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Quantitative Assessment of Fetal Ventricular Function:

Establishing Normal Values of the Myocardial Performance Index in the Fetus

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Objective: Assessment of ventricular function in the fetus has been limited for many reasons, including relative cardiac size and atypical orientation of fetal cardiac structures. A myocardial performance index (MPI) has been described in adult and pediatric populations as an echocardiographic measure of global (systolic and diastolic) ventricular performance. Because the MPI is a Doppler index, it is independent of ventricular geometry and can be applied to both left and right ventricular function. This study attempts to define the MPI in a group of normal fetuses and compare these data to other published studies of this index. Study Design: The right ventricular (RV) and left ventricular (LV) MPI were measured in 125 normal fetuses (20–40 weeks gestation, mean age 28 weeks). These fetuses were divided into five gestational age groups for comparison. These data were compared to 152 normal children (age 3–18 years, mean age 9.3 years). Results: In normal fetuses, the LV MPI was 0.36 ± 0.06 and the RV MPI was 0.35 ± 0.05. This was not statistically different from the group of normal children in whom the LV MPI was 0.35 ± 0.03 and the RV MPI was 0.32 ± 0.03. In addition, no significant change in the fetal MPI was seen with advancing gestational age. Conclusion: This study demonstrates that fetal ventricular function can be quantitatively measured with the MPI. The MPI provides an easily obtainable and reproducible measure of fetal ventricular performance that can be readily incorporated into all fetal echocardiographic examinations. (ECHOCARDIOGRAPHY, Volume 18, January 2001)

myocardial performance index, fetal ventricular function, echocardiography, Doppler echocardiography

Quantitative assessment of ventricular function has historically been based on models that assume a specific geometric shape. Quantitative assessment of ventricular function in the fetus has been inherently difficult due to many unique imaging challenges. Limitations include relative cardiac size in the developing fetus, atypical orientation of fetal cardiac structures, fetal movement, and suboptimal maternal abdominal ultrasonic windows.

Routine assessment of ventricular function in the fetus typically relies on M-mode measurement of left ventricular (LV) or right ventricular (RV) shortening fraction.[1,12-17] Alternatively, with difficult fetal imaging planes, the echocardiographer is forced to rely on a visual estimation of ventricular function. Routine measurement of fetal diastolic function is not commonly measured. A quantitative measurement of fetal systolic and diastolic ventricular performance that is simple, reproducible, and nongeometric would be most advantageous.

A myocardial performance index (MPI) has been described as a noninvasive Doppler measurement of global ventricular function.[2] This index has been shown to correlate well with other invasive and noninvasive measures of LV function in adults.[3-8] More recent studies have shown that the MPI has significant clinical utility in predicting outcome in patients with dilated cardiomyopathy, pulmonary hypertension, and acute myocardial infarction.[3-7] In addition, a study in pediatric patients has demonstrated that this index can quantitatively

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assess RV and LV dysfunction in a group of patients with Ebstein anomaly.[9]

The MPI is a ratio between the sum of isovolumic time intervals, namely isovolumic contraction time (ICT) and isovolumic relaxation time (IRT), and ejection time (ET). Due to the fact that the MPI incorporates measures of both systolic and diastolic ventricular function, this index is reported to be a measure of global ventricular performance. These intervals can be easily obtained by routine Doppler techniques during a standard echocardiographic examination.[10-11] Since this index is a ratio of time intervals, it is not limited by the geometric shape of the ventricle.

The purpose of this study was to determine the MPI in a group of normal fetuses at varying gestational ages and to compare these data to established MPI values in the pediatric age group.

Materials and Methods

Study Populations

The study group consisted of 125 normal fetuses (age range 20–40 weeks gestation, mean age 28 weeks) referred for fetal echocardiography due to a family history of congenital heart disease or suspected congenital heart disease based on an obstetrical ultrasound. A group of normal children served as the reference population.[9] This pediatric group was comprised of 152 children (age range 3–18 years, mean age 9.3 ± 2.6 years). A group of normal adults was studied in similar fashion and reported elsewhere.[2-3] The fetal population was obtained from retrospective review of the Loyola University echocardiographic database (1997 to 1999). Fetuses were divided into five gestational age categories. Twenty-five random fetuses were selected from this database in each age category. Since this was a retrospective analysis, fetuses who lacked any of the Doppler signals utilized in the measurement of the MPI or lacked an adequate M-mode measurement of ventricular shortening fraction were excluded from analysis. Fetuses with isolated premature atrial or ventricular contractions were not excluded; however, Doppler signals from premature beats were not measured. Potential study patients diagnosed with congenital heart lesions were excluded.

