Circumferential and Longitudinal Ventricular Strain in the Normal Human Fetus

Tetsuko Ishii, MD, Doff B. McElhinney, MD, David M. Harrild, MD, Edward N. Marcus, MSc, David J. Sahn, MD, Uyen Truong, MD, and Wayne Tworetzky, MD, *Boston, Massachusetts; Portland, Oregon*

Background: Echocardiography with speckle tracking is a novel, angle-independent technique for assessing global and regional cardiac function. Normal data on longitudinal strain have been reported for human fetuses. The aim of this study was to define circumferential left ventricular (LV) strain in a normal fetal population.

Methods: Singleton fetuses between 17 and 42 weeks in gestational age with no adverse maternal health issues or fetal abnormalities were studied. Regional and averaged cardiac strain were measured using syngo Velocity Vector Imaging software.

Results: Data from 81 fetuses were analyzed (mean gestational age, 29.2 ± 5.7 weeks). Overall, average midventricular circumferential strain was 18.7 ± 3.3%, LV longitudinal strain was 15.2 ± 2.7%, and right ventricular longitudinal strain was 16.0 ± 3.3%, with no correlation with gestational age.

Conclusion: This is the first study to report normal fetal LV circumferential strain. These data may be useful as a reference for assessing fetal cardiac function. The retrospective study design and relatively low frame rates used in this study were important limitations. (J Am Soc Echocardiogr 2012;25:105-11.)

Keywords: Fetus, Echocardiography with speckle tracking, Circumferential strain

Fetal cardiac function can be affected by a variety of conditions and prenatal interventions, including cardiac disease, twin-twin transfusion syndrome, thoracic anomalies, and procedures to treat them.[1] The accurate assessment of fetal cardiac function may help improve the understanding of disease processes and prognosis, as well as the evaluation of prenatal interventions for conditions such as twin-twin transfusion syndrome or fetal cardiac diseases.

Echocardiography with speckle tracking (STE) is a novel, angle-independent technique for assessing global and regional cardiac function. STE makes it possible to assess not only the global condition of the fetal heart chambers but also segmental function, and the angle independency broadens its potential application in the face of varying fetal positioning. Although STE allows the assessment of longitudinal, circumferential, and radial strain, only data on longitudinal function have been reported for fetuses.[2-9] However, some conditions, such as fetal aortic stenosis (AS) or consequent endocardial fibroelastosis, may have different effects on circumferential and longitudinal left ventricular (LV) contraction, and it may be important to assess cardiac function in different axes.[10,11]

The aim of this study was to define circumferential strain values for the normal fetal population. In addition, to confirm the reliability of this study, we compared our findings with those of previously published studies. We also compared these values with strain measurement obtained from fetuses with AS to assess the usefulness of circumferential strain among fetuses with possible cardiac dysfunction.

From the Department of Cardiology, Children's Hospital Boston, and Department of Pediatrics, Harvard Medical School, Boston, Massachusetts (T.I., D.B.M., D.M.H., E.N.M., W.T.); and Department of Pediatrics (Cardiology), Oregon Health & Science University, Portland, Oregon (D.J.S., U.T.).

Reprint requests: Wayne Tworetzky, MD, Children's Hospital Boston, Department of Cardiology, 300 Longwood Avenue, Boston, MA 02115 (E-mail: wayne.tworetzky@cardio.chboston.org).

0894-7317/$36.00

doi:10.1016/j.echo.2011.09.016

METHODS

Study Population

We retrospectively evaluated cardiac ultrasound studies in fetuses referred to Children's Hospital Boston for fetal echocardiography for a family history of congenital heart disease or suggested fetal arrhythmia from 2004 to 2010. From these, we identified singleton fetuses between 17 and 42 weeks in gestational age (GA), with no maternal disease, fetal structural disease, or arrhythmia. After review of the echocardiographic studies, those with images felt to be sufficiently clear for STE were sequentially selected and analyzed. About 20 studies were selected for each GA subgroup (≤24, 25–29+6/7, 30–34+6/7, ≥35), with the intent of selecting a balanced distribution of fetal GA.

We identified fetuses with AS and moderate or less LV dysfunction. The AS gradient was estimated using the modified Bernoulli equation and LV volumes and LV ejection fraction using the single-plane area-length method. We selected five fetuses with AS to represent different physiologic states. Patients 1 and 2 had moderate LV dysfunction and substantial AS gradients, patients 3 and 4 had normal or mildly depressed LV function and substantial AS gradients, and patient 5 had normal LV function and a mild AS gradient. STE was performed retrospectively in these fetuses and was not used to determine whether to perform fetal aortic valvuloplasty (fAVP) or to determine the timing of fAVP.

Abbreviations

AS = Aortic stenosis

fAVP = fetal Aortic valvuloplasty

GA = Gestational age

LV = Left ventricular

STE = Echocardiography with speckle tracking

VVI = Velocity Vector Imaging

The study was performed in conjunction with a protocol that was approved by the Children's Hospital Committee for Clinical Investigations.

