

Fetal echocardiography at 11–13 weeks by transabdominal high-frequency ultrasound

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ABSTRACT

Objectives To assess the accuracy of fetal echocardiography at 11–13 weeks performed by well-trained obstetricians using a high-frequency linear ultrasound transducer.

Methods Fetal echocardiography was performed by obstetricians immediately before chorionic villus sampling for fetal karyotyping at 11–13 weeks. Digital videoclips of the examination stored by the obstetrician were reviewed offline by a specialist fetal cardiologist.

Results The obstetrician suspected 95 (95%) of the 100 cardiac defects identified by the fetal cardiologist and made the correct diagnosis in 84 (84%) of these cases. In 54 fetuses, the defect was classified as major and in 46 it was minor. In 767 (86.6%) cases, the heart was normal and in 19 (2.1%) the views were inadequate for assessment of normality or abnormality. A subsequent second-trimester scan in the normal group identified major cardiac defects in four cases. Therefore, the first-trimester scan by the obstetricians and cardiologists identified 54 (93.1%) of the 58 major cardiac defects.

Conclusions A well-trained obstetrician using high-resolution ultrasound equipment can assess the fetal heart at 11–13 weeks with a high degree of accuracy. Copyright © 2011 ISUOG. Published by John Wiley & Sons, Ltd.

INTRODUCTION

Abnormalities of the heart and great arteries are the most common congenital defects and account for approximately 20% of all stillbirths and 30% of neonatal deaths due to congenital defects¹. Several studies have established that routine ultrasound screening

in pregnancy fails to identify the majority of fetuses with major cardiac defects^{2,3}. By contrast, the majority of such defects are amenable to prenatal diagnosis by specialist fetal echocardiography^{4,5}. Consequently, effective population-based prenatal diagnosis necessitates improved methods of identifying the high-risk group for referral to specialists and/or improved standards of scanning in those undertaking routine screening.

Traditionally, high-risk groups have been identified for referral for specialist fetal echocardiography, for example, those with a family history of cardiac defects, maternal history of diabetes mellitus and maternal exposure to teratogens. However, the performance of this method of screening is poor, with a detection rate of only approximately 10% of cases of fetal cardiac defects⁶. A major improvement in screening for cardiac defects came with the widespread introduction of four-chamber view screening during the routine mid-trimester scan⁷. First-trimester screening for aneuploidies by measurement of fetal nuchal translucency (NT) thickness identified another important high-risk group⁸. A meta-analysis of studies examining the screening performance of NT thickness for the detection of cardiac defects in euploid fetuses reported that the detection rate was 23% for an NT cut-off of the 99th centile⁹. There is also evidence that the detection rate may be improved further by the additional early sonographic markers of aneuploidy, abnormal flow through the ductus venosus¹⁰ and across the tricuspid valve¹¹. In the presence of abnormal flow, the risk for cardiac defects in euploid fetuses is increased.

In the last 10 years, as a consequence of inclusion of 'aneuploidy sonographic markers' in screening for cardiac defects, there has been a shift in specialist fetal echocardiography from the second to the first trimester of pregnancy^{12,13}. A technical limitation in such early echocardiography is visualization of the desired structures.

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The aim of this study was to assess the accuracy of fetal echocardiography at 11–13 weeks, performed by well-trained obstetricians, in women at high risk for aneuploidies using high-frequency linear ultrasound.

METHODS

In this prospective study, fetal echocardiography was performed between April 2008 and May 2009, immediately before chorionic villus sampling (CVS) for fetal karyotyping. The women chose to have CVS after risk assessment by a combination of maternal age, fetal NT thickness, assessment of the nasal bone, blood flow in the ductus venosus or flow across the tricuspid valve, and maternal serum-free β -human chorionic gonadotropin and pregnancy-associated plasma protein-A¹⁴. In a minority of cases, CVS was carried out for maternal request or for genetic testing. Maternal weight and height were measured on the day of the scan and maternal body mass index (BMI) was calculated in kg/m². Echocardiography was undertaken by obstetricians with extensive experience in second-trimester anomaly scanning and first-trimester ultrasound.

