Advances in fetal echocardiography

Helena M. Gardiner*

The Fetal Center at Children's Memorial Hermann Hospital, McGovern Medical School at UTHealth, The University of Texas Health Sciences Center at Houston, Houston TX, USA

Keywords:
Congenital heart disease
Echocardiography
Fetal
First trimester

Abstract

The development of fetal echocardiography and success in prenatal cardiac screening programs over the past 30 years has been driven by technical innovation and influenced by the different approaches of the various specialties practicing it. Screening for congenital heart defects no longer focuses on examining a limited number of pregnant women thought to be at increased risk, but instead forms an integrated part of a high-quality anatomical ultrasound performed in the second trimester using the 'five-transverse view' protocol. A prenatal diagnosis is feasible in almost all cardiac lesions and the advantages to parents and to health professionals are well recognized. Prenatal evaluation can usually determine the level of care required at delivery, thereby reducing perinatal morbidity. However, only half of the babies undergoing surgery within the first year of life have a prenatal detection, and practical training programs to support and provide feedback to sonographers remain essential for continued improvement.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

The development and growth of fetal echocardiography and success in prenatal cardiac screening programs over the past 30 years has been driven by technical innovation and, unlike most specialties with relatively homogeneous roots, has been influenced by the different approaches of the various specialties practicing it.

Its original practice was pioneered by obstetricians and radiologists, and biomedical engineers. More recently, it has been developed by specialists from fetal medicine, prenatal diagnosis, and pediatric cardiology. Screening programs for fetal abnormalities in different countries are performed by those with a technical training or by nurses with midwifery experience.

Software development and improved computer processing power have made ultrasound a powerful tool for prenatal diagnosis. Importantly the technology is relatively adaptable, not requiring an expensive environment as with magnetic resonance imaging or computed tomography, and so it has gained worldwide acceptance.

This prenatal hybrid specialty grows at scientific gatherings where its practitioners meet to cross-fertilize ideas and produce outstanding research. These factors make the specialty barely recognizable from 30 years ago and its growth is a tribute to the efforts of expert teams and the ultrasound manufacturers who work together to continue to push the boundaries of what can be seen and measured. This has permitted development of fetal cardiovascular medicine beyond its initial aim, the identification of structural congenital heart defects, and has opened up possibilities to observe development and function non-invasively in both normal and complicated pregnancies.

2. Second trimester screening

The birth of a baby with a congenital heart defect (CHD) is a relatively frequent occurrence given that CHD is one of the most prevalent birth defects, affecting almost 1% of all pregnancies. A prenatal diagnosis is feasible in almost all lesions and the advantages to parents and to health professionals are well recognized [1,2]. Prenatal diagnosis has been shown to improve morbidity and pre-surgical mortality and reduce costs associated with transportation and resuscitation of collapsed newborns [3,4]. Prenatal screening programs allow the pregnant woman to discuss further investigations including prenatal genetic testing and imaging and to inform reproductive decision-making. The family can come to terms with the perinatal management plan, including the prospect of cardiac surgery, over a period of months rather than in hours when a cardiac diagnosis is made only after delivery. However, prediction of quality of life for children with CHD remains difficult [5,6].
2.1. Expectations and advantages

In most cases a baby with CHD can be born at term by vaginal delivery, ideally in a maternity unit within, or co-located, with the cardiac center. Cesarean section is indicated for fetuses with complete heart block who cannot be monitored safely during labor, or with poor cardiac function. However, in practice a prenatal diagnosis is associated with earlier delivery and higher rates of operative delivery for a variety of reasons, usually because of associated lesions or poor fetal growth [7,8]. There is also the option to plan for palliative perinatal management for fetuses that are extremely sick, or have multiple abnormalities, or life-limiting genetic disorders [9].

Prenatal evaluation can usually determine the level of care required at delivery, so health professionals with the appropriate skills can confidently manage the transitional circulation and any extra-cardiac malformations in the certainty of an accurate prenatal cardiac diagnosis and thereby reduce perinatal morbidity and mortality [10].