Image Acquisition

Images were acquired using Siemens Sequoia (Siemens Medical Solutions USA, Inc., Mountain View, CA) and Phillips Sonos 5500 and iE33 (Philips Medical Systems, Bothell, WA) machines. Phased-array sector or linear probes ranging from 4.0 to 7.0 Hz were used. The short-axis view was obtained by scanning perpendicular to the long axis of the heart.[12] For circumferential strain, short-axis images containing some part of both papillary muscles without any mitral valve tissue through the whole cardiac cycle were selected as mid–papillary muscle–level images; for longitudinal strain, four-chamber views were selected. All the images were stored in Digital Imaging and Communications in Medicine format and analyzed offline. Fetal echocardiographic images were automatically stored at a frame rate of 30 Hz.

Offline Analysis

Regional cardiac function was measured using syngo Velocity Vector Imaging (VVI) software (Siemens Medical Solutions, USA, Inc.). Among images stored as Digital Imaging and Communications in Medicine clips in routine screening, well-visualized four-chamber and short-axis views were selected. Images that were acquired by Phillips Sonos 5500 or iE33 machines were reformatted to be compatible with syngo VVI software.

To define a fetal cardiac cycle, using superimposed M-mode tracings, end-diastole was defined as the point just before closure of the atrioventricular valve. For short axis, the longest LV dimension was used to define end-diastole. After manually tracing the subendocardial surface of the ventricle on the frame, VVI software calculated strain automatically using the feature-tracking algorithm (Figure 1). Feature-tracking accuracy was visually confirmed, and the tracing was corrected until consistent endocardial tracking was obtained. Only one cardiac cycle was used for analysis instead of averaging over multiple cardiac cycles, to avoid artifacts due to fetal movement or change of cardiac cycle. Analysis was performed by one examiner, who was blinded to outcomes and other echocardiographic parameters.

Because of the variable fetal cardiac location, some rearrangement was needed to match the actual segment of the fetal heart and the segment displayed on the screen. The segment consisting primarily of the septum and closest to the tricuspid valve (Figure 2) was defined as septal, and other segments were defined in order.

Longitudinal and circumferential negative peak strains were used for strain values. Longitudinal strains for all segments were averaged to express global strain.

Data Analysis

To assess intraobserver and interobserver variability, a randomly selected subset of 15 data sets, analyzed by two examiners who were blinded to each other's measurements, was used. Bland-Altman analysis bias was calculated and presented with the standard deviation. To assess the success rate of analysis, χ^2 tests were conducted, and significance was set at $P \leq .05$. To assess relationships between GA and speckle-tracking echocardiographic data, linear regression was performed. Data are presented as mean ± SD.

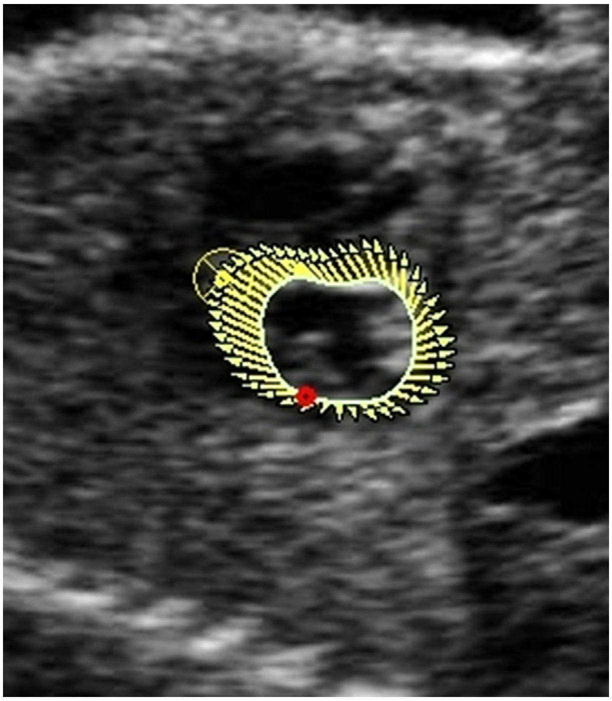

Figure 1 A still frame of the short axis of the left ventricle with velocity vectors. The *arrow* represents magnitude of the tissue velocity and the direction of movement of the myocardium.

RESULTS

General Characteristics

Indications for fetal echocardiograms in the normal cohort included the following: sibling of child with congenital heart disease, possible fetal arrhythmias detected by primary obstetrician, and maternal congenital heart disease. From 150 sequential fetal studies, mothers with congenital heart disease (except for one with a small atrial septal defect), significant fetal arrhythmias, and fetuses with any anomalies were excluded. Because a majority of fetuses were evaluated in the middle of the second trimester, we selected 81 of those 150 fetuses with the intent of selecting a balanced distribution of fetal GA that met demographic and diagnostic inclusion criteria for analysis. At the time of the examination, there were no identified obstetric abnormalities. GA at the time of echocardiogram ranged from 19 to 42 weeks (mean, 29.2 ± 5.7 weeks), and the average heart rate was 140 ± 9 beats/min. Among 81 fetuses, strain analysis was performed successfully in 62 (77%) for LV longitudinal function, 64 (79%) for RV longitudinal function, and 49 (64%) for LV circumferential function (Table 1). The frequency of successful analysis was lower for LV circumferential analysis, especially in late-gestation fetuses.

Longitudinal and Circumferential Strain

Global RV and LV longitudinal strains were 16.0 ± 3.3% and 15.2 ± 2.7%, respectively, and average mid-LV circumferential strain was 18.7 ± 3.3%. There was no correlation between GA and RV longitudinal strain, LV longitudinal strain, or LV circumferential strain