All examinations were carried out transabdominally using a 9-MHz linear transducer (9L, Acuson Sequoia 512, Imagegate, Siemens, Erlangen, Germany). In each case, we aimed to demonstrate the following: 1) abdominal situs and position of the heart within the chest; (2) four-chamber view of the heart to show first, atrioventricular valve offsetting (Figure 1) and second, equal filling of the ventricles with the use of color flow mapping (Figure 2); (3) crossing of the aorta and the main pulmonary artery (X sign) by color Doppler (Figure 3); and (4) forward flow and equal size of the aortic arch and the ductus arteriosus at their confluence (V sign) by color flow mapping (Figure 4).

Digital videoclips of the cardiac scans were stored in the ultrasound equipment and subsequently exported to a DVD for offline review by a fetal cardiologist, who was not aware of the obstetrician's assessment, NT measurement, any extracardiac ultrasound findings or the fetal karyotype.

The outcome data included transabdominal fetal echocardiography at 18–22 weeks by a specialist fetal cardiologist or an obstetrician with experience in fetal cardiology and/or neonatal clinical examination.

The Mann–Whitney *U*-test was used to compare maternal BMI and fetal crown–rump length (CRL) between patients in whom adequate views of the fetal heart were obtained and the group of unsuccessful examinations. The data were analyzed using the statistical software SPSS 12.0 (SPSS, Chicago, IL, USA) and Excel for Windows 2000 (Microsoft Corp., Redmond, WA, USA).

RESULTS

The median maternal age was 35.6 (range 16–46) years and the median maternal BMI was 24.2 (range

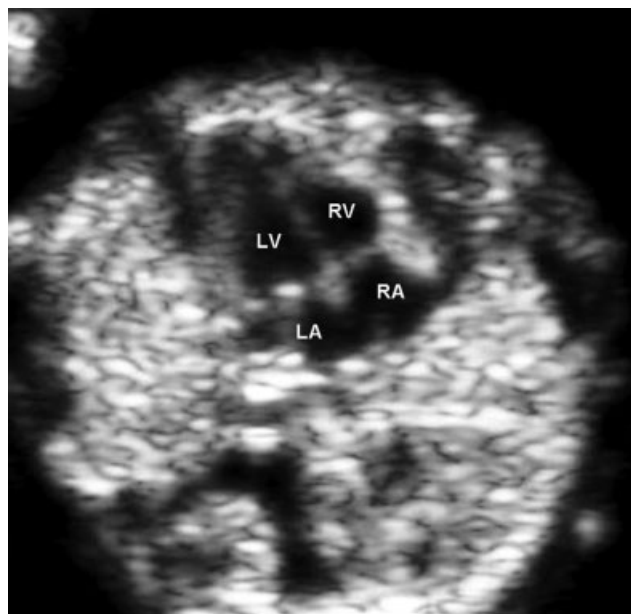


Figure 1 Ultrasound image at 12 weeks demonstrating a normal four-chamber view with equal ventricles and normal offsetting of the atrioventricular valves. LA, left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle.

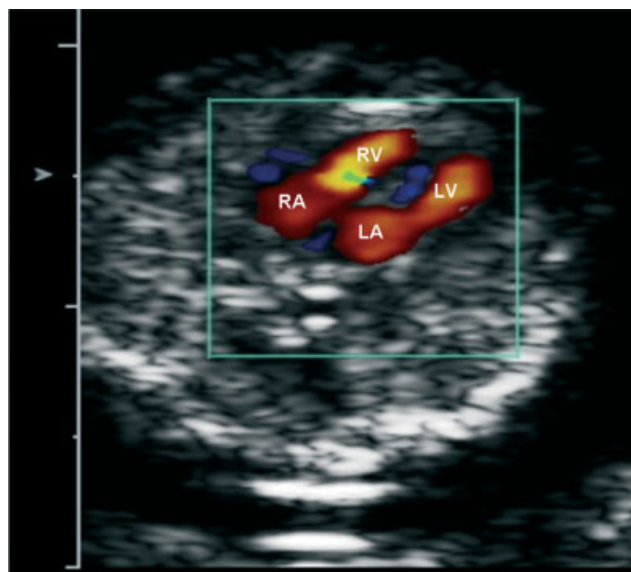


Figure 2 Color Doppler image at 12 weeks demonstrating a normal four-chamber view with forward flow and equal filling of both ventricles. LA, left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle.

