomerism with a complex cardiac anomaly and AV block may be associated with fetal hydrops and intrauterine death. A detailed analysis is of major importance, therefore, and venous Doppler ultrasound can be a very helpful tool for prenatal surveillance.

Table 25.**14** Most common findings in right isomerism (adapted from [32])

Right isomerism (asplenia)	
Association with a heart defect	Almost 100%
Stomach	Left, right, or central
Liver	Often central, asymmetrical
Aorta and inferior vena cava	Usually on the same side (left or right)
Dextrocardia	40%
Anomalous pulmonary venous return	Almost 100%
Bilateral superior vena cava	Almost 100%
AV canal	85%
Single ventricle	50%
TGA	60%
Pulmonary stenosis or atresia	70%

Table 25.**15** Most common findings in left isomerism (adapted from [32])

Left isomerism (asplenia)	
Association with AV block (bradycardia)	Frequent
Interruption of inferior vena cava and persistence as azygos (or hemiazygos) vein	70%
Azygos (or hemiazygos) vein dilated	Posterior to the aorta
Aorta	Centrally locatede
Stomach and liver	Left or right
ASD	35%
AV canal	43%
TGA, DORV	20%
Dextrocardia	35%
Bilateral superior vena cavae	50%

Anomalies of Systemic and Pulmonary Venous Return

Total and Partial Anomalous Pulmonary Venous Return

Definition. Total or partial anomalous pulmonary venous return (TAPVR or PAPVR) is present when all or some of the pulmonary veins drain into the right atrium or into the venae cavae that enter the right atrium.

Incidence. These anomalies occur in approximately 1.5% of all live births with a congenital heart defect.

Associated anomalies and chromosomal abnormalities. The anomaly may be isolated but is more commonly associated with right or left isomerism (approximately 100% in asplenia syndrome, 70% in polysplenia syndrome). Also, it is common to find TAPVR associated with atrial septal defects or an AV canal. Other associated cardiac anomalies include pulmonary vein stenoses. Extracardiac anomalies mainly involve the lung and gastrointestinal tract.

Ultrasound Diagnosis

B-mode image. Prenatal diagnosis is extremely difficult in the absence of associated cardiac anomalies. Possible suggestive signs include a left atrium that is somewhat smaller than the right atrium or the presence

of a persistent left superior vena cava (Figs. 25.**47**, 25.**48**). There are cases where the pulmonary veins are clearly defined in the standard four-chamber view (Fig. 25.**49**), but color Doppler is generally more rewarding than the B-mode scan.

Color and spectral Doppler. Often the pulmonary veins are plainly defined with color Doppler at a low velocity setting (low PRF), and different types of anomalous drainage patterns can be identified. This requires an examiner who is very experienced in the Doppler interrogation of slow flows and the interpretation of subtle findings. It is hoped that these anomalies can be detected by the consistent, systematic visualization of the pulmonary veins with color Doppler (17).

Differential diagnosis. The pulmonary arteries and veins close to the atria are apt to be confused in the B-mode image, and so the diagnosis should rely on color Doppler. When the right pulmonary veins are evaluated on an oblique plane, they are easily confused with the hepatic veins. In cases of isomerism, moreover, anatomic orientation is often very complicated, making it difficult to identify and evaluate the pulmonary veins.

Intrauterine course and prognosis. The emphasis in follow-up is on associated cardiac anomalies. There has been no experience with isolated forms of fetal TAPVR. But since the fetal pulmonary circulation as a whole does not affect hemodynamics, there should be no circulatory compromise during the prenatal period.

Persistent Left Superior Vena Cava (PLSVC)

Definition. This condition, known also as left superior vena cava (LSVC), is the most common venous anomaly. It results from a failure of obliteration of the left cardinal vein. The vessel is located anterior to the aortic arch, often running in front of the ductus arteriosus on the left side (Fig. 25.**48**). It usually bypasses the left atrium (Fig. 25.**47**), opens into the coronary sinus from below, and drains directly into the right atrium. In rare cases it opens directly into the left atrium, and in approximately 20% of cases the right superior vena cava is not present.

Associated anomalies. PLSVC may be associated with other cardiac anomalies (e.g., heterotaxia syndromes or anomalous pulmonary venous return), but its occurrence as an isolated anomaly is not uncommon.

Ultrasound diagnosis. PLSVC is relatively easy to diagnose in fetal echocardiography (when it is considered) by demonstrating a venous vessel on the left side wall of the left atrium in the four-chamber view (Fig. 25.**47**) or by demonstrating a "fourth" vessel with venous flow adjacent to the ductus arteriosus in the three-vessel view (plane V) (Fig. 25.**48**). Not infrequently, the right atrium appears slightly broader than the left atrium in the four-chamber view.

