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BRIEF REPORT

Myocardial Strain Measurement With 2-Dimensional Speckle-Tracking Echocardiography

Definition of Normal Range

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The interpretation of wall motion is an important component of echocardiography but remains a source of variation between observers. It has been believed that automated quantification of left ventricular (LV) systolic function by measurement of LV systolic strain from speckle-tracking echocardiography might be helpful. This multicenter study of nearly 250 volunteers without evidence of cardiovascular disease showed an average LV peak systolic strain of −18.6 ± 0.1%. Although strain was influenced by weight, blood pressure, and heart rate, these features accounted for only 16% of variance. However, there was significant segmental variation of regional strain to necessitate the use of site-specific normal ranges. (J Am Coll Cardiol Img 2009;2:80–4) © 2009 by the American College of Cardiology Foundation

Accurate and reproducible measurement of left ventricular (LV) systolic function remains the most difficult skill in echocardiographic interpretation, especially in evaluation of regional function and especially in patients with suboptimal image quality. The availability of automated and accurate measurement of regional and global LV systolic function could therefore facilitate its performance by less-expert readers, especially in the emergency department and operating theater.

Two-dimensional speckle-tracking echocardiography (STE) is based on frame-by-frame tracking of tiny echo-dense speckles within the myocardium and subsequent measurement of LV deformation (1). The routine application of parameters such as myocardial strain in clinical practice requires the definition of a normal range. These parameters might potentially be influenced by both patient (age, gender, race, ethnicity, anthropometric), hemodynamic (heart rate, blood pressure), and cardiac factors (LV size, wall thickness). In this multicenter study of healthy volunteers, we sought to address these issues and to define normal values for LV systolic strain.

METHODS

Study population. Two hundred forty-two healthy volunteers, stratified according to age, were enrolled in the study from the 3 sites—University of Queensland, Brisbane, Australia (n = 94), Rhine-Westphalia Technical University, Aachen, Germany (n = 51), and Cleveland Clinic, Cleveland, Ohio (n = 97). Subjects from 18 to 80 years of age were enrolled from the community rather than from the diagnostic laboratory and were free from any known cardiovascular disease or cardiovascular risk factors. The study was approved by the individual hospitals' ethics committees, and informed written consent for participation was obtained from all subjects.

Detailed clinical evaluation, biochemistry, and standard echocardiography were performed in each individual to exclude any underlying pathology that could alter cardiovascular structure and function.

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The clinical evaluation included information regarding past medical history, symptoms suggestive of any cardiovascular illness, anthropometric measurements (height, weight, and waist circumference), general physical examination (including blood pressure measurement), and cardiovascular examination. Fasting blood sugar and fasting lipid profile were done to exclude diabetes or hypercholesterolemia. Conventional 2-dimensional and Doppler echocardiography was performed to exclude any unrecognized structural heart disease such as valvular disease, LV hypertrophy, cardiomyopathy, or pericardial disease.

STE. The methods of image acquisition and postprocessing of strain measurement with speckle-tracking have been described previously (1). Briefly, echocardiography was performed with a commercially available standard ultrasound scanner (Vivid 7, General Electric Medical Systems, Horten, Norway) with a 2.5-MHz transducer. All the images were obtained at a frame rate of 50 to 70 frames/s (Fig. 1). Strain and strain rate measurements were performed offline with dedicated automated software (EchoPAC PC, version 6.0.0, GE Healthcare, Chalfont St. Giles, United Kingdom). Each LV wall was divided into 3 segments, and a tracking-quality (TQ) score was obtained for each myocardial segment. The TQ scores were derived with a block-matching algorithm to define the quality of speckle-tracking, ranging between 1.0 (excellent tracking) and 3.0 (poor tracking). Segments with TQ persistently measured as 3 were excluded.

