A Systematic Approach to Prenatal Diagnosis of Transposition of the Great Arteries Using 4-Dimensional Ultrasonography With Spatiotemporal Image Correlation

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Abbreviations
STIC, spatiotemporal image correlation; TGA, transposition of the great arteries

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Spatiotemporal image correlation (STIC) is a recent technological advance in ultrasonographic imaging that allows dynamic multiplanar slicing and surface rendering of the fetal heart.[1–5] In a previous study, a technique was developed to systematically visualize the outflow tracts from volume data sets acquired with STIC.[3,4] The addition of color and power Doppler imaging to STIC technology made it possible to dynamically display rendered views of the outflow tracts with minimal manipulation of the volume data set.[5]

Prenatal diagnosis of transposition of the great arteries (TGA) is associated with a significant reduction in both preoperative and postoperative mortality, a decrease in the rate of metabolic acidosis and multiorgan failure during the neonatal period, reduced need for ventilatory support, and shorter hospitalization time.[6,7] Unfortunately, prenatal detection rates for TGA have been low in most of the studies published to date.[8–15] Among the reasons for failure to prenatally detect most cases of TGA are the absence of risk factors to identify a target population for screening and the need to systematically examine the outflow tracts to establish the diagnosis.[6,16] Despite recommendations by scientific societies such as the American Institute of Ultrasound in Medicine to extend the basic fetal cardiac examination to include visualization of the outflow tracts whenever technically feasible,[17] this examination remains a technical challenge for many sonographers.[6,18]

Four-dimensional volume data set acquisition followed by a systematic approach to image the outflow tracts may reduce the operator dependency of prenatal ultrasonography. Volume acquisition is still operator dependent with current commercially available technology. However, once a good-quality volume data set is acquired, the outflow tracts can be systematically imaged by following algorithms developed for gray scale,[3,4] color, or power Doppler[5] imaging. It is anticipated that algorithms developed to image specific cardiac structures with 3- or 4-dimensional volume data sets may eventually become automated by computer software (automated multiplanar imaging).[19]

The objective of this report was to describe the ultrasonographic findings of TGA on the basis of a systematic approach of 4-dimensional echocardiography with STIC.

Case Report

A 43-year-old white patient, gravida 12, para 8038, was approached at 20 3/7 weeks' gestation to participate in a 4-dimensional ultrasonographic study after a suspected finding of a heart anomaly on 2-dimensional ultrasonography. The objective of the examination was to verify whether our previously described techniques for systematic visualization of the outflow tracts using 4-dimensional volume data sets acquired by STIC could be used to examine the heart.[3–5] The patient gave written informed consent before participation in the study, which was conducted under protocols approved by the Institutional Review Boards of both Wayne State University and the National Institute of Child Health and Human Development.

The obstetric history was remarkable for a previous child with spina bifida, a 20-week stillbirth of unknown etiology, and 2 first-trimester miscarriages. There was no family history of congenital heart disease and no history of maternal or gestational diabetes or exposure to teratogenic agents known to affect heart development.

Two-dimensional ultrasonography revealed a normal 4-chamber view (Figure 1A and Video 1). Visualization of the outflow tracts showed the great arteries exiting the ventricular chambers in parallel (Figure 1B).

Volume data sets were then acquired by STIC with a Voluson 730 Expert ultrasound system (General Electric Medical Systems, Kretztechnik, Zipf, Austria). Gray scale ultrasonography as well as gray scale plus power Doppler imaging were used during volume acquisition. The acquisition time ranged from 7.5 to 15 seconds, and the acquisition angle ranged from 25° to 35°. The power Doppler settings at the time of acquisition were as follows: pulse repetition frequency, 5.0 kHz; quality status, normal (normal color resolution and medium frame rate); and wall motion filter, mid1 (the manufacturer preset settings for wall motion filter are low1, low2, mid1, mid2, high1, high2, and max).

