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Evaluation of the Fetal Heart by Four-dimensional Echocardiography

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INTRODUCTION

Four-dimensional ultrasonography is a technology that adds the temporal dimension (motion) to 3-dimensional imaging.[1] Four-dimensional visualization of the fetal heart became a practical reality with the incorporation of spatiotemporal image correlation (STIC) algorithms into commercially available equipments.[2,3] STIC is a technique that allows acquisition of fetal heart volume and visualization of cardiac structures as a 4D cine sequence.[2,3] In this technique, the array inside the transducer housing performs a single slow sweep, recording a single 3D dataset. STIC derives the heart rate from the periodicity of the movements of the cardiac structures, and eventually a single virtual cardiac cycle, each frame of which is the result of the overlay of many acquired frames, is reconstructed. This volume consists of a high number of 2D frames. The acquisition of high-quality volume datasets is crucial for the successful examination of the fetal heart by 4D US.[4,5] Until recently, only gray scale volumes could be acquired with STIC. A new technological advance has added the possibility of incorporating color and power Doppler, B-flow and high-definition flow Doppler information into the volume dataset. Color and power Doppler have a slower frame rate compared with gray scale during scanning, which leads unavoidably to a reduction in image quality using color STIC when compared with gray scale STIC.

PLANE OF ACQUISITION

Once acquired, the volume is opened and can be used offline for multiplanar navigation and/or four-dimensional image renderings using the various modes described below. It must be kept in mind that in case of fetal arrhythmias this technique cannot be used since the anomalous fetal heart rate would compromise the adequacy of the acquired volume. The quality of the heart volume dataset depends on the frame rate of the two-dimensional (2D) image, the angle sweep and the acquisition time.[4]

If the operator is interested in the evaluation of the 4-chamber, 5-chamber and 3-vessels and trachea views, the best approach to acquire an adequate volume is to start the acquisition procedure while displaying an apical 4-chamber view. Instead, if the examiner wants to review the aortic and ductal arches, or the venous return to the heart, high-quality volume datasets are best acquired using sagittal sweeps through the fetal thorax.[4]

Acquisition Angle

The volume of interest is acquired with a sweep angle of approximately 20-35° (depending on the size of the fetus) that are usually sufficient to include the stomach, the heart, and its vascular connections in the volume dataset.

Acquisition Time

The acquisition time can be selected by the user and usually ranges from 7.5 to 12.5 sec. Using the longest possible acquisition time, the highest spatial resolution of the volume dataset is obtained. However, the longer the sweep takes, the higher the likelihood that artifacts related to fetal motion may be present in the volume dataset.[4,5]

Multiplanar Display

Volume datasets are displayed using multiplanar slicing and the original plane of acquisition is displayed in plane A (upper left panel) of the screen and the 2 orthogonal planes to the reference plane in the right upper panel (plane B) and left lower panel (plane C), respectively (Fig. 1).

The basic approach to the examination of a volume dataset of the fetal heart is to simply scroll through the volume from the top to the bottom along the original plane of acquisition. In this way all echocardiographic planes can be obtained offline with the multiplanar mode.

The reference dot guides the operator in navigating within the volume, as it is anchored at the point of intersection of the three planes (Fig. 1). It has to be underlined that the lightness with which a beginner as well as an experienced operator can navigate the volume of the heart and great vessels contributes significantly to a better understanding of the three-dimensionality of the central cardiovascular structures.

Tomographic Ultrasound Imaging (TUI)

This modality allows for the simultaneous display of up to 8 parallel planes, whose distance can be adjusted for a better