MPI

To obtain the sum of ICT and IRT, the ET (interval "b") is subtracted from the interval

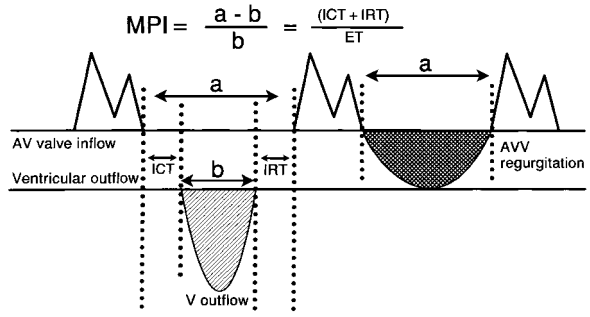

Figure 1. *Myocardial Performance Index (MPI). Interval "a" represents the duration (msec) from atrioventricular valve closure to opening for either the tricuspid or mitral valve. Interval "b" represents ventricular ejection time (msec) for either right or left ventricular outflow duration. MPI is calculated for either ventricle as follows: (Interval "a" - Interval "b")/(Interval "b").*

from the atrioventricular valve closure to the opening (interval "a") for either ventricle. This difference is then divided by the ET to derive the MPI for the corresponding ventricle. The interval from the atrioventricular valve closure to the opening is obtained from a pulse-wave Doppler signal at the leaflet tips of either atrioventricular valve in the fetal four-chamber view. The Doppler signal is measured from the end of the A wave to the beginning of the E wave of the subsequent cardiac cycle. Ventricular ET is measured from a pulse-wave Doppler signal from the corresponding outflow tract. To account for slight variations in fetal heart rate, each time interval was measured on five consecutive beats and then averaged. In fetuses with either premature atrial or ventricular beats, care was taken to exclude these ectopic beats when determining the MPI.

Echocardiographic Examination

Complete two-dimensional Doppler and color-flow Doppler examinations were performed according to previously described techniques.[10-17] The Doppler examination was recorded at a paper speed of 100 mm/sec and included pulse-wave Doppler velocity profiles from atrioventricular valve inflows as well as Doppler ejection profiles from the respective outflow tract. Assessment of fetal systolic ventricular function was performed utilizing M-mode derived shortening fraction in fetuses with acceptable M-mode imaging planes (fetal short-axis or fetal four-chamber views). Fetuses who lacked an obtainable M-mode imaging plane were excluded. Examinations were

performed utilizing an Acuson XP 128 or Acuson Sequoia (Acuson Corp., Mountain View, CA, USA) cardiovascular ultrasound system. All data analyses were performed by one clinical observer retrospectively utilizing the Acuson's internal measurement software.

Statistics

Statistical comparisons were performed on continuous variables with unpaired student *t*-tests. P values < 0.05 were used to indicate differences between groups that were not attributable purely to chance. Results are expressed as mean ($\pm$ 1) standard deviation. All data analyses were performed with a commercially available statistical analysis software package (Microsoft Excel, Microsoft Corp., Redmond, WA, USA).

Results

Description of Study Subjects

This study consisted of 125 normal fetuses with a gestational age ranging from 20–40 weeks and a mean age of 28 weeks gestation. Mean fetal heart rate was 143 $\pm$ 15 beats/min. Heart rate was not significantly different between the various gestational age groups. Normal variations in fetal heart rate (range 120–160 beats/min) did affect the duration of each measured Doppler time interval. However, in this study and in previous studies, the MPI, which is a ratio of these time intervals, was not significantly impacted by heart rate variability.[3-5,9]

Doppler Time Intervals and the MPI

The Doppler time intervals and the MPI for both the RV and LV are summarized in Table I. The MPI in normal fetuses was 0.35 $\pm$ 0.05 for the RV and 0.36 $\pm$ 0.06 for the LV. MPI values for the pediatric control group were not statistically different from those of normal fetuses. In normal children, the RV MPI was 0.32 $\pm$ 0.03 and the LV MPI was 0.35 $\pm$ 0.03.

The RV and LV MPI in the fetal groups were then analyzed with respect to advancing gestational age. Although each subgroup was small, there was no significant difference for either the LV or RV MPI with increasing fetal age.

