Early four-dimensional echocardiography by Spatio-temporal-Image-Correlation

Dario PALADINI, MD
Associate Professor of Obstetrics and Gynecology Head, Fetal Medicine & Cardiology Unit Dept.OB/GYN - University Federico II Naples, Italy
INTRODUCTION

There are several recent factors which have jointly been pushing towards an earlier use of ultrasound to assess fetal cardiac anatomy. The never-ending trend to earlier diagnosis of fetal anomalies is the most important clinical drive behind this shift, together with the worldwide implementation of the Nuchal Translucency screening. At the same time, the dramatic recent advances in ultrasound definition and in four-dimensional ultrasound technology have made this rush towards an earlier assessment of fetal anatomy not only feasible but successful.

As far as the fetal heart is concerned, another important factor which has catalysed the shift of fetal echocardiography towards earlier gestational ages than the conventional 18-22 weeks period is represented by the notation that fetuses with enlarged NT and normal karyotype are at increased risk of having a heart defect[1-3]. After an initial enthusiasm, most authors are now agreeing that the chances of a fetus with an enlarged NT and normal karyotype to have congenital heart disease is in the range of 20-30%(2,3).

However, current advanced technologies with high frequency transvaginal transducers allow not only to assess cardiac anatomy in the 12-15 weeks range period, when the cardiogenesis is completed, but to peek at the edge of the organogenetic phase.

In this article, we will briefly review the technique and the possible advantages of four-dimensional echocardiography.

MODIFICATION OF THE STIC PROTOCOL FOR TV SCANNING

If fetal echocardiography represent the frontier of ultrasound, in terms of complexity and cultural background, early fetal echo is really another step beyond. Hence, all personnel involved in early fetal echo are by definition familiar with conventional mid-trimester fetal echocardiography and, if they are using 3D-4D technology, with the STIC protocol. In this section, we will illustrate a few tips and trick to adapt the conventional STIC technique used in the 2nd trimester to the late 1st trimester.

A first issue regards the transducer: with high frequencies the erythrocytes moving in the blood vessels become visible, due to the high resolution and speckle reflection and refraction. This phenomenon, called natural B-flow, is more evident with the 6-12 MHz probe than with the 5-9 MHz one, due to the shift in frequency range. The solution is simple: the best way to get rid of this phenomenon is to remove the harmonic imaging and to reduce the B-gain; in this way the lumens of the vessels and the cardiac chambers will return to black. Needless to add that, due to the extremely high frequencies, the natural B-flow effect is virtually non removable with the 6-12 MHz probe; but in this case there is no negative effect on the image. Is is also useful to remind that for fetuses older than 14 weeks the 6-12 MHz probe may have a limited use, due to the deeper region of interest. A final, practical point regarding the use of the 6-12 MHz probe regards the sheath used. If latex gloves are used rather than specific probe covers, please be careful to use powder-free gloves, because it is common experience that the talcum powder may significantly impair ultrasound wave transmission; this applies to a lesser extent to the 5-7 MHz transducer.

TRANS-ABDOMINAL (TA) vs TRANS-VAGINAL (TV) SCANNING

One of the first doubts the expert as well as the less expert operator who wants to train in early fetal echo is confronted with is whether to go for a transvaginal or a transabdominal approach. The only condition in which the TA access does not represent an option is maternal obesity, which is becoming a real pandemy. In this case, although vaginal ultrasound may not be easy at all, the region of interest will be so deep with the TA approach to be out of the field of view for the high frequency convex probes needed for early scanning. Except for this condition, whether to use a TA or a TV approach is a matter of experience – pediatric cardiologists are not used to vaginal ultrasound – and of gestational age. At this regard, it should be considered that a number of papers have shown that at 12-13 gestational weeks the TV approach is probably more effective while after 14 week the TA access may be more convenient.

However, it is really a matter of experience and everyday confrontation. The last important factor is the quality of the transducer: if a good high frequency transvaginal transducer is not available, then the TV route is out of question.