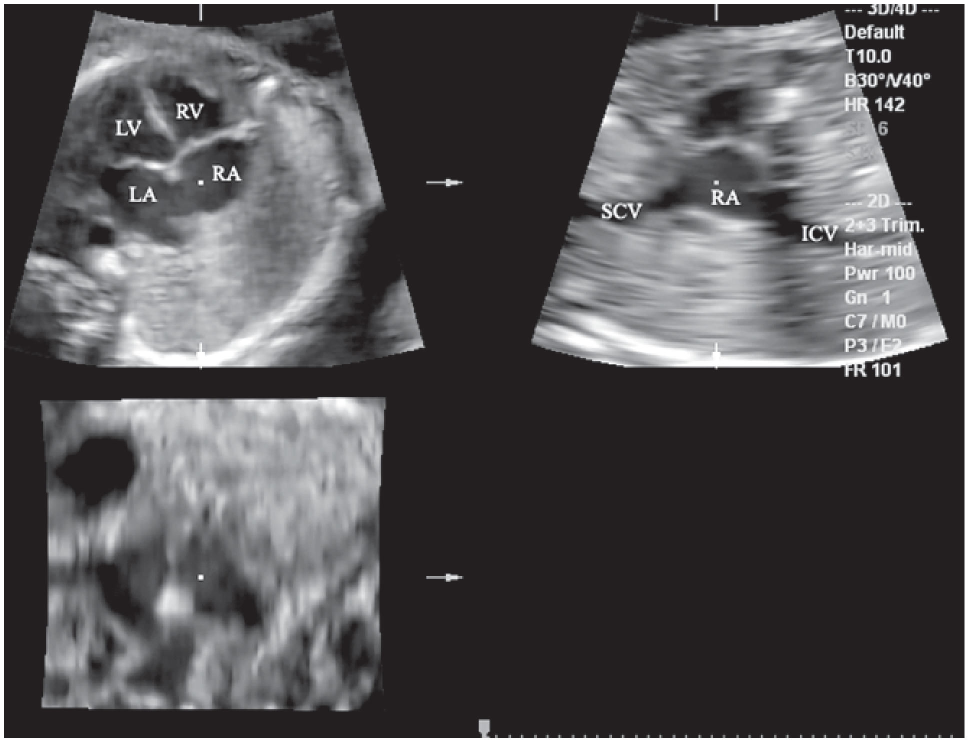

Fig. 1: STIC displayed in the multiplanar mode. The A-plane (upper left panel) is the acquisition plane, the B-plane (right upper panel) is the orthogonal plane vertical to the A-plane and the C-plane (left lower panel) is the orthogonal plane horizontal to the A-plane. The navigation point is placed on the right atrium in the A-plane; the B-plane shows the right atrium with superior and inferior caval vein. LA—left atrium; LV—left ventricle; RA—right atrium; RV—right ventricle; ICV—inferior caval vein; SCV—superior caval vein

visualization of anatomic planes as in a computed tomographic or magnetic resonance imaging scan. With this approach, if the acquisition is performed orthogonal to the fetal body, all information regarding the sequential anatomy of the heart from the venous afferent vessels to the arterial outflows and arches is readily available on a single panel that includes all significant echocardiographic planes (Fig. 2).[6,7] By showing simultaneously the central cardiovascular connections on a single panel, TUI-STIC may improve the understanding of cardiac anatomy in cases of both normal and severely abnormal cardiac connections.

B-flow

B-flow imaging is a new technique that uses digitally encoded sonographic technology to provide direct visualization of blood echoes in gray scale. It displays simultaneously both tissue morphology and blood flow using the same gray scale schemes. The B-flow image does not interfere with the information produced by B-mode because both utilize the same spatial resolution and frame rate. When compared with color and power Doppler sonography, B-flow sonography has a higher frame rate and better spatial resolution. It allows angle-independent detection of weak blood reflectors from vessels. This modality allows a better visualization of small vessels[8] with low flow velocity (Fig. 3) and, then, it may help to characterize complex CHD.

Rendering Mode

There are different rendering modes that may enhance the characterization of cardiac anatomy in normal and abnormal conditions.

Surface Mode

This mode can be used to visualize any intracardiac structure. These techniques provide an in-depth perspective to the structure under examination, and can be used to optimize the contrast of the myocardial borders, septa and valves, or to obtain realistic images of particular structures of interest. In particular, this mode allows planes to be visualized that cannot be obtained with 2D ultrasound,[9] such as the coronal view of the atrioventricular valves (Fig. 4) or the en-face view of the interventricular septum (Fig. 5).

Inversion Mode

This mode is a post-processing tool that inverts the gray scale of the volume voxels. Therefore, anechoic structures such as