Statistical methods. The statistical analysis was done on SPSS for Windows (release 14.0, SPSS Inc., Chicago, Illinois). Values are expressed as mean, SD, and SEM. Comparisons between the patients were made with the independent samples *t* test or analysis of variance (ANOVA) as appropriate; comparisons between segments were performed with ANOVA with a repeated measures design. A p value of <0.05 was considered statistically significant. A general linear model was performed to assess the correlates of variation in strain and strain rate, and the amount of variance accounted for by these correlates was derived from the global r^2 of the model.

RESULTS

Subject characteristics. The subjects were 51 ± 12 years old, 44% were men, and their height and weight were 170 ± 9 cm and 75 ± 12 kg (body surface area 1.86 ± 0.18 m^2), respectively. Recruitment was stratified to provide approximately equal proportions of <40, 40 to 49, 50 to 59 and >60 years of age. The systolic and diastolic blood pressures were 130 ± 16 mm Hg and 72 ± 11 mm Hg.

Feasibility of strain measurements. Tracking quality <3 was obtained in 3,067 segments and 192 patients (79%). The tracking quality of the segments in studies analyzed is summarized in Figure 2. Tracking was best in the septum and inferior wall and worst in the anterolateral walls, especially in the apex.

Normal strain. Peak systolic strain (mean ± SEM) was −18.6 ± 0.1% with peak systolic strain rate −1.10 ± 0.01/s and diastolic strain rate −1.55 ± 0.01/s, and there were no differences between the sites (Table 1). Segmental normal ranges are summarized in Table 2. There were significant differences between means across all segments ($p < 0.0001$). The mean strain varied according to level ($p < 0.0001$), and each level differed significantly from the others in every wall except the lateral. Strain also differed significantly between walls ($p < 0.0001$), with the mean inferior and posterior strains being significantly different from all other walls.

Determinants of normal range. Table 3 summarizes the independent correlates of strain (weight, blood pressure, and heart rate), systolic SR (diastolic blood pressure), and diastolic (E) SR (age, gender, anthropometrics, diastolic blood pressure). From the global r^2 of the model, these noncardiac factors were found to account for 32% of the variance of diastolic strain rate and 26% of systolic strain but only 7% of systolic strain rate.

Reliability. Interobserver reproducibility (comparison between sites) was measured in 253 segments. The mean difference in measurements was 0.24 percentage points, with 95% confidence intervals between −11.4% and +11.8%. Thirty-eight patients underwent successive tests within 1 h; the test–retest variability showed no systematic bias, and 95% confidence intervals were between −9.6% and +9.7%.

ABBREVIATIONS AND ACRONYMS

2DS = 2-dimensional strain
ANOVA = analysis of variance
LV = left ventricle/ventricular
SR = strain rate
STE = speckle-tracking echocardiography
TQ = tracking quality

DISCUSSION

This study defines the normal ranges and variability of myocardial deformation derived from 2-dimensional speckle tracking as well as the patient, hemodynamic, and cardiac influences on these findings. Despite limited contributions of age and hemodynamic factors in this select group of truly normal individuals with a low probability of coronary artery disease, the 95% confidence intervals for mean strain varied from

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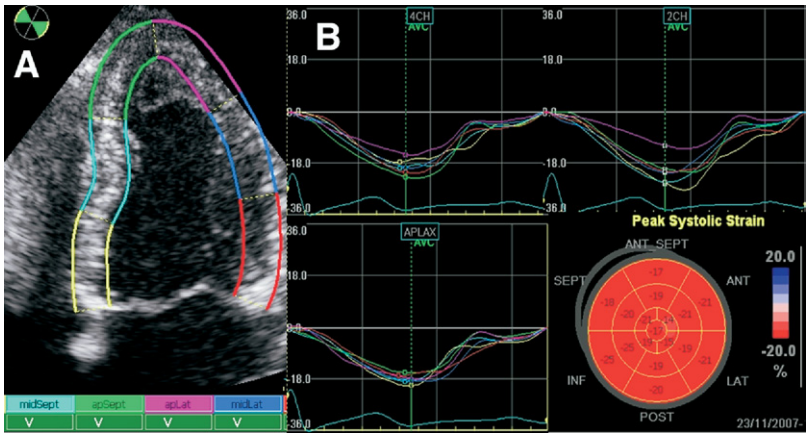

Figure 1. Processing and Presentation of 2DS

(A) Tracking quality (TQ) approval screen; segments with adequate tracking are assigned a green V mark (TQ <3). **(B)** Strain profiles from each apical view. Average segmental values in each segment are used to generate a parametric ("bull's eye") display of the entire left ventricle. 2CH = 2-chamber; 4CH = 4-chamber; ANT = anterior; APLAX = apical long-axis; AVC = atrioventricular canal; INF = inferior; LAT = lateral; POST = posterior; SEPT = septal.