A 4-step approach to evaluate the fetal heart using multiplanar display images was applied to a 4-dimensional volume data set obtained with STIC through a transverse sweep of the fetal thorax (Figure 2 and Video 2). Images from a normal case at the same gestational age are shown in Figure 3 for comparison (Video 3). Transposition of the great arteries was shown in steps 3 and 4: on rotation of the volume data set around the y-axis (step 3; Figure 2C), 2 vessels could be visualized leaving the ventricular chambers in parallel. Once the reference dot was positioned at the center of the vessel leaving the left ventricle (step 4; Figure 2D, panel A), the sagittal orthogonal view confirmed that this vessel was actually the pulmonary artery (step 4; Figure 2D, panel B).

Volume-rendered power Doppler images of the outflow tracts (Video 4) of a normal case (Figure 4A)[5] were compared to this case with TGA (Figure 4B). In the case with TGA (Figure 4B), the great vessels were visualized leaving the ventricular chambers in parallel, in contrast to crisscrossing of the great arteries in the normal case (Figure 4A). The technique used to obtain the rendered images is illustrated in Figure 5 (Video 5).[5]

The findings of the 2 previous scans were independently confirmed by fetal and neonatal echocardiography performed at the Department of Fetal Cardiology of the Children's Hospital of Michigan.

Discussion

Transposition of the great arteries is one of the most common cyanotic congenital heart defects in the neonatal period,[20] occurring in approximately 0.2 to 0.4 per 1000 live births[20] and representing 2.5% to 5% of all congenital heart defects.[21] In this anomaly, the pulmonary artery arises from the left ventricle, and the aorta arises from the right ventricle. Associated anomalies may include ventricular septal defects (10%–20%), pulmonary stenosis, and coarctation of the aorta.[20] As the 2 ventricles function in parallel, oxygenation after birth is dependent on mixing of blood through a patent foramen ovale and, to a lesser extent, the ductus arteriosus or a ventricular septal defect.

Prenatal diagnosis of TGA is associated with a reduction in perinatal morbidity[7,22] and mortality.[7] Bonnet et al[7] compared the preoperative and postoperative morbidity and mortality in 68 neonates with prenatal diagnosis of TGA versus 250 neonates with diagnosis only in the neonatal period. Prenatal diagnosis of TGA was associated with (1) a reduced requirement for mechanical ventilation (18% [12 of 68] versus 38% [96 of 250];

