Early Evaluation of the Fetal Heart

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Keywords

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Abstract

Evaluation of the fetal heart at 11–13 + 6 weeks of gestation is indicated for women with a family history of congenital heart defects (CHD), a previous child with CHD, or an ultrasound finding associated with cardiac anomalies. The accuracy for early detection of CHD is highly related to the experience of the operator. The 4-chamber view and outflow tracts are the most important planes for identification of an abnormal heart, and can be obtained in the majority of fetuses from 11 weeks of gestation onward. Transvaginal ultrasound is the preferred route for fetal cardiac examination prior to 12 weeks of gestation, whereas, after 12 weeks, the fetal heart can be reliably evaluated by transabdominal ultrasound. Cardiac defects, such as ventricular septal defects, tetralogy of Fallot, Ebstein's anomaly, or cardiac tumors, are unlikely to be identified at ≤ 14 weeks of gestation. Additional ultrasound techniques such as spatiotemporal image cor-

relation and the evaluation of volumes by a fetal-heart expert can improve the detection of congenital heart disease. The evaluation of the fetal cardiac function at 11–13 + 6 weeks of gestation can be useful for early identification of fetuses at risk of anemia due to hemoglobinopathies, such as hemoglobin Bart's disease.

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Introduction

Congenital heart defects (CHD) are the most common fetal structural anomalies, either isolated or in association with other fetal anatomical defects [1, 2]. CHD are strongly associated with chromosomal anomalies and genetic syndromes and can significantly modify the clinical outcome of affected fetuses [3–6]. The prevalence of major cardiac defects varies from 3 to 12 per 1,000 pregnancies [7, 8] in relation to the type of defect and study population, and to minor geographic variations included across different studies [1, 9].

Women at a higher risk of fetal cardiac anomalies are those with: (1) a family or an obstetric history of CHD [10–12]; (2) fetuses having an abnormal basic cardiac examination during the first trimester scan [13]; (3) the

Table 1. Risk factors associated with the presence of congenital heart defects (CHD)

Indication	Association with cardiac defects
Noncardiac structural anomalies [91]	21%
Previous history of CHD [10]	8.7%
Abnormal ductus venosus [92]	7.5%
Increased nuchal translucency [93]	7%
Monochorionic twins [23]	5.5% (9.3% in cases with TTS)
Tricuspid regurgitation [18]	5.1%
Aberrant right subclavian artery [33]	5.1%
Consanguinity [94]	4.4%
Assisted reproductive technologies [24]	4.3%

presence of indirect markers for fetal CHD, such as increased nuchal translucency [14, 15], abnormal flow in the ductus venous [16, 17], or tricuspid regurgitation [18]; (4) fetuses with chromosomal anomalies [19, 20]; (5) fetuses with any other associated structural defect [21, 22]; (6) monochorionic (MC) twin pregnancies [23]; and (7) pregnancies from assisted reproductive technologies (ART) [24] (Table 1). Early identification of specific cardiac anomalies, such as aortic stenosis, might allow intra-uterine treatment to improve the perinatal outcome [25]. Complete cardiac examination might be considered as part of the routine fetal anatomy scan at 11–13 + 6 weeks of gestation.

Ultrasound Findings Suggestive of Fetal Cardiac Anomalies

The main ultrasound finding suggestive of cardiac defect is an increased nuchal translucency. Iliescu et al. [26] evaluated 5,472 unselected patients with a 0.54% prevalence of cardiac defects (*n* = 30). The authors reported that 8.7% of fetuses with increased nuchal translucency had major cardiac anomalies, a result almost 10 times higher than fetuses with normal nuchal translucency for which the prevalence of major CHD was 0.98%. Similar results were observed by Becker and Wegner [27] who reported that fetuses with increased nuchal translucency (≥ 2.5 mm) had a 9.8% prevalence of heart defects, whereas fetuses with a normal nuchal translucency (< 2.5 mm) had a 0.3% prevalence of heart defects.

The relationship between the heart and the thorax is one of the main parameters related to cardiac anomalies.

