FETAL DOPPLER ECHOCARDIOGRAPHIC ASSESSMENT OF CARDIAC BLOOD FLOW VELOCITY IN NORMAL FETUSES AND IN THOSE WITH CONGENITAL HEART DISEASE

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Synopsis Ninety fetal Doppler echocardiographic examinations were performed on 72 normal fetuses and 5 with congenital heart disease [2 pulmonary stenosis (PS), 1 pulmonary atresia (PA), 1 tetralogy of Fallot (TOF) and 1 endocardial cushion defect (ECD)] at 16 to 40 weeks of gestational age. The maximum transmitral (MVMax), transtricuspid (TVMax), transmitral (AVMax) and transpulmonary blood flow velocity waveforms (PVMax) were assessed. The detection rates for MVMax, TVMax, AVMax and PVMax in normal fetuses were 69.4%, 68.2%, 77.6% and 43.5%, respectively. MVMax, TVMax, AVMax and PVMax correlated well with gestational age, in the normal fetuses. However, there was no correlation between MVMax, TVMax, AVMax, PVMax and heart rate, in the normal fetuses, respectively. The TVMax/MVMax ratio was one and over in 3% of normal fetuses (96.4%), and PVMax/AVMax ratio was one and over in 12% of normal fetuses (41%). In cases of PS, the TVMax was relatively low, but the PVMax was definitely high. The TVMax/MVMax ratios in cases of PS were 0.8 and 1.0, respectively. AVMax in a fetus with TOF was definitely low and markedly decreased in the case of ECD. Therefore, fetal Doppler echocardiography is a pertinent diagnostic tool which can be used to analyze cardiac hemodynamics in all fetuses, in utero.

Key words: Fetus • Doppler echocardiography • Maximum velocity • Congenital heart disease

Introduction

Fetal echocardiography has become a routine obstetric ultrasound examination, and numerous reports of the antenatal diagnosis of congenital heart disease (CHD) and in utero fetal cardiac functions have been done\(^3\)\(^{11}\)\(^{13}\)\(^{15}\)\(^{21}\). With advances in Doppler echocardiography, in utero fetal cardiac hemodynamics in physiologic and pathologic conditions have been evidenced\(^2\)\(^{10}\)\(^{14}\)\(^{21}\). In the present study, we assessed the transvalvular maximal velocities of left and right atrioventricular and semilunar valves of the fetal heart, using Doppler echocardiography and we studied the change of in utero circulatory hemodynamics in normal fetuses and those with CHD.

Materials and Methods

Ninety fetal Doppler echocardiographic examinations were performed on 72 normal fetuses, all appropriate for date babies (AFD), and five with CHD [2 pulmonary stenosis (PS), 1 pulmonary atresia (PA), 1 tetralogy of Fallot (TOF) and 1 endocardial cushion defect (ECD)] at 16 to 40 weeks of gestation. All the mothers were Japanese and informed consent was obtained from each mother for the study. The deliveries and studies all took place at Shimane Medical University Hospital.

The apparatus used was an Aloka SSD-730 with a 2-MHz transducer and it is applicable for either pulsed or continuous-wave Doppler modes. In the continuous-wave Doppler mode, velocities can be measured up to 6m/s, but with loss of range resolution. Wall filters (200Hz) were used to eliminate low-frequency signals occurring from valve signals and wall noise.

The Doppler beam was aligned in parallel to the long axis of the left ventricle, right ventricle, aorta and pulmonary artery, respectively, to measure transvalvular blood flow velocities. In diastole, 2 peaks of the blood flow velocity waveforms were recognized in transmitral and transtricuspid blood flow velocity waveforms (Fig. 1). In systole, a sharp peak blood flow velocity waveform was distinct in transaortic and transpulmonary blood flow.
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Fig. 1. Transmitral blood flow velocity waveform in a normal fetus at 37 weeks of gestation.