Cardiomyopathies

Definition. This group includes a number of heart diseases whose common feature is an impairment of myocardial contractility.

Etiology and pathogenesis. Cardiomyopathies have a broad etiologic spectrum ranging from infectious diseases to congenital metabolic storage diseases. In most cases, however, the cause is not discovered and the cardiomyopathy is described as "idiopathic."

Forms. It is not uncommon in prenatal diagnosis to find decreased myocardial contractility in association with fetal hydrops (immune or nonimmune). This ***secondary cardiomyopathy*** can aggravate the severity of the hydrops as a result of cardiac failure. These cases require differentiation from the primary idiopathic forms, which may present either as ***hypertrophic*** or ***dilatative cardiomyopathy.*** In the hypertrophic form, the myocardium is thickened and has a very narrow lumen. But in the dilatative form, the heart appears "stretched out" and remains compensated until a relatively late stage. Dilatative cardiomyopathy is usually manifested by cardiomegaly.

Prognosis. In our experience, both forms have an unfavorable prognosis. In cases that have a known cause such as arrhythmia, volume overload (e.g., acceptor in fetofetal transfusion syndrome), pressure overload (e.g., constriction of the ductus arteriosus, IUGR), or diabetes mellitus, the prognosis is determined chiefly by the primary disease.

Cardiac Tumors

On the whole, cardiac tumors very rarely occur as congenital anomalies. The majority are benign and consist of rhabdomyomas (60% of cases) or teratomas (20%). Cardiac rhabdomyomas may be multiple (Fig. 25.**50**), often affect the interventricular septum, and sometimes undergo spontaneous remission. They may be detected incidentally in the fetus, but often there are associated supraventricular extrasystoles or nonimmune hydrops due to circulatory obstruction by the tumor.

Associated anomalies and chromosomal abnormalities. Although most cardiac tumors occur in isolation, rhabdomyoma is an exception: 50–90% of these tumors are a symptom of tuberous sclerosis (Bourneville–Pringle disease), which is associated with mental retardation and seizures. This disease is usually inherited as an autosomal-dominant trait, but it also has a high spontaneous mutation rate. Thus, genetic family counseling is indicated whenever a cardiac tumor is detected prenatally, and the fetus should be examined sonographically for CNS abnormalities (dilatation of cerebral ventricles) and renal tumors.

Fetal Arrhythmias

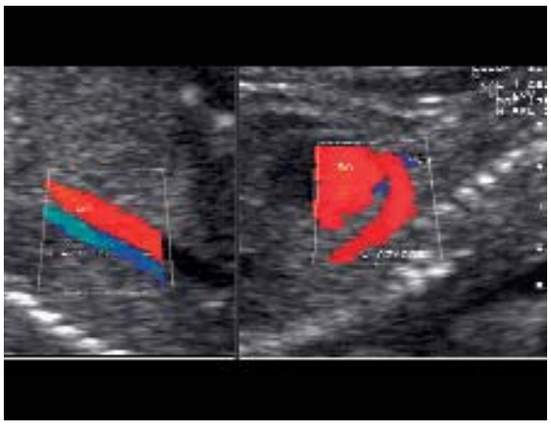
Incidence and significance. Arrhythmias are among the most common "cardiologic" symptoms in fetuses, with an incidence between 0.2% and 2%. Transient fetal arrhythmias are also a common finding (10%) in pregnancies that are evaluated by auscultation, CTG, or ultrasound. As a result, fetal arrhythmias are one of the most frequent indications for fetal echocardiographic evaluation. Except in fetuses with a heart block, arrhythmias are rarely associated with cardiac anomalies (< 5% of cases).

Cause, course, and prognosis. Cardiac arrhythmias are a nonhomogeneous group that can vary greatly in their cause, course, and prognosis, and so a differentiated approach is recommended. An accurate diagnostic workup is essential, relying particularly on prenatal M-mode and Doppler examination (only the QRS complex can be recorded in the fetal ECG).

Special Aspects in the Analysis of Fetal Arrhythmias

The examiner who evaluates a fetus with an arrhythmia should keep in mind several aspects that distinguish fetal from postnatal arrhythmias:

- **Immaturity.** The development of the heart, like that of other fetal organs, is not yet completed at birth. The physiologic immaturity of the impulse formation and conduction system in the fetal heart may be manifested by arrhythmias. Most of these arrhythmias are caused by ectopic stimuli in the atria or ventricles, which are registered as extrasystoles.



