Tissue Doppler Imaging Measurement of Left Ventricular Systolic Function in Children: Mitral Annular Displacement Index Is Superior to Peak Velocity

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Background: Doppler tissue imaging (DTI)–derived mitral annular systolic peak S-wave velocity (S′) correlates with left ventricular (LV) ejection fraction (EF). The authors hypothesized that DTI mitral annular displacement, which is equal to the velocity-time integral of the DTI S′ wave, might be superior to S′ to analyze LV systolic function. Because S′ varies with age, it was expressed as S*z*, the *z*-score variance from normal S′ for each subject. Because displacement varies with heart size, it was expressed as a displacement index, or the DTI S′-wave velocity-time integral divided by the end-diastolic distance from the mitral annulus to the LV apex. The aims of this study were to (1) measure the accuracy, sensitivity, specificity, and positive and negative predictive values of displacement index compared with S*z* to detect systolic dysfunction; (2) compare displacement index with other quantitative parameters of longitudinal systolic function, including color DTI–derived strain and two-dimensional speckle-tracking echocardiography (2D)–derived mitral annular displacement and strain; and (3) determine the effects of age, heart rate (HR), and body surface area (BSA) on displacement index.

Methods: Displacement index and S*z* results were compared with EF and with each other using statistical tests, including independent *t* tests, linear regression, receiver operating characteristic curve analysis, and 2×2 probability tables. Displacement index was also compared with other parameters of longitudinal systolic function, age, HR, and BSA using regression analysis.

Results: Forty-six patients had normal (EF $\geq$ 55%) and 34 abnormal (EF < 55%) LV function. Groups were statistically equivalent ($P > .05$) for age, HR, and BSA and statistically different ($P < .001$) for all measured parameters of systolic function. Displacement index and EF were linearly related. Receiver operating characteristic curve analysis showed the sensitivity of displacement index to be greater than that of S*z* throughout the study range. Probability table analysis demonstrated that for predicting EF < 55%, the sensitivity, accuracy, and negative predictive value were greater for displacement index than for S*z*. Displacement index was linearly correlated with 2D mitral annular longitudinal displacement, 2D LV basal segment longitudinal strain, and color DTI LV basal segment longitudinal strain. Displacement index was not affected by age, HR, or BSA.

Conclusions: Displacement index is linearly related to EF and also to other parameters of longitudinal systolic function. Displacement index has some advantages over S*z* for assessing ventricular systolic function and should prove useful in measuring longitudinal and global LV systolic function. (J Am Soc Echocardiogr 2009;22:376-382.)

Keywords: Doppler tissue imaging, Systolic function, Myocardial strain, Mitral annular displacement

Pulsed-wave Doppler tissue imaging (DTI) analysis of myocardial tissue velocities and time intervals is used to assess longitudinal and global systolic and diastolic myocardial function.[1-7] The most widely used DTI parameter for analyzing systolic function is DTI systolic peak S-wave velocity (S′) of the mitral annulus. S′ varies with age, heart rate (HR), body surface area (BSA), and heart size.[8,9] It can be easily measured in most children, observer variability is low, and normal values, utility, and some limitations have been reported.[8,9]

Although usually concordant with other echocardiographic and clinical parameters of left ventricular (LV) systolic function, we have encountered a small but apparently significant number of patients in whom LV systolic function was decreased, but DTI S′ was normal (ie, falsely negative). We therefore began measuring DTI mitral annular displacement by measuring the velocity-time integral (VTI) of the DTI mitral annular S′ wave and found that it might be more sensitive and accurate than S′ to assess LV systolic function.

This study was undertaken to determine whether there is any advantage in using DTI-derived mitral annular longitudinal displacement over DTI S′ to detect LV systolic dysfunction and to determine how well displacement index (see "Definitions") correlates with other quantitative parameters of global and longitudinal systolic

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function. The effects of age, HR, and BSA on displacement index were also analyzed.

METHODS

Study Aims

The aims of this study were to (1) measure the accuracy, sensitivity, specificity, and positive and negative predictive values of DTI displacement index compared with *Sz* (see "Definitions") to detect low ejection fraction (EF); (2) determine the correlation between displacement index and EF and the correlations between displacement index and other quantitative parameters of longitudinal systolic function, including color DTI–derived strain and two-dimensional speckle-tracking echocardiography (2D)–derived mitral annular displacement and strain; and (3) determine the effects of age, HR, and BSA on displacement index in normal children. This study complied with all institutional guidelines related to patient confidentiality and research ethics, including institutional research board approval.

Definitions

Because S′ varies with age and age is the best predictor of S′ on multivariate analysis,[8] S′ was expressed as *Sz*, the *z*-score variance from normal S′ for each subject. Because mitral annular displacement varies with heart size, it was expressed as displacement index, or DTI S′-wave VTI divided by the end-diastolic distance from the mitral annulus to the LV apex (see Figure 1).