An abnormal heart-to-chest area ratio > 0.28 at 11–13 + 6 weeks of gestation might suggest cardiomegaly and a possible cardiac anomaly [28]. Fetuses with cardiac defects might show an abnormal deviation of the cardiac axis. McBrien et al. [29] reported that in early gestation the cardiac axis is oriented more to the midline of the thorax and then rotates to the left, changing from 39° at 11 weeks to 50° at 14 weeks. Sinkovskaya et al. [30] reported a normal variation in the cardiac axis from 34.5° at 11 weeks to 56.8° at 13 + 6 weeks of gestation, and that an abnormal cardiac axis can be associated with coarctation of the aorta, Ebstein’s anomaly, transposition of the great vessels, and heterotaxy. The same group reported that 74.1% of fetuses with confirmed CHD had an abnormal cardiac axis when evaluated between 11 and 13 + 6 weeks/days of gestation [31]. In their study, the cardiac axis performed better than increased nuchal translucency, tricuspid regurgitation, or reversed atrial waveform in the ductus venosus in detecting major fetal cardiac defects.

Abnormal Ductus Venosus

Borrell et al. [16] reported that 39% of fetuses with congenital heart disease identified at 11–13 + 6 weeks had a reversed atrial waveform in the ductus venosus. Clur et al. [32] suggested that the evaluation of the ductus venosus pulsatility index, instead of only absence/reversed atrial velocities, might improve the detection rate of fetal cardiac anomalies to 70%.

Pereira et al. [18] studied 85 euploid fetuses with major CHD during the first-trimester ultrasound scan and found an increased nuchal translucency (> 95 th percentile) in 35.3%, tricuspid regurgitation in 32.9%, and reversed A wave in the ductus venosus in 28.2% of them. Rembouskos et al. [33] reported an association between aberrant right subclavian artery (ARSA) and fetal cardiac defects. The authors studied 4,566 fetuses and identified 89 fetuses with ARSA. The prevalence of fetal cardiac defects in chromosomally normal fetuses was 4/77 (5.1%), including tetralogy of Fallot (*n* = 1), aberrant umbilical vein (*n* = 1), and tricuspid atresia (*n* = 2).

What Constitutes an Early Fetal Cardiac Examination?

The main anatomical planes for early cardiac examination are the 4-chamber view and the outflow tracts [34] (Fig. 1, 2). These planes can be obtained in almost 100% of fetuses between 12 and 14 weeks of gestation. Other planes have also been proposed for the detection of CHD

Fig. 1. Cross-sectional image of the fetal heart at the level of the 4-chamber view at 13 + 5 weeks of gestation. **a** Four-chamber view. **b** Highlighted anatomical structures: LA, left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle. Note the pulmonary veins reaching the left atrium. **c** Heart-to-thorax ratio. **d** Cardiac axis. Courtesy of Dr. Raúl García-Posada.

Fig. 2. Outflow tracts and 3-vessel view. **a** Left outflow tract and aorta. LA, left atrium; RV, right ventricle. **b** Right outflow tract and pulmonary valve obtained from a short axis. **c** Three-vessel view. **d** Slightly oblique plane from the 3-vessel view to obtain the pulmonary valve.

Fig. 3. Sagittal images. **a** Aortic arch and descending aorta. **b** Pulmonary artery and ductal arch. RV, right ventricle. **c** Inferior and superior vena cava.

Fig. 4. High-definition color directional Doppler. **a** Cross-sectional view of the fetal heart and interventricular septum. LA, left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle. **b** Joint of the aorta and pulmonary artery with blood flow moving in the same direction. **c** Ductal arch and descending aorta. **d** Inferior vena cava and superior vena cava.

with a lower success rate such as: visualization of the ductal and aortic arches that can be obtained in 70–80% of cases (Fig. 3a, b), the 3-vessel and tracheal views obtained in 60–70% of fetuses (Fig. 2c, 4b), and the pulmonary veins observed in 25–55% of fetuses [35, 36]. An extended cardiac examination at 11–13 + 6 weeks of gestation has been suggested by Yagel et al. [37]. They reported a 64% detection of CHD by evaluating the following cardiac planes: upper abdomen, 4-chamber view, 5-chamber view, bifurcation of the pulmonary artery, 3-vessel and tracheal view, and the short axis of the right ventricle. The authors also suggested that transvaginal ultrasound might be better than transabdominal ultrasound for a detailed examination of the fetal heart. Carvalho [34] proposed

the following components for cardiac examination: situs solitus, normal cardiac axis, normal and symmetrical 4-chamber view, 2 separate atrioventricular valves, normal aortic and pulmonary outflow tracts, 2 great arteries of similar size, and visualization of the aortic and ductal arches (Fig. 3, 4c). The author also mentioned that some cardiac anomalies, such as septal defects and evolving cardiac lesions, cannot always be visualized. Khalil and Nicolaides [38] proposed the following steps for cardiac evaluation in early pregnancy: assessment of the fetal position, orientation of the fetal heart, visualization of the 4-chamber view, assessment of the tricuspid valve and tricuspid regurgitation, visualization of the outflow tracts, and identification of the aortic and pulmonary arches.