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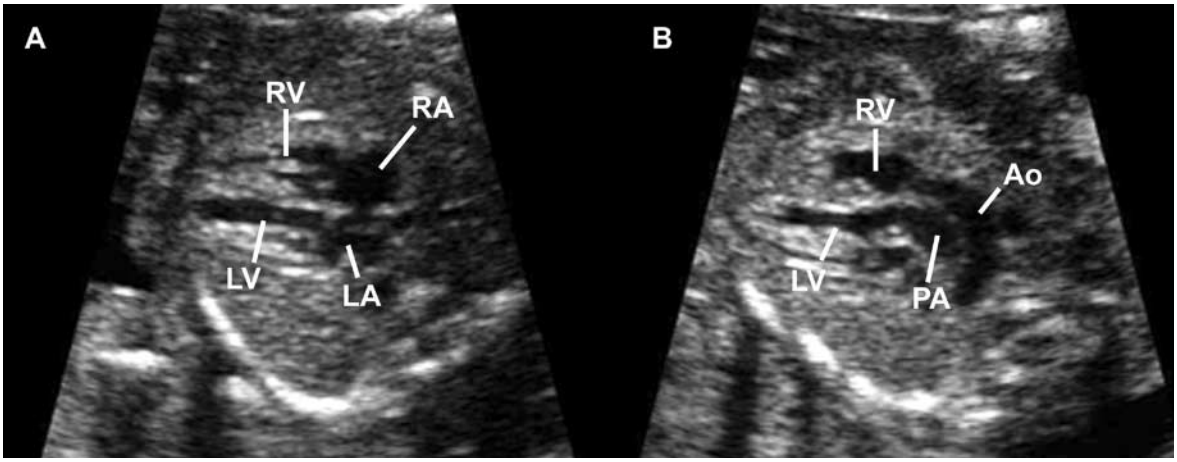
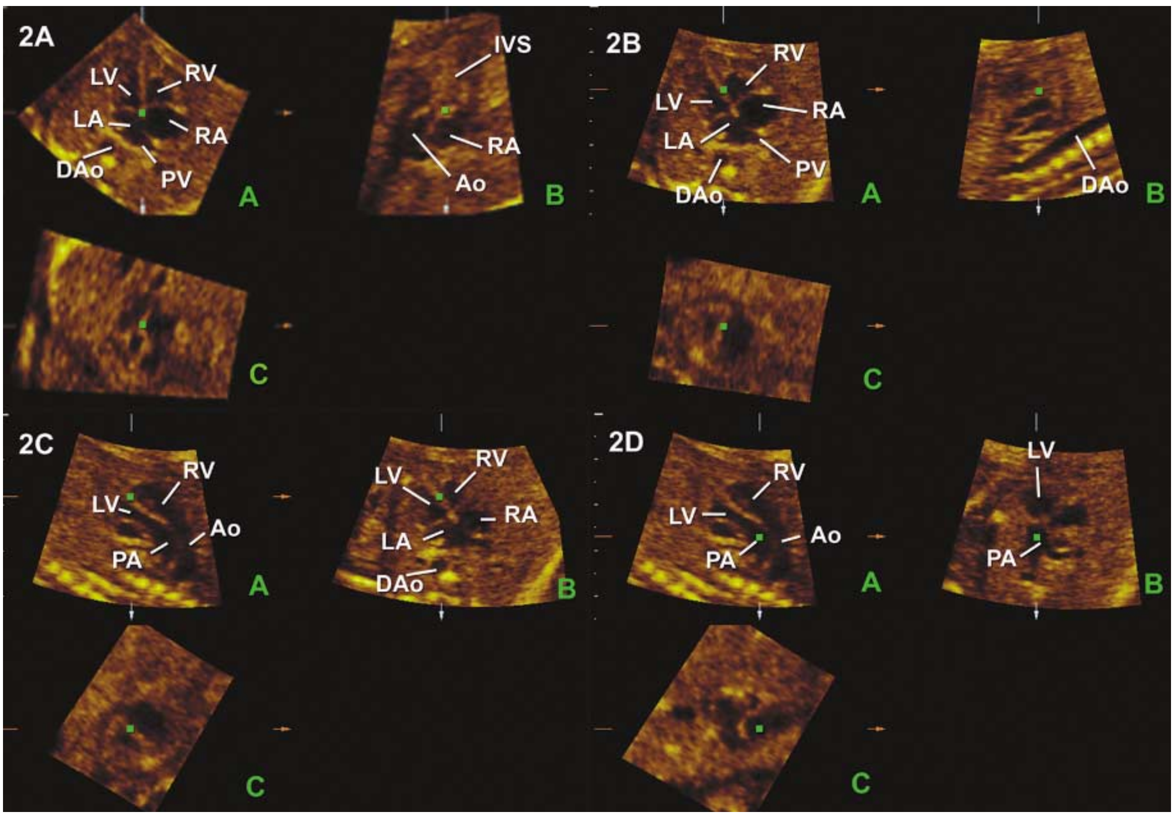


Figure 1. Two-dimensional ultrasonographic images of TGA. **A**, Normal 4-chamber view of the fetal heart. **B**, Visualization of the outflow tracts. The great arteries leave the ventricles in parallel: the pulmonary artery is connected to the left ventricle, and the aorta is connected to the right ventricle. Ao indicates aorta; LA, left atrium; LV, left ventricle; PA, pulmonary artery; RA, right atrium; and RV, right ventricle.

Figure 2. Multiplanar slicing of TGA. Panels **A–C** represent the 3 orthogonal planes (**A**, transverse; **B**, sagittal; and **C**, coronal). **2A**, Apical 4-chamber view of the fetal heart. **2B**, The volume data set is rotated counterclockwise 30° to 40° degrees around the z-axis, and the reference dot is moved to the middle of the interventricular septum. **2C**, As the volume is rotated clockwise around the y-axis, 2 vessels can be visualized leaving the ventricular chambers in parallel. **2D**, The reference dot is moved to the vessel leaving the left ventricle; a sagittal orthogonal image shows bifurcation of the pulmonary artery in panel **B**. DAo indicates descending aorta; IVS, interventricular septum; and PV, pulmonary vein. Other abbreviations are as in Figure 1.