However, no matter what approach is chosen, most experts agree that if echocardiography is carried out after 13 completed weeks, the resolution and, consequently, the anatomic details, will be much clearer that at 11-12 weeks. And this represents the first Take-Home Message.
Another important point concerns the technique. As everybody familiar with 3D-4D ultrasound knows, fetal movements are a problem, in most occasion the only problem standing in the way between you and a perfect acquisition! I regret to remind that this problem becomes even more pronounced in early gestation, due to the smallness of the fetal structures to be insonated and the more frequent fetal movements. Therefore, the operator should keep in mind to be contented with a fast and reliable acquisition rather than a longer and more detailed one: 7.5 to 10 seconds acquisition time is necessary in most cases and does not guarantee against a cumbersome and long wait for the baby to be still and quiet. From experience, it could be expected that, if the acquisition is activated only with a still fetus, up to 20-30% of the processes will be aborted (or unsuccessful, if the acquisition is not interrupted prematurely) due to unforeseen fetal movements. As a comparison, less than 10% of the acquisitions, in the same operating conditions, need to be aborted in 2nd trimester 4D-fetal echocardiography (unpublished data, personal experience).

Therefore, the Take-Home Message is: in early fetal echo, profit from fetal stillness when it is there, without waiting to get a perfect axial/sagittal view: every manipulation of the uterus may wake the baby up with dire consequences for the operator.

CARDIAC ANATOMY ASSESSMENT (12-15 WEEKS)

As a premise, it should be considered that, from now onwards, only TV echocardiography will be considered and, hence, all technical comments will regard this technique. Before going into details with early cardiac anatomy assessment, two points which need be kept in mind should be underscored: 1) no matter what the resolution, the central cardiovascular structures are tiny indeed at this gestational age, and 2) consider that acquisitions started from the 4-chamber view will need more time (larger angles) than those acquired from the sagittal aortic arch view. These two notations will result in: 1) color Doppler volumes often add details not visible on greyscale ultrasound, and 2) for ductal and aortic arch assessment, prefer volumes acquired from the sagittal view.

Going into details, the first thing to state is that STIC assessment of cardiac anatomy in the early fetus is not only feasible but of clinical diagnostic value. In fig.1, normal cardiac anatomy is shown in greyscale and color Doppler. Compare with fig.2 in which the same pieces of information are displayed on a single panel of images with Tomographic Ultrasound Imaging. It should be underlined that, in selected cases, the use of rendered images with very thin slices enhances the clinical interpretation, due to the higher signal to background noise ratio that overlaying a few frames determines. As an example, in fig.3 the 4-chamber view of a 13 week fetus is displayed on sectional imaging and in rendering. Note the different sharpness of the two images.

As we stated above, anatomy characterization is much more detailed from 13 weeks onwards that in earlier periods. To fully appreciate the entity of the change in a single gestational week, in fig.4 the central views are compared side by side at 12 vs 14 weeks of gestation.

As mentioned above, we have found that, for the assessment of the arches and the systemic returns longitudinally acquired volumes with color (HD-flow) Doppler or B-flow represent the best option. At this regard, it should be considered that B-flow imaging does represent an outstanding way of assessing not only the arches and neck vessels but also the systemic venous returns both in later gestation and as early as 12 weeks. In fig.5, normal cardiovascular anatomy is shown with B-flow.

By 15 weeks, the clinical information that can be achieved is of impressive quality. Most details of the heart are fully visible, the myocardium is more developed, and the circulation has changed into that appreciable the 2nd trimester (fig.6).
Normal sequential anatomy at 13+1 weeks: A-C): 4-chamber view; B-D) three-vessel view. Note how much more straightforward is the identification of the central connections with color Doppler (B, D) in comparison with greyscale imaging (A, C).
(Ao: ascending aorta; arrowhead: trachea; LV: left ventricle; Pa: Pulmonary artery; RV: right ventricle)

Same case as figure 1. Tomographic Ultrasound Imaging contributes to demonstrate normal sequential anatomy on a single panel of images (from top left, clockwise: reference plane, three-vessels view, 4-chamber view, left outflow tract): A) diastole; B) systole. (Ao: ascending aorta; arrowhead: trachea; LV: left ventricle; Pa: Pulmonary artery; RV: right ventricle)

Comparison of image resolution in sectional vs rendered greyscale imaging. 13 weeks’ fetus: A) on sectional imaging, the edges of the myocardium are ill defined in some areas; B) on thin slice surface-rendering, the edge recognition is enhanced. (LV: left ventricle; RA: right atrium)
Anatomy characterization improves dramatically after 13 weeks. Compare the neatness of the images
A) Tricuspid Atresia at 12+1 weeks; B) Malalignment septal defect in tetralogy of Fallot at 13+4 weeks.