Table 2. Visualization of fetal cardiac structures during the early ultrasound fetal cardiac examination between 11 and 13 + 6 weeks of gestation

	10 weeks	11 weeks	12 weeks	13 weeks	13 + 6 weeks
Four-chamber view	Yes	Yes	Yes	Yes	Yes
Outflow tracts	–	–	Yes	Yes	Yes
Aortic and ductal arches	–	–	Yes	Yes	Yes
Both cava veins	–	–	Yes	Yes	Yes
Pulmonary veins	–	–	–	Yes	Yes

Is There a More Practical Method to Evaluate the Fetal Heart in Early Pregnancy?

Quarello et al. [39] recently proposed a simplified examination to evaluate the fetal heart in low-risk populations at 11–13 + 6 weeks, including the 4-chamber and the 3-vessel and tracheal views using color or directional power Doppler ultrasound. They included 60 sonographers performing 597 ultrasound scans, either transabdominally or transvaginally, and reported 86 and 79% success rates for the adequate visualization of the 4-chamber view and the 3-vessel and tracheal views, respectively; in 7 and 8% of cases, respectively, the planes were seen but the images were not optimal; and in 7 and 13% of cases, respectively, it was not possible to obtain the planes. The authors reported that gestational age seems not to affect the success rate for obtaining a 4-chamber view; however, the 3-vessel and tracheal views were better visualized when the crown-rump length was >75 mm. A similar approach including the 4-chamber and the 3-vessel and tracheal views was performed by Wiechec et al. [40] who screened 1,084 women during the first trimester of pregnancy with a prevalence of cardiac defects of 3.2% ($n = 35$; 16 with aneuploidy). They reported a sensitivity of 88.7% for cardiac defects combining the 2 proposed planes as well as an improved detection rate when color Doppler was applied.

When Is the Optimal Time to Perform an Early Fetal Cardiac Evaluation?

The 4-chamber view and outflow tracts can be visualized in the majority of fetuses after 12 weeks of gestation, whereas at 11 weeks these structures can be seen in only 20–37% of fetuses [41, 42]. Some authors, such as Smrcek et al. [43], reported a high success rate for visualization of

cardiac structures starting at 10 weeks of gestation while obtaining the following planes: the 4-chamber view, 3-vessel view, origin and crossing of the great arteries, and aortic and ductal arches. They also recommended the transvaginal route and the use of color directional Doppler and power Doppler and unlimited scanning time to improve the detection rate of CHD.

Vimpelli et al. [44] reported an improvement in the visualization of the following anatomical planes: the 4-chamber view, longitudinal views of the aorta and pulmonary trunks, the crossing of the great arteries, and the aortic and ductal arches from 43% at 11 weeks to 62% at 13 + 6 weeks of gestation. The authors also mentioned that it is not always possible to visualize the aortic and ductal arches and the pulmonary veins at this gestational age. McAuliffe et al. [45], studying a high-risk group for fetal cardiac anomalies, reported that the aortic and ductal arches and the pulmonary veins were visualized in 45 and 16%, respectively, of fetuses at 13 + 5 weeks of gestation (Table 2).

Operator Experience and Route of Ultrasound Examination

Experience of the operators and technological resources are the main factors associated with a high detection rate of CHD [46]. Hartge et al. [47] studied a group of 3,521 pregnant women with a prevalence of 2.1% of CHD ($n = 77$). The ultrasound scans were performed by highly trained operators using state-of-the-art ultrasound systems with high-frequency transvaginal probes. They reported 85.7% detection rate of cardiac anomalies at 11–13 + 6 weeks of gestation. The authors mentioned that, in 64.2% of cases, only the transabdominal route for ultrasound evaluation was needed. The authors also reported that cardiac anoma-

Table 3. Studies on the diagnostic capacity of early ultrasound for the identification of congenital heart disease (CHD) (from 2000, older to newer)