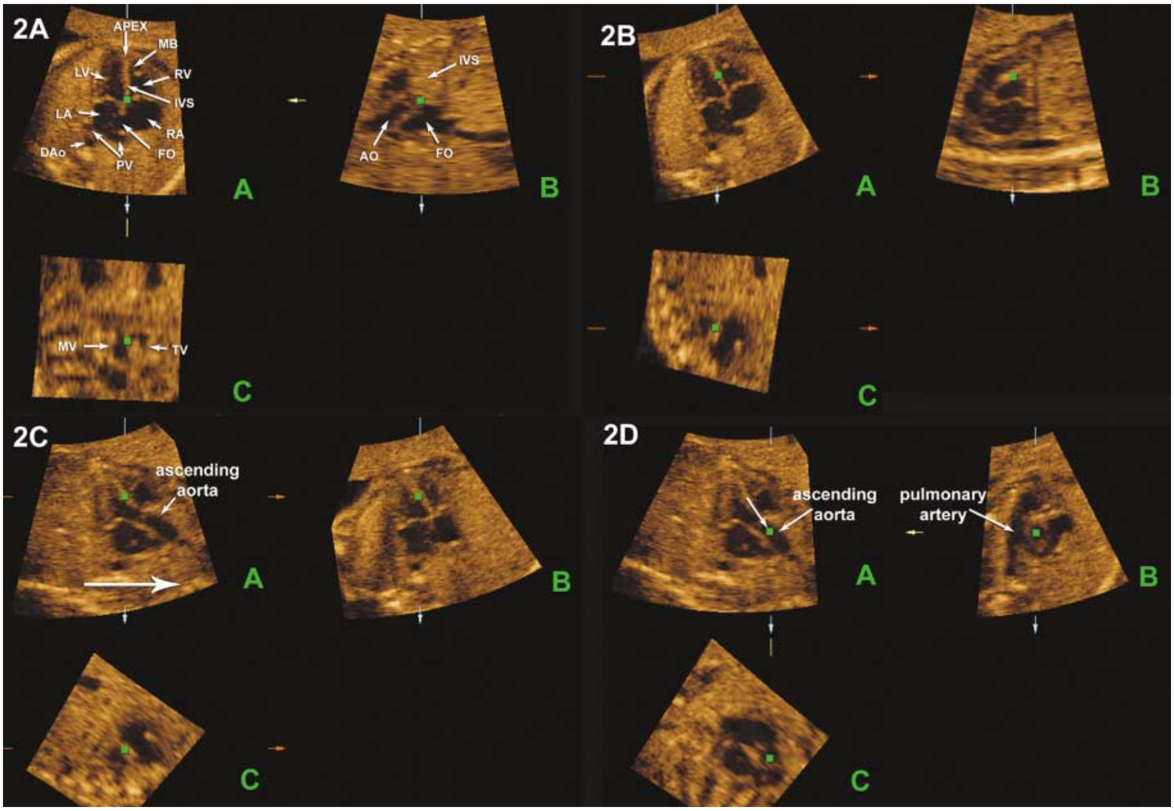


P < .01), (2) a decreased frequency of metabolic acidosis and multiorgan failure (12% [8 of 68] versus 22% [56 of 250]; *P* < .05), (3) shorter hospitalization stays (24 ± 11 versus 30 ± 27 days [mean ± SD]; *P* < .01), and (4) decreased preoperative mortality (0% [0 of 68] versus 6% [15 of 250]; *P* < .05) and postoperative mortality (0% [0 of 68] versus 8.5% [20 of 235]; *P* < .05). The definitive treatment for TGA is the "arterial switch" operation.[23,24] Surgical mortality of the arterial switch operation can be as low as 2% and is less than 5% in most hospitals. Preoperative mortality is, therefore, an important issue in the treatment and outcome of fetuses with TGA.[22,25,26]

This report illustrates that 4-dimensional gray scale and power Doppler STIC can be used to systematically visualize the abnormal relationship of the outflow tracts in fetuses with TGA. Volume acquisition required only clear visualization of the apical 4-chamber view during 2-dimensional ultrasonography for 7.5 to 15 seconds. The detection rate of TGA by standard obstetric ultrasonographic evaluation is low (Table 1),[8–15] and this disappointing performance has been attributed to issues related to technical difficulties in consistently imaging the outflow tracts.[6,16,18]