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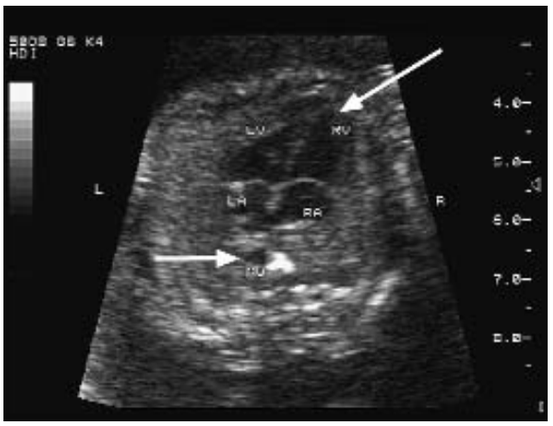

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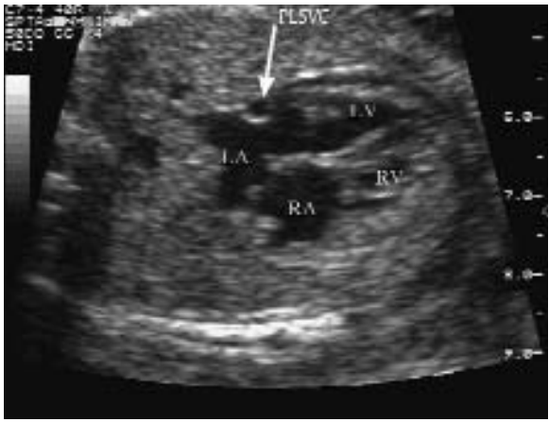

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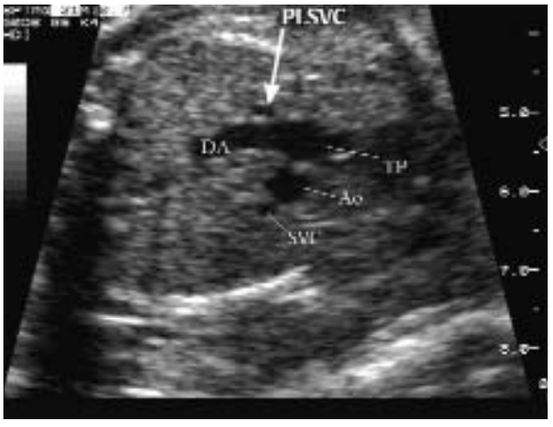

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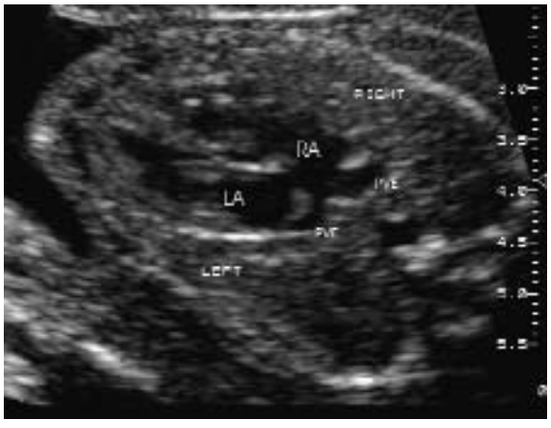

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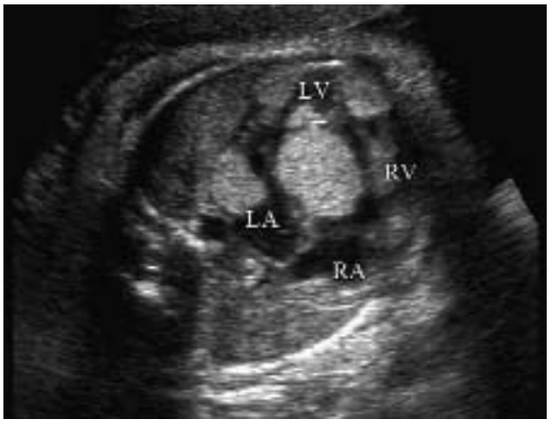

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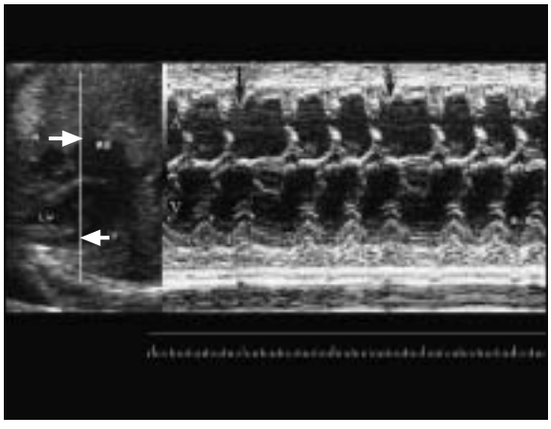

