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● *Original Contribution*

FOUR-DIMENSIONAL ECHOCARDIOGRAPHY WITH SPATIOTEMPORAL IMAGE CORRELATION AND INVERSION MODE FOR DETECTION OF CONGENITAL HEART DISEASE

Yue Qin,* Ying Zhang,* Xiaohang Zhou,† Yu Wang,* Wei Sun,* Lizhu Chen,* Dan Zhao,* Ying Zhan,* and Ailu Cai*

*Department of Sonography, Shengjing Hospital of China Medical University, Heping District, Shenyang, People's Republic of China; and †College of Basic Medical Science of China Medical University, Heping District, Shenyang, People's Republic of China

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Abstract—The aim of this study was to evaluate the use of 4-D echocardiography with inversion mode and spatiotemporal image correlation (IM-STIC) in the detection of normal and abnormal fetal hearts. We retrospectively studied 112 normal fetuses and 16 fetuses with a confirmed diagnosis of congenital heart disease. Two volumes were acquired from each of the fetuses using transverse and sagittal sweeps. Volumes were reconstructed with IM-STIC. In normal fetuses, IM-STIC facilitated visualization of the interior structures of the fetal heart and great vessels. The visualization rates of intended planes obtained from IM-STIC 4D data ranged from 55% to 100%. In 16 fetuses with congenital heart disease, IM-STIC was able to display the cardiac malformations using digital casting. Some of the malformations were suspected during pre-natal 2-D echocardiography, and their pre-natal IM-STIC diagnoses were confirmed by post-natal echocardiography, surgery and/or autopsy. Hence, 4-D IM-STIC allows better visualization of complex congenital heart disease and should be considered a very useful addition to 2-D echocardiography. (E-mail: qyningmengcha@163.com or caial1224@sina.com) © 2014 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Ultrasound, 3-D and 4-D, Fetal heart, Spatiotemporal image correlation, Inversion mode, Pre-natal diagnosis.**

INTRODUCTION

Congenital heart disease is a major cause of death among infants. Because most fetuses with congenital heart disease are born to mothers without any known risk factors, it is necessary to examine the fetal heart during pregnancy (Sun et al. 2011; Wu et al. 2012). Two-dimensional ultrasound is the basic tool used to do so. However, 2-D ultrasound presents some limitations, as fetal position oligohydramnios, operator-dependent examination limitations and time-consuming image acquisition may all affect the diagnostic coincidence (Devore et al. 1993). Four-dimensional ultrasound does offer additional capabilities for examining the fetus (*e.g.,* multiplanar, rendered and automatic slicing displays) compared with 2-D ultrasound. Preliminary evidence suggests that this may decrease the examination time with minimal impact on the visualization rates of anatomic structures. Therefore, the introduction of 4-D ultrasound has provided a new tool for assessing the fetal heart, in particular, some complex congenital heart diseases (Allan et al. 1989; Gindes et al. 2009; He et al. 2013).

Spatiotemporal image correlation (STIC) is a technique in which ultrasound is used to reconstruct a 3-D image of the fetal heart from which volume can be determined. STIC allows analysis of the volume data that combines spatial and temporal information in a complete cardiac cycle after a single automatic volume sweep. This can show the beating fetal heart in multiplanar and surface-rendered displays dynamically. By use of STIC gating, a more comprehensive investigation of the fetal heart is feasible because motion artifacts can be largely removed (Devore et al. 2003; Gonçalves et al. 2003; Yagel et al. 2007). Automatic segmentation in fetal cardiac ultrasound volumes may be useful for both

Address correspondence to: Ailu Cai, Department of Sonography, Shengjing Hospital of China Medical University, 36 Shanhao Street, Heping District, Shenyang 110004, People's Republic of China. E-mail: qyningmengcha@163.com or caial1224@sina.com

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structural and functional analysis. Successful application of such an algorithm could aid in diagnosis, might indicate a volume acquisition of high quality or may even hint at structural defects. Clear recognition of the sequential connections and spatial relationships has been achieved. Working on 4-D data sets of normally available quality, semi-automated, rather than completely automated, programs appears to segment the cardiac chambers more efficiently. This is because the operator can exclude areas involving artifacts (Deng and Rodeck 2006; Tutschek and Sahn 2008).