2.2. Screening guidelines and referral

Screening for CHD no longer focuses on examining a limited number of pregnant women thought to be at increased risk of fetal CHD [11,12]. Fetal echocardiography forms an integrated part of a high-quality anatomical ultrasound performed in the second trimester using the ‘five-transverse view’ protocol [13]. This is a practical and effective population screening tool which uses five ultrasound planes through the fetal body to provide views of abdominal situs, the four-chamber view, the outflow tracts and the three-vessel and tracheal view (Fig. 1). The details of screening programs vary from country to country, but the most successful programs offer pregnant women a first trimester scan, followed by a detailed anatomical scan at around 20 gestational weeks [13–16]. Professional societies such as the International Society for Ultrasound in Obstetrics and Gynecology (ISUOG) and the American

Fig. 1. The five transverse views through the fetal body displaying the cardiac screening planes. This is an educational poster developed by Dr Gardiner and GE Healthcare.
Institute of Ultrasound in Medicine (AIUM) have updated their screening protocol guidelines to reflect the five-transverse view protocol [13] and provide continuing education in various aspects of fetal cardiology [17,18]. Guidelines promoting practical protocols that are achievable during a busy screening schedule have improved prenatal detection of all lesions, including those one would have expected to recognize on four-chamber views alone in the past. Today outflow tracts and arch abnormalities are being detected regularly for the first time in population-based studies [19,20]. Improved detection rates result from increasing competence and confidence of the screeners, and hands-on training of the first-line sonographers, combined with feedback from their fetal medicine unit, will lead to improved detection rates of CHD [11]. Other aspects of an effective program for technicians and nurses are ongoing training and local support to encourage early referral for sonographic abnormalities. Whereas prenatal detection rates of 85% are possible in well-run, supported programs, barriers to learning are not well understood and still require further research [1]. The 2014 National Institute for Cardiovascular Outcomes Research report on UK population-based screening for CHD shows a doubling of overall antenatal diagnosis since 2003, from 23% to 48% (Fig. 2). These values represent the proportion of children undergoing surgery for major CHD during the first year of life with an antenatal diagnosis and are similar to recent reports from the USA [21].

2.3. Referral for a diagnostic opinion and evaluation

Fetal echocardiography by experienced practitioners provides a complete cardiovascular diagnosis in more than 95% of fetuses with CHD. It is no longer considered best practice to image the fetal heart in isolation in a pediatric cardiology setting. In many large centers worldwide, imaging the fetal heart takes its logical place within a fully integrated fetal medicine center and is performed by those with an obstetric as well as cardiology training [1,12–20].

An integrated approach to the fetal cardiovascular system by fetal medicine specialists and fetal cardiologists with support from genetic counselors and experienced midwives allows for optimal diagnosis and management of the pregnant woman expecting a baby with CHD. A multidisciplinary team (MDT) is essential to manage referrals for CHD, as one-third of pregnancies with CHD also have genetic abnormalities, and/or involvement of other organ systems [22]. The genetic evaluation will be based on perceived risk following an assessment of the extended family history, specific cardiac diagnosis and involvement of other organ systems. Whereas about 20% of fetuses with CHD have a chromosomal defect, attempts to describe the likelihood of aneuploidy for a specific cardiac lesion remain poor. In part this is due to the historical nature of the data, the highly selected referred populations and lack of uniform prenatal genetic testing (chorionic villus sampling or amniocentesis) [22,23]. More recent technologies such as chromosomal microarrays have been incorporated into genetic testing. The additional diagnostic gain of using array comparative genomic hybridization (aCGH) to detect copy number variants (CNVs) in fetal CHD was explored in a meta-analysis of 13 studies comprising 1131 cases of CHD. This technique gave an increased yield of 7% (95% confidence interval (CI): 5.3–8.6%) for the detection of CNVs (excluding fetuses with aneuploidy and 22q11 microdeletion), Sub-group analysis confirmed previous reports [24] that the increased yield was greatest in pregnancies with multiple congenital abnormalities (9.3% (95% CI: 6.6–12%)) compared with isolated CHD at 3.4% (95% CI: 0.3–6.6%) [25]. The clinical importance of this is that it may provide additional information if karyotyping and 22q11 microdeletion analysis are normal by traditional testing with G-banded karyotype and fluorescent in-situ hybridization. As with all new technologies, the significance of some variants is still unknown and will require correlation with detailed phenotypic and developmental outcomes to ascertain their likely importance. Some affected fetuses will require urgent or semi-urgent surgery for associated malformations, such as omphalocele or dia-phragmatic hernia after birth, and prenatal counseling with the appropriate cardiac and pediatric surgeon or interventional cardiologist is desirable.