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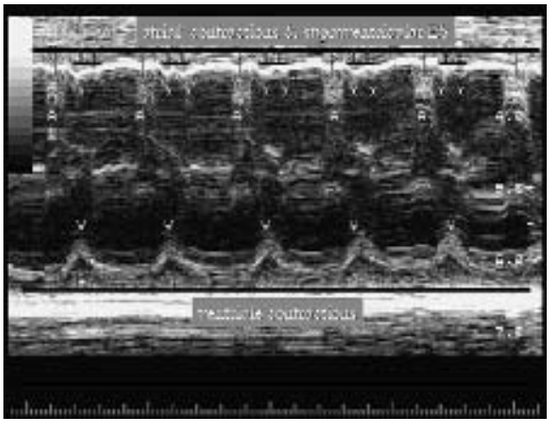

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Fig. 25.**45** Same fetus as in Figs. 25.**43** and 25.**44**. Left: Color Doppler shows the aorta and azygos vein side-by-side in the longitudinal scan. Right: Another longitudinal scan shows the termination of the azygos vein at the superior vena cava.

Fig. 25.**46** Dextrocardia. In this fetus the descending aorta is found to the left of the spine (lower arrow) but the cardiac apex points to the right (upper arrow). Only about one-third of the heart is located in the left hemithorax.

Anomalies of systemic and pulmonary venous return

Fig. 25.**47** Persistent left superior vena cava (PLSVC) in the four-chamber view. The vessel appears in transverse section directly adjacent to the left atrium.

Fig. 25.**48** Same fetus as in Fig. 25.**47**. The persistent vessel is seen more clearly in the "three-vessel view" (plane 5), appearing as a fourth vessel to the left of the pulmonary trunk. Aorta and (right) superior vena cava (SVC).

Fig. 25.**49** Termination of the pulmonary veins at the right atrium in total anomalous pulmonary venous return. Associated right isomerism was detected initially.

Cardiac tumors

Fig. 25.**50** Multiple echogenic cardiac tumors (rhabdomyomas). Tuberous sclerosis should be considered when this type of lesion is found.

Fetal arrhythmias

Fig. 25.**51** Supraventricular extrasystole. The M-mode cursor is positioned in the four-chamber view so that it passes through a ventricle (below), the interventricular septum, and an atrium (above). The M-mode tracing shows two supraventricular extrasystoles in the atrium (arrows), which are not conducted to the ventricle.

Fig. 25.**52** Blocked extrasystoles, 23 weeks. The M-mode cursor is aligned across the right ventricle (below) and right atrium (above). The extrasystoles from the atrium reach the impulse conduction system of the ventricle while it is still refractory, and so only the next atrial beat is conducted.

- **Structural anomalies.** When evaluating a fetal arrhythmia, the examiner should always consider that a structural anomaly in the heart may be the underlying cause. This means that fetal echocardiography should be performed without delay.
- **Vagal dominance.** It is not unusual to find transient bradycardia, especially in the second trimester, as a manifestation of vagal dominance. Every examiner is familiar with episodes (e.g., at about 20 weeks) in which the fetal heartbeat stops briefly during the ultrasound examination and then slowly resumes a few seconds later.
- **Short circuits.** Connective-tissue development in the atrioventricular (AV) plane is not yet complete in the fetus, and this can cause ventricular contractions to be initiated via "short circuits" between the atria and ventricles. In some cases, for example, a supraventricular extrasystole can trigger circuitous excitations via these accessory pathways (or even through the AV node itself). This reentry mechanism in the fetus can trigger paroxysmal tachycardia, which when sustained can lead to cardiac failure.
- **Maternal factors.** It should be kept in mind that the fetus is a "patient within a patient." When seeking the cause of a fetal arrhythmia, therefore, the examiner should also look for maternal factors that could adversely affect the fetal heart rhythm. For example, maternal diseases such as systematic lupus erythematosus, diabetes mellitus, hyperthyroidism, as well as smoking, alcohol consumption, and the use of (cardioactive) drugs can provoke fetal cardiac arrhythmias.

Differential Diagnosis of Fetal Arrhythmias as a Basis for Optimum Management

Before deciding whether a detected fetal arrhythmia should be treated, the examiner should first exclude a structural heart defect using B-mode ultrasound and then accurately classify the arrhythmia using the M-mode technique (7). In this technique the M-mode cursor is positioned under B-mode guidance to produce a simultaneous tracing of heart activity as a function of time. The cursor should be placed so that it passes through an atrium and a ventricle (or across a semilunar valve). This makes it possible to analyze atrioventricular (AV) conduction and determine whether it is impaired (AV block). The high temporal resolution in the M-mode tracing also allows precise measurement of the heart rate, as the examiner cannot distinguish between paroxysmal tachycardia and atrial flutter by using B-mode alone. Modern color-encoded M-mode echocardiography is useful both for classifying the arrhythmia and analyzing its hemodynamic effects.