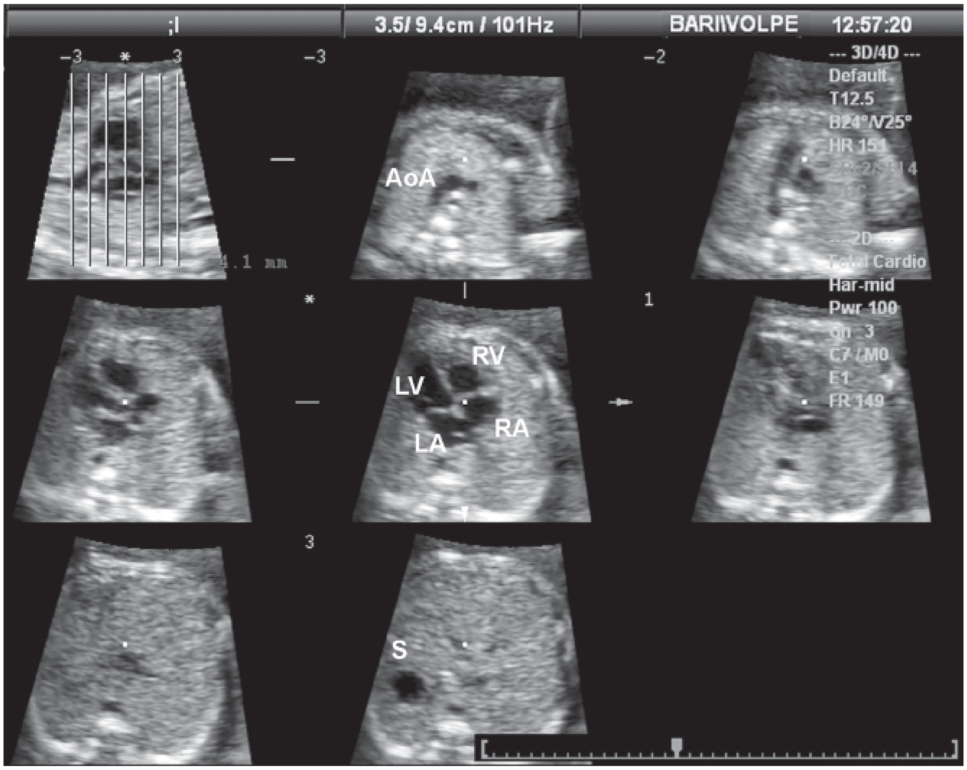

Fig. 2: STIC and tomographic ultrasound imaging (TUI). This image modality allows one to display on a single panel a variable number of parallel reconstructed 2D sections that are orthogonal to the plane of acquisition. The upper left window shows a sagittal view of the fetal thorax; lines correspond to the views shown in the other windows. These images show a normal heart: the sequential anatomy can be assessed, from the abdominal situs (lower row, central window) up to the aortic arch (upper row, central window). AoA—aortic arch; LA—left atrium; LV—left ventricle; RA—right atrium; RV—right ventricle; S—stomach

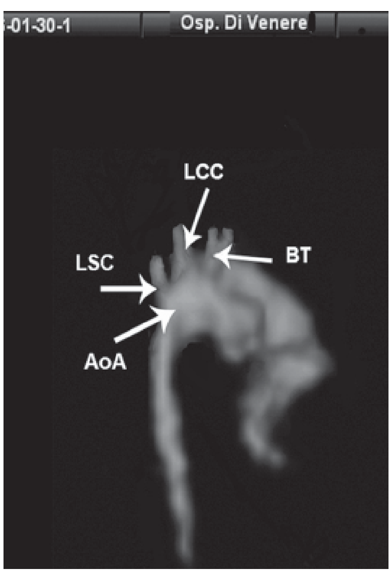

Fig. 3: STIC and B-flow imaging of the aortic arch (AoA), showing the neck vessels. BT—brachiocephalic trunk; LCC—left common carotid artery; LSC—left subclavian artery

Fig. 4: Surface rendering of coronal view of the atrioventricular plane; scanning plane not obtainable with 2D echocardiography. This is a normal heart: the reconstructed coronal view allows visualization of the two leaflets of the mitral valve (arrows) and the three leaflets of the tricuspid valve (arrowheads)

Fig. 5: Surface rendering of en face view of the interventricular septum; scanning plane not obtainable with 2D echocardiography. Ultrasound images showing normal interventricular septum in three-dimensional rendering mode. Note the rough appearance of the septum (arrows) from within the trabeculated right ventricle. The outflow tract of the great arteries can be seen. Ao—aorta; P—pulmonary artery