−18.5% to −18.7%. Regional variations in mean strain were identified.

Normal ranges of LV deformation. Although normal ranges of strain have been described with other modalities, these might not be applicable to 2DS, given the technical differences between the methods, and these reports generally involved small numbers of subjects of limited age range. With various techniques, previous publications show normal strain to vary from 16% to 19% (2–4).

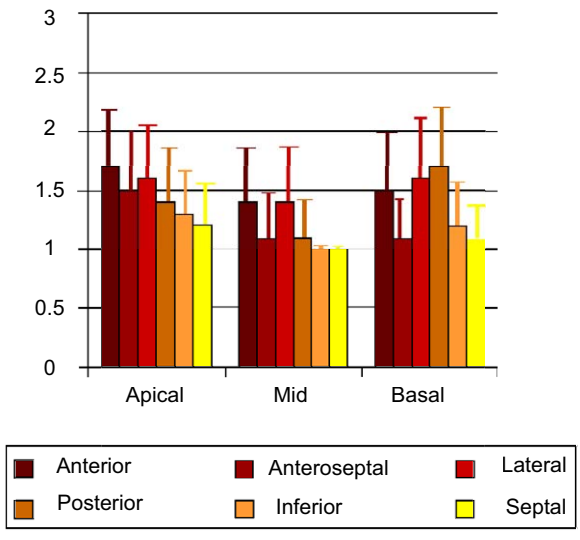

Figure 2. Relationship Between TQ and Segment Location

Relationship between tracking quality (TQ) (mean and SD of TQ score, y axis), wall (color coded, see legend), and segment location (x axis). The TQ scores are best (closest to 1) in the mid-wall and worst (averages >1.5) in the anterior and posterolateral walls. This regional variation emphasizes the role of image quality (especially edge detection) on TQ.

The different techniques have given variable results regarding the uniformity of strain from base to apex, with magnetic resonance imaging and 2DS reporting higher strain in the apex but tissue velocity imaging not showing much variation from base to apex—perhaps reflecting the implications of imaging angle on apical measurements. In contrast, magnetic resonance imaging shows relatively uniform strains between the walls, whereas tissue velocity imaging-based strain is lower in the lateral and inferior than the septal and anterior walls. This finding might be attributable to issues of signal intensity and angle-dependence, but the variations observed in this study support the proposal that regional variation might relate to both curvature and myocardial architecture. Although a 1% to 2% strain difference seems small, this variation represents 10% to 20% of normal strain, which could be clinically important. These findings suggest that a single normal cutoff value is difficult to justify, and segmental cutoffs might be more appropriate.

Clinical application. The dependence of STE on frame-by-frame tracking of the myocardial pattern makes it dependent on image factors including reverberation artifacts and attenuation. Indeed, technical proficiency remains important in image processing. Placing basal points on the atrial side of the mitral annulus might result in apparent basal dyskinesia, and positioning too close to the aortic valve results in poor

Table 1. Left Ventricular 2-Dimensional Longitudinal Strain and SRs in Subjects at Different Sites

Parameter	Peak Systolic Strain (%)	Peak Systolic SR (1/s)	Early Diastolic (E) SR (1/s)	Late Diastolic (A) SR (1/s)
Mean ± SEM	−18.6 ± 0.1	−1.10 ± 0.01	1.55 ± 0.01	1.02 ± 0.01
Lower 95% limit	−18.5	−1.09	1.54	1.01
Upper 95% limit	−18.7	−1.11	1.56	1.03

Selected for tracking quality (TQ) <3.
SR = strain rate.

tracking. Excessive region-of-interest width (e.g., including the pericardium) might have an adverse influence on tracking quality, and insufficient region-of-interest width might increase the variability of strain by compromising the reproducibility of these measurements.

