4D ULTRASOUND IN THE STUDY OF FETAL HEART

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Prenatal diagnosis of congenital fetal abnormalities still represents one of the most important challenge for ultrasound specialist. As reported by "Eurocat", congenital anomalies had a prevalence of about 23/1000 of total pregnancies between 1998-2010 in Europe[1]. Despite the rapid progress of fetal ultrasonography, both in terms of images quality and of the huge efforts of ultrasound societies on training operators to achieve an accurate evaluation of the fetal anatomy, the prenatal detection rate of congenital anomalies remains below 50%[2-4]. Congenital anomalies can be part of complex syndromes, such as chromosomal abnormalities, or can occur as isolated defects. In the case latter prenatal identification becomes very difficult but remains particularly important because it allows us to prepare adequately for the management of potentially sick newborn babies at delivery. The importance of prenatal diagnosis cannot be underestimated. Conventional 2-dimensional (2D) ultrasound (US) has limited display possibilities because it only allows for imaging of single planes. Furthermore, visualization of standard anatomical planes for the examination of the fetal body with 2D US are obtained through an adequate manual positioning of the transducer. As a consequence the quality and the success rate of such images depend on the experience and the technical skill of the sonographer performing the ultrasound examination. Several studies have demonstrated how the detection rate of congenital anomalies is higher in a referral unit than in a peripheral unit with sonographers who lack experience[5-8]. In contrast to 2D US, three dimensional (3D) and four-dimensional (4D) US offer an amazing variety of displays that do not exist in 2D imaging, providing important advantages in imaging technology for clinical practice. However, one technical limitation of 3D/4D US which is difficult to overcome is that high-quality 3D/4D images require good-quality 2D images. 3D technology allows us to acquire a selected volume of the fetal body (i.e. fetal heart, head, trunk) and obtain an infinite number of 2D planes on the target volume for further analysis. In the multiplanar mode, which represents the basic mode in 3D ultrasound, all three orthogonal scan planes (the coronal, axial and sagittal planes) are displayed simultaneously on the monitor. It is possible to manipulate the acquired volume and navigate through it in order to reconstruct useful scan planes. Consequently 3D/4D US may reduce operator dependency and open up a new horizon in prenatal diagnosis: telemedicine. Indeed this technique allows for the acquisition of volumes containing all the necessary anatomical information and then send these volumes, using internet network capabilities, to a referral center. The aim of this review has been to report the potential applications of 3D and 4D ultrasound in the identification and the diagnosis of the most common congenital defects: congenital heart diseases.

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CONGENITAL HEART DISEASES

Congenital heart diseases (CHD) are among the most common malformations with a prevalence of about 71/10.000 of total pregnancies in Europe[1]. Prenatal diagnosis and exact definition of congenital heart abnormality are crucial not only to allow for adequate parental counseling but also to allow for planning the delivery at tertiary centers with potential improvement of perinatal outcome. However, the detection rate of screening programs is still far too low to produce acceptable results, particularly when the fetal heart is only examined by use of the "4 -chambers view"[9]. Current guidelines for screening CDH suggest to adding the evaluation of "abdominal view", left and right ventricular outflow tracts and "3VT" view to increase prenatal detection rate [10,11]. This approach promises to produce appreciable results but

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the experience of sonographers has a significant impact on the effectiveness of the screening. Several studies reported that a “4C view” can be obtained in up to 96-98% of the fetus during II trimester routine examinations[9]. Others cardiac planes are more difficult to visualize. As showed by Tegnander et al, the learning curve of a “less experienced” sonographers, already capable of obtaining a “4C view”, to visualize the ventricular outflow tracts requires a time interval of almost three years[12]. 4D-fetal echocardiography is an emerging technology that may reduce dependency on the examiner’s experience and allows offline examination of the fetal heart. Spatiotemporal image correlation (STIC) allows clinicians to quickly acquire a full fetal heart beating cycle in real-time to save the volume to navigate offline in a multiplanar way obtaining all the diagnostic planes. Starting from the 4C view, a plane that can be easily obtained during II trimester scan, the array inside the ultrasound transducer housing performs a slow, single sweep, similar to that carried out by the operator when sliding the transducer to obtain the five views. Furthermore, rendered views of the great vessels can be obtained with inversion mode for volume datasets acquired by using gray scale only, color Doppler, power Doppler, or B-flow imaging allowing to obtain a rendered reconstruction of cardiac structures with a “virtual contrast” between cardiac chambers, vessels lumen as well as shunts.

Several algorithms have been proposed to explore volume dataset of fetal heart obtained with STIC, including the “spin technique”[13], simple targeted arterial rendering (STAR)[14] and four chamber view and swing technique’(FAST)[15] techniques, the systematic visualization of the sagittal view of the ductal arch[16] and tomographic ultrasound imaging (TUI)[17-18]. Our group described a straightforward and rapid technique called “three steps view” that allows us to obtain a 4C view and outflow tracts in about 82% of the cases in an average of 4 min[19]. After an adequate volume acquisition the apex of the heart is positioned at 11 o’clock, then the reference dot is placed on the crux of the heart in plane A and lateral to the aorta in plane B (sagittal) in order to study the characteristics of the 4C view. The second step consists in moving the reference dot in plane A in the middle of the interventricular septum and to rotate on the y-axis until the left ventricle outflow is displayed. Finally, right ventricle flow tract is visualized by moving the reference dot on the aortic valve on plane A (video 1). Overall, the “abdominal view” and “3VT view” can be obtained by scrolling through plane A.