The pregnant woman is usually seen on three or four occasions by the fetal cardiologist before delivery to check for the development of new or progression of obstructive lesions (Fig. 3) to monitor heart function and importantly to check pulmonary venous connections and monitor for signs of their obstruction in later pregnancy [26]. The fetal medicine specialists may see the pregnant woman monthly to monitor fetal growth and any identified pregnancy complications such as polyhydramnios, short cervix, placenta previa or accreta.

2.4. Perinatal planning

Appropriate transfer of care for delivery in the perinatal center will ensure that the family feels supported and that the baby...
3. Overview of congenital heart defects and their detection

Heart defects are classified in a variety of ways, most often divided into morphological or physiological groupings, with ductal dependency characterizing the defects as “critical CHD” [1,29]. Ductal-dependent lesions are the most important to detect before delivery as the baby will need blood flowing through the arterial duct to perfuse the systemic or pulmonary circulation. One example of a ductal-dependent systemic circulation is coarctation of the aorta, and an example of a ductal-dependent pulmonary circulation is Tetralogy of Fallot with pulmonary atresia. As this article deals with ultrasound screening, it is most appropriate to characterize CHD based on their morphology and describe the ultrasound plane where their diagnostic features are best displayed (Fig. 1). Historically, abnormalities seen on a four-chamber view are the most frequently detected lesions. This is largely because only the four-chamber view was used for CHD screening until about 15 years ago and sonographers remain most familiar with it. Table 1 shows the prevalence of different types of CHD and the differences in the proportions between pre- and postnatally diagnosed lesions from a population-based study over a period of 21 years (1986–2006) in the Czech Republic. The most frequently detected lesions were those with four-chamber view abnormalities showing ventricular imbalance, such as hypoplastic left heart syndrome (Fig. 3) or those with large septal defects as in atrioventricular septal defect (AVSD) (Fig. 4) or double-outlet right ventricle. Hearts with absent connections such as mitral or tricuspid valves are rarer, but should be readily identifiable as they are often associated with a “single ventricle” appearance, or as having a dominant ventricle and rudimentary pouch (Fig. 5).

Obstruction of the semilunar valves (aortic and pulmonary valves) is usually associated with involution of the supporting ventricle, which may be the first indication of valvar abnormality and is seen on the four-chamber view (Fig. 3). Theoretically, a good evaluation of the four-chamber view can detect about half of all cases of CHD, but in practice this is not the case. Before the five-transverse views were adopted as the optimal screening protocol, detection of all lesions was as low as 29%, even for those lesions with characteristic four-chamber view abnormalities such as AVSD [30]. In most population studies there is a marked era effect, with prenatal detection rising once introduction of the outflow tracts was introduced into routine screening [21,22].

One explanation for this is greater rigor in training and the ability to provide feedback through audit. Another factor is the rise in detection of conotruncal lesions that include Tetralogy of Fallot (ToF), with pulmonary stenosis or atresia, double-outlet left ventricle lesions (DORVs) and common arterial trunk (CAT). These lesions usually have left axis deviation and a large ventricular septal defect (VSD) and so should theoretically be detectable on a four-chamber view. However, although described more than 20 years ago, recognition of the association of an abnormal fetal cardiac axis and CHD has only recently been emphasized in both first and second trimester screening programs [31,32]. Moreover, in conotruncal malformations, the VSD is often more evident in the outlet

Table 1


<table>
<thead>
<tr>
<th>Congenital heart defect</th>
<th>% total CHD</th>
<th>Detected prenatally</th>
<th>Detected postnatally</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atrioventricular septal defect</td>
<td>15.1</td>
<td></td>
<td>3.9</td>
</tr>
<tr>
<td>Hypoplastic left heart syndrome</td>
<td>15.0</td>
<td></td>
<td>3.9</td>
</tr>
<tr>
<td>Ventricular septal defect</td>
<td>9.1</td>
<td></td>
<td>46.1</td>
</tr>
<tr>
<td>Double-outlet right ventricle</td>
<td>8.7</td>
<td></td>
<td>1.1</td>
</tr>
<tr>
<td>Pulmonary atresia</td>
<td>6.0</td>
<td></td>
<td>2.2</td>
</tr>
<tr>
<td>Transposition of the great arteries</td>
<td>5.4</td>
<td></td>
<td>5.4</td>
</tr>
<tr>
<td>Tetralogy of Fallot</td>
<td>5.2</td>
<td></td>
<td>3.8</td>
</tr>
<tr>
<td>Aortic stenosis</td>
<td>4.9</td>
<td></td>
<td>7.8</td>
</tr>
<tr>
<td>Single ventricle</td>
<td>4.8</td>
<td></td>
<td>1.1</td>
</tr>
<tr>
<td>Common arterial trunk</td>
<td>3.8</td>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td>Coarctation of the aorta</td>
<td>3.6</td>
<td></td>
<td>5.4</td>
</tr>
<tr>
<td>Tricuspid atresia</td>
<td>3.4</td>
<td></td>
<td>0.3</td>
</tr>
<tr>
<td>Ebstein anomaly</td>
<td>2.1</td>
<td></td>
<td>0.3</td>
</tr>
<tr>
<td>Pulmonary stenosis</td>
<td>1.6</td>
<td></td>
<td>7.8</td>
</tr>
<tr>
<td>Miscellaneous congenital heart defects</td>
<td>11.1</td>
<td></td>
<td>29.9</td>
</tr>
</tbody>
</table>