Four-dimensional ultrasonography may overcome technical limitations related to the skills required to obtain appropriate planes of a section. This technology allows for automatic volume acquisition of the fetal heart, including the surrounding areas, while the heart is in motion. Spatiotemporal image correlation stores complete volume data sets of the fetal heart and reduces dependency on the examiner's experience.[1–5] The user can digitally store the data, optimize and slice the images in an iterative manner as required for diagnosis, and even transport and transmit the images to an expert in

Figure 3. Multiplanar slicing of a normal fetal heart at 20 weeks' gestation. Panels **A–C** represent the 3 orthogonal planes (**A**, transverse; **B**, sagittal; and **C**, coronal). **2A**, Apical 4-chamber view of the fetal heart. **2B**, The volume data set is rotated counterclockwise 30° to 40° around the z-axis, and the reference dot is moved to the middle of the interventricular septum. **2C**, As the volume is rotated clockwise around the y-axis, 2 vessels can be visualized leaving the ventricular chambers in parallel. **2D**, The reference dot is moved to the vessel leaving the left ventricle (aorta); the short axis view of the right ventricular outflow tract is shown in panel **B**. FO indicates foramen ovale; MB, moderator band; MV, mitral valve; and TV, tricuspid valve. Other abbreviations are as in Figures 1 and 2.



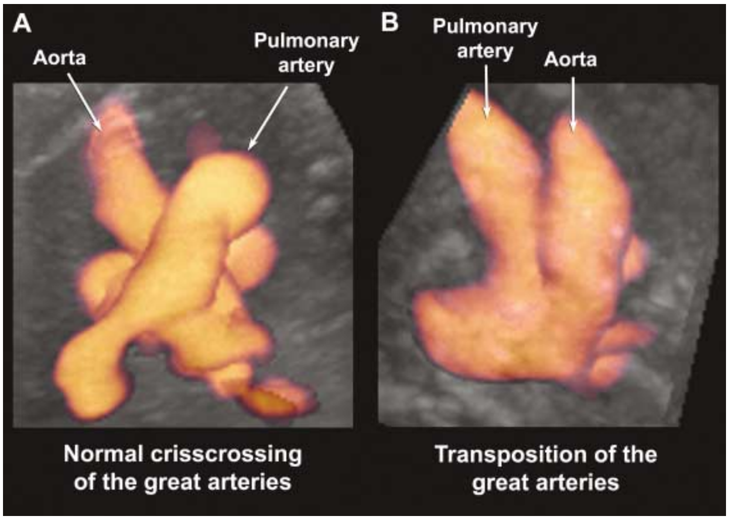


Figure 4. Rendered images from volume data sets of the fetal heart in a normal case[5] (**A**) and TGA (**B**). The volumes were acquired through a transverse sweep of the fetal chest using power Doppler 4-dimensional ultrasonography with STIC. In the normal case, normal crisscrossing of the great arteries is observed, whereas in TGA, the vessels leave the ventricles in parallel. The technique used to render the volume data sets is explained in Figure 5. **A**, Reproduced from the *Journal of Ultrasound in Medicine*.[5]

Figure 5. Multiplanar image of the fetal heart during systole acquired by power Doppler STIC. The size and position of the rendering box are shown, as well as the direction of view used to obtain the volume-rendered images of the ventricular outflow tracts in this case of TGA. **A**, Transverse section. **B**, Sagittal section. **C**, Coronal section. **D**, Volume-rendered image of the outflow tracts. DA indicates ductus arteriosus; and Rt PA, right branch of the pulmonary artery. Other abbreviations are as in Figures 1 and 2.

