Quantification of Regional Nonuniformity and Paradoxical Intramural Mechanics in Hypertrophic Cardiomyopathy by High Frame Rate Ultrasound Myocardial Strain Mapping

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This study tested the hypothesis that linear mapping of regional myocardial strain comprehensively assesses variations in regional myocardial function in hypertrophic cardiomyopathy. Hypertrophic cardiomyopathy is characterized by disorganized myocardial architecture that results in spatial and temporal nonuniformity of regional function. Left ventricular deformation was quantified in 20 patients with hypertrophic cardiomyopathy and compared with 25 age- and sex-matched control subjects. Abnormalities in subendocardial strain ranged from reduced longitudinal shortening to paradoxical systolic lengthening and delayed regional longitudinal contractions that were often located in small subsegmental areas. These variations were underestimated significantly by arbitrary measurements compared with linear mapping, in which a region of interest was moved across the longitudinal length of left ventricle (difference of peak and least strain, 10.7% ± 5.1% vs 17% ± 5.5%; $P < .001$). Echocardiographic assessment of variations in regional strain requires careful mapping and may be inappropriately assessed if left ventricular segments are sampled at arbitrary focal locations. (J Am Soc Echocardiogr 2005;18:737–742.)

Hypertrophic cardiomyopathy (HCM) is a primary myocardial disease recognized clinically by an abnormally thick myocardial wall.[1] However, the apparently hypertrophied myocardium shows marked regional disarray and scarring.[1,2] Such structural alterations are widely distributed, occupying a substantial portion of the left ventricular (LV) wall. Disruption of the ordered arrangement of myofibers alters normal cardiac mechanical function, resulting in temporal and spatial heterogeneity in regional myocardial contractility. Although global LV function is generally unaltered, asynchrony and asynergy in regional function lead to delayed diastolic relaxation and impaired diastolic filling.[3-6]

Regional hypertrophy and disarray are associated with altered distribution of segmental shortening; however, establishing a direct relationship between structural and functional abnormalities has required measuring the altered strain pattern for patients with HCM. Marked regional variations in myocardial strain can be identified with magnetic resonance myocardial tagging, but its spatial and temporal resolution and clinical availability are limited.[4,7] Recently, ultrasound-based strain rate imaging has been introduced as an accurate technique for quantifying regional myocardial function, with high spatial and temporal resolution.[8] This technique has been used to quantify segmental asynchrony and asynergy in patients with HCM.[6,9] Regional function is known to be altered particularly in the interventricular septum, where changes in regional strain can range from the absence of or reduced regional shortening to paradoxical systolic expansion.[9] However, regional strain has been evaluated conventionally by arbitrarily interrogating a small length of myocardium in each segment. Because myocardial architecture has a wide regional variation in HCM, focal alterations in myocardial deformation are not necessarily limited by segmental boundaries. Therefore, focal estimates of myocardial function could likely underestimate the overall extent of abnormalities and regional variations in these patients.

We hypothesized that a detailed linear mapping of regional variations in longitudinal myocardial strain would provide a superior assessment of regional nonuniformity in myocardial function for patients with HCM.

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0894-7317/$30.00

doi:10.1016/j.echo.2005.03.008

Table 1 Comparison of clinical features of 20 patients with hypertrophic cardiomyopathy and 25 control subjects

Feature	Patients	Control subjects
Age, y	32 ± 14	30 ± 10
Male:female	16:4	15:5
Heart rate, beats/min	80 ± 9	73 ± 7
NYHA class	2.4 ± 1.2	1*
LA, cm	3.83 ± 0.82	3.05 ± 0.42*
IVS (d), cm	2.63 ± 0.62	0.78 ± 0.10*
PW (s), cm	1.54 ± 0.34	0.86 ± 0.13*
IVS/PW	1.66 ± 0.5	0.92 ± 0.11*
FS, %	0.53 ± 0.17	0.32 ± 0.06*
LVID (d), cm	3.78 ± 0.75	4.38 ± 0.14*
LVID (s), cm	1.88 ± 0.57	2.91 ± 0.48*
LVEDV, mL	43.31 ± 15.39	84.58 ± 12.92*
LVESV, mL	15.05 ± 6.82	36.28 ± 6.27*
EF, %	0.64 ± 0.08	0.57 ± 0.03*
SSR, l/s	−0.77 ± 0.33	−1.18 ± 0.17*
ESR, l/s	0.75 ± 0.41	1.94 ± 0.42*
ASR, l/s	0.58 ± 0.85	0.79 ± 0.21*
Strain, %	−8.65 ± 4.20	−18.67 ± 3.84*

