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Prenatal diagnosis of congenital anomalies

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Abstract

Up till the early 1970s, prenatal diagnosis of congenital anomalies was primarily aimed at detecting chromosomal abnormalities by amniocentesis.¹ Over the last two decades, prenatal diagnosis has greatly benefited from advances in ultrasound technology and in our ability to detect microscopic and submicroscopic chromosome abnormalities as well as single gene disorders, leading to substantive improvements in detection of such congenital anomalies.² At present, invasive prenatal diagnosis continues to be the gold standard for pregnancies at increased risk for chromosomal anomaly or other genetic disease, with chorionic villus sampling being the procedure of choice for the first trimester,³ whereas mid-trimester amniocentesis continues to be the most common form of invasive procedure for prenatal diagnosis.⁴ Still, invasive techniques are restricted to subgroups at risk for anomalies, for whom such time-consuming procedures are believed to be cost-effective, also accounting for procedure-related abortive risks. In the low-risk population prenatal diagnosis generally consists of screening procedures by means of ultrasound and maternal serum biochemistry.

MeSH: prenatal diagnosis, ultrasonography, fetal anomalies, heart defects, congenital, fetal echocardiography

The distinction should be made clear between a diagnostic and a screening test. The former confirms or refutes the existence of an actual anomaly in a fetus believed to be at increased risk, whereas the latter identifies an increased likelihood of a fetal abnormality in an apparently normal pregnancy.⁵ The value of a screening test is outlined by the fact that most congenital anomalies are found among newborns from pregnancies with no risk factors. At our institution in Turin, 92% of 320 central nervous system anomalies and 70% of 350 cardiac malformations prenatally detected over the last 10 years were found in low-risk population.

1. Ultrasound in prenatal diagnosis

Diagnostic potential of ultrasound

Initial data on the potential of ultrasound for detecting structural malformations were derived from populations at specific risk investigated at centers of excellence by expert operators, with sensitivities as high as 85-90% (Fig 1-4).⁶ Those promising data could not be replicated in the general population. Indeed, data on detection rates using ultrasound for screening for fetal malformations do vary widely, showing a range from 8.7% to 85%.⁷ Such wide differences reflect varying criteria for definition of malformation, postnatal examination, selection of study population, prevalence of specific anomalies within a population, and other methodology issues (e.g., single hospital versus multicenter setting, expertise and skills of operators, use of standardized protocols for ultrasonographic examination).⁸

Fig. 1 Duodenal atresia at 28 weeks of gestational age. Transverse scan of the abdomen (ST, stomach; D, dilatated duodenal bulb; SP, fetal spine)



Fig. 2 Umbilical cord at the level of insertion into the fetal abdomen. Hemangioma (arrows); UC, umbilical cord; P, pseudocyst



Fig. 3 Bilateral polycystic kidney. Transverse section of the abdomen at 28 weeks (K, kidney; S, fetal spine)

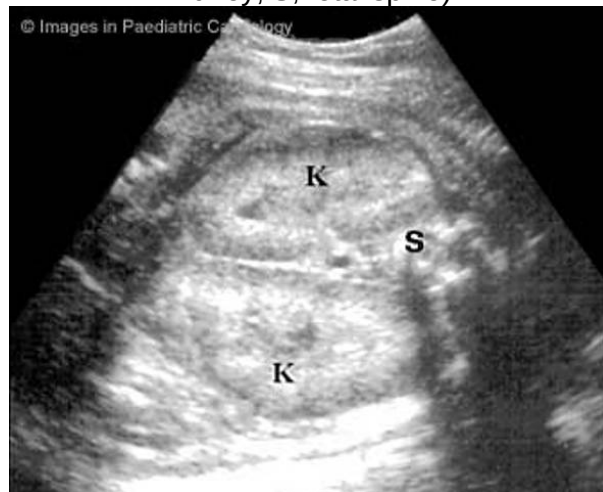
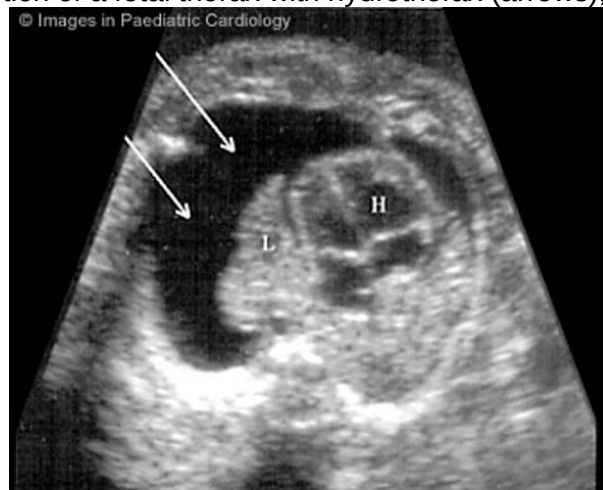


Fig 4 Cross section of a fetal thorax with hydrothorax (arrows); L, lung; H, heart



Additional imaging techniques

Magnetic resonance imaging may help investigate specific anomalies, such as agenesis of corpus callosum, posterior fossa cysts, cerebral cleft, migrational disorders such as lissencephaly.⁹ Use of magnetic resonance imaging is nonetheless uncommon in clinical practice, being restricted to specific indications.¹⁰

Ultrasound screening

Ultrasound imaging is now routinely used in most European countries for the purpose of screening pregnancies for fetal malformations. The modalities, reliability and value of such screening, however, are controversial.