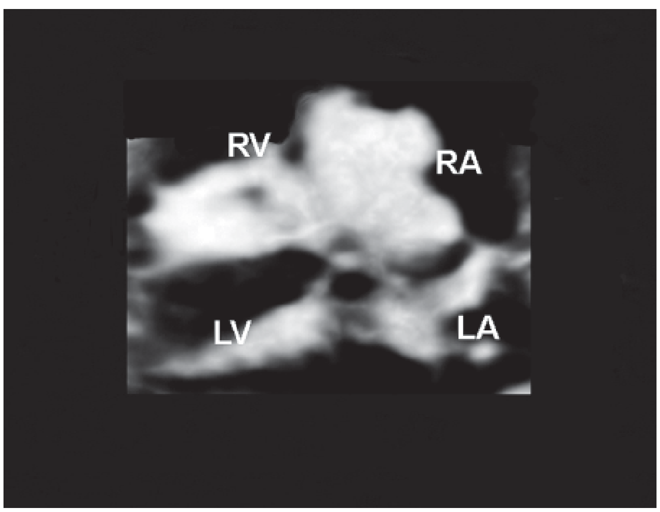

Fig. 6: Coarctation of the aorta. Three-D inversion mode image of the 4-chamber view showing the significant prevalence of right cardiac sections over left ones. This image modality inverts the color assigned to the black and white pixels, providing a cast-like image of the cardiac chambers. RV—right ventricle; LV—left ventricle; RA—right atrium; LA—left atrium

the heart chambers, vessel lumen and the stomach appear echogenic, whereas structures that are normally echogenic before gray scale inversion appear anechoic.[10] In fetal echocardiography it can be applied to create 'digital casts' of the cardiac chambers and vessels that may resemble those seen during cardiac catheterization (Fig. 6). Since this technique does not use color or power Doppler sonography, it does not have the inherent limitations to image reconstruction related to the angle of insonation, temporal resolution, or intensity of the Doppler signal.

Glassbody Mode

This mode allows to display as a single image gray scale and color Doppler information.[5] The possibility of coupling a transparent mode for the gray scale image with a surface mode for the color Doppler signal allows a display on the same image of the diastolic filling of the ventricles and the systolic ejection of blood through the great vessels, giving a striking 3D cast of the crossover (Fig. 7A). This approach also contributes to the understanding of the relatively complex anatomy of the anomalous outflow tracts (Fig. 7B).

Role of 4D Echocardiography

Four-dimensional echocardiography gives us another look at the fetal heart. The possibility of navigating through the volume dataset and examining the fetal heart in the absence of the patient can be shared for expert review, interdisciplinary consultation, parental counseling, or teaching.[5,11] A well-executed STIC acquisition from a apical four-chamber view of the heart, contains all the necessary planes for evaluation of the five classic transverse planes of fetal echocardiography. The operator can examine the fetal upper abdomen and stomach, then scroll cephalad to obtain the familiar 4-chamber view, the five-chamber view, the bifurcation of the pulmonary arteries, and finally the three-vessel and trachea view. Using color or power Doppler or B-flow surface rendering is possible to obtain a reconstruction of the outflow tracts with demonstration of the spatial relationships between the aorta and the pulmonary artery in a single image.

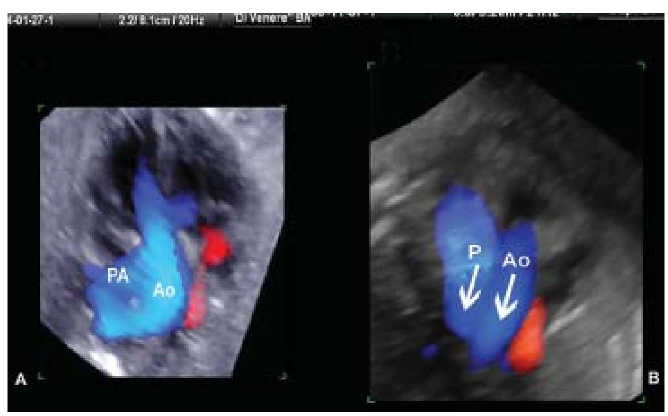

Fig. 7: Glassbody rendering with transparent maximum mode. A) The normal crossover of the great arteries is recognizable on a single image (PA—pulmonary artery; Ao—aorta). B) Anomalous parallel course of the great arteries (arrows) are clearly seen on a single image in a case of transposition of the great arteries

In a diagnostic setting, the possibility of investigating cardiac defects using virtual planes that are generally inaccessible in 2D cardiac scanning, such as the coronal view of the atrioventricular valves, significantly increases the confidence with which some difficult diagnoses can be reached.

Finally, it seems to provide information that may improve the prenatal visualization of some cardiac defects.[8,10-12]

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