Fetal cardiac examination by STIC can be summarized essentially in two steps: volume acquisition and post-processing evaluation. We recently conducted a study with the aim of evaluating the rate of successful postprocessing of STIC volumes acquired in peripheral centers by sonographers who perform routine fetal examination but who lack specific experience in fetal echocardiography. Cardiac volumes were acquired in 94,8% of the pregnancies and in most of the cases, expert reviewers reconstructed all the cardiac planes from these volumes[20].

This data suggests that one of the advantages of STIC volume acquisition is the potential for telemedicine. This means that every examiner able to obtain a “4C view” in peripheral centers may acquire more than one STIC volume datasets, analyse volumes off-line him-self, after proper software training, or send the cardiac volume of the fetus suspected of being affected by a CHD or by a “classical” risk factor (i.e. familiar, maternal), using internet networking capabilities, to a referral center. This approach can be used to avoid unnecessary referrals for echocardiography to tertiary centers, particularly in countries in which patients are screened at large distances from referral centers[21,22,23]. A relevant issue is to evaluate whether 4D echocardiography is accurate in the diagnosis of CHDs in high risk populations. Bennasar et al[24] evaluated the volume datasets of 342 fetuses referred for suspected CHD and examined by both 2D and 4DUS. This is the largest series of cases with CHD evaluated by STIC and the overall accuracy for diagnosis of CHD was 91% for 4DUS compared to 94.2% for 2DUS, but the difference was not statistically significant. The Collaborative Study on Four-dimensional Echocardiography for the Diagnosis of Fetal Heart Defects (COFEHD) cross-sectionally studied the ability of “experts” in post processing the cardiac volume and properly identifying CHD. Ninety volumes were randomly selected for a blind analysis. They reached a sensitivity of 93% (range, 77-100) and a specificity of 96% (range, 84-100) for all CHD respectively, with excellent intercenter agreement (κ=0.97)[25]. The authors concluded that 4DUS and STIC is an accurate and reliable method of fetal echocardiography because good-quality volume data sets contain sufficient information for the diagnosis of specific CHDs.

In one recent study, Yagel documented that diagnosis, in 12/181 (6%) cases of fetal anatomical cardiovascular anomalies, was possible only using 3D/4D[26].

Two additional aspects of 4D echocardiography should be pointed out given their relevance. First, starting from acquired volume datasets expert operators can obtain high quality imaging allowing for subtle additional diagnosis (such as ventricular septal defect[27], venous anomalies[28] or aorta coarctation[29]) or characterization of difficult abnormalities such as major collateral pulmonary arteries in the setting of pulmonary atresia with VSD[30], interrupted aortic arch with associated cervical origin of the right subclavian artery[31], and total anomalous pulmonary venous return[32-33]. Recently, specific software to automate the extraction of standard fetal echocardiography views from volume datasets has been developed and we has shown that it is possible to diagnose complex disorders such as transposition of the great arteries[34].

From such volumes high 4D quality imaging can be obtained and used for educational objectives or multidisciplinary analyses (video 2,3).

The second aspect is that several groups have reported the feasibility of volumetric measurements of fetal cardiac structures using 4DUS volume datasets. Volumes can be measured using both manual and automatic software, as reported in video 4 and 5 . Parameters such as ventricular mass, ventricular-septum area, end-diastolic volume, end-systolic volume and derived functional parameters, such as stroke volume, ejection fraction and cardiac output, have been measured with good reproducibility[34-43].

The revolution in diagnostic ultrasound that occurred with the advent of 3D/ 4D applications may overcome the problems of operator dependency of 2D ultrasound allowing offline examination of the fetal anatomy. With this technique, every sonographer able to obtain standard diagnostic view (e.g four chamber view) may acquire a full volume datasets. Once acquired, the "digital volume" can be examined by searching additional conventional planes (e.g. outflow tracts, sagittal or to obtain offline any other virtual anatomic plane (e.g. en face view of the ventricular septum), views of the fetal anatomy that are difficult or impossible to obtain with conventional 2D ultrasound.

Further in the near future, by using the new diagnostic advances allowed by 3D/4D US, it will become possible to refer only selected patients to experts team in fetal anomaliesywhere a detailed antenatal diagnosis can be obtained and a multidisciplinar discussion done with the parents regarding the risks, surgical intervention required and longterm outcome[44].

Finally future developments will be dependent by the technology available but there are already some evidences of the possibility to generate non-linear virtual reality object movies of volume images acquired prenatally[45]. Virtual reality have been currently applied to assist in complex surgical procedure in medical imaging and education and there is no doubt that will be applied in the near future also to the study of the fetal anatomy.

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Video Legends

Video 1: The 3 steps technique. Example of volume navigation from the 4 chamber view to the outflow tract visualization

Video 2: Rendering of a normal 4 chamer view

Video 3: Rendering of a case of tetralogy of Fallot with aorta overiding both ventricles

Video 4: Example of automatic calculation of ventricular volume in a ferus with restrictive left ventricle

Video 5: Example of simultaneous assessment of volume of both ventricles

Video footage available on: *www.echoplodu.fetalecho.pl* and via our newsletter: POLSKA KARDIOLOGIA PRENATALNA Echo Płodu

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