Screening for fetal structural anomalies

As to the time in pregnancy at which ultrasound screening should be performed, it should be first noted that most structural anomalies are increasingly detected with advancing gestation.¹¹ In early pregnancy, it is possible to recognise with confidence certain types of fetal malformations, like anencephaly, which can be reliably diagnosed at 10-14 weeks of pregnancy.¹² In some cases omphalocele and limb anomalies are also definable using ultrasound in the first trimester, while other structural anomalies, like urinary tract abnormalities, are detectable later in pregnancy.¹³

Screening for neural tube defects may ideally involve ultrasound examination in conjunction with maternal serum alpha-fetoprotein screen.¹⁰ On comparison of the two methods, maternal serum screening was found to have a slightly greater sensitivity compared to ultrasound.¹⁴

Ultrasound screening for fetal structural abnormalities is generally recommended at 19-21 weeks of gestational age. The accuracy in detecting malformations by ultrasound, however, shows great variability among centres and operators. In one multicenter study, the accuracy of ultrasonographic studies performed before 24 gestational weeks was compared between tertiary versus nontertiary ultrasound laboratories involved, all of which were equipped with state-of-the-art equipment and were provided with in-service training, review and additional training conducted as necessary. Nonetheless, the overall sensitivity for ultrasonographically detectable fetal malformations was 35% in tertiary facilities significantly higher compared to 13% in community hospitals, suggesting that operator experience, skills, and training are important determinants.⁸ Other factors affecting sensitivity are: single vs multicentre study, type of malformation (major vs minor, single vs multiple, natural history of the disease during fetal life), gestational age at ultrasound examination, length and accuracy of follow-up (some malformations are detected in early or even late infancy).¹⁵ In a European multicenter study involving 3686 malformed fetuses the overall detection rate was 56%, but only 44% of the cases were diagnosed before 24 weeks.¹¹ As shown in Table 1, sensitivity was higher for some and lower for other malformations.

Table 1 Sensitivity of ultrasound by type of anomaly in 4615 malformations¹¹

Anomaly	Prevalence (%) of all anomalies	Sensitivity (%)
Central nervous system	16	88
Cardiovascular	21	28
Musculoskeletal	23	37
Urinary tract	21	88
Digestive system	5	54
Cleft lip and palate	7	18
Total	100	56

Therefore, prevalence data of specific malformations in different studies also affect overall sensitivity of ultrasound within a given population. (Table 2).^{16–18}

Screening for chromosomal anomalies

In the late 1990's, ultrasound screening at 10-14 weeks has increasingly included measurement of nuchal translucency, which is the maximum thickness of the subcutaneous translucency between the skin and the soft tissue overlying the cervical spine of the fetus.¹⁹ An increased nuchal translucency is associated with aneuploidy and cardiac malformations.²⁰

Either combined with ultrasound results or alone, maternal serum biochemistry is also used for screening for chromosomal anomalies toward the end of the first trimester or in the early midtrimester.²¹

As previously said, ultrasound at around 20-21 weeks has long been considered for screening pregnancies for structural malformations. Use of second trimester ultrasound for detection of chromosomal anomalies was first suggested in 1985.²² Chromosomal defects were progressively found to be associated with certain sonographic features, including biometric parameters (e.g., short length of femur and humerus, pyelectasis, large nuchal fold, ventriculomegaly, early fetal growth

restriction) and morphologic signs (e.g., choroids plexus cysts, echogenic bowel, echogenic intracardiac focus). Data on the validity of those markers as predictors of chromosomal anomalies (mostly related to Down syndrome) are at variance depending upon the author.²³ Their reliability is undoubtedly increased in pregnant women at increased risk for Down syndrome, but the positive predictive value for each marker is dramatically decreased in low-risk women when applying the Bayes' theorem.²⁴ Also, "Down syndrome markers" make up a heterogeneous group, including common findings in normal fetuses, like the echogenic intracardiac focus which occurs in approximately 5% of fetuses. As a result, ultrasound soft markers lead to a small increase in detection of congenital anomalies but a large increase in false positives. The detection of any of the above markers during a routine sonogram warrants careful scanning aimed at identifying additional markers because the finding of multiple markers indicates high risk for chromosomal anomaly.²⁵ Notably, computerised programmes have been developed which permit to estimate the adjusted risk for aneuploidy by combining background risk (based on maternal age) and biochemical screening together with the above ultrasound features.²⁶ These are useful when a marker is a chance finding during routine ultrasound scanning. However, at present, in the absence of studies validating second trimester sonography for the purpose of screening the general population for chromosomal anomalies, such use of ultrasound is not a recommended procedure.²⁷ For example, it has been shown that the inclusion of soft markers when screening at 20 – 22 weeks improves the detection rate of malformations from 50% to 54%; however, it also increases the number of false positive results from 0.04% to 0.53%.²⁸ In this study two terminations of pregnancies carrying unaffected fetuses were performed. Moreover, the finding of a marker may adversely affect the pregnancy due to anxiety caused to the mother.²⁹