15–55) kg/m². The median fetal CRL was 68.7 (range 45–84) mm.

In the first-trimester scan carried out by obstetricians, the heart appeared normal in 772 (87.2%) of the 886 cases and abnormal in 95 (10.7%) cases. In 19 (2.1%) cases, the views were inadequate for assessment of normality or abnormality. The cardiologists who reviewed the videoclips of the cardiac scans were in agreement with the findings of the obstetricians in defining normality or abnormality of the heart, except in five cases in which the examiner thought that the heart was normal,

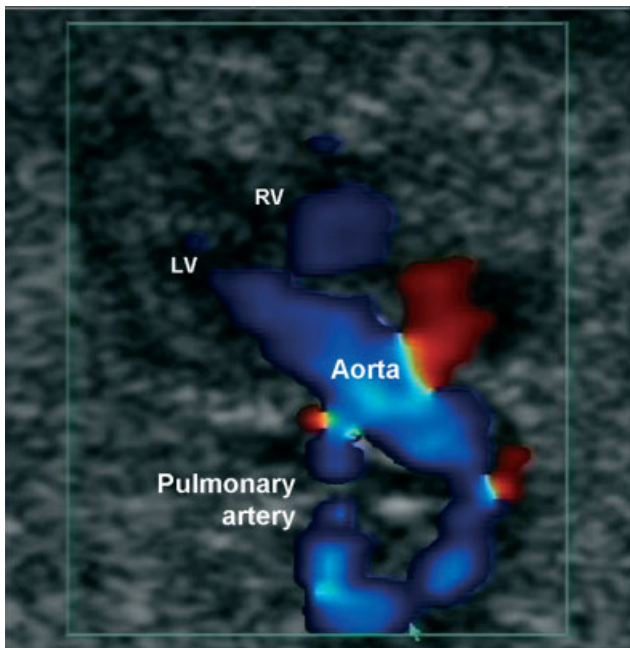


Figure 3 Color Doppler image at 12 weeks demonstrating crossing of the aorta and the pulmonary artery (X sign).

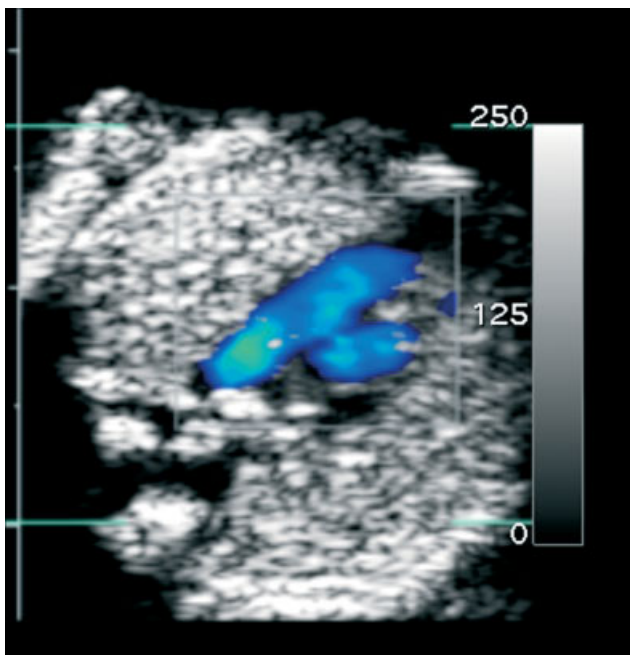


Figure 4 Color Doppler image at 12 weeks demonstrating forward flow and equal size of the aortic arch and the ductus arteriosus at their confluence (V sign).

but the cardiologist found disproportion of the ventricles and/or the great arteries. Therefore, the first-trimester scan would have identified 100 cases with cardiac defects. In 84 (84%) of these cases, the description of the cardiac defect reported by the obstetrician was in agreement with that of the cardiologist, but in seven (7%) cases the latter identified additional features to those reported by the obstetrician. In four (4%) cases there was agreement on the fact that the heart was abnormal, but the obstetrician's diagnosis was different from the one made by the cardiologist.