Fig. 2. Transpulmonary blood flow velocity waveform in a normal fetus at 36 weeks of gestation.

velocity waveforms (Fig. 2). The maximal velocities of blood flow can be calculated by the equation: 
\[ V = \frac{\Delta f \cdot C}{2f \cdot \cos \theta} \]
where \( V \) = maximal velocity, \( \Delta f \) = frequency shift, \( f \) = transmitted ultrasound frequency and \( C \) = speed of sound in tissue. In this study, the Doppler beam was aligned parallel to the long axis of left ventricle, right ventricle, aorta and pulmonary artery to ensure recording of maximal Doppler shifts. Therefore, the angle between the direction of blood flow and the Doppler beam (\( \theta \)) is assumed to be 0 because the Doppler beam is kept in parallel to the direction of the blood flow. On each record, 4 to 5 separate cardiac cycles were examined to determine mean maximal velocity. To limit exposure of the fetus to the Doppler the scanning time of Doppler recordings was kept to within 2 min and the gain control was reduced to the minimum necessary to record adequate blood flow velocity waveforms.

Results

Maximal velocities of transmitral (MVMax), transtricuspid (TVMax), transaortic (AVMax) and transpulmonary blood flow velocity waveforms (PVMax) were assessed. Rates of detection of MVMax, TVMax, AVMax and PVMax in normal fetuses were 69.4%, 68.2%, 77.6% and 43.5%, respectively.

MVMax in AFD increased gradually with advancing gestation (Fig. 3). Similarly, TVMax in AFD increased gradually with advancing gestation (Fig. 4).

Fig. 3. Transmitral maximal velocity and gestational age. AFD: appropriate for date baby, PS: pulmonary stenosis, ECD: endocardial cushion defect.

Fig. 4. Transtricuspid maximal velocity and gestational age. AFD: appropriate for date baby, PS: pulmonary stenosis, ECD: endocardial cushion defect.
Fig. 5. Transtricuspid maximal velocity/transmitral maximal velocity ratio and gestational age. AFD: appropriate for date baby, PS: pulmonary stenosis, ECD: endocardial cushion defect.

Fig. 6. Transaortic maximal velocity and gestational age. AFD: appropriate for date baby, PS: pulmonary stenosis, PA: pulmonary atresia, ECD: endocardial cushion defect, TOF: tetralogy of Fallot.

Fig. 7. Transpulmonary maximal velocity and gestational age. AFD: appropriate for date baby, PS: pulmonary stenosis, ECD: endocardial cushion defect.

Fig. 8. Transpulmonary maximal velocity/transaortic maximal velocity ratio and gestational age. AFD: appropriate for date baby, PS: pulmonary stenosis, ECD: endocardial cushion defect.

4). There was no correlation between MVMax, TVMax and heart rate, respectively. The ratio of TVMax/MVMax was one and over in 53 of 55 normal fetuses (96.4%) (Fig. 5).

AVMax in AFD correlated well with gestational age (Fig. 6) and PVMax in AFD increased gradually with advancing gestation (Fig. 7). There was no correlation between AVMax, PVMax and heart rate, respectively. The ratio of PVMax/AVMax was one and over in 11 of 25 normal fetuses (44%) (Fig. 8).

In cases of PS, TVMax as relatively low, but the PVMax was definitely high. Moreover, TVMax/MVMax ratios in cases of PS were 0.8 and 1.0, respectively. AVMax in a fetus with TOF was definitely low and markedly decreased in case of ECD.

Discussion

With recent advances in Doppler ultrasound, studies of cardiac hemodynamics can be performed in adults and children, and numerous studies have been done using pulsed and continuous-wave Doppler ultrasounds to obtain data on fetal blood flow velocity waveforms from the umbilical artery and vein, cerebral artery and aorta. However, only few studies on normal fetuses have been reported in case of in utero fetal cardiac hemodynamics, as determined by Doppler ultrasound. Moreover, little is known of in utero fetal cardiac blood flow velocity waveforms.
in cases of the CHD. We assessed the transvalvular maximal velocities of left and right atrioventricular and semilunar valves of the fetal heart, using Doppler echocardiography and studied changes of in utero circulatory hemodynamics in normal fetuses and in those with CHD.