* Excluding hypoplastic left heart syndrome, tricuspid atresia, and some pulmonary atresia.
septum and can be better appreciated by extending the screening plane cephalad to trace the left ventricular outflow tract (LVOT).

The diagnosis of complete transposition of the great arteries (TGA) has lagged behind that of other conotruncal abnormalities, because the four-chamber view may seem entirely normal. Diagnosis of this lesion requires a good appreciation of lack of crossover of the outflow tracts. Incorporating the three-vessel and tracheal (3VT) view into the screening program, however, provides an additional opportunity to detect conotruncal lesions as this view is usually abnormal, with one great artery seen instead of two. Recognition of this allows the sonographer to re-evaluate their previous assessment of the heart and helps to avoid missed diagnoses. Introduction of the 3VT plane has revolutionized the prenatal detection of critical life-threatening lesions of the aortic arch such as coarctation of the aorta and interrupted aortic arch as well as double aortic arch and vascular rings [14]. These are detected more easily prenatally than after birth in most cases. Symptoms often manifest as failure to thrive, with inability to swallow solid foods and “asthma” with a delay in recognizing the true diagnosis. Their prenatal detection allows earlier treatment and reduces the long-term morbidity associated with tracheal and esophageal compression during childhood.

4. Advances in first trimester cardiac screening

Many countries offer their population a first trimester ultrasound screen, including cardiac views [15,16]. First trimester screening was developed for the early detection of aneuploidy, but as CHD is the most prevalent malformation, and frequently associated with genetic abnormalities, the ultrasound screening also provides an opportunity to detect CHD. The approach of first trimester screening has changed in recent years. Initially, the finding of an increased nuchal translucency (NT) along with abnormal ductus venosus (DV) flow and tricuspid regurgitation was used to create a group at increased risk for CHD and early fetal echocardiography was offered to this cohort. The timing of this cardiac scan varied but was most frequently performed after the karyotype/microarray result was known at 14–16 weeks, when imaging is more definitive [35,36]. In the past five years, a limited cardiac screening protocol using two of the five transverse view planes was introduced. The four-chamber and 3VT views with color Doppler have been adopted with promising reports, some achieving a 75% detection rate of the CHDs in an unselected population [37]. A recent study of ultrasound at 12–13 weeks in women undergoing the combined test reported that 63% of all anomalies were detected: 24/53 (45.3%) structural and all the chromosomal anomalies (97% had raised nuchal translucency or combined test >1:200). Importantly, all life-limiting abnormalities were detected with false-positive results that were six-fold lower than at the 20-week scan [38]. Of the 12 CHD in this population, four (TGA, VSD, ToF, and complex CHD) were detected at the early scan, whereas five similar lesions were not detected until the 20-week scan. One TGA, one total anomalous pulmonary venous connection (TAPVC) and an insignificant VSD were only detected after delivery [38]. Others have published recently on the success of first trimester cardiac scanning, concluding that it is currently clinically worthwhile from about 11 gestational weeks and that pregnancy choices made following this scan appear to alter the balance of cardiac defects seen in later pregnancy [39–41].
5. Safety of ultrasound

First trimester ultrasound guidelines for safe practice were published in 2009 by the British Medical Ultrasound Society (BMUS) [42] and in 2011 by ISUOG [43]. Both urge caution: BMUS concluded that, provided the thermal index is kept below 0.7, there was no requirement to restrict scanning times either before or after 10 gestational weeks, but ISUOG recommend that routine color Doppler should not be used, except for certain examinations; this likely includes cardiac screening. ISUOG promotes the ALARA principle, “as low as reasonably achievable” and keeping the thermal index <1.0 and Doppler use short, at 5–10 min. More advanced technology may enable the collection of more information with shorter capture times and could lead to improved diagnostic capabilities with less risk of exposure to Doppler ultrasound [44,45].