Reproducibility of Doppler Time Intervals

Doppler recordings of 20 normal fetuses were randomly selected for intraobserver and interobserver reproducibility of the MPI. Measurements by the same observer (BWE) had a mean percentage error of 3.2%. When two independent observers analyzed these 20 normal fetuses (BWE and FC), the mean interobserver difference was 4.0%. These data are similar to previously reported measurement variability of the MPI.[2-7]

TABLE I

Summary of Doppler Time Intervals in Normal Fetuses and Normal Children

	Normal Fetuses	Normal Children
Left Ventricle		
N	125	152
Mitral C-O (msec)	250 (12)	394 (26)*
LVET (msec)	183 (10)	292 (17)*
LV MPI	0.36 (0.06)	0.35 (0.03)†
Right Ventricle		
N	125	152
Tricuspid C-O (msec)	252 (17)	388 (26)*
RVET (msec)	188 (15)	291 (18)*
RV MPI	0.35 (0.05)	0.32 (0.03)†

†P = NS compared to preceding column; *P < 0.001 compared to preceding columns.
N = number of patients; LV = left ventricle; RV = right ventricle; Mitral C-O = mitral valve closure to opening time interval; LVET = left ventricular ejection time; MPI = myocardial performance index; Tricuspid C-O = tricuspid valve closure to opening time interval; RVET = right ventricular ejection time.

Comment

The assessment of fetal ventricular function involves the measurement of both systolic and diastolic ventricular performance.[12-17] Two-dimensional and M-mode echocardiography rely on the geometric shape of the LV for quantification of systolic ventricular function, namely ejection fraction. Due to the unique size and orientation of the fetal heart, routine quantitation of fetal ventricular function can be challenging. A simple reproducible nongeometric method of quantitative functional assessment would be very useful.

The MPI is a nongeometric Doppler-derived measure of ventricular performance. This index has been described and validated in both normal adult[2-3] and pediatric patients[9] as well as in patients with structural and functional cardiac disease.[4-7,9] A recent study also has established values of the MPI in normal neonates.[18] The MPI utilizes simple reproducible

Doppler signals readily obtained during standard transthoracic echocardiography. This index does not rely on the size, shape, or orientation of the heart; therefore, it can be applied easily in the measurement of ventricular function in the developing fetus. Since this index incorporates both systolic and diastolic components of ventricular performance, the MPI is a measure of global ventricular function.[2-9,18]

Studies in adult and pediatric patients have shown that the value of the MPI increases as ventricular function worsens.[2-9] In addition, the MPI has been shown to have important clinical utility as a predictor of mortality in adult patients with dilated cardiomyopathy, pulmonary hypertension, acute myocardial infarction, and amyloidosis.[3-7] In pediatric patients with Ebstein anomaly, increasing values of the MPI correlated with increasing degrees of RV dysfunction.[9] The MPI also has been shown to be independent of heart rate in adults and children with heart rates varying between 50–120 beats/min.[2-3,9]

Our study demonstrates the application of the MPI in the quantitative echocardiographic assessment of fetal ventricular function. Since the MPI is a nongeometric measure of global ventricular performance, it is an ideal measurement to avoid the inherent geometric limitations present in the fetal cardiac examination.

Study Limitations

Shortening fraction is commonly used as a measure of systolic performance. However, lack of an alternative measurement of fetal ventricular function is a major limitation in the evaluation of a novel measurement technique. The MPI has been invasively and noninvasively validated in adult studies[2-8] and in neonatal and pediatric patients[9,18] and therefore, it is reasonable to believe that this index also can be applied meaningfully to assessment of global fetal ventricular performance.

Recent studies have suggested a very minor impact of ventricular volume loading on the MPI.[19] Mancini et al. studied a similar index of ventricular function and found a minimal impact of alterations in loading conditions on their index.[20,21] Ongoing prospective invasive studies in children and adults with altered loading conditions or structural heart anomalies need to be better defined. Since this was a retrospective review, longitudinal serial studies of individual fetuses were not available. Therefore, serial reproducibility of the MPI in individual fetuses through various gestational ages could not be addressed in this study. Finally, persistent abnormalities of fetal cardiac rhythm would be expected to alter the various time intervals measured by the MPI and need further definition.

Conclusions

This study establishes the normal value of the MPI in the developing fetus. The MPI is an easily obtained, reproducible, quantitative measure of ventricular performance. The use of this nongeometric index in the assessment of fetal ventricular function is ideal due to the lack of geometric limitations inherent in other conventional echocardiographic measurements of function. This study suggests important potential clinical utility of this index in the comprehensive assessment of fetal ventricular function. Further study of the MPI in fetuses with congenital heart lesions is warranted.

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