Sonographic Appearance of Fetal Structural Heart Diseases Determined Using Wide-band Doppler

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**Background:** The objectives in this report are to present data on echocardiographic imaging of fetuses with congenital structural heart diseases using wide-band Doppler and to discuss the practical application of this unique display modality in the field of fetal echocardiography.

**Methods:** We performed fetal echocardiography using wide-band Doppler technology and examined fetuses that were at various gestational ages between January 2004 and December 2007.

**Results:** Satisfactory blood flow signals could be obtained using the wide-band Doppler; this has increased the understanding of fetal cardiovascular hemodynamics.

**Conclusions:** Wide-band Doppler appears a color flow mapping method that can contribute toward better understanding of fetal cardiovascular hemodynamics; it is also expected to provide greater accuracy in fetal echocardiography.

**KEY WORDS** — congenital heart defects, Doppler echocardiography, fetal ultrasonography

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**Introduction**

Over the last two decades the sensitivity of color Doppler technology has steadily improved. To increase sensitivity, conventional color Doppler imaging uses a long burst pulse, that is, narrow-band frequency transmission. However, a narrow-band frequency transmission results in insufficient distance resolution and resultingly the technology has certain limitations with regard to the detailed evaluation of small vessels. The high level of clutter and overpainting provide further shortcomings in color Doppler technology.

Dynamic flow was initially developed in 2000. This technology employs a short pulse that is a wide-band transmission which results in a significant improvement in distance resolution. It has been demonstrated that this color mapping method is effective when used with a contrast agent, and particularly for evaluating the detailed vascularity of...
liver or pancreatic tumors [1–4]. Currently the Advanced Dynamic Flow (ADF) provided by the Toshiba Aplio series also provides high quality images that are very similar to those obtained by B-mode ultrasound even on non-contrast imaging. Despite being a Doppler-based technique, ADF has higher resolution, good penetration, and a wide dynamic range [5]. ADF also exhibits less blooming and therefore is considered more useful for visualizing small vessels. Currently, this technology is also reported to significantly facilitate the investigations in the field of hepatology [6,7] as in the case of the original dynamic flow method.

Apart from hepatological examinations, fetal echocardiography also requires detailed evaluation of small vessels, although contrast agents cannot be used in this field. I hypothesize that it is possible to optimally apply the wide-band Doppler for fetal echocardiography. Here, I present data on echocardiographic imaging of fetuses with congenital structural heart diseases using this unique display modality and discuss its application to fetal echocardiography.

Methods

A wide-band advanced dynamic flow is embedded in the Aplio 80 and Aplio XV systems (Toshiba, Tokyo, Japan) in the Doppler ultrasonography device. I performed fetal echocardiography using these machines, and 40 fetuses with CHD at various gestational ages were investigated between January 2004 and December 2007. A 3.5-MHz real-time convex transducer was used as the probe. The echocardiographic examination was carried out such that it included a four-chamber view, both the outflow tracts (the pulmonary artery and ascending aorta), transverse aortic arch, the inferior and superior vena cava, and the long or short axis of the left ventricle. The diagnoses of heart disease were confirmed postnatally based on the findings of diagnostic procedures such as ultrasonography, cardiac catheterization, and angiocardiography and cardiac surgery (if performed) and autopsy results (in case of death).

Results

During the study period, I routinely performed echocardiography using wide-band advanced dynamic flow for all CHD-affected fetuses. The representative six cases and their clinical data are summarized in Table 1.