The 100 cases with suspected cardiac defects included 54 (54%) in which the defect was classified as major and 46 (46%) in which it was classified as minor. Fetal cardiac defects are defined as major if they are either lethal or require surgery or interventional cardiac catheterization during the first year of postnatal life. The types of cardiac defects diagnosed at the 11–13-week scan and their frequency in relation to different fetal karyotypes are shown in Table 1. The most common major abnormality was atrioventricular septal defect (Figure 5) and the predominant minor abnormality was disproportion of the ventricles and/or the great arteries (Figure 6).

A verification of the early ultrasound findings by fetal echocardiography at 18–22 weeks and/or neonatal clinical examination was available in 622 (91%) of the 686 continuing pregnancies with adequate views at the 11–13-week scan, including 19 cases of fetal cardiac defect (Table 2). In 169 cases, the patients opted for termination of pregnancy following diagnosis of chromosomal or genetic abnormality or severe structural defects, and there were 12 cases of miscarriage. The second-trimester scan identified four major cardiac defects that had been missed in the first-trimester scan. Review of the first-trimester videoclips for these four cases confirmed that in two cases the heart looked normal (one each of partial atrioventricular septal defect and pulmonary stenosis), but in the other there was a defect that had been missed (one case of tetralogy of Fallot and one of left atrial isomerism). Therefore, there were 58 major cardiac defects and 54 (93.1%) of these were diagnosed in the first trimester. Of the 19 cases with inadequate views at the 11–13 weeks' scan, a normal heart was documented by a later scan or after birth in 12 cases. In the remaining seven cases, the parents opted for termination of pregnancy due to a chromosomal abnormality or a genetic disease.

There was no significant difference in mean maternal BMI (25.2 vs. 28.7 kg/m², $P = 0.059$) or CRL (68.5 vs. 66.2 mm, $P = 0.288$) between the cases in which a successful examination was carried out and those in which adequate views of the heart could not be obtained. Table 3 illustrates the proportion of scans in relation to different CRL ranges, including cases in which the heart was thought to be normal at 11–13 weeks and found to be abnormal in the second trimester and those with inadequate views.

Tricuspid regurgitation was found in 78 (11.2%) of the 696 euploid fetuses, 56 (63.6%) of the 88 fetuses with trisomy 21, 12 (40%) of the 30 fetuses with trisomy 18, 4 (36.3%) of the 11 fetuses with trisomy 13 and 1 (5.2%) of the 19 fetuses with Turner syndrome. The frequency distribution of tricuspid regurgitation in cases with a cardiac defect and those with a normal heart was 16 (61.5%) of 26 and 62 (9.2%) of 670 in euploid fetuses, 23 (82.1%) of 29 and 33 (55.9%) of 59 in fetuses with trisomy 21, 8 (53.3%) of 15 and 5 (33.3%) of 15 in fetuses with trisomy 18, 4 (40%) of 10 and 0 (0%) of 1 in fetuses with trisomy 13, and 1 (8.3%) of 12 and 0 (0%) of 7 in fetuses with Turner syndrome.

Table 1 Cardiac findings at the 11–13-week scan and their relation to fetal karyotype

Cardiac defect	n	Abnormal karyotype					
		All	T21	T18	T13	Turner	Other
Normal heart	767*	95 (12)	60	15	1	7	12
Minor defect	46	—	—	—	—	—	—
Cardiomegaly	5	5 (100)	—	—	2	—	3
Ventricular septal defect	2	2 (100)	—	2	—	—	—
Disproportion	39	33 (85)	9	6	6	8	4
LV < RV	12	10 (83)	2	2	2	2	2
Ao < PA	4	4 (100)	1	1	—	2	—
LV < RV, Ao < PA	15	12 (80)	2	1	3	4	2
LV < RV, PA < Ao	1	0 (0)	—	—	—	—	—
RV < LV	2	2 (100)	1	1	—	—	—
RA > LA	5	5 (100)	3	1	1	—	—
Major defect	54	—	—	—	—	—	—
Atrioventricular septal defect	23	20 (87)	16	2	—	1	1
Transposition of great arteries	3	0 (0)	—	—	—	—	—
Tetralogy of Fallot	9	4 (44)	2	1	—	—	1
Hypoplastic left heart	2	2 (100)	—	—	—	2	—
Pulmonary atresia	2	1 (50)	1	—	—	—	—
Complex defect	11	9 (82)	—	4	2	1	2
Other	4	0 (0)	—	—	—	—	—

