Changes in Fetal Left and Right Ventricular Strain Mechanics during Normal Pregnancy

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Background: The aim of this study was to detect normal changes in fetal two-dimensional speckle-tracking echocardiography–derived values for global and regional longitudinal left and right ventricular strain, strain rate, and time to peak (T2P) global strain during pregnancy.

Methods: Forty-four healthy fetuses were examined prospectively during the second-trimester and third-trimester ultrasound examinations (20–24 and 30–34 weeks, respectively). Clips with high frame rates (mean, 120 frames/sec) of two-dimensional (B-mode) grayscale images of apical or basal four-chamber views of both ventricles were used for offline analyses of global and regional walls and segments (basal, mid, and apical) of myocardial strain and strain rate as well as T2P global strain in the longitudinal direction.

Results: There were statistically significant decreases in global and regional strain of the right ventricle between the second and third trimesters. No statistically significant changes were observed in global and regional strain of the left ventricle. Global and regional strain rates of both ventricles decreased in a similar way during pregnancy. The mean T2P longitudinal left ventricular global strain (adjusted for heart rate) increased mildly during fetal life. Whereas T2P longitudinal strain of the left ventricle at 20 to 24 weeks was statistically significantly shorter than that of the right ventricle, no difference in T2P longitudinal strain was found at 30 to 34 weeks of gestation between both ventricles.

Conclusions: The establishment of these changes between the second-trimester and third-trimester two-dimensional speckle-tracking echocardiography–derived reference values is a mandatory prerequisite for its use in evaluating (pathologic) changes in both ventricular functions during pregnancy. (J Am Soc Echocardiogr 2013;26:1193-200.)

Keywords: Strain, Myocardial deformation, Two-dimensional speckle-tracking echocardiography, 2D STE, Fetal, Second-trimester ultrasound

General antepartum obstetric ultrasound has become a standard part of gestational care and is commonly used for the determination of fetal age, size, gender, and well-being and for the detection of congenital anomalies. Guidelines and standards for physician performance and interpretation of fetal echocardiography have been provided.[1,2] However, quantification of ventricular myocardial function in fetuses with and without congenital heart disease remains a challenge. Traditional echocardiographic methods are often used to evaluate global left ventricular (LV) function.[3] These methods are not always applicable to fetal hearts and provide little information about regional changes in ventricular myocardial deformation and time to peak (T2P) deformation during a normal pregnancy.

Two-dimensional (2D) speckle-tracking echocardiography (STE) is one of the newer diagnostic, commercially available imaging modalities that allow the assessment of myocardial deformation.[4,5] Interestingly, speckle-tracking-derived deformation measurements assessed using different ultrasound machines and software packages are not always comparable.[6] Normal strain and strain rate values in a healthy fetal cohort are scarce.[7-10] The published correlations of global and regional strain and strain rate data with advancing pregnancy are based on cross-sectional data (e.g., gestational age range 13–40 weeks).[7,9,11-16] Finally, T2P global (left and right ventricular [RV]) strain and its degree of synchronicity in healthy fetuses have been studied only in the second trimester.[10]

Comparison between different speckle-tracking and color tissue Doppler techniques to measure global and regional myocardial deformation in children is not always possible.[6] There is a need to use age-specific reference values, assessed with the same ultrasound and software package, for the adequate interpretation of 2D speckle-tracking echocardiographic measurements and their changes during the same pregnancy. Recently, we assessed reference values for 2D speckle-tracking-derived longitudinal strain, strain rate, and

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Abbreviations
AV = Atrioventricular valve
IVS = Interventricular septum
LV = Left ventricular
RV = Right ventricular
STE = Speckle-tracking echocardiography
T2P = Time to peak
2D = Two-dimensional
VVI = Velocity Vector Imaging

T2P deformation of the fetal heart during second-trimester echocardiography. In the present study, we aimed to assess the normal changes in global and regional LV and RV myocardial strain, strain rate, and T2P global strain in the longitudinal direction in a healthy fetal cohort between the second-trimester and third-trimester screenings.

METHODS

Study Population

Mothers who were referred to the outpatient clinics at three major prenatal diagnostic centers in Israel for routine second-trimester fetal evaluation between August 1, 2010, and May 1, 2011, were invited to enroll in the study. This routine echocardiographic examination was performed according to the national obstetric guidelines between 20 and 24 weeks of gestation. Fetuses with structural (congenital) heart defect or failure, abnormal cardiac rhythm, and intrauterine growth retardation were excluded. Other exclusion criteria were monochorionic twins, maternal hypertension, chronic maternal illness, recent acute illness, and poor echocardiographic image quality. The women were asked to return for second echocardiographic screenings during the third trimester, between 30 and 34 weeks of gestation. Informed consent was obtained from each participant. This study was approved by the institutional committee on human research.