Table 2 Accuracy of second trimester ultrasound screening by prevalence of type of malformations and study setting

Author (year)	Overall sensitivity (%)	Specificity (%)	Relative prevalence (%) of <u>central nervous system</u> anomalies	Relative prevalence (%) of <u>cardiovascular</u> anomalies	Relative prevalence (%) of <u>digestive system</u> anomalies	Relative prevalence (%) of <u>urogenital</u> anomalies	Relative prevalence (%) of <u>skeletal</u> anomalies
Lys** (1989) ¹⁷	18	> 99	12	30	7	17	27
Rosendhal* (1989) ¹⁶	63	> 99	18	22	25	33	9
Todros* (1992) ¹⁸	65	> 99	16	20	12	28	15

* single center

** multicenter

Cardiac malformations

Epidemiology

Twenty years elapsed since the advent of fetal echocardiography. To date, almost every structural congenital heart disease (CHD) described in postnatal life has been detected in utero by fetal cardiac ultrasound.¹⁵

Prenatal diagnosis has allowed new insights into the epidemiology of CHD. From published series of structural cardiac anomalies detected during fetal life it is apparent that the closest figure to the true incidence of CHD in the general population of fetuses is 1 percent.³⁰ Discrepancy between prenatal and postnatal

series can be partly explained by the unexpectedly high tendency towards spontaneous intra-uterine demise and early postnatal death of fetuses with cardiac abnormalities.³¹

It is clear that there is a strong association between the presence of fetal cardiac disease, extracardiac abnormalities and aneuploidies.³² While the incidence of chromosomal abnormalities in fetuses with CHD ranges from 17 to 48 per cent,^{32–35} only 5-10 per cent of infants with congenital heart disease are found to be chromosomically abnormal.³⁶ Associated extracardiac structural malformations are more frequent as well, i.e. 19% prenatally compared to 13% at birth in the largest Italian series.³¹ This discrepancy is likely to be due to the tendency toward spontaneous fetal loss of pregnancies carrying chromosomically and/or structurally abnormal fetuses; however it is difficult to prove it, because of the high pregnancy termination rate altering the natural history of disease. We recently reported on 67 cases of anomalies of ventricular outlets which were diagnosed prenatally: chromosomal aberrations and extracardiac malformations were found in 18% and 37%, respectively.³⁷ There were 48% livebirths in isolated cases and 15% in cases with extracardiac anomalies. The frequency of association with aneuploidies and/or extracardiac anomalies is different for differing congenital heart diseases, being highest for atrio-ventricular septal defects (48%) and lowest for complete transposition of the great arteries i.e. concordant atrioventricular connections with discordant ventriculoarterial connections (0-2.6%).^{31,32}

Screening and diagnosis

Ultrasound screening for fetal cardiac malformations is part of routine ultrasound screening at 19-21 weeks, according to scanning protocols including the four-chamber view.³⁰

In the setting of a low-risk population, a four-chamber view of the fetal heart potentially allows, at the best of its performance, the detection of only 40% of fetuses with complex heart disease;³⁸ most missed cardiac lesions commonly involve outflow tract anomalies such as complete transposition, common arterial trunk, and aortic coarctation or minor anomalies such as atrial septal defects (septum secundum), small ventricular septal defects, mild pulmonary or aortic stenosis.^{8,15,30} The same considerations reported above for screening of congenital defects hold true for cardiac malformations, namely, different sensitivities for different settings and malformations (Table 3).^{6,30,39} Incorporating visualization of the outflow tracts and the great arteries into the scanning protocol would increase the detection rate to 65-70%. However, data on this type of screening is still limited^{40,41} and further multicentric studies might show less encouraging results.

Table 3 Results of routine scanning for cardiac anomaly detection

Author (year)	n screened	n CHD (%) [*]	CHD prevalence (per 1000)	Sensitivity (%)	Specificity (%)
Luck [°] (1992) ⁶	8523	27 (15) [*]	3.2	36	99.9
Todros ^{°°} (1997) ³⁰	8299	40 (57) [*]	4.8	15	99.9
Buskens ^{°°} (1996) ³⁹	5319	57 (79) [*]	10.7	4.5	99.9

CHD=congenital heart disease

[°] single center

^{°°} multicentre

^{*}Percent of CHD cases not associated with an abnormal four-chamber view; as this percentage is higher, sensitivity is lower

Both the four-chamber view, the basic cardiac examination commonly included in routine obstetric scanning, and the extended basic cardiac examination in which ventricular outflow tracts are visualized, must be distinguished from a true fetal echocardiographic examination. The latter includes, in addition to the two-dimensional approach, colour-coded Doppler echocardiography and pulsed Doppler. Colour Doppler echocardiography may, in some instances, provide essential diagnostic and prognostic information. The use of high-quality ultrasound machines, along with expertise and thorough training of the examiners are also required.¹⁵ Figures 5-11 illustrate the sections studied during a standard echocardiographic examination (four-chamber, short axis, long axis pulmonary artery, long axis aorta, aortic arch, ductus arteriosus, systemic venous return, pulmonary venous return). Fetal echocardiography should be performed in groups selected on the basis of patient history and sonographic anomalies or markers, including extracardiac anomalies, maternal diabetes, infection, suspicious scan on screening, chromosomal aberrations. Fetuses with diagnosed extracardiac anomalies should be evaluated with fetal echocardiography because the detection of a cardiac anomaly may dramatically affect prognosis. Additional high-risk groups eligible for formal fetal cardiac scanning include hydrocephalus, omphalocele, congenital diaphragmatic hernia, abnormal cardiac position, visceral situs inversus and single umbilical artery. In this context, also should be listed abnormal biochemical screening or maternal age older than 34 years coupled with refusal of invasive karyotyping, increased nuchal translucency, early onset (below 32 weeks) fetal growth restriction, fetal arrhythmias, family history of congenital heart disease, hydrops, exposure to teratogenic agents.^{15,42}