6. Newer technologies

The quality of imaging has improved greatly with modern transducer technology and improved processing power. There are many advances in 2D probes, such as biplane, to allow visualization of structures in two orthogonal planes, thus clarifying anatomical details and shortening the examination time. Modifications to increase contrast resolution allow better visualization of tissue planes.

New electronic probes contain rows of elements that can send and receive the ultrasound beam. Thus, image acquisition is no longer confined to a 2D beam with a certain thickness, but rather a broad 3D beam captures a stereoscopic volume, rather than reflecting surface interfaces. This allows for a more realistic image quality and true live fetal heart scanning, rather than spatio-temporal image correlation or STIC technology. STIC obtains cardiac volumes by ordering slices temporally over a virtual cardiac cycle. This allows off-line manipulation and assessment by experts through telemedicine links. In cardiac imaging, faster acquisition now reduces the chance of artifact. Additionally the volume can be acquired with color or power Doppler to provide more clinically important balance between acquiring diagnostic images while keeping the thermal index below 0.7.

7. Future developments in fetal echocardiography

Despite technical advances, barriers to ever-earlier cardiac assessment include the maturational features of the human heart. Whereas the connections are present in the early first trimester, developmental features such as delamination of valves and growth of the atrioventricular septum may make recognition of true pathology more difficult before 13 weeks [36]. Moreover, certain defects such as isolated total anomalous pulmonary venous connection (TAPVC) are infrequently detected, even in the second trimester, and progression of malformations, such as stenosis of aortic and pulmonary valves, means that diagnosis of these lesions is only feasible in some cases later in the third trimester, or that diagnosis may not be made prenatally at all.

As almost half of the major congenital defects can be diagnosed in the first trimester scan, including about one-third of major cardiac lesions, the effect of introducing first trimester cell-free DNA testing on this early scanning opportunity has been debated [49] and is addressed by Harris et al. in this issue of Seminars. General opinion is that the second trimester detection of cardiac defects will remain the bedrock of diagnosis. Assessment of efficacy of many first trimester studies is reduced because termination of pregnancy and spontaneous fetal demise reduces the ability to confirm abnormal first trimester ultrasound findings in later pregnancy, or after birth.

8. Conclusions

Collaboration between specialties will ensure continued advances in the diagnosis and assessment of fetal cardiovascular abnormalities in the future. Clinical application of this knowledge requires a collaborative approach to research with sufficient power. The Fetal Heart Society has been established with the primary aim to encourage multicenter research to provide answers and increase our knowledge for the benefit of families and babies with cardiovascular anomalies [50].

Conflicts of interest

None declared.

Funding sources

None.

References

https://doi.org/10.1016/j.ajog.2017.05.049 [Epub ahead of print].

Friedberg MK, Silverman NH. Changing indications for fetal echocardiography 

Yagel S, Cohen SM, Achiorn R. Examination of the fetal heart by five short-axis 
views: a proposed screening method for comprehensive cardiac evaluation. 


Khalil A, Nicolaides KH. Fetal heart defects: potential and pitfalls of first-

Chur SA, Bilardo CM. Early detection of fetal cardiac abnormalities: how 
effective is it and how should we manage these patients? Prenat Diagn 
2014;34:1235–45.

International Society of Ultrasound in Obstetrics and Gynecology, Carvalho JS, 
screening examination of the fetal heart. Ultrasound Obstet Gynecol 2013;41: 
348–59.

American Institute of Ultrasound in Medicine. AIUM practice guideline for the 

van Velzen CL, Chur SA, Bijlaard MM, et al. Prenatal detection of congenital 

Marek J, Tonski V, Skovranej J, et al. Prenatal ultrasound screening of 
congenital heart disease in an unselected national population: a 21-year 

org.uk/child/anaeards/nicomeContent/Abnormal%20Diagnosis?Opendocument.

Donofrio MT, Moon-Grady AJ, Horbner UK, et al. Diagnosis and treatment of 
fetal cardiac disease: a scientific statement from the American Heart Associ-

Wimalasundera RC, Gardiner HM. Congenital heart disease and aneuploidy. 