Study	Total, <i>n</i>	Scan route	GA, weeks	Prevalence of CHD, <i>n</i> (%)	Early detection, <i>n</i> (%)
Mavrides et al. [95]	7,339	TA	10–14	24 (0.33)	4 (16.7)
Michailidis and Economides [96]	6,650	TA, TV	10–14	9 (0.14)	2 (22.2)
Orvos et al. [97]	4,309	TV	10–13	32 (0.74)	–
Taipale et al. [98]	4,789	TV	10–16	18 (0.38)	1 (5.6)
Chen et al. [99]	1,609	TA, TV	12–14	7 (0.44)	4 (57.1)
Bahado-Singh et al. [100]	8,167	TA	10–14	6 (0.07)	–
Bruns et al. [101]	3,664	?	11–14	9 (0.25)	–
Becker and Wegner [27]	3,094	TA, TV	11–14	11 (0.36)	6 (54.5)
Westin et al. [51]	16,260	TA	12–14	29 (0.18)	–
Muller et al. [102]	4,144	TA	10–14	13 (0.31)	–
Chen et al. [103]	7,642	TA	10–14	19 (0.25)	7 (36.8)
Hildebrand et al. [50]	21,189	?	11–14	62 (0.29)	0
Syngelaki et al. [53]	44,859	TA, TV	11–13	106 (0.24)	36 (34)
Volpe et al. [52]	4,445	TA, TV	11–14	28 (0.63)	23 (82.1)
Grande et al. [104]	13,723	TA, TV	11–14	44 (0.32)	25 (56.8)
Hartge et al. [47]	3,521	TA, TV	11–13 + 6	77 (2.1)	66 (85.7)
Iliescu et al. [26]	5,472	TA, TV	12–13 + 6	30 (0.54)	27 (90)
Persico et al. [56]	886	TA	11–13	100 (11.2)	96 (96)
Eleftheriades et al. [54]	3,774	TA	11–13 + 6	29 (0.77)	13 (44.8)
Volpe et al. [88]	870	TA	11–14	62 (0.17)	56 (90.3)

lies, such as coarctation of the aorta, hypoplastic left heart resulting from aortic stenosis, and tetralogy of Fallot, might not be identified during this stage of pregnancy. It is difficult to establish how many ultrasound scans are necessary to obtain an optimal degree of expertise. Tegnander et al. [48] reported that sonographers with previous experience of more than 2,000 examinations of the fetal heart had a 52% detection rate of CHD as compared to a 32.5% detection rate of operators performing fewer than 2,000 cardiac examinations. Rasiah et al. [49] performed a systematic review of the diagnostic performance of fetal echocardiography in the first trimester of pregnancy. They identified 10 studies conducted in tertiary centers with good quality control and reported a combined sensitivity of 85% (95% CI 78–90%) and specificity of 99% (95% CI 98–100%), a positive likelihood ratio (LR) of 59.6 (95% CI 26.5–133.6), and a negative LR of 0.25 (95% CI 0.1–0.6) for the identification of CHD. They mentioned that, although transvaginal ultrasound is thought to be a better modality for visualization of the fetal heart than transabdominal ultrasound, experienced operators using transabdominal ultrasound can lead to similar detection rates.

Detection of CHD at 11–13 + 6 Weeks of Gestation

Low-Risk Populations

Hildebrand et al. [50] evaluated a large group of 21,189 unselected pregnant women in southern Sweden where ultrasound scans were performed by trained midwives (Table 3). No congenital heart anomalies were detected during the first-trimester scans, and only 5.3% of CHD were identified in the second-trimester ultrasound scans. Westin et al. [51], in a large multicenter study, also from Sweden, reported an 11% detection rate of cardiac anomalies during routine fetal ultrasound examinations at 12 weeks of gestation and 15% at 18 weeks of gestation. In the 2 studies, the authors suggested that limited operator's expertise was associated with a low detection rate. Volpe et al. [52] studied 4,445 low-risk fetuses with a 0.9% prevalence of cardiac defects ($n = 42$). A total of 39 cases were identified prenatally, 29 (69%) during the first-trimester scans, and 10 (23.8%) at later stages of pregnancy. The authors mentioned that ultrasound markers, such as increased nuchal translucency, tricuspid regurgitation, and reversed atrial waveform in the ductus venosus, were associated with a higher prevalence of fetal cardiac defects. The authors also reported that an abnormal 4-cham-

Fig. 5. Abnormal 4-chamber view; atrioventricular septal defect (power Doppler ultrasound).