With continuous-wave Doppler ultrasound, velocities are recorded all along the sound beam, and there is no range resolution. In our study, the Doppler beam was aligned parallel to the long axis of left ventricle, right ventricle, aorta and pulmonary artery, respectively, to measure transvalvular blood flow velocities. MVMax and TVMax were recorded on the four-chamber view, AVMax on the long-axis view or a view of the four-chamber with aortic root and PVMax on the short-axis view or view of the right ventricular outflow tract. Each view of the fetal heart can be readily depicted by two-dimensional echocardiography and the rates of detection for each view are high, in utero. In our study, rates of detection of MVMax, TVMax, AVMax and PVMax in normal fetuses were 69.4%, 68.2%, 77.6% and 43.5%, respectively. The Doppler beam was aligned parallel to the long axis of the left ventricle, right ventricle, aorta and pulmonary artery to keep the Doppler beam in parallel to the direction of the blood flow. Moreover, the fetal movement is rapid and the fetal position changes, chronologically. Therefore, the rates of recording for each blood flow velocity waveform in this study are thought to be lower. However, the continuous-wave Doppler ultrasound is most useful for obtaining maximal velocity waveforms because all velocities are recorded along the sound beam. Therefore, the continuous mode was used to determine maximal velocities of transvalvular blood flows of the fetal heart.

Reed et al. reported that the MVMax decreased with advancing gestational age while the TVMax did not change. However, in our study, the MVMax increased gradually with advancing gestation (r = 0.37, 0.001 < p < 0.01), as did the TVMax (r = 0.41, 0.001 < p < 0.01). In cases of PS, the TVMax was relatively low, because the end-diastolic pressure of the right ventricle might be elevated due to valvular stenosis. Regarding the ratio of TVMax/MVMax, Huhta et al. reported that the average TVMax/MVMax was 1.09, Shimada et al. stated that the TVMax/MVMax was 1.0 to 1.3 (mean 1.12) and Reed et al. noted that the mean ratio of TVMax/MVMax was 1.13. In the present study, TVMax/MVMax was at least 1 in 53 of 55 normal fetuses (96.4%). In previous work with M-mode echocardiography, we noted that the right ventricular dimension was somewhat larger than that of the left. Therefore, the right ventricle of the fetus might be dominant because the blood flow was calculated as blood flow velocity x the cross-sectional area of atrioventricular valve orifice. Similarly, Reed et al. reported that the valve volume flow across the tricuspid valve was greater than that across the mitral valve in normal human fetuses, determined using Doppler echocardiography. These findings are consistent with the right heart dominance demonstrated in normal fetal animals. On the other hand, TVMax/MVMax ratios in cases of PS were 0.8 and 1.0, respectively.

In our study, the AVMax correlated well with gestational age (r = 0.60, p < 0.001) and the PVMax increased gradually with advancing gestation (r = 0.43, 0.001 < p < 0.01), in the normal fetuses. Therefore, cardiac maximal velocities increased gradually with advancing gestational age, under physiologic conditions. AVMax in the fetus with TOF was definitely low and markedly decreased in the case of ECD. Moreover, PVMax was definitely high in case of PS. Silverman et al. reported that the syndrome of atrioventricular valve insufficiency, nonimmune hydrops, and structural heart disease had a poor prognosis. In the present study, in utero tricuspid regurgitant flow was noted in only one case of PA and the prognosis was poor. Therefore, the in utero status of various CHDs can be evaluated noninvasively, using fetal Doppler echocardiography. The PVMax/AVMax ratio was reported to be from 0.86 to 0.97 (1317325). In our study, the PVMax/AVMax ratio was at least 1 in 11 of 25 normal fetuses (44%). Kenny et al. found that the pulmonary arterial diameter consistently exceeded the aortic diameter and that the right ventricular stroke volume exceeded that of the left ventricle, thus confirming right ventricular dominance, in utero. However, we did not calculate the volume flow as a substantial error may have been present. Reed et al. stressed that even though annular diameters varied by only about 1 mm, this could still represent a 20% error in
diameter measurement in some of the smaller fetuses and might induce a 30% change in cardiac flow.

In conclusion, fetal Doppler echocardiography is a pertinent diagnostic tool for perinatologists and cardiologists to assess in utero cardiac hemodynamics, under physiologic and pathologic conditions.

Acknowledgments

We thank Prof. C. Mori for the comment on the manuscript, M. Ohara for advice on the manuscript and the staff of Department of Obstetrics and Gynecology, Shimane Medical University, for kind co-operation. This study was presented in part at the 39th Annual Meeting of Japan Society of Obstetrics and Gynecology, March 1987, Tokyo, Japan.

References