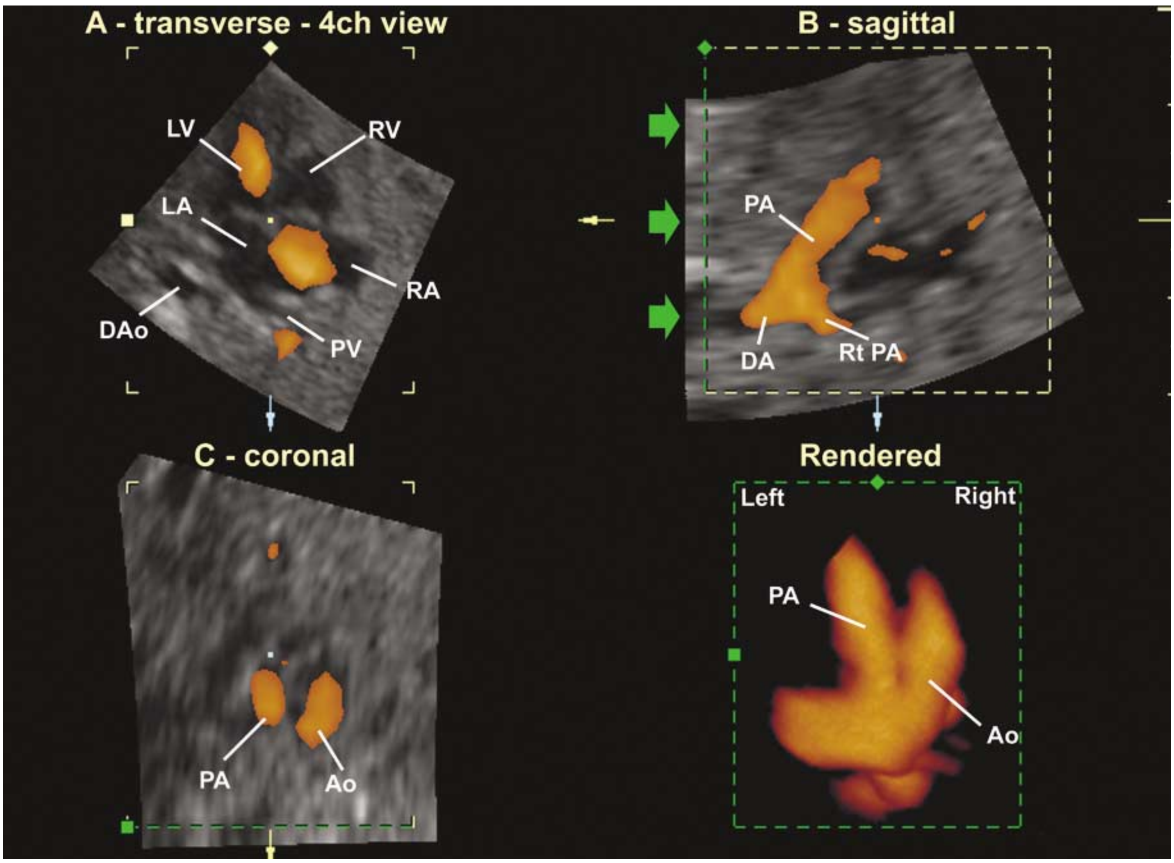


Table 1. Prenatal Detection Rate for TGA

Reference	Year	Period	n	Detection Rate, % (n)	
				CHD	TGA
Stoll et al[8]	1993	1987–1988	26,490	9.2 (84/912)	9.6 (6/62)
Stoll et al[9]	1998	1990–1993	92,021	13.7 (107/779)	51.0 (24/47)
Montaña et al[10]	1996	1990–1994	1,589	6.1 (97/1589)	6.3 (5/80)
Kirk et al[11]	1997	1990–1995	16,121	65.7 (73/111)	62.5 (5/8)
Bull[12]	1999	1993–1995	4,799	23.4 (1124/4799)	3.0 (12/391)
Jaeggi et al[13]	2001	1994–1996	240,000	15.0 (97/562)	0.0 (0/77)
Garne et al[14]	2001	1996–1998	2,454	25.0 (613/254)	19.0 (17/91)
Levi et al[15]	2003	1990–1993	3,633	34.0 (271/798)	24.1 (14/58)

CHD indicates congenital heart disease.

fetal cardiology if necessary.[2] Additional potential clinical benefits of STIC are improved temporal resolution, an increased number of stored 2-dimensional images, and complete rotation of the heart to examine the 3-dimensional multiplanar anatomy around a 360° axis.[1] Last, the clear contrast between the images of the normal fetal heart compared with those of the heart affected by TGA as obtained by 4-dimensional rendering techniques (Figure 4, A and B) may result in a better understanding of the congenital cardiac abnormality by the parents and enhance prenatal counseling.

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