Fig. 6. Abnormal 4-chamber view; small left ventricle and increased thickness of the left ventricular walls. LA, left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle.

Fig. 7. Abnormal 4-chamber view; asymmetric size of the ventricles, early manifestation of a hypoplastic right ventricle. LA, left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle.

ber view had a 50% detection rate for major cardiac defects (Fig. 5).

Syngelaki et al. [53] studied nearly 45,000 patients at 11–13 + 6 weeks of gestation and reported an overall detection rate of 34% for cardiac anomalies, a 50% detection rate for hypoplastic left or right ventricles (Fig. 6, 7), transposition of the great arteries, and double outlet right ventricle; a 33% detection rate for coarctation of the aorta, tetralogy of Fallot, and atrioventricular septal defects and no acceptable detection rates for ventricular septal defects, Ebstein's anomaly, aortic and pulmonary stenosis, tricuspid atresia, and cardiac tumors.

Eleftheriades et al. [54] studied 3,774 fetuses with a prevalence of 0.77% of congenital heart anomalies ($n = 29$); 45% of them were identified at 11–13 + 6 weeks of gestation. The authors observed a high association between major cardiac defects and increased nuchal translucency and suggested that the evaluation of the 4-chamber view should be considered as part of the routine fetal examination in all pregnant women at 11–13 + 6 weeks of gestation.

Rossi and Prefumo [55] performed a systematic review of the evaluation of the fetal heart during the first trimester of pregnancy for a low-risk population. The overall diagnostic performance at 11–13 + 6 weeks for detection of CHD was 48%. They also mentioned that an apparently normal fetal cardiac examination at this gestational age does not exclude discovery of a cardiac defect later in pregnancy.

High-Risk Populations

Persico et al. [56] evaluated the fetal heart in 855 pregnant women undergoing chorionic villus sampling due to the presence of ultrasound markers or altered maternal biochemical markers suggestive of fetal chromosomal anomalies. They reported 100 (11.6%) cases for which a cardiac defect was suspected (54% major and 46% minor) and a 93.1% detection rate of cardiac anomalies using transabdominal ultrasound. A high association between CHD and increased nuchal translucency and tricuspid regurgitation was also documented.

Carvalho et al. [57] reported a 96% diagnostic accuracy for major cardiac defects at the end of the first and early second trimesters of pregnancy in 230 high-risk women referred due to increased nuchal translucency, a family history of CHD, or an abnormal routine ultrasound scan. Smrcek et al. [58] studied 2,165 fetuses from both low- and high-risk populations, using the combination of a 2-D ultrasound image and color directional Doppler, and reported a detection rate of 63.0% (29/46) for CHD. Fetuses with an abnormal cardiac examination had a prevalence of 65.8% for chromosomal anomalies; a prevalence of 51.2% for abnormal ductus venosus; and a prevalence of 32.2% for increased nuchal translucency. The authors mentioned that cardiac defects that tend to progress, such as myocardial hypertrophy, ventricular hypoplasia, fibroelastosis, and coarctation of the aorta, might not be identified during the ultrasound scan performed at 11–13 + 6 weeks.

Twin pregnancies have a higher risk of CDH. Best and Rankin [59] evaluated the prevalence of CHD in twins in North England from 1998 to 2010 and reported a prevalence of CDH in dichorionic twins of 1.3%, and of 2.5% in MC twins as compared to 0.7% in singleton pregnancies. The authors reported that among all CHD observed in twins, 68–74% were minor defects such as septal defects; 10.6–26% moderated defects such as pulmonary atresia or stenosis, common trunk, and transposition; and 4.2–6.4% severe anomalies such as hypoplastic left or right heart. They concluded that the risk of CHD increases to 49% in dichorionic twins and to 172% in MC twins compared to singleton pregnancies.

In MC twins, the prevalence of CHD increases in presence of twin-to-twin transfusion syndrome (TTTS) [60]. Bahtiyar et al. [61] reported that MC twins with TTTS had a relative risk (RR) of 15.4 (95% CI 9.78–23.13) for CHD as compared to MC twins without TTTS (RR 6.5, 95% CI 4.23–10.01). The cardiac defects more frequently reported were pulmonary stenosis and septal defects. MC/monoamniotic twins have the highest risk of CHD with a significantly increased prevalence of disturbances of laterality and heterotaxy [62, 63].