Three groups. Fetal arrhythmias are divided into three groups based on practical criteria:

- The large group of extrasystoles (85% of all arrhythmias): the supraventricular and ventricular forms with a basal heart rate in the normal range.
- The group of sustained bradycardias (incidence 5–10%), in which the basal heart rate is lower than 100 bpm.
- The group of sustained tachycardias (incidence 10%), in which the basal heart rate is higher than 190 bpm.

Extrasystoles

Incidence and etiology. Extrasystoles are by far the most common type of fetal arrhythmia, with an incidence between 80% and 90%. Most extrasystoles are supraventricular (Fig. 25.**51**). Ventricular extrasystoles are much less common. Extrasystoles are usually attributed to the immaturity of the impulse formation and conduction system in the fetal heart. This immaturity also makes the heart susceptible to exogenous agents (including beta mimetic drugs). Sinus arrhythmias are also observed in association with fetal movements (including hiccups). Although extrasystoles are an innocuous finding, a morphologic cause is detectable in 1–2% of cases.

Prognosis. This type of arrhythmia has a very good prognosis (except for cases with a heart defect). The condition resolves spontaneously in most fetuses, and in most other cases it ceases during the initial weeks after birth.

In 1–2% of cases, however, this harmless arrhythmia can progress to sustained paroxysmal tachycardia, most likely through a reentry mechanism (58). This poses a danger of cardiac decompensation with the development of NIHF. For this reason, fetuses with extrasystoles should be examined at regular intervals. Prenatal treatment is unnecessary owing to the good prognosis, and follow-ups can be conducted on an ambulatory basis.

Bradyarrhythmias

Three principal subgroups are distinguished antenatally:

- Blocked atrial extrasystoles
- Sinus bradycardia
- Congenital heart block (second or third degree AV block)

Blocked Atrial Extrasystoles

When, following a normal excitation pattern, an atrial extrasystole reaches an AV node that is still in a refractory state, the impulse will not be transmitted to the ventricles, and ventricular systole will not occur until the arrival of the next normal impulse (Fig. 25.**52**). When these extrasystoles alternate with sinus beats, the heart appears to be contracting in a bradycardiac rhythm. Although this arrhythmia is perceived as bradycardia on auscultation, it is actually a type of extrasystole from an electrophysiologic standpoint. In any case, it is a rare condition that usually resolves spontaneously, has a good prognosis, and requires maternal (transplacental) digitalis therapy only when it persists.

Sinus Bradycardia

The most common form is a transient, harmless bradycardia that occurs in the second trimester as an expression of vagal dominance. Sinus bradycardia very rarely occurs as a persistent, sustained bradycardia, which is usually a preterminal event caused by fetal hypoxia. This category would include intrapartum bradycardias that necessitate a cesarean delivery. Sinus bradycardia has also occasionally been found in fetuses with heterotaxia syndromes (e.g., polysplenia). Transient sinus bradycardia may be induced by compression of the skull or umbilical cord. Not infrequently, we have found low basal fetal heart rates of 90–110 bpm in women who are heavy smokers.

Complete Congenital Heart Block (CCHB, Second- or Third-Degree AV Block)

Definition. In fetuses with a third-degree heart block, the atria beat at a normal rate (120–160 bpm) while the ventricles beat at their own (bradycardiac) rate with no evidence of AV conduction (Fig. 25.**53**). In the much less common second-degree heart block, an impulse is conducted to the ventricles at every other atrial contraction (which occur at equal intervals) (Fig. 25.**54**). These forms often progress to a third-degree heart block.

Association with heart defects. Among the arrhythmias, AV blocks have the highest association with heart defects, which are present in up to 40% (!) of cases (7). Most of these defects consist of morphologic abnormalities at the AV level, particularly AV canal, AV discordance with corrected TGA, and heterotaxia syndrome (e.g., polysplenia syndrome).

Association with maternal connective-tissue diseases. If a structural heart defect is not found in the B-mode image, an immediate search should be made for a maternal connective-tissue disease. The most frequent of these disorders are systemic lupus erythematosus (SLE) and Sjögren syndrome, in which anti-Ro or anti-La antibodies (also called anti-SS-A or anti-SS-B antibodies) can be detected in the maternal serum (7). Etiologically, it has been found that these IgG autoantibodies are able to cross the placenta, enter the fetal circulation, and bind to the impulse conduction system at the AV level. There they incite a nonspecific inflammation that heals with fibrous tissue transformation, creating an irreversible break within the conduction system. It is interesting that the pregnant women are often (still) asymptomatic at this stage, so that the detection of fetal CCHB and maternal antibodies leads to the diagnosis of SLE.

