Time-Resolved Analysis of Left Ventricular Shear Wave Amplitudes in Cardiac Elastography for the Diagnosis of Diastolic Dysfunction

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Objectives: The aim of this study was to investigate the diagnostic potential of changes in left ventricular (LV) shear wave amplitudes (SWAs) over the cardiac cycle measured by cardiac magnetic resonance elastography.

Materials and Methods: Electrocardiography-triggered SWA-based cardiac magnetic resonance elastography with 24.13-Hz external vibration frequency was performed in asymptomatic young (n = 10) and old (n = 10) subjects and patients (n = 30) with echocardiographically proven mild, moderate, or severe diastolic dysfunction. The temporal delay between change in SWA and morphological change in the LV wall, that is, time of isovolumetric elasticity relaxation normalized against heart rate, was calculated for diastole (τR_0). Diastolic levels of LV SWA were calculated and normalized against SWA in the chest wall (U_0[dia]). Nonparametric testing was used for statistical evaluation. Accuracy of the parameters was investigated using receiver operating characteristic analysis against echocardiography. Interobserver and intraobserver variability for the temporal delay between change in SWA and morphological changes was tested according to Bland and Altman.

Results: Young and old control subjects showed median (standard error of mean, interquartile range) τR_0 of 99 (5, 93–103) and 82 (7, 66–95). In patients with diastolic dysfunction, τR_0 was 131 (20, 107–171), 158 (14, 108–172), and 138 (14, 107–174) with statistically significant differences between old subjects and patients with diastolic dysfunction ($P = 0.01$).

U_0(dia) was 0.94 (0.05, 0.86–1.04) and 0.71 (0.06, 0.61–0.92) in young and old controls, respectively ($P = 0.063$). Compared with young subjects, patients with mild, moderate, and severe diastolic dysfunction displayed significantly reduced U_0(dia) of 0.69 (0.06, 0.53–0.82), 0.56 (0.04, 0.46–0.64), and 0.48 (0.04, 0.43–0.61) ($P < 0.001$).

$\tau R_0/U_0$(dia) cutoff values for prediction of diastolic dysfunction were 107/0.66, corresponding to the area under the receiver operating characteristic values of 0.84/0.87 with 74%/74% sensitivity and 85%/85% specificity. Interobserver and intraobserver variability ranged from −0.05 to 0.05 with 95% agreement.

Conclusions: In diastolic dysfunction, low-frequency SWAs show distinct changes in the normalized time of isovolumetric elasticity relaxation for the LV (τR_0) and the diastolic level of SWA (U_0[dia]). Both parameters have good diagnostic performance for diagnosis of diastolic dysfunction.

Key Words: magnetic resonance elastography, heart, diastolic dysfunction, cardiac time intervals

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Cardiac dysfunctions are classified into systolic and diastolic functional disorders. Although systolic dysfunction can be diagnosed by measuring ventricular size at end-systolic contraction and end-diastolic dilation, diastolic dysfunction often remains elusive when conventional imaging methods are used.[1] Today, the criterion standard for the diagnosis of diastolic dysfunction is the measurement of ventricular filling based on echocardiographic indices, which relate to the morphology, velocity, or deformation of the myocardium.[2,3] However, these indices do not directly reflect the primary driving force of the heart—the variation in the myocardial shear modulus during the cardiac cycle. Therefore, elastography techniques have been developed for the quantification of the myocardial shear modulus in vivo or for generating shear modulus–related imaging contrast.[4–8] The latter can be achieved by analyzing the amplitudes of externally induced shear waves. The feasibility of this approach was demonstrated in healthy volunteers and patients using ultrasound or magnetic resonance imaging (MRI).[7,9–12] From these studies, it is known that shear wave amplitudes (SWA) change between systolic and diastolic cardiac phases and that these changes precede the inward and outward movement of the ventricular wall during systolic contraction and diastolic dilatation, respectively.

Recently, the diagnostic potential of averaged shear SWAs was investigated in groups of patients with different degrees of diastolic dysfunction.[10] However, this study did not account for the temporal variation of the SWA signal and could thus not provide an elasticity-based marker specifically related to the diastolic phase of the heart. Such a diastolic elastographic marker would be desirable for the assessment of relaxation abnormalities. Two preliminary studies have addressed time-resolved SWA[7,8] but without consideration of their diagnostic potential. The aim of the present study was to investigate the diagnostic potential of changes in left ventricular (LV) SWAs over the cardiac cycle measured by cardiac magnetic resonance elastography (MRE). Therefore, diastolic elastographic markers are derived, and their diagnostic power is determined. We will focus on the normalized elasticity relaxation time (τR_0), that is, the time ventricular dilatation lags behind the diastolic SWA increase and the normalized level of SWA during diastole U_0(dia). These parameters are determined in healthy volunteers and patients with different grades of diastolic dysfunction.

METHODS

Patients and Volunteers

The study was approved by the responsible local ethics committee (EA 1/055/07-5). All participants gave written informed consent to

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