Fig 5 Apical four chamber view of the fetal heart (LV, left ventricle; RV, right ventricle; LA, left atrium; RA, right atrium; MB moderator band; PV, pulmonary veins; D Ao, descending aorta; S, fetal spine)

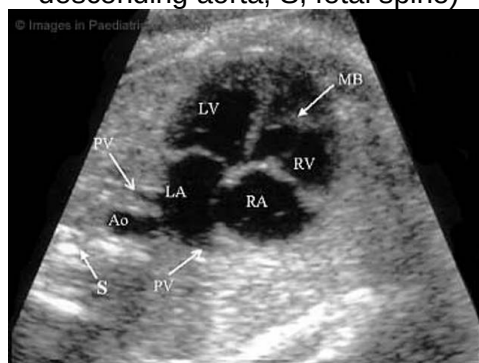


Fig 6 Short axis of the great vessels (RV, right ventricle; PV, pulmonary valve; PA pulmonary artery; RA, right atrium; Ao, aorta)



Fig. 7 Long axis Aorta (Ao, aorta; RV, right ventricle; IVS, interventricular septum; LV, left ventricle; LA, left atrium)



Fig. 8 Ductus arteriosus (D, ductus arteriosus; RV, right ventricle; PA pulmonary artery; D Ao, descending aorta; A Ao, ascending aorta)

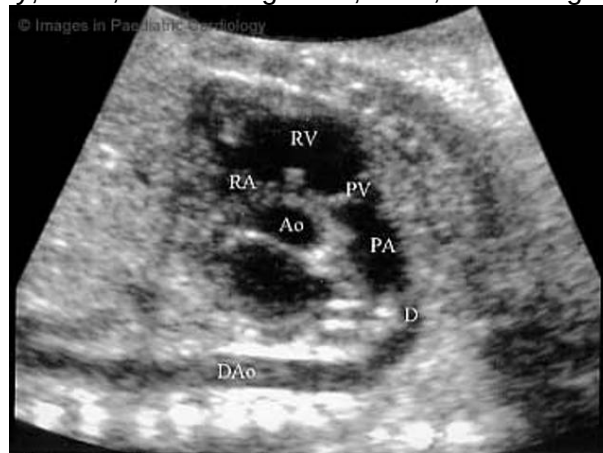


Fig. 9 Right parasagittal scan of fetal trunk demonstrating the inferior and superior venae cavae (IVC, SVC) entering the right atrium (RA)



Fig. 10 The aortic arch (Ao) as viewed from the back of the fetus (PA, pulmonary artery; head and neck vessels are indicated by the small arrows)



Fig. 11 The aortic arch (Ao) as viewed from the anterior thoracic wall (PA, pulmonary artery; head and neck vessels are indicated by the small arrows)



Estimates of diagnostic accuracy of fetal echocardiography depend on the prevalence of those anomalies which are most difficult to detect, like mild pulmonary stenosis, small septal defects, and aortic coarctation (table 4).⁴³

Table 4 Accuracy of prenatal diagnosis of congenital heart disease⁴³

Author (year)	n screened	n CHD	Sensitivity (%)	Specificity (%)	Positive predictive value (%)	Negative predictive value (%)
Allan (1984)	1200	34	87.5	99.8	94.5	99.6
Copel (1986)	266	14	100	100	100	100
Steward (1987)	2060	109	88	99.7	96	99.3
Benacerraf (1987)	-	49	57	100	-	-
Crawford (1988)	989	91	81.3	100	98.6	98
Bromley (1992)	-	69	83	-	-	-
Todros	2120	79	86	99.7	92	99.4

Echocardiographic images of structural cardiac anomalies in the fetus are shown in figures 12-16.