Case 1 was that of tetralogy of Fallot (TOF). TOF is a congenital disorder comprising four anatomical abnormalities—a ventricular septal defect, pulmonary artery stenosis, the presence of an aortic valve that overrides the interventricular septum, and hypertrophy of the right ventricle; the forth condition may not be observed during fetal life. Figure 1 shows the overriding aorta in this affected fetus with an estimated body weight of 300 g. Blood

<table>
<thead>
<tr>
<th>Case no.</th>
<th>Maternal age</th>
<th>GA at examination (wk)</th>
<th>Diagnosis of heart disease</th>
<th>Hydropic change</th>
<th>Associated anomaly</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>31</td>
<td>25</td>
<td>TOF</td>
<td>Negative</td>
<td>Unilateral MCK</td>
</tr>
<tr>
<td>2</td>
<td>27</td>
<td>33</td>
<td>Critical PS</td>
<td>Positive</td>
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<tr>
<td>3</td>
<td>26</td>
<td>21</td>
<td>VSD, CoA</td>
<td>Negative</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>38</td>
<td>31</td>
<td>Absent PV</td>
<td>Negative</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>28</td>
<td>31</td>
<td>TGA</td>
<td>Negative</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>27</td>
<td>32</td>
<td>TA, PA</td>
<td>Negative</td>
<td></td>
</tr>
</tbody>
</table>

GA = gestational age, TOF = tetralogy of Fallot, PS = pulmonary stenosis, VSD = ventricular septal defect, CoA = coarctation of aorta, PV = pulmonary valve, TGA = transposition of the great arteries, TA = tricuspid atresia, PA = pulmonary atresia, MCK = multicystic kidney.
flow from both ventricles to the aorta was clearly shown by wide-band ADF.

Case 2 was that of critical pulmonary stenosis, which resulted in neonatal death. In fetuses with this condition, right ventricular hypertrophy may be severe. This finding resembles that observed during pulmonary atresia with an intact ventricular septum. Figure 2 shows the four-chamber view of this case. Wide-band ADF mapping of the tricuspid valve in the systolic period illustrated severe regurgitation caused by high right ventricular pressure. In this figure, the red-colored signal indicated regurgitation through the tricuspid valve, and the blue-colored signal indicated the rebound from the right atrial wall. The latter signal (rebound flow) suggested the severity of regurgitation. Subsequently, the patient with this condition developed a hydropic change that included pericardial effusion and skin edema.

Case 3 was that of coarctation complex. First, the perimembranous ventricular septal defect was ultrasonographically demonstrated at 21 weeks of gestation. Figure 3 shows the wide-band ADF imaging in this case. In this figure, blood flow can be clearly observed through the atrial valve to the ascending aorta, and the left-right shunt flow through the ventricular septal defect. A perimembranous ventricular septal defect is likely to be associated with other defects, including coarctation or interruption of the aortic arch and abnormalities of outlet tracts; therefore this finding has to be investigated carefully. In this case, the coarctation of the aorta arch was suspected prenatally and confirmed immediately after birth by pediatric cardiologist.

Case 4 was that of an absence of the pulmonary valve. An absence of the pulmonary valve is usually associated with TOF and is characterized by pulmonary regurgitation and a variable degree of dilation of the branch pulmonary arteries. The dilation of the pulmonary arteries extends to the distal vessels and causes bronchial compression, which leads to severe respiratory distress after birth. Figure 4 shows an image of pulmonary trunk in this case. Turbulent flow in the pulmonary artery during the systolic period and reversed flow to the right ventricle during the diastolic period were clearly demonstrated by wide-band ADF.

Case 5 was that of transposition of the great arteries. Transposition of the great arteries is a heart
defect, in which the two main arteries leaving the heart are reversed (transposed). In transposition of the great arteries, these two arteries (the aorta and the pulmonary artery) are connected to the wrong chambers of the heart. Figure 5 shows images of this case. In conventional color Doppler mode, two arteries are observed to be joined because of overpainting. In wide-band Doppler images, two arteries located close to each other can be distinctly observed as separate routes.

Case 6 was that of tricuspid atresia and pulmonary atresia. In this condition, the systemic venous return has to traverse from the right to the left atrium through the foramen ovale, and the pulmonary blood supply is achieved by the reverse flow from the ductus arteriosus. Figure 6 shows the blood flow in the pulmonary artery observed in this case. Wide-band ADF mapping showed the turbulent flow in the pulmonary artery. This flow included the reversed flow from the ductus arteriosus to the pulmonary valve, and the rebound flow from the pulmonary valve. These different flow routes were separately depicted.