A number of potential causes explaining the reported variability in LV function with other modalities, including both technical and biological, might apply equally to 2DS. The 95% confidence intervals of 2-dimensional ejection fraction (>10%) are greater than that reported for 2DS in this study. The extent to which strain measurements obtained by this technique are influenced by various demographic, hemodynamic, and technical factors is small and unlikely to be clinically meaningful.

CONCLUSIONS

The present study demonstrates that semi-automated measurement of 2DS with STE is highly feasible and reproducible. However, the clinical application of this methodology has some important caveats. First, the ranges are only pertinent to conventional segmentation of the LV. Second, the normal values might only pertain to the equipment used in this study. Addi-

Table 2. Comparison of Segmental Values (Mean and SD) for LV Strain (TQ <3), With a Repeated Measures Design

	All Levels	Apical	Mid	Basal	p Value (Levels)
All walls	−18.6 ± 5.1	−20.2 ± 5.6	−18.7 ± 3.8	−17.0 ± 5.2	<0.0001
Anterior	’−19.5 ± 4.2	−19.4 ± 5.4	−18.8 ± 3.4	−20.1 ± 4.0	0.001
Anteroseptal	−18.8 ± 4.2	−18.8 ± 5.9	−19.4 ± 3.2	−18.3 ± 3.5	0.001
Inferior	−20.0 ± 4.5*	−22.5 ± 4.5	−20.4 ± 3.5	−17.1 ± 3.9	<0.0001
Lateral	−18.3 ± 4.7	−19.2 ± 5.4	−18.1 ± 3.5	−17.8 ± 5.0	0.06
Posterior	−16.3 ± 6.3†	−17.7 ± 6.0	−16.8 ± 5.0	−14.6 ± 7.4	<0.0001
Septal	−18.3 ± 5.3	−22.3 ± 4.8	−18.7 ± 3.0	−13.7 ± 4.0	<0.0001
p (walls)	<0.0001	<0.0001	<0.0001	<0.0001	

*Inferior was significantly different from all other walls ($p < 0.001$ except anterior $p = 0.02$), in the comparison of walls at all levels. †Posterior was significantly different from all other walls ($p < 0.0001$). In the comparison of levels in all walls, each level was significantly different ($p < 0.0001$).
LV = left ventricular; TQ = tracking quality.

Table 3. Independent Correlates of Global Strain (Model-Adjusted $r^2 = 0.26$), Global Systolic SR (Model-Adjusted $r^2 = 0.07$), and Global Diastolic (E) SR (Model-Adjusted $r^2 = 0.32$)

	Global Strain		Global Systolic SR		Global Diastolic SR	
	β	p Value	β	p Value	β	p Value
Age (yrs)	−0.02	0.37	0.001	0.55	−0.01	<0.0001
Height (m)	−0.05	0.18	−0.001	0.84	0.007	0.13
Weight (kg)	0.05	0.03	0.001	0.41	−0.006	0.017
Systolic BP (mm Hg)	−0.31	0.10	−0.002	0.18	0.002	0.34
Diastolic BP (mm Hg)	0.09	0.02	0.007	0.01	−0.008	0.09
Heart rate (beats/min)	0.04	0.06	0.000	0.72	−0.003	0.24
Gender	−0.76	0.25	0.009	0.84	0.211	0.009

SR = strain rate.

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tional studies will be required with other equipment, and preliminary comparative data suggest that deformation assessment obtained by different methodologies might provide different measurements of strain. Finally, although the application of myocardial deformation might be used as an adjunct to expert visual assessment, this study does not provide sufficient evidence to propose it as a replacement for visual assessment.

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Key Words: regional left ventricular function ■ strain ■ speckle tracking.