Fig. 12 Four chamber apical view in a third trimester fetus with multiple cardiac rhabdomyomas (T, tumor; RV, right ventricle; LV, left ventricle; RA, right atrium; LA, left atrium)

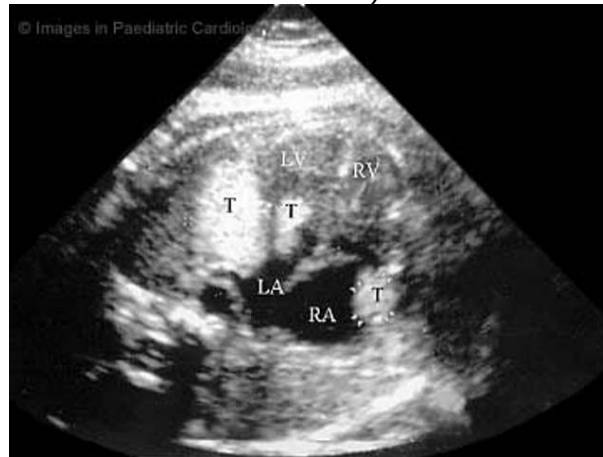


Fig. 13 Four chamber view reveals a muscular ventricular septal defect (arrow), RV, right ventricle; LV, left ventricle; RA, right atrium; LA, left atrium

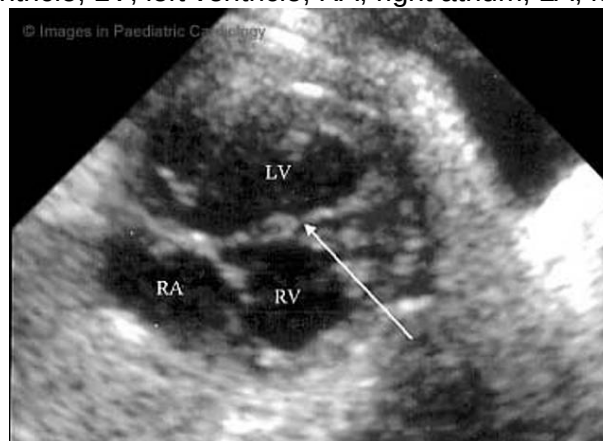
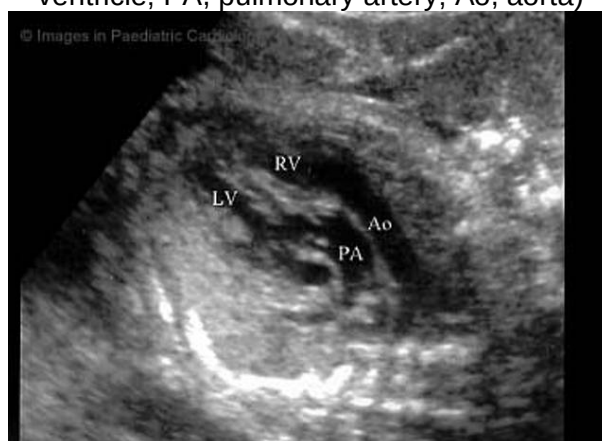


Fig. 14-15 Four chamber view and color Doppler of the same fetus reveals bidirectional flow through the ventricular septal defect (arrows)



Fig. 16 Transposition of great arteries in a 28 weeks fetus (LV, left ventricle; RV, right ventricle; PA, pulmonary artery; Ao, aorta)



Clinical implications

Congenital malformations occur in 2-4% of all births. Despite their relatively low prevalence, fetal malformations are responsible for approximately 30% of perinatal deaths in addition to considerable infant morbidity in developed countries.⁴⁴⁻⁴⁶

Prenatal diagnosis of congenital disease provides information for decisions during pregnancy and appropriate treatment perinatally (timed delivery in tertiary care centers) and it is assumed to improve perinatal and long term outcome. However, this assumption has been demonstrated only for few specific subsets of malformations, and with conflicting results. Bonnet et al⁴⁷ showed that prenatal diagnosis reduced to nihil pre- and post-operative mortality in fetuses affected by complete transposition. In another study⁴⁸ preoperative conditions were improved in cases with complete transposition and hypoplastic left heart, without no improvement in perinatal mortality. Survival at 2 years was the same in diagnosed as in undiagnosed fetuses with pulmonary atresia with intact ventricular septum.⁴⁹ No improvement was seen in cases of hypoplastic left heart diagnosed antenatally.⁵⁰

A major impact of antenatal diagnosis of malformations is related to the severity of the malformations detected. Most severe defects are reportedly detected earlier than minor ones, which is especially relevant in many countries where only before viability is termination of pregnancy authorized by law.¹¹ The gestational age at which a severe malformation is diagnosed is therefore crucial to further management of the pregnancy. A recent metaanalysis assessing the use of routine ultrasound compared to selective ultrasound before 24 weeks gestation has shown that where detection of fetal abnormality was a specific aim of the ultrasonographic examination, earlier detection of clinically unsuspected fetal malformation occurred. As a result, an increased rate of pregnancy termination was recorded in study groups undergoing ultrasound screening (odds ratio 3.19; CI 1.54- 6.6).⁵¹ The impact of the high pregnancy termination rate is a decrease in prevalence of livebirths affected with severe malformations, of the order of 20%-30%.^{28,52,53}

In one retrospective study conducted on a community hospital over a 5-year period, with a relatively high detection rate for fetal malformations (averaging 72%), continuing significant improvement was recorded in the sensitivity of ultrasound examinations (from 53% in the first year to 79% at the end of the study). Accordingly, a trend toward more pregnancy terminations and fewer newborns with anomalies was apparent over the years.⁵² In another study,⁵³ fetal cardiac screening was found to impact on the prevalence and types of congenital heart disease because many

affected pregnancies (more than half of the 23% diagnosed prenatally) were terminated.