Data are given as *n* or *n* (%). *Includes four cases in which the second-trimester scan demonstrated major cardiac defects. T13, trisomy 13; T18, trisomy 18; T21, trisomy 21; Ao, aorta; LA, left atrium; LV, left ventricle; PA, pulmonary artery; RA, right atrium; RV, right ventricle.

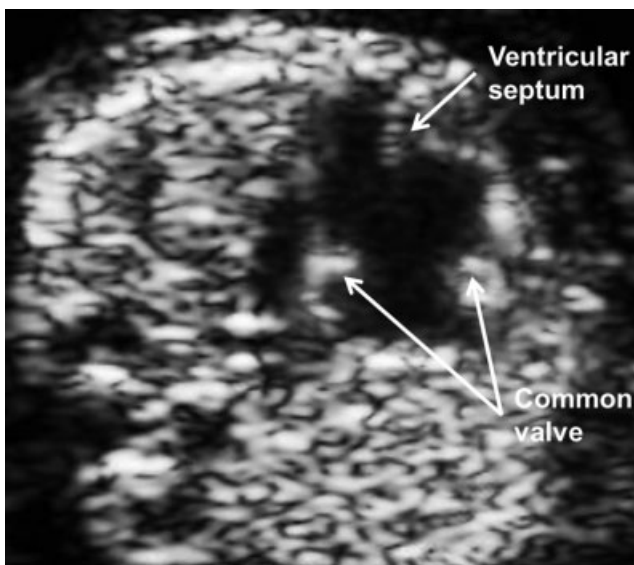


Figure 5 Ultrasound image at 12 weeks showing a complete atrioventricular septal defect with a large ventricular component.

The incidence of cardiac defects, in all cases with adequate ultrasound views at 11–13 weeks or with available follow-up data, increased with fetal NT thickness from 3.5% (17 of 479) for NT < 2.5 mm, to 7.1% (15 of 211) for NT 2.5–3.4 mm, 20.6% (14 of 68) for NT 3.5–4.4 mm, 28.6% (10 of 35) for NT 4.5–5.4 mm and 50.0% (43 of 86) for NT ≥ 5.5 mm ($P < 0.004$).

DISCUSSION

The findings of this study confirm the high association between increased fetal NT and fetal cardiac defects and therefore the need for fetal echocardiography in such

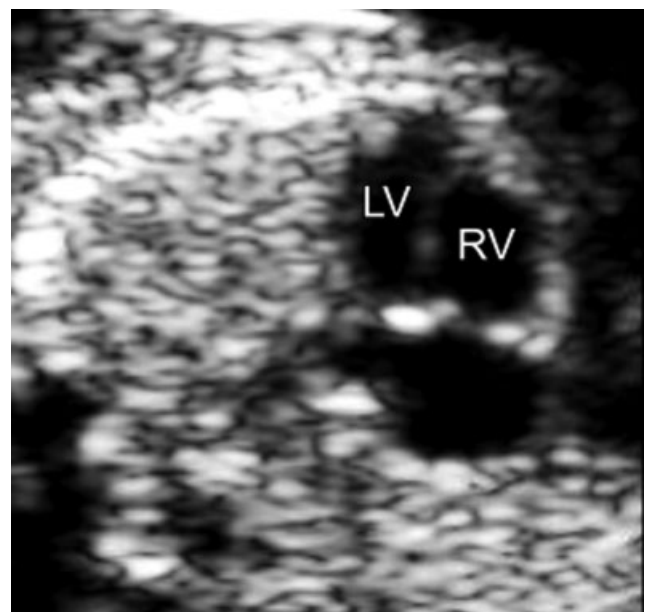


Figure 6 Ultrasound image at 12 weeks showing ventricular disproportion. LV, left ventricle; RV, right ventricle.

cases. The data demonstrate that in a high-risk population successful transabdominal ultrasound assessment of the fetal heart can be carried out at 11–13 weeks by well-trained obstetricians in > 95% of cases and that > 90% of major cardiac defects can be identified at this gestation.