Prognosis. The prognosis of CCHB depends on its etiology. Fetuses with a cardiac malformation are prone to intrauterine cardiac decompensation with the development of NIHF leading to the death of the fetus or neonate. By contrast, fetuses with CCHB based on maternal SLE have a good prognosis unless the fetus develops nonimmune hydrops due to the connective-tissue disease.

Treatment. There is disagreement whether CCHB is accessible to prenatal medical treatment with orciprenaline or other beta-mimetic drugs. A major consideration is whether it is desirable to increase the ventricular rate. In cases with a maternal connective-tissue disease, we have had good results with serial plasmapheresis and corticosteroid therapy.

Tachyarrhythmias

Three principal subgroups are distinguished:
- Sinus tachycardia
- Paroxysmal supraventricular tachycardia
- Atrial flutter

Ventricular tachycardia is extremely rare.

Sinus Tachycardia

With a basal heart rate in the range of 180 to 205 bpm, a CTG with good variability can still be recorded.

Etiology. Sinus tachycardia can occur in response to exogenous factors such as tocolytic therapy with beta mimetics, infection (fever, chorioamnionitis!), and hyperthyroidism. Persistent accelerations are occasionally seen in the CTG of a particularly active fetus.

Treatment. Causal treatment can produce remission, but follow-ups are still necessary to watch for potential complications or a recurrence. Antiarrhythmic therapy is not indicated in these cases, and the arrhythmia itself has a favorable prognosis.

Paroxysmal Supraventricular Tachycardia

Etiology and pathogenesis. Paroxysmal supraventricular tachycardia (heart rate 210–300 bpm) is usually caused by a reentry mechanism in which extrasystoles, usually of supraventricular origin, set up circuitous, repetitive excitations via accessory conduction pathways or through the AV node itself. Since the heart responds to the fastest pacemaker, the reentrant impulses cause it to beat at a very rapid rate, typically between 220 and 260 bpm. Often the examiner notices a sudden onset of the reentry tachycardia, and in some cases it may cease spontaneously. M-mode ultrasound can clearly document this type of arrhythmia and differentiate it from other forms (Fig. 25.**55**).

Prognosis. Paroxysmal supraventricular tachycardia poses a significant hazard to the fetus, because if it persists, it can lead to heart failure with the development of nonimmune hydrops. In a number of cases, however, the tachycardia is not detected until the fetus is being evaluated for nonimmune hydrops. It is believed that heart failure will not develop if the tachycardia is interrupted by periods with a normal heart rate, even if these periods are of only a few minutes" duration.

Treatment. These fetuses are considered to be at very high risk, and there is an urgent need for treatment. Intrauterine therapy aimed at pharmacologic cardioversion and the clearing of fluid collections should be instituted without delay. Since earlier treatment means a better chance of success, these fetuses should be referred at once to the nearest prenatal center that is experienced in this area. The prognosis in such cases is very good, with less than a 10% mortality rate. Today, fetal tachycardia belongs to the diseases that can be treated antenatally with considerable success.

To interrupt the reentry circuit, the antiarrhythmic drug should suppress the formation of extrasystoles, delay AV conduction, and prolong the refractory period of the AV node. The prenatal drug of choice is digoxin, which also improves myocardial contractility owing to its positive inotropic effect.

Second-line drugs include a number of antiarrhythmic agents, most notably verapamil and flecainide (e.g., in NIHF) (3). Further details on the treatment of fetal arrhythmias can be found in the specialized literature (3, 7) (Fig. 25.**57**) (see also Chapter 47).

Atrial Flutter

Etiology and pathogenesis. Atrial flutter (> 300 bpm) is much less common than the other tachyarrhythmias. It is caused by a reentry circuit at the atrial level. An atrial rate of 400–480 bpm is often found in association with a 2 : 1 to 4 : 1 AV block, and so the ventricular rate may be 200–240 bpm or less (Fig. 25.**56**). Atrial flutter is indistinguishable from paroxysmal supraventricular tachycardia (PSVT) in the B-mode image, and so M-mode is used to count the rates of the atria and ventricles and evaluate AV conduction.

Prognosis and treatment. Like PSVT, atrial flutter can lead to nonimmune hydrops culminating in fetal death. In the absence of a complex cardiac anomaly, fetal therapy should be instituted without delay. With few exceptions, the treatment is the same as for PSVT (see above).