As already discussed for congenital heart disease, the spectrum of malformations diagnosed in utero is different from that observed in postnatal series, having the former a more severe prognosis due to the higher association with other structural or chromosomal anomalies.^{31,35,36} By implication, it may be difficult in some instance for the team of health-care professionals to have adequate data with which to counsel the parents after a fetal malformation has been diagnosed. This is particularly true for congenital heart diseases. People involved in the management of affected fetuses, e.g. obstetricians, paediatrician cardiologists, and paediatric cardiac surgeons, should all be aware that most prognostic data in the literature refer to postnatal series, while the prognosis to give parents should be drawn from studies of prenatally detected cases.⁵⁰

Future directions

Future directions require the assessment of cost-effectiveness of screening ultrasound in differing settings in terms of populations and health care provision systems. A large, multicentre study of minor markers of Down syndrome is needed on low-risk patients to replace the data extrapolated from high-risk patient to the low-risk population.^{24,29}

Apart from methodological issues, our knowledge of certain conditions is to be improved. For example, screening ultrasonography has been shown to increase the frequency of prenatally diagnosed hydronephrosis. Given the fact that many infants with congenital hydronephrosis remain without symptoms for months or even years before diagnosis, it should be important to establish whether prenatal diagnosis would benefit otherwise asymptomatic infants by preserving their renal function. Similarly, still poorly understood and currently under investigation is the in utero development of some types of congenital heart defects.⁵⁴ Further assessment is needed of the incorporation of visualization of outflow tracts into the ultrasound screening protocol for congenital heart disease.⁵⁵

Because ultrasound can detect associations of specific anomalies, detection of patterns of anomalies may help make a diagnosis or determine which pregnant women should be offered invasive testing. The specificity of associations of the most frequent patterns has been analysed, and different patterns were found to aggregate in a relatively small number of clusters, so that several patterns can be considered in non-random associations.⁵⁶ Thus, proper analysis of antenatal sonographic data sets might enable detection of new patterns of associations of anomalies, thereby enhancing further the diagnostic potential of ultrasound.

It has not been established to what extent information provided by magnetic resonance imaging may warrant changes in patient counselling and management, so that further studies are needed to assess how additional information from magnetic resonance imaging may affect outcome.⁵⁷ In the meantime, real-time fast magnetic resonance imaging acquisition methods are being developed.

References

1. Steele MW, Breg WR. Chromosome analysis of human amniotic fluid cells. *Lancet.* 1966;1:383–385. [PubMed: 4159775]
2. Chitayat D, Babul-Hirji R. Genetic counselling in prenatally diagnosed non-chromosomal fetal abnormalities. *Curr Opin Obstet Gynecol.* 2000;12:77–80. [PubMed: 10813567]
3. Jenkins TM, Wapner RJ. First trimester prenatal diagnosis: chorionic villus sampling. *Semin Perinatol.* 1999;23:403–413. [PubMed: 10551793]
4. Douglas Wilson R. Amniocentesis and chorionic villus sampling. *Curr Opin Obstet Gynecol.* 2000;12:81–86. [PubMed: 10813568]
5. In: Fetal Abnormalities. Guidelines for Screening, Diagnosis and Management. London, UK: RCPCH, RCOG; 1997. Royal College of Obstetricians and Gynaecologists, Royal College of Paediatrics and Child Health. Background evidence supporting the guidelines; p. 5.
6. Luck CA. Value of routine ultrasound scanning at 19 weeks: a four year study of 8849 deliveries. *Br Med J.* 1992;304:1474–1478. [PMCID: PMC1882215] [PubMed: 1611369]
7. Romero R. Routine obstetric ultrasound. *Ultrasound Obstet Gynecol.* 1993;3:303–307. [PubMed: 12797251]
8. Crane JP, LeFevre ML, Winborn RC, Evans JK, Ewingman BG, Bain RP, Frigoletto FD, McNellis D. RADIUS Study Group. A randomised trial of prenatal ultrasonographic screening: Impact on the detection, management, and outcome of anomalous fetuses. *Am J Obstet Gynecol.* 1994;171:392–399. [PubMed: 8059817]
9. Levine D, Barnes PD, Madsen JR, Abbot J, Tejas Meta T, Edelman R. Central nervous system abnormalities assessed with magnetic resonance. *Obstet Gynecol.* 1999;94:1011–1019. [PubMed: 10576192]
10. Pilu G, Perolo A, Falco P, Visentin A, Gabrielli G, Bovicelli L. Ultrasound of the central nervous system. *Curr Opin Obstet Gynecol.* 2000;12:93–103. [PubMed: 10813570]
11. Grandjean H, Larroque D, Levi S. Eurofetus Study Group. The performance of routine ultrasonographic screening of pregnancies in the Eurofetus Study. *Am J Obstet Gynecol.* 1999;181:446–454. [PubMed: 10454699]
12. Johnson P, Sebire NJ, Snijders RJM, Tunkel S, Nicolaides KH. Ultrasound screening for anencephaly at 10-14 weeks of gestation. *Ultrasound Obstet Gynecol.* 1997;9:14–16. [PubMed: 9060123]
13. Chitty LS, Pandya PP. Ultrasound screening for fetal abnormalities in the first trimester. *Prenat Diagn.* 1997;17:1269–1281. [PubMed: 9509545]
14. Sebire NJ, Noble PL, Thorpe-Beeston JG, Snijders RJ, Nicolaides K. Presence of the 'lemon' sign in fetuses with spina bifida at the 10-14-week scan. *Ultrasound Obstet Gynecol.* 1997;10:403–407. [PubMed: 9476325]
15. Gembruch U. Prenatal diagnosis of congenital heart disease. *Prenat Diagn.* 1997;17:1283–97. [PubMed: 9509546]
16. Rosendhal H, Kivinen S. Antenatal detection of congenital malformation by routine ultrasonography. *Obstet Gynecol.* 1989;73:947–51. [PubMed: 2657525]
17. Lys F, Dewals P, Borlee Gremee I, Billeet A, Vincotte-Mols M, Levi S. Evaluation of routine ultrasound examination for the prenatal diagnosis of malformation E. J. O.G. R.B. 1989;30:101–109.
18. Todros T, Viora E, Scali R. Diagnostica prenatale dei difetti congeniti. Predittività degli esami ecografici di primo livello. Atti LXVII Congresso Nazionale della Società Italiana di Ginecologia e Ostetricia. 1992
19. Nicolaides KH, Azar G, Byrne D, Mansur C, Marks K. Fetal nuchal translucency:ultrasound screening for chromosomal defects in first trimester of pregnancy. *Br Med.* 1992;304:867–889.

