Two-dimensional acoustic pattern derived strain parameters closely correlate with one-dimensional tissue Doppler derived strain measurements

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Tissue Doppler; Strain; Two-dimensional strain echocardiography

Abstract
Background: Two-dimensional strain echocardiography (2D-SE) calculates tissue velocities via frame-to-frame tracking of unique acoustic markers within the image and provides strain parameters in two dimensions. Novel 2D-SE software allows semi-automated strain measurements and increased averaging capabilities optimizing signal–noise ratio.

Aim: We tested whether 2D-SE and the currently used and well-validated tissue Doppler derived strain echocardiography (TD-SE) yield similar information in the clinical setting.

Methods and results: We performed 2D-SE and TD-SE on 17 patients with amyloid cardiomyopathy and 10 age-matched healthy volunteers. Single walls from standard apical views (2- and 4-chamber) were acquired at high frame rates (~200 fps). Offline analysis was performed by observers blinded to clinical data using the EchoPAC program with custom 2D-SE software. Longitudinal strain rate and strain from the basal, mid and apical segments of the septal and lateral walls were determined by each method (TD-SE and 2D-SE). Ejection fraction was >0.55 in healthy volunteers and ranged from 0.30 to 0.80 in cardiomyopathy group. A total of 54 walls (162 segments) were examined. Acceptable quality strain data was available in 92% and 85% segments by 2D-SE and TD-SE, respectively. Two-dimensional strain echocardiography values correlated closely with TD-SE values (r = 0.94 and 0.96 for strain rate and strain, respectively).

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Conclusions: Deformation analysis by 2D-SE is feasible in a clinical setting and 2D-SE values correlate closely with TD-SE measurements over a wide range of global systolic function. Two-dimensional strain echocardiography may help to facilitate the routine clinical implementation of deformation analysis.

Tissue Doppler derived strain echocardiography (TD-SE) measures regional myocardial deformation and has been well validated in in vitro and in vivo studies. Furthermore, TD-SE has demonstrated potential utility in various cardiac pathologies. However, TD-SE is limited by the inherent Doppler angle dependence and signal noise, which could potentially affect routine clinical application.

Two-dimensional strain imaging is a novel method for real-time quantitative assessment of myocardial function on the basis of new software for quantitative echocardiography, allowing the determination of global and regional myocardial parameters. Two-dimensional strain echocardiography (2D-SE) enables calculation of tissue velocities via frame-to-frame tracking of unique acoustic patterns within the image. It provides strain data in two planes and is angle independent. Novel 2D-SE software also allows semi-automated strain analysis and increased averaging capabilities that improve signal to noise ratio. Thus, 2D-SE has the potential to facilitate the implementation of strain measurements in routine clinical echocardiography. However, at this time, it is unclear how 2D-SE measurements relate to existing and extensively validated TD-SE measurements.

We tested whether 2D-SE and currently implemented TD-SE yielded similar information regarding regional myocardial deformation in the clinical setting.

Methods

Study population

The protocol was approved by the Institutional Review Board. We imaged 17 patients with amyloid cardiomyopathy. All amyloid patients had fat and/or bone marrow biopsy positive for Congo red birefringence and monoclonal protein in serum/urine. All amyloid patients also had positive conventional echocardiographic criteria for amyloid cardiomyopathy such as ventricular wall thickening (≥13 mm) with reduced cavity size, severe diastolic dysfunction (restrictive filling pattern), valvular thickening and spiculated appearance of myocardium. We also recruited 10 age-matched volunteers from the community with no symptoms and no risk factors for cardiovascular disease. All volunteers then underwent a screening echocardiogram and were found to have normal conventional echo-Doppler examination, including ejection fraction (EF) ≥ 0.55, normal wall motion, normal diastolic function, ventricular wall thickness ≤ 12 mm and normal valve morphology. All subjects (amyloid patients and normal volunteers) had no history of hypertension, diabetes, coronary artery or significant valvular heart disease, or tobacco use and had normal regional wall motion by conventional echocardiography (visual assessment). We excluded patients with bundle branch block or AV block, pacemaker and atrial fibrillation.

Conventional echocardiography

Conventional echocardiography was performed using a Vivid 7 machine (General Electric, Milwauk ee, WI) with a 2.5 MHz phased array transducer by an experienced sonographer. All the measurements were made on line with the optimal digital images selected by the sonographer from three cycles and averaged to yield a final value. M-mode and two-dimensional echocardiography images were obtained in the parasternal long- and short-axis views. The thickness of the interventricular septum and posterior wall, and left ventricular dimensions were determined at the level of the papillary muscle, on the parasternal long-axis view. Two-dimensional 2- and 4-chamber apical view images were registered and left ventricle end-systolic and end-diastolic volumes were outlined and a modified bi-plane Simpson’s method was used to calculate LV EF. Left ventricular mass was calculated by previously validated methods where LV mass = 1.04[(LVID + PWT + IVST)³ – LVID³] × 0.8 + 0.6 (LVID is LV internal diameter, PWT is posterior wall thickness, IVST is ventricular septal thickness, 1.04 is specific gravity