Bahtiyar et al. [64] studied the prevalence of CHD in pregnancies from ART. They evaluated 749 pregnancies resulting from in vitro fertilization and reported a prevalence of 1.1% risk for CHD. The authors concluded that in the past, more embryos were transferred, thus increasing the risk of CHD. Nevertheless, the risk is still higher than that from spontaneous pregnancies, and a detailed evaluation of the fetal heart is recommended in pregnancies from ART. Similar findings were reported by Heisey et al. [65]; they evaluated 4,064 pregnancies from ART and showed an increased risk (RR 1.54, 95% CI 1.12–2.12) for CHD as compared to spontaneous pregnancies. The authors also mentioned that this risk is mainly related to twin pregnancies. The mild increment in risk of CHD in pregnancies from ART has been also reported by other authors [66, 67].

Additional Imaging Modalities to Evaluate the Fetal Heart at 11–13 + 6 Weeks of Gestation

Spatiotemporal Image Correlation

For clear visualization of the fetal cardiac structures, four-dimensional spatiotemporal image correlation (STIC) volumes should be obtained using the highest quality of acquisition from an apical 4-chamber view, with the fetal spine located between the 5 and 7 o'clock

positions, without shadows from the ribs, without fetal or maternal movements or fetal breathing, with an angle of acquisition between 20 and 35° depending on gestational age, and with a normal heart rate [68, 69] (Fig. 8).

Four-dimensional ultrasound and STIC can be applied for the off-line evaluation of the fetal heart to confirm/exclude CHD [70]. Bennasar et al. [71] reported that an off-line evaluation of a STIC volume obtained at 11–13 + 6 weeks can adequately show the 4-chamber view, the crossing of the great vessels, left and right cardiac outflows, and the 3-vessel view. They reported excellent agreement among operators in the visualization of the 4-chamber view and outflow tracts when evaluating the same cardiac STIC volume. The same authors reported that STIC volumes in early pregnancy allowed the correct identification of 95% of fetuses with suspected cardiac anomalies [72]. Espinoza et al. [73] reported 79% sensitivity and 90% specificity for the identification of fetal cardiac defects using the STIC modality at 11–14 weeks of gestation. The authors concluded that the acquisition of cardiac STIC volumes and the evaluation by a fetal heart expert can be used to confirm/exclude the presence of a cardiac defect. Lima et al. [74] reported that the combination of color Doppler ultrasound and STIC volumes allowed identification of most fetal cardiac planes in 90.6% of patients. Tudorache et al. [75] also reported excellent reproducibility while obtaining STIC volumes for the evaluation of fetal cardiac structures during early pregnancy. Turan et al. [76] studied STIC fetal cardiac volumes during the first trimester of pregnancy; the authors were able to visualize in all fetuses the 4-chamber view, and in 85% of fetuses the following structures: descending aorta, heart size, cardiac axis, 2 equal-size atria and ventricles, 2 opening atrioventricular valves, 2 great arteries, the crossing and adequate size of the 2 great arteries, and the presence of the aortic and ductal arches with forward flow in both. Vinals et al. [70] reported the acquisition of STIC volumes during the first trimester of pregnancy and a successful interpretation by an experienced operator located remotely from the acquisition site.

Fetal Cardiac Function in Early Pregnancy

Assessment of early fetal cardiac function has been proposed for as early as 10 weeks of gestation by means of pulsed Doppler imaging and the presence of atrioventricular valve regurgitation [77]. Using M-mode in a transverse 4-chamber view, several authors reported an increment in the left and right ventricular shortening fractions in fetuses with trisomy 21 [78, 79]. In a large

Fig. 8. Spatiotemporal imaging correlation and tomographic ultrasound imaging showing 7 cross-sectional planes of the fetal heart at 13 + 2 weeks of gestation where the main cardiac structures can be seen.

study evaluating cardiac function in fetuses with chromosomal anomalies, the results showed that fetuses with trisomy 21 had a higher prevalence of an increased pulsatility index in the ductus venosus, increased E/A ratios, and a higher prevalence of tricuspid regurgitation as compared with fetuses with no chromosomal anomalies [80]. Turan et al. [81] reported reduced left E/A ratios, prolongation of the isovolumetric relaxation time (IRT) in both ventricles, reduction in the isovolumetric contraction time in the left ventricle, and a prolonged myocardial per-

formance index in the 2 ventricles in early pregnancy in fetuses from noncontrolled diabetic patients.