The inversion mode is a volume analysis approach to 3-D/4-D ultrasonographic visualization of anechogenic fetal structures. This technique transforms anechogenic voxels into echogenic ones. This mode is capable of providing additional anatomic information, as well as the intuitive "digital casts" of fetal cardiac chambers, great vessels and the points of attachment of atrioventricular valves. More recently, this technique has been applied to visualizing the outflow tracts of the fetal heart, and it is capable of displaying abnormalities of the fetal heart (Benacerraf 2006; Espinoza et al. 2005; Gonçalves et al. 2004; Hata et al. 2009, 2010; Messing et al. 2007).

The primary objective of this study was to evaluate 4-D echocardiography with inversion mode combined with spatiotemporal image correlation (IM-STIC) in the examination of the normal and abnormal fetal heart.

METHODS

We retrospectively studied cardiac volume data sets obtained by 4-D ultrasound with STIC from 128 fetuses. All of the fetuses were singletons and selected from an echocardiographic study in our hospital between February and May 2012. The 128 mothers were in good health and were non-smokers, without a history of illegal drug use and other high risk factors (diabetes, hypertension, maternal medication) at the time they were enrolled. Maternal age ranged from 18 to 36 (median, 31.1) y. Of the 128 fetuses, 112 were normal and 16 had congenital heart disease. Gestational age was determined based on sonographic measurements of biparietal diameter and femur length. All recruited normal 112 fetuses had structurally normal hearts of appropriate size for gestational age on conventional 2-D ultrasound. The 16 fetuses with congenital heart disease included one case of double-outlet right ventricle, one case of transposition of the great arteries, one case of corrected transposition of the great arteries, one case of restrictive foramen ovale, five cases of tetralogy of Fallot, four cases of ventricular septal defect and three cases of Ebstein's anomaly. All fetuses had their diagnoses confirmed. All 112 normal cases underwent post-natal echocardiographic follow-up, whereas post-natal echocardiography, surgery or autopsy was performed on the 16 fetuses with congenital heart disease. The study was approved by the institutional review board of the hospital, and all pregnant women gave verbal informed consent before examination.

All of the fetal hearts were examined by 4-D ultrasound with STIC using a Voluson E8 ultrasound system (GE Healthcare, Kretztechnik, Zipf, Austria) equipped with transabdominal transducers (RAB 2–5 or 4–8 MHz). Two volumes were acquired from each patient. The volume data sets were obtained using transverse and sagittal sweeps, and the four-chamber view and long-axis view of the aortic arch were acquisition planes, respectively. The regions of interest included the ventricular and atrial chambers, the outflow tracts and the great arteries arising from and veins returning to the fetal heart. The volume was acquired with a sweep angle from 25° to 35° (depending on the size of the fetus). Volume acquisition was performed in the absence of fetal movement. Mothers were asked to momentarily suspend breathing. The data sets were stored on a compact disk-recordable for further offline analysis with a personal computer software program (4D Viewer, Version 10.3, GE Medical Systems, Zipf, Austria).

All volume data sets were analyzed by the first sonographer (Q.Y.). All volume data sets displayed using the multiplanar modality, which allowed simultaneous display of images in three orthogonal planes (panels A, B and C) (Fig. 1). The surface rendered image was reconstructed and displayed in panel D. The 4-D reconstructions were carried out using the "inversion"-rendering mode. The surface was displayed in a mixture of minimum mode and surface-smooth mode, with a 20% to 80% ratio in the mixed imaging. We chose the transverse volume (of which the initial plane was a four-chamber view) with render mode, then decreased the size of the sampling box in panel B and adjusted panel A in x-axis and reference slice; the left ventricular outflow tract view and the right ventricular outflow tract view were then shown in turn. In the same way, we chose the sagittal volume (of which the initial plane was a long-axis view) with render mode. The size of the sampling box in panel B was decreased to clearly visualize the aortic arch, ductal arch, superior vena cava, inferior vena cava and brachiocephalic artery in panel D. Threshold and transparency levels were lowered until the structures of interest were visualized. All volumes were treated by the MagicCut function to remove the structures of non-interest that blocked the views of the structures of interest.

Inter-observer variability for 4-D ultrasound with IM-STIC was determined by having another experienced sonographer (Z.Y.) re-process and re-analyze the 4-D volumes in 20 randomly selected normal fetuses and all fetuses with congenital heart disease. The fetal intended

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