Three physicians with extensive experience in performing fetal echocardiograms from tertiary obstetrics (Z.W. in Haifa, S.H. in Tiberias) and pediatric cardiology centers (A.L. in Haifa) participated in the study. A complete transthoracic fetal echocardiographic examination was performed according to the recommendations of the American Society of Echocardiography. Image acquisition was done using a strict protocol. For each of the fetuses, a minimum of three clips of 2D images of three to eight cardiac cycles from the apical (with the apex pointed toward the transducer) or basal (with the apex pointed away from the transducer) four-chamber view of each ventricle were stored as raw data and provided for offline 2D speckle-tracking echocardiographic analyses. All echocardiographic recordings were made using a Vivid I digital ultrasound scanner (GE Vingmed Ultrasound AS, Horten, Norway) equipped with a 5-MHz linear transducer (available at all three centers). Special attention was given to achieve a high frame rate: B-mode image depth was reduced and sector width was narrowed to achieve high frame rates (aiming at ≥90 frames/sec). Data were stored at the same frame rate as the acquisition frame rate. Fetal electrocardiograms were not recorded.

Only one experienced pediatric cardiologist (L.K.), who did not take part in the prenatal screenings and was blinded to the studies, performed the 2D speckle-tracking echocardiographic analyses offline. The analyses were performed on one workstation equipped with EchoPAC software (GE Vingmed Ultrasound AS).

Analysis of 2D Images

Clips with 2D (B-mode) grayscale images of apical or basal four-chamber views with the RV free wall, the interventricular septum (IVS), and the LV free wall were chosen. The original frame rate was displayed on the image. Heart rate could not be displayed, because of inability to record fetal electrophysiologic signals. To identify the beginning and end of one cardiac cycle, the mitral valve was followed in time. End-diastole was defined by the complete closure of the atrioventricular valve (AV). The time cursor was placed just before AV (mitral or tricuspid) closure ("first beat") and again just after a consequent second event of AV closure ("second beat"). Heart rate could then be calculated from the beat-to-beat time intervals and automatically recorded for each analysis.

Measurements of global and regional longitudinal myocardial strain, strain rate, and T2P global longitudinal strain were taken in the following manner (see also Figure 1): images of the left and right ventricles were analyzed either simultaneously (from the same clip) or separately (from different clips) during the same examination. The reader was required to mark the endocardial border of each ventricle separately, starting from the basal septum through the apex until the basal free wall of the left and right ventricles, respectively. The endocardial borders of each ventricle were automatically detected and could be adjusted manually if necessary. The points with the lowest strain (first and second AV closures, respectively) were then chosen as the initial muscle length (and marked as zero in the strain curve). The myocardium shortened in the systolic period and lengthened in the diastolic period and returned to its original length at the end of the diastolic period. The LV and the RV myocardium were each automatically divided into six equal-sized segments (two basal, two mid, and two apical segments per ventricle). The left ventricle included the septum and LV free wall, while the right ventricle included the septum and RV free wall, thus providing for identical regional segmentation for both ventricles (readers were blinded to the results). Global longitudinal strain, strain rate, and T2P global longitudinal strain of each ventricle, as well as the regional (segmental) strain and strain rate data, were automatically recorded (Figure 1B). For each subject, all analyses were repeated using three different heart cycles (these three values were averaged for statistical analyses).

To assess the normal changes in global and regional LV and RV myocardial strain, strain rate, and T2P global strain in the longitudinal direction in a healthy fetal cohort, all analyses were done on both time intervals (second-trimester and third-trimester screening).

Statistical Analysis

Data were analyzed using SAS version 9.2 (SAS Institute Inc., Cary, NC) statistical software. Statistical significance was defined as a P value ≤ .05.

Study variables are expressed as mean ± SD. Ninety percent reference ranges (fifth-percentile and 95th-percentile values) and their respective 95% confidence limits were calculated for global strain, strain rate, and T2P strain for the third trimester (30–34 weeks). Second-trimester reference ranges are presented elsewhere.[10]

Repeated-measures analysis-of-variance models were fitted to the strain, strain rate, and T2P strain data. Global strain, strain rate, and T2P strain were modeled as a function of ventricle (left and right). Frame rate and heart rate were modeled in a similar manner. Regional measurements were modeled as a function of wall (e.g., LV free wall, RV free wall, septum) and segment (apical, middle, and basal) with an interaction term (wall × segment). To compare the two measurement times, weeks 20 to 24 versus weeks 30 to 34, an additional covariate termed time and relevant interaction terms were added to the models. Model-estimated means (LSmeans) were obtained from the models with 95% confidence intervals; pairwise comparisons of the LSmeans are presented. Associations of strain, strain rate, and T2P strain with frame rate, heart