Discussion

CHD is one of the most common congenital disorders and has a significant impact on perinatal morbidity and mortality. Currently, color Doppler imaging is considered an established and useful method that enables prenatal hemodynamic studies...
Fig. 5. The images show that two main arteries leaving the heart are reversed using (A) B-mode ultrasound, (B) ADF and (C) conventional color Doppler.

Fig. 6. ADF mapping shows the turbulent flow in the pulmonary artery; this flow includes the reversed flow from the ductus arteriosus to the pulmonary valve (blue-colored signal) and the rebound flow from the pulmonary valve (red-colored signal). The right ventricle is hypoplastic. Viewed with (A) B-mode ultrasound, (B) ADF, and (C) conventional color Doppler. Ao = aorta, RV = right ventricle, PA = pulmonary artery.
of CHD in utero [8–14]. By using this method, we can demonstrate the presence and accurate direction of blood flow. It can also be used to demonstrate regurgitation at any valve, shunt flow through a defective ventricular septum, abnormal connection of vessels, reversed flow in the pulmonary artery or aorta, etc. However, conventional color Doppler has some shortcomings such as insufficient distance resolution and a high level of clutter and overpainting. Therefore, the flow signal quality of conventional color Doppler may occasionally be insufficient for visualization during fetal cardiac examination.

Wide-band Doppler is a flow velocity mapping method that achieves distance resolutions and frame rates that can compare to those of real-time B-mode ultrasound but with less blooming. Fetal echocardiography has some serious and unique challenges, including the small size of the target; higher heart rate as compared to that of adults; and artifacts due to fetal movement, breathing movement and cardiac contraction. Due to the small size of the target, high-resolution B-mode ultrasound and color flow mapping are vital for obtaining detailed images of intracardiac structures and the blood flow inside and outside the heart. Further, the recommended frame rate is more than 15 frames per second because of the higher heart rate (120–160 bpm). It is possible that blood flow signals obtained using conventional color Doppler may not provide acceptable image quality due to artifacts resulting from fetal movement, including breathing and cardiac movement. The experiences that we have documented in this report suggest that wide-band ADF can overcome the abovementioned limitations and is suitable for a more accurate depiction of blood flow in fetal echocardiography. In case nos. 4 and 6, the distinction between the normal-directional flow and reversed flow in the pulmonary artery are demonstrated due to high distance resolution and less blooming. In case nos. 3 and 5, two blood flow routes are located very close to each other, but could be distinctly observed as separate routes. In case no. 2, the severity of regurgitation through the tricuspid valve was suggested as the rebound flow from the right atrium was depicted clearly. This appeared to contribute better understanding of intracardiac hemodynamics.

Previous studies have suggested that the accuracy of fetal echocardiography largely depends on the skill of the examiners [15–17]. However, the hemodynamics of the fetal cardiovascular system appears to be complex, thereby making it difficult to comprehend for clinicians. In Japan, it is estimated that only 10% of CHDs are diagnosed prenatally. A majority of heart disease cases are prenatally diagnosed in pregnancies with no obvious risk factor [18–20], therefore fetal echocardiography is expected to be widely applied to obtain greater accuracy in general obstetric practice. As shown here, the images obtained by using wide-band Doppler can contribute towards a better understanding of fetal cardiovascular hemodynamics. I believe most CHDs are prenatally diagnosed with sufficient accuracy even by a conventional color Doppler in the presence of expert opinion; however, I expect that use of this color flow mapping method can familiarize younger, less-experienced obstetricians with fetal echocardiography, thereby enabling more accurate prenatal evaluation of CHDs in general obstetrics. In the future, further study to provide enhanced diagnostic sensitivity and specificity may result in superior diagnostic efficacy in general obstetric practice compared with conventional color Doppler ultrasound.

Acknowledgments

I wish to thank Aya Hidaka for her encouragement and self-sacrificing support.

References