Except for male-to-female ratio, all values are mean ± SD.
ASR, Late diastolic strain; *d,* diastolic; *EF,* ejection fraction; *ESR,* early diastolic strain rate; *FS,* fractional shortening; *IVS,* interventricular septum; *LA,* left atrium; *LVEDV,* left ventricular end-diastolic volume; *LVESV,* left ventricular end-systolic volume; *LVID,* left ventricular internal dimension; *NYHA,* New York Heart Association; *PW,* posterior wall; *s,* systolic; *SSR,* systolic strain rate.
*$P < .001$.

METHODS

Study Population

The study group consisted of 20 consecutive patients with HCM (asymmetrical septal hypertrophy in 15 patients and generalized hypertrophy in 5) whose ventricular septal and posterior wall thickness exceeded 15 and 11 mm, respectively. The baseline clinical features of the study group are listed in Table 1. Seventeen patients had a resting LV outflow tract gradient (mean, 78 ± 42 mm Hg). A total of 25 age- and sex-matched healthy volunteers were used as control subjects.

Echocardiographic Study

Data acquisition. The echocardiographic examination included a detailed 2-dimensional, M-mode, and Doppler examination (System V, GE Vingmed, Horten, Norway), using a 2.5- to 3.5-mHz probe. Two-dimensional color Doppler myocardial imaging data were recorded from the LV using apical views at a frame rate of 150 ± 10 frames/s. For real-time Doppler myocardial imaging scanning, the sector was limited to 30 degrees and each myocardial wall was interrogated individually and aligned in parallel below the transducer to avoid any insonating angle. The velocity scale was optimized to avoid aliasing. Four color Doppler datasets were obtained in each case, that is, from the anterior, inferior, septal, and lateral walls of the LV, and stored in a digital format for offline analysis with dedicated software (TVI, GE Vingmed).

Myocardial strain measurement. In each wall, myocardial strain rate and strain were measured by two methods (Figure 1). Tracings of mean myocardial velocity and strain rates were obtained from the basal, mid, and apical segments (Figure 1). Measurements were taken from the subendocardial region with a sampling size of 3 × 3 mm. Longitudinal strain rate was estimated by measuring the spatial velocity gradient over a length of 10 mm. The region of interest was tracked spatially throughout the cardiac cycle for obtaining values from the same region of subendocardium and for avoiding sampling of the LV cavity. The variations in peak systolic and early and late diastolic strain rate (1/s) and integrated strain (%) of 3 segments (basal, mid, apical) from each wall were displayed as linear data over a cardiac cycle. In the linear mapping method (Figure 1), myocardial strain and strain rate were evaluated by moving the 10-mm or smaller sampling gate linearly over the entire length of myocardial wall from the base to the apex. The sampling gate was moved carefully in the subendocardial layer and care was taken to avoid sampling from outside the myocardium. After the regions with lowest and highest strains were identified, the region of interest was tracked spatially throughout the cardiac cycle for obtaining values from the same area of the subendocardium. In each wall, the maximum and minimum systolic and early and late diastolic strain rates and strain were recorded.

Statistical Analysis

All results were expressed as mean ± SD. Echocardiographic and other variables from the patients and control subjects were compared by the unpaired Student *t* test with a Bonferroni adjustment. The observations made with the conventional and linear strain mapping technique for the presence of paradoxical intramural mechanics and delayed longitudinal contractions were compared by using the McNemar test for paired data. $P < .05$ was considered statistically significant.

RESULTS

The myocardial strain and strain rates obtained from measurements in 12 segments with the conventional technique were homogeneous and uniformly negative in all myocardial segments in the control group. In contrast, these values were attenuated significantly in patients with HCM, compared with those of control subjects (Table 1). Patients with HCM also showed wide regional variations in the extent and pattern of regional strain in one or more walls. In 9 patients (45%), one or more myocardial segments showed positive strain, indicating paradoxical cardiac muscle lengthening in systole. In 6 patients (30%), strain rate imaging identified waves of postejection longitudinal contractions as an acces-