Study Design

Eighty children were prospectively divided into two groups on the basis of EF: low systolic function was defined as EF < 55%, and normal function was defined as EF ≥ 55%. *Sz* and displacement index results were compared with EF to determine their respective ability to assess global LV systolic function. Because displacement index is a new parameter of longitudinal systolic function, in the last 40 patients (20 with normal and 20 with abnormal systolic function), it was compared with other quantitative parameters of longitudinal systolic function, including color DTI LV basal segment longitudinal strain, 2D mitral annular displacement, and 2D LV basal segment longitudinal strain. Last, to determine the effects of age, HR, and BSA, an additional separate cohort of 234 normal children with complete echocardiograms with entirely normal results were studied.

Measurements

Basic echocardiographic measurements and DTI mitral annular measurements were made as previously described.[8,9] Displacement index, a dimensionless unit, was calculated by dividing the VTI of S′ by the end-diastolic distance from the mitral annulus to the LV apex, as seen in Figure 1. Longitudinal strain of the basal posterior LV segment by color DTI, 2D mitral annular displacement, and 2D longitudinal strain of basal posterior LV segment images were measured as previously described.[10-16]

Echocardiography

Echocardiography was performed using the Philips Sonos iE33 echocardiographic system (Philips Medical Systems, Andover, MA). Complete 2-dimensional, pulsed-wave Doppler blood flow analysis, color Doppler flow mapping, and longitudinally directed tissue pulsed-wave Doppler analysis at the mitral valve annulus were performed

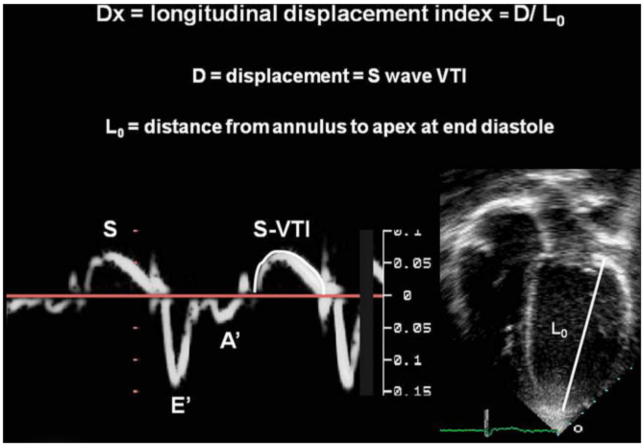

Figure 1 Method of measurement of longitudinal mitral annular systolic displacement index from DTI. *A′*, tissue Doppler late diastolic wave; *D*, displacement; *E′*, tissue Doppler early diastolic wave; *L_0*, distance from mitral valve annulus to LV apex at end-diastole; *S-wave VTI*, VTI of tissue Doppler systolic S wave.

in all patients. EF was measured using the modified biplane Simpson's method. The Tei index was measured using the mitral annular DTI method. DTI was performed using low gain and low filter settings to exclude high-frequency signals. A sample volume gate length of 2 to 3 mm and a sweep speed of 100 mm/s were used. Adjustments were made on a patient-by-patient basis to optimize DTI waveforms to define clear borders and minimize background noise. The apical 4-chamber view was used, and care was taken to align the sample volume at the mitral valve annulus as vertically as possible with respect to the cardiac apex. Transducer rotation and angulation along with adjustments in gain and compression and various imaging preset algorithms and occasional harmonic imaging were used to optimize image quality, avoid foreshortening of the left ventricle, and minimize artifact. All measurements were made during periods of stable HR, hemodynamics, and echo parameter waveforms. Images were recorded and stored digitally for offline analysis. Three cardiac cycles were used, and a mean value was calculated for each of the parameters. In the last 40 patients of the study group, color DTI strain, 2D mitral valve annular displacement, and 2D longitudinal strain images were acquired from the apical 4-chamber view and analyzed with Philips Q-lab strain quantification and tissue motion quantification software.

Statistical Analysis

Continuous data were reported as mean ± SD. Independent *t* tests were used to determine significant differences of continuous data between groups. A receiver operating characteristic curve was generated and the area under the curve calculated to compare the sensitivity of displacement index and *Sz* to detect LV systolic dysfunction (EF < 55%), and normal cutoff values for displacement index and *Sz* that best balanced sensitivity and specificity were determined. A 2 × 2 classification table was used to calculate the accuracy, sensitivity, specificity, positive predictive value, and negative predictive value of displacement index compared with *Sz* for detecting LV systolic dysfunction. Linear regression analysis was performed to determine the relationship between displacement index and EF and the relationships between displacement index and other parameters of LV longitudinal systolic function. Generalized linear modeling for multivariate