20. Souka AP, Snijders RJM, Novakov A, Soares W, Nicolaides KH. Defects and syndromes in chromosomally normal fetuses with increased nuchal translucency thickness at 10-14 weeks of gestation. *Ultrasound Obstet Gynecol.* 1998;11:391–400. [PubMed: 9674084]
21. Spencer K, Souter V, Tul N, Snijders RJM, Nicolaides KH. A screening program for trisomy 21 at 10-14 weeks using fetal nuchal translucency, maternal serum free beta-human chorionic gonadotropin and pregnancy-associated plasma protein-A. *Ultrasound Obstet Gynecol.* 1999;13:231–237. [PubMed: 10341399]
22. Benacerraf B, Barss V, Laboda L. A sonographic sign for the detection in the second trimester of the fetus with Down's syndrome. *Am J Obstet Gynecol.* 1985;151:1078–1079. [PubMed: 3157321]
23. Snijders RJM, Nicolaides KH. In: *Ultrasound markers for fetal chromosome defects.* Canforth, UK: Parthenon Publishing; 1996. Assessment of risks; pp. 63–120.
24. Benacerraf BR. Should sonographic screening for fetal Down syndrome be applied to low risk women? *Ultrasound Obstet Gynecol.* 2000;15:451–455. [PubMed: 11005109]
25. Drugan A, Johnson MP, Evans MI. Ultrasound screening for fetal chromosome anomalies. *Am J Med Genet.* 2000;90:98–107. [PubMed: 10607945]
26. Bahado-Singh RO, Oz AU, Kovanci E, Deren O, Copel J, Baumgarten A, Mahoney J. New Down syndrome screening algorithm: ultrasonographic biometry and multiple serum markers combined with maternal age. *Am J Obstet Gynecol.* 1998;179:1627–1631. [PubMed: 9855608]
27. Viora E, Grassi Pirrone P, Bastonero S, Errante G, Sciarrone A, Campogrande M. Minor sonographic markers of fetal chromosomal anomalies: a review. *It J Gynaecol Obstet.* 1999;11:79–86.
28. Boyd PA, Chamberlain P, Hicks NR. 6-year experience of prenatal diagnosis in an unselected population in Oxford, UK. *Lancet.* 1998;352:1577–1781. [PubMed: 9843102]
29. Filly RA. Obstetrical sonography: the best way to terrify a pregnant woman. *J Ultrasound Med.* 2000;19:1–5. [PubMed: 10625182]
30. Todros T, Faggiano F, Chiappa E, Gaglioti P, Mitola B, Sciarrone A. Gruppo Piemontese for Prenatal Screening of Congenital Heart Disease. Accuracy of routine ultrasonography in screening heart disease prenatally. *Prenat Diagn.* 1997;17:901–906. [PubMed: 9358568]
31. Fesslova V, Nava S, Villa L. Fetal Cardiology Study Group of the Italian Society of Pediatric Cardiology. Evolution and long term outcome in cases with fetal diagnosis of congenital heart disease: Italian multicentre study. *Heart.* 1999;82:594–549. [PMCID: PMC1760776] [PubMed: 10525516]
32. Allan LD, Sharland GK, Milburn A, Lockhart SM, Groves AMM, Anderson RH, Cook AC, Fagg NL. Prospective diagnosis of 1,006 consecutive cases of congenital heart disease in the fetus. *J Am Coll Cardiol.* 1994;23:1452–1458. [PubMed: 8176106]
33. Touati GD, Fermont L, Neveux JY, Vouhe PR, Gay F, Kachaner J. Effects of a systematic fetal detection on the outcome of severe congenital heart disease. *Circulation.* 1988;78:396.
34. Raymond FL, Simpson JM, Sharland GK, Mackie Ogilvie CM. Fetal echocardiography as a predictor of chromosomal abnormality. *Lancet.* 1997;350:930. [PubMed: 9314874]
35. Paladini D, Calabro R, Palmieri S, D'Andrea T. Prenatal diagnosis of congenital heart disease and fetal karyotyping. *obstet Gynecol.* 1993;81:679–682. [PubMed: 8469453]
36. Yates R. Fetal cardiac abnormalities and their association with aneuploidy. *Prenat Diagn.* 1999;19:563–566. [PubMed: 10416974]