Fetal anemia can be caused by several conditions such as hemoglobinopathies, infection, hemorrhage, and red blood cell alloimmunization. In hemoglobinopathies, and especially in hemoglobin (Hb) Bart's disease, fetal hemodynamic changes can occur as early as in the first trimester of pregnancy and may lead to an increased cardiac workload. Ultrasound signs of cardiac dysfunction can be detected during the early phase of fetal adaptation,

Table 4. Congenital heart defects that can be identified during the early ultrasound fetal cardiac examination at 11–13 + 6 weeks of gestation

Cardiac defects that should be detected	Transposition of the great arteries Double outlet right ventricle Hypoplastic left heart
Cardiac defects that might be detected	Coarctation of the aorta Tetralogy of Fallot AV canal or atrioventricular septal defects Truncus arteriosus
Cardiac defects unlikely to be detected	Ventricular septal defects Ebstein’s anomaly Mild aortic and pulmonary stenosis Cardiac tumors Myocardial hypertrophy Fibroelastosis Abnormal pulmonary venous return

such as cardiac enlargement before the presence of fetal hydrops. Cardiomegaly, which may be simply determined by cardiac diameter/thoracic diameter ratio (CTR), is a good sonographic marker for fetal anemia in early gestation [82–84]. In the late first and early second trimesters of pregnancy (12–15 weeks of gestation), a CTR cut-off value of 0.5 has a 90.7% sensitivity and a 97.2% specificity for Hb Bart’s disease [83]. Recent studies on cardiac function have shown that fetuses affected with Hb Bart’s disease during the first trimester of pregnancy can show a significantly increased myocardial performance index ($p < 0.001$) as well as an increased isovolumetric contraction time ($p = 0.006$), whereas the IRT and ejection times (ET) did not change [85]. Both IRT and ET tend to increase in anemic fetuses during the second half of pregnancy [86].

Potential Risks for Evaluating the Fetal Heart at 11–13 + 6 Weeks

Due to the high rate of false positives and false negatives of the early fetal cardiac evaluation at 11–13 + 6 weeks, an extended cardiac examination might provide inaccurate information to the parents, and some of them might decide to terminate the pregnancy in a structurally normal heart (Table 4). Gardiner [87] reported that some cardiac structures, such as the atrioventricular septum and the offset of the mitral and tricuspid valves, might not be completely developed before 14 weeks of gestation,

and this was corroborated by high resolution epicardic microscopy. Volpe et al. [88] evaluated the contribution of the first and second trimester echocardiography to the diagnosis of CHD; they also suggested caution in defining the presence/absence of a CHD, as a considerable proportion of cases showing an abnormal cardiac examination might actually have a structurally normal heart.

Conclusions

Early evaluation of the fetal heart as a screening or an indicated procedure should be considered in women with (1) a family or obstetrical history of CHD; (2) any fetal noncardiac structural defect, increased nuchal translucency, tricuspid regurgitation, reversed atrial waveform in the ductus venosus, ARSA, abnormal cardiac axis, or hydrops; (3) MC twins; and (4) pregnancies resulting from ART.

Experience and training of the operators are the most important factors related to a successful identification of fetal cardiac defects. Working with low-risk groups, well-trained operators can achieve a 40–50% detection rate of CHD, whereas for high-risk women, this detection can increase to >80% [89, 90].

Before 12 weeks of gestation, transvaginal ultrasound provides adequate images for cardiac examination, whereas from 12 weeks of gestation onward, transabdominal ultrasound provides reliable fetal cardiac images.

The 4-chamber and outflow tract views are the most important ultrasound planes to achieve good detection of CHD.

The 4-chamber and outflow tract views can be identified from 12 weeks of gestation onward in almost all fetuses. The majority of cardiac planes of the basic (4-chamber view and outflow tracts [34]) and extended (upper abdomen, 4-chamber view, 5-chamber view, bifurcation of the pulmonary artery, 3-vessel and tracheal view, and the short axis of the right ventricle [37]) fetal cardiac evaluations can be obtained from 13 weeks of pregnancy.

Disclosure Statement

The authors declare no conflicts of interest.

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