Conclusions

In closing, it should be emphasized that a knowledge of the basic pathophysiology of fetal arrhythmias and the optimum use of ultrasound in the setting of fetal echocardiography are essential for making a precise diagnosis and differential diagnosis. The appropriate management is decided only after the arrhythmia has been classified. Recommended approaches to the management of fetal arrhythmias are reviewed in Tables 25.**16**–25.**19**. The indications for treatment and the details of therapy should be decided on an individual basis. Ultimately, the lack of fetal response to many otherwise effective cardiac drugs emphasizes the need to develop new drugs that are tailored specifically to the fetal heart.

Table 25.**16** Steps to follow when a fetal arrhythmia has been diagnosed

- Check fetal anatomy
- Exclude a cardiac anomaly
- Exclude NIHF
- Use M-mode to diagnose and classify the arrhythmia
- Exclude maternal disease, drug use, and other exogenous factors
- Refer to a specialized center

Table 25.**17** Management of irregular cardiac arrhythmias

- Supraventricular or ventricular extrasystole?
- Exclude cardiac anomalies (including foramen ovale prolapse)
- Discontinue caffeine, nicotine, alcohol, and "cardiac drugs"
- Check weekly for potential complications of tachycardia (reentry!)

Table 25.**18** Management of bradyarrhythmias

Use M-mode to evaluate atrioventricular conduction

Management after diagnosis

- Sinus bradycardia
  - Intermittent? Vagal dominance, immaturity
  - Persistent? Possible hypoxia? Doppler, CTG, induction of labor?
- Blocked atrial extrasystoles (see Table 25.17)
  - Transplacental digoxin therapy rarely necessary
- Complete congenital heart block (third-degree heart block)
  - Exclude cardiac anomaly!!! (isomerism with AV discordance, AV canal, etc.)
  - Maternal connective tissue disease? (anti-Ro antibodies?)

Check weekly for signs of nonimmune hydrops (= poor prognosis)

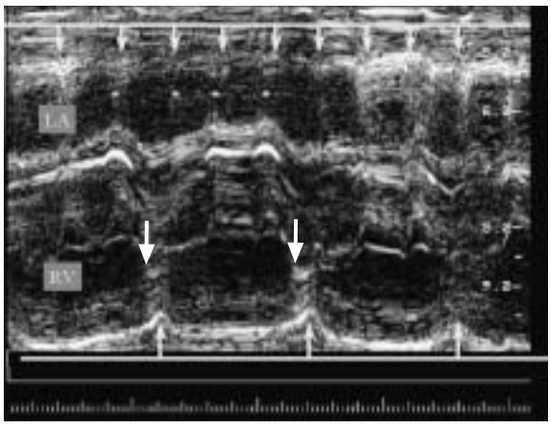
May consider prophylactic beta-mimetic agent, corticosteroids

Table 25.**19** Management of tachyarrhythmias

- Classify the tachycardia using M-mode
- Hospitalize the patient
- Exclude NIHF

- Sinus tachycardia? Identify and treat the cause (maternal or fetal)

- Paroxysmal supraventricular tachycardia or atrial flutter (with or without AV block)
  - Check indication for intrauterine therapy
  - Consult with pediatric cardiologist and neonatologist
  - Induce lung maturity
  - Select drug therapy. First choice: digoxin. If no response, add a medication (see Chapter 47)
  - Select mode of therapy: transplacental; with NIHF, direct therapy + plasma assay (rarely indicated today)



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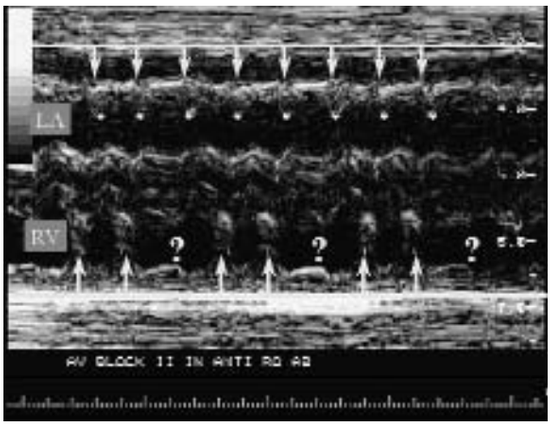