37. Paladini D, Rustico M, Todros T, Palmieri S, Gaglioti P, Russo MG, Chiappa E, D'Ottavio G. Conotruncal anomalies in prenatal life. *Ultrasound Obstet Gynecol.* 1996;8:241–246. [PubMed: 8916376]
38. Klein SK, Cans C, Robert E, Jouk PS. Efficacy of routine ultrasound screening for congenital heart disease in Isere County, France. *Prenat Diagn.* 1999;19:318–322. [PubMed: 10327135]
39. Buskens E, Grobbee DE, Frohn-Mulder IME, et al. Efficacy of routine fetal ultrasound screening for congenital heart disease in normal pregnancy. *Circulation.* 1996;94:67–72. [PubMed: 8964120]
40. Stoll C, Alembik Y, Dott B, Meyer MJ, Pennerath A, Peter MO, De Geeter B. Evaluation of prenatal diagnosis of congenital heart disease. *Prenat Diagn.* 1998;18:801–807. [PubMed: 9742567]
41. Hafner E, Scholler J, Schucter K, et al. Detection of congenital heart disease in a low-risk population. *Prenat Diagn.* 1998;808–815. [PubMed: 9742568]
42. Todros T. Prenatal diagnosis and management of fetal cardiovascular malformations. *Curr Opin Obstet Gynecol.* 2000;12:87–92. [PubMed: 10813569]
43. Gagliardi L, Todros T, Candiani G. B, Danesino V, Ostetricia Gastaldi A, editors. *Le cardiopatie fetali. Principi di diagnosi e terapia.* 1996:182–192. Masson, Milano.
44. Marden PM, Smith DW, McDonald MJ. Congenital anomalies in the newborn infant, including minor variations. *J Pediatr.* 1964;64:357–371. [PubMed: 14130709]
45. Kalter H, Warkany J. Congenital malformations (first of two parts) *N Engl J Med.* 1983;308:424–431. [PubMed: 6337330]
46. Kalter H, Warkany J. Congenital malformations (second of two parts) *N Engl J Med.* 1983;308:491–497. [PubMed: 6337336]
47. Bonnet D, Coltri A, Butera G, Fermont L, Le Bidois J, Kachaner J, Sidi D. Detection of transposition of the great arteries in fetuses reduces neonatal morbidity and mortality. *Circulation.* 1999;99:916–918. [PubMed: 10027815]
48. Kumar RK, Newburger JW, Gauvreau K, Kamenir SA, Hornberger LK. Comparison of outcome when hypoplastic left heart and transposition of the great arteries are diagnosed prenatally versus when diagnosis of these two conditions is made only postnatally. *Am J Cardiol.* 1999;83:1649–1653. [PubMed: 10392870]
49. Daubeney PEF, Sharland GK, Cook AC, Keeton BR, Anderson RH, Webber SA. Pulmonary atresia with intact ventricular septum. Impact of fetal echocardiography on incidence at birth and postnatal outcome. *Circulation.* 1998;98:562–566. [PubMed: 9714114]
50. Kern JH, Hayes CJ, Michler RE, Gersony WM, Quaegebeur JM. Survival and risk factor analysis for the Norwood procedure for hypoplastic left heart syndrome. *Am J Cardiol.* 1997;80:170–174. [PubMed: 9230154]
51. Neilson JP. Ultrasound for fetal assessment in early pregnancy. *The Cochrane Database of Systematic Reviews.* 2000;2
52. Zimmer EZ, Avraham Z, Sujoy P, Goldstein I, Bronshtein M. The influence of prenatal ultrasound on the prevalence of congenital anomalies at birth. *Prenat Diagn.* 1997;17:623–628. [PubMed: 9249862]
53. Bull C. Current and potential impact of fetal diagnosis on prevalence and spectrum of serious congenital heart disease at term in the UK. *Lancet.* 1999;354:1242–1247. [PubMed: 10520632]
54. Todros T, Presbitero P, Gaglioti P, Demarie D. Pulmonary stenosis with intact ventricular septum: documentation of development of the lesion echocardiographically during fetal life. *Int J Cardiol.* 1988;19:335–360. [PubMed: 3397197]
55. AIUM Technical Bulletin. Performance of the basic fetal cardiac ultrasound examination. *J Ultrasound Med.* 1998;17:601–617. [PubMed: 9733183]
56. Farina A, Malone FD, Bianchi DW. Fetal sonographic findings: analysis of the most frequent patterns and their specificity of association. *Am J Med Genet.* 2000;91:331–339. [PubMed: 10766993]

T Todros, E Capuzzo, and P Gaglioti. Prenatal diagnosis of congenital anomalies. *Images Paediatr Cardiol.* 2001 Apr-Jun; 3(2): 3–18.

57. Levine D, Barnes PD, Edelman RR. Obstetric MR imaging. *Radiology.* 1999;211:609–617. [PubMed: 10352581]

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