Three factors are likely to have contributed to the high success rate in the early assessment of the fetal heart. First, we examined a high-risk population in a department with extensive experience in both the 11–13-week scan and early fetal echocardiography. A previous study on fetal echocardiography at 13–15 weeks reported that the rate

Table 2 Cardiac findings in the 19 fetuses with a cardiac defect diagnosed at 11–13 weeks for which follow-up data were available

<i>Cardiac findings at:</i>		
<i>11–13 weeks</i>	<i>18–22 weeks</i>	<i>Outcome</i>
Atrioventricular septal defect	Atrioventricular septal defect	Termination
Atrioventricular septal defect	DORV, PS	Termination
Atrioventricular septal defect, LAI	Atrioventricular septal defect, LAI	Fetal death (31 weeks)
LAI	Atrioventricular septal defect, LAI, PS	Termination
Transposition of great arteries	Transposition of great arteries	Fetal death (32 weeks)
Transposition of great arteries, PS, VSD	Transposition of great arteries, PS, VSD	Termination
Tetralogy of Fallot	Tetralogy of Fallot	LB, tetralogy of Fallot
Tetralogy of Fallot	Tetralogy of Fallot	LB, tetralogy of Fallot
Tetralogy of Fallot, pulmonary atresia	Tetralogy of Fallot, pulmonary atresia	Termination
Tetralogy of Fallot, RAA	Tetralogy of Fallot, RAA	LB, tetralogy of Fallot, RAA
Complex cardiac defect	Tetralogy of Fallot	LB, tetralogy of Fallot, multiple VSDs
Ebstein's anomaly	Ebstein's anomaly	Termination
Cardiomegaly	Cardiomegaly	Fetal death (40 weeks)
Disproportion LV < RV, Ao < PA	Possible coarctation of the aorta	Miscarriage
Disproportion LV < RV, Ao < PA	Possible coarctation of the aorta	Termination
Disproportion LV < RV, Ao < PA	Coarctation of the aorta, VSD	Fetal death (28 weeks)
Disproportion LV < RV, Ao = PA	Coarctation of the aorta	LB, coarctation of the aorta
Disproportion LV < RV, Ao = PA	Possible coarctation of the aorta	LB, normal arch
Disproportion LV < RV, PA < Ao	Tetralogy of Fallot, DORV	Termination

Ao, aorta; DORV, double outlet right ventricle; LAI, left atrial isomerism; LB, live birth; LV, left ventricle; PA, pulmonary artery; PS, pulmonary stenosis; RAA, right aortic arch; RV, right ventricle; VSD, ventricular septal defect.

Table 3 Proportion of scans carried out at 11–13 weeks in relation to different crown–rump length ranges

	n	<i>Fetal crown–rump length</i>		
		<i>45–59 mm</i>	<i>60–74 mm</i>	<i>75–84 mm</i>
Normal heart	763	128 (16.7)	418 (54.8)	217 (28.5)
Cardiac defect	100	38 (38)	46 (46)	16 (16)
Missed diagnosis	4	1 (25)	1 (25)	2 (50)
Inadequate views	19	7 (36.8)	7 (36.8)	5 (26.4)

Data are given as *n* or *n* (%).

of adequate visualization of the heart was much higher in the high-risk group than in the low-risk population (77% vs. 48%)¹⁵. Second, we used transabdominal rather than transvaginal sonography. Although in transvaginal scanning the high frequency of the transducers and the small distance between the ultrasound source and the fetus provide a high resolution of the fetal organs examined, this approach is dependent on fetal position and has a lower flexibility in terms of the ability to examine different scanning planes. A recent study on a large number of patients by Ebrashy *et al.*¹⁶ showed that transvaginal ultrasound improves the rate of adequate visualization of most of the fetal organs at 11–13 weeks, but there was no difference between the two approaches in the rate of successful examination of the fetal heart (61.4% vs. 62.7%, $P = 0.414$).