Shaffer LG, Rosenfeld JA, Dabell MP, et al. Detection rates of clinically signif-
icient genomic alterations by microarray analysis for speciﬁc anomalies detected 

Jansen FAR, Blumenfeld YJ, Fisher A, et al. Array comparative genomic hy-
bridization and fetal congenital heart defects: a systematic review and meta-

Sakai AN, Carvalho JS, Gardiner HM, et al. Total anomalous pulmonary venous 
connection: impact of prenatal diagnosis. Ultrasound Obstet Gynecol 

history and management including successful in utero surgery. Am J Obstet 

oxidation in neonates with severe congenital diaphragmatic hernia: a 26-
https://doi.org/10.1093/ejcts/ezx120 [Epub ahead of print].

Bottino LD, Lin AE, Rhee-Colorusso T, Malik S, Correa A. The national birth 

Heide H, Thomson JD, Wharton GA, Gibbs JL. Poor sensitivity of routine 
fetal anomaly ultrasound screening for antenatal detection of atrioventricular 

Sinkovskaya ES, Chauvi R, Karl K, Andreeva E, Zhuchenko L, Abubamad AZ. 
Fetal cardiac axis and congenital heart defects in early gestation. Obstet 

Shipp TD, Bromley B, Horbner LX, Nadel A, Benacerraf BR. Levorotation of 
the fetal cardiac axis: a clue for the presence of congenital heart disease. 

cardiac defects: a pooled analysis of major fetal echocardiography centers. Am 

Peresca S, Canapathy R, Syngleali A, Maiz N, Nicolaides KH. Contribution of 
fetal tricuspid regurgitation in first-trimester screening for major cardiac 

Karim JN, Roberts NW, Salomon LJ. Papageorghiou AT. Systematic review of 
first trimester ultrasound screening in detecting fetal structural anomalies 

Gardiner HM. First-trimester fetal echocardiography: routine practice or 

De Robertis V, Rembouskos G, Fanelli T, Volpe G, Muto B, Volpe P. The three-
vesSELs and trachea view (3VT) in the ﬁrst trimester of pregnancy: an addition-
tool in screening for congenital heart defects (CHD) in an unselected 
[Epub ahead of print].

diagnosis of fetal congenital anomalies in the cell-free DNA era. Ultrasound 
of print].

ocardiography—identiﬁcation of cardiac structures for screening from 6 to 13 weeks’ 
J.echo.2017.03.017 [Epub ahead of print].

Iliescu D, Todorache S, Comanescu A, et al. Improved detection rate of 
structural abnormalities in the first trimester using an extended examination 

the natural history of congenital heart disease? Analysis of outcome of regional 

British Medical Ultrasound Society. Guidelines for the safe use of diagnostic 

Salvesen K, Lees C, Abramowicz J, Brezinka C, Ter Haar G, Marsial K. Board 
of international society of ultrasound in obstetrics and Gynecology (ISUOG). 
ISUOG statement on the safe use of doppler in the 11 to 13 +6-week fetal 

Turun S, Turan OM, Desai A, Harman CR, Baschat AA. First-trimester fetal 
cardiac examination using spatiotemporal image correlation, tomographic 
ultrasound and color Doppler imaging for the diagnosis of complex congenital 
heart disease in high-risk patients. Ultrasound Obstet Gynecol 2014;44: 
662–7.

Goncalves LF, Lee W, Chaiworapongsa T, et al. Four-dimensional ultrasonogra-
phy of the fetal heart with spatiotemporal image correlation. Am J Obstet 
Gynecol 2003;189:1792–802.

Vinaila F, Ascenzo R, Naveas R, Huggon I, Giuliano A. Fetal echocardiography at 
11 + 0 to 13 + 6 weeks using four-dimensional spatiotemporal image cor-
relation telemedicine via an Internet link: a pilot study. Ultrasound Obstet 

Adriaanse BM, Tromp CH, Simpson JM, et al. Interobserver agreement in 
detailed prenatal diagnosis of congenital heart disease by telemedicine using 
four-dimensional ultrasound with spatiotemporal image correlation. Ultra-

Garcia M, Yeo L, Romero R, et al. Prospective evaluation of the fetal heart 
using fetal intelligent navigation echocardiography (FINE). Ultrasound 

Affrevec Z, Bilardo CM, Salomon LJ, Tabor A. Women who choose cell-free 
DNA testing should not be denied first-trimester anatomy scan. Br J Obstet 
of print].

Donofrio MT, Rychik J. Fetal Heart Society Governing Board and Steering 
Committee. Multidisciplinary collaboration in fetal cardiovascular research: the 