Cardiovascular tree evaluated in a 12 weeks’ old fetus with B-flow. Note how the whole fetal circle can be followed: umbilical vein (uv), ductus venosus (dv), inferior vena cava, the heart (LV: left ventricle; RV: right ventricle), the aortic arch (AA) with the neck vessels (arrowhead), the ductal arch (DA), the descending aorta (DA) with the inferior mesenteric artery (IMA).

Echocardiography at 15+ weeks. A) Normal 4-chamber view on three-dimensional surface-rendering at 14+3 weeks: note the entering of the inferior vena cava into the right atrium (arrow); B) moderate tricuspid dysplasia in trisomy 21 at 15+2 weeks. Note the details of the image and the thickened tricuspid leaflets (arrowhead); C) moderate tricuspid dysplasia in trisomy 21 at 15+2 weeks. On color Doppler, the moderately severe tricuspid insufficiency is clearly demonstrated (arrowheads). (LA: left atrium; RA: right atrium; RV: right ventricle)
CONGENITAL HEART DISEASE

Several articles published in the literature over the last years have demonstrated a high degree of accuracy for early fetal echocardiography (1-3). The use of STIC allows clear demonstration of most CHD in early gestation, and some examples are shown in fig. 7, 8. However, it should be considered that if univentricular heart anatomy is clearly visible, as is AVSD, the same concept does not apply to conotruncal defects, which show, on 2D echocardiography, a relatively lower diagnostic accuracy, due to the relatively difficult evaluation of the septo-aortic continuity. It is possible that 4D-echocardiography, using STIC, might improve the detection rate of these abnormalities also, considering the option of multiplanar image correlation. In selected cases, the use of the 6-12 MHz transvaginal transducer yields dramatic results also in this relatively advanced (as far as the transvaginal approach is concerned) gestational age. In fig. 8, an inlet ventricular septal defect of 0.8 mm is demonstrated in a fetus referred earlier for enlarged NT and in whom Down syndrome was found on CVS.

Fig. 7

Right atrial isomerism at 15+4 weeks. A) on color Doppler, a single atrio-ventricular inflow in a single ventricular chamber, on the left side of the heart, is shown; B) on three-dimensional surface-rendering, the single A-V valve is visible, with single inflow (arrow); C) on Volume Contrast Imaging of the coronal plane (VCI-C static), the abnormal position of the stomach in the right hemiabdomen is seen. Complete heart block, with ventricular heart rate of 70 bpm was also present. The fetus had been referred three weeks earlier due to enlarged NT (4.5 mm). (lt & rt: left & right sides of the body; H: heart; LL: left lung; RL: right lung; ST: stomach; SV: single ventricle)

Fig. 8

Ventricular septal defect detected at 15+6 weeks in a fetus with trisomy 21. Transvaginal echocardiography with the high frequency (6-12 MHz) transducer allows diagnosis of very small defects such as this 0.08 millimeters inlet perimembranous ventricular septal defect. This type of VSD is commonly associated with Down syndrome.
EMBRYO-STAGE ECHOCARDIOGRAPHY

Using high frequency transvaginal ultrasound transducers the resolution obviously increases dramatically, as already pointed out. This technical factor together with the higher signal to background noise ratio warranted by using slightly thicker slices ensures that central cardiovascular structures can be visualised consistently earlier than expected. In fig.9, normal ventricular inflows and three-vessels view are shown as early as 9-5 weeks of gestation, at a CRL of 32 mms.

It goes without saying that this should not represent a reason to move diagnostic ultrasound even earlier in gestation. It is only mentioned to demonstrate that in the near future ultrasound could probably also be used to get important live information on the cardiac organogenesis phase and on the interaction between cardiac function and morphology already in the embryo stage.

Fig.9

Fetal echo at 9+5 weeks. A) 4-chamber view; B) three-vessels view (Ao: ascending aorta; IVC: inferior vena cava; LV: left ventricle; Pa: pulmonary artery; RA: right atrium)

REFERENCES