The third factor which contributed to the high success rate in the assessment of the first-trimester fetal heart was the use of a high-frequency linear transducer which provides a high resolution to a depth of at least 8 cm. This is particularly useful in first-trimester scanning because the organs are small and the depth of the fetus is rarely > 8 cm. The linear transducer also provides a high-color spatial

resolution which is essential for accurate examination of the first-trimester heart through demonstration of forward flow to both ventricles, exclusion of large ventricular septal defects and assessment of the outflow tracts. The convex probe most commonly used in obstetric ultrasound has been designed for second-trimester imaging because it provides a large field of view and deep penetration to allow visualization of fetal organs many of which are often > 8 cm away from the transducer at this gestation. However, the consequence of the divergent ultrasound beams produced by the convex probe is a decrease in image line density and therefore lower resolution in both B-mode and color flow imaging with increasing depth. A previous study¹⁷ using a linear transducer also reported a high rate of successful examinations of the fetal heart. Lombardi *et al.*¹⁷, examined 608 patients at 11–13 weeks, including three with cardiac defects, and reported successful examination of the heart in 99% of the cases and diagnosis of all cardiac defects.

Our data show that, in the vast majority of cases, a well-trained obstetrician can correctly distinguish between a normal and abnormal heart at 11–13 weeks and make the correct diagnosis in the presence of a cardiac defect. In addition, our results suggest that all cases classified as abnormal should be referred for specialist fetal echocardiography if this service is available, for better evaluation of the abnormality, to confirm the correct diagnosis and to provide appropriate counseling to the parents. In addition, in all continuing pregnancies, the early scan should always be followed by a midtrimester assessment of cardiac anatomy to confirm normality of the fetal heart, to monitor and reassess those cases with abnormal findings at 11–13 weeks, and to identify the few cardiac defects missed in the first trimester.

In approximately 70% of our fetuses with cardiac defects the karyotype was abnormal and this is the likely explanation for the frequency distribution of the defects we observed. The predominant major abnormality was an atrioventricular septal defect and 87% of these had aneuploidy, mainly trisomy 21. Similarly, the predominant minor abnormality was disproportion of the ventricles and/or the great arteries, and 85% of these had aneuploidy. In five of the six continuing pregnancies with a diagnosis of disproportion at 11–13 weeks, coarctation of the aorta was suspected or diagnosed at the midtrimester scan. In one of these cases, the diagnosis was confirmed by postnatal echocardiography, whereas in another case with suspected coarctation prenatally the heart was found to be normal after birth (Table 2). In three cases, the pregnancy resulted in a second-trimester miscarriage or intrauterine death. Disproportion of the ventricles and/or the great arteries before 28 weeks is a nonspecific cardiac finding which can be associated with chromosomal abnormalities, major cardiac defects and adverse pregnancy outcome, or can represent a temporary finding in an otherwise normal heart.

A limitation of this study is the nonavailability of post-mortem examination in cases in which parents opted for termination of pregnancy because of aneuploidy or major fetal defects. However, in all cases, the final diagnosis was made by pediatric cardiologists with extensive experience in fetal echocardiography. In addition, in the majority of cases, the early ultrasound findings were confirmed by second-trimester fetal echocardiography and/or neonatal clinical examination.

Our results confirm that tricuspid regurgitation at 11–13 weeks is more commonly found in fetuses with chromosomal abnormalities, above all trisomy 21, than in euploid fetuses. In addition, the prevalence of tricuspid regurgitation in our study was higher in fetuses with cardiac defects than in those with a normal heart, regardless of fetal karyotype. Ultrasound assessment of tricuspid flow increases substantially the performance of first-trimester combined screening for chromosomal abnormalities¹¹. In the same ultrasound view required to assess tricuspid flow it is possible to evaluate the four chambers of the fetal heart. Once this view is obtained, the use of color Doppler and a slow sweep of the transducer toward the fetal head can easily allow demonstration of arterial crossing and forward flow in the aortic and ductal arches.

This study cannot be used to define the performance of first-trimester fetal echocardiography in the detection of cardiac defects in an unselected population, but it demonstrates the high performance of such a scan carried out by a well-trained obstetrician in patients referred to specialist centers.

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