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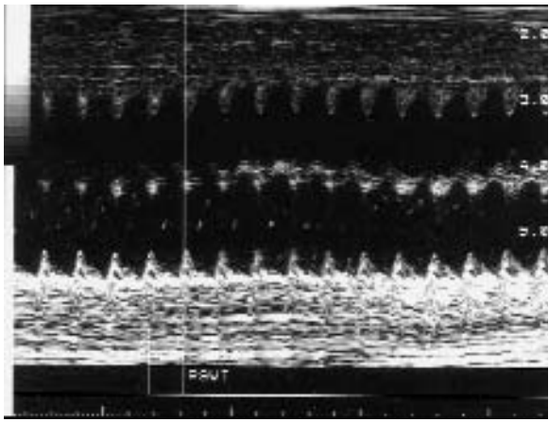

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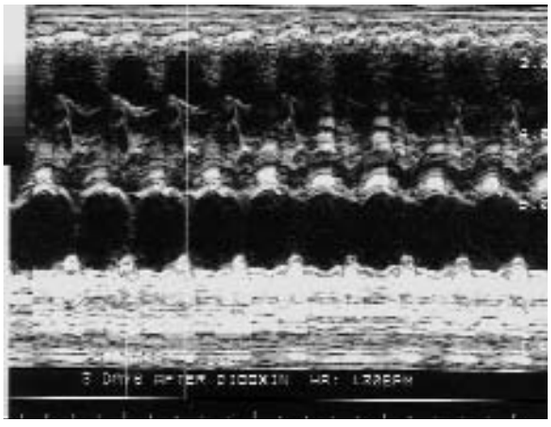

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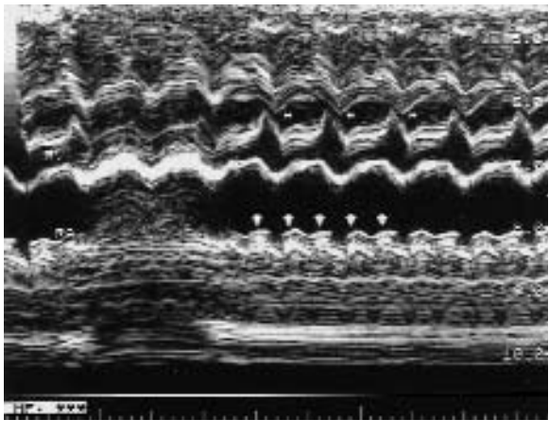

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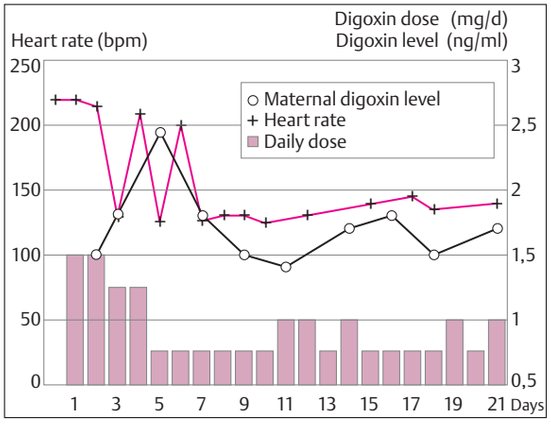

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Fig. 25.**53** Congenital complete heart block. In a third-degree atrioventricular heart block, the atria and ventricles beat independently of one another. The M-mode cursor is placed across a ventricle (below) and an atrium (above). The atria (A) show a rate of 130 bpm, while the ventricles (V) have a rate of only 60 bpm. The mother in this case had a previously undiagnosed case of visceral lupus erythematosus (detection of anti-Ro antibodies).

Fig. 25.**54** Second-degree congenital heart block. While the left atrium (LA) shows regular contractions, one ventricular contraction is skipped after every second atrial beat.

Fig. 25.**55** Paroxysmal supraventricular tachycardia (PSVT), 30 weeks.
- **a** M-mode cursor across atrium (below) and ventricle. The atria and ventricles in this fetus are beating at a rate of 222/min. Before hydrops developed, this fetus was quickly treated with maternally administered digoxin.
- **b** M-mode tracing three days later demonstrates cardioversion with a rate of 113/min.

Fig. 25.**56** Atrial flutter with a 2:1 block, 30 weeks. This case was referred for persistent tachycardia. Only M-mode (ventricle above, atrium below) can classify the tachycardia as an atrial flutter with a 2:1 block. The atria are beating at a rate of 460/min (RA and arrows), the ventricles at a rate of 230/min (RV and ∗). Cardioversion was achieved by means of direct intrauterine digoxin therapy.

Fig. 25.**57** Example of the intrauterine treatment of paroxysmal supraventricular tachycardia, 27 weeks. Days since the start of treatment are shown on the abscissa. Heart rate in beats per minute (bpm) is shown on the left ordinate, and the digoxin levels (ng/mL) and daily digoxin dose (mg/d) are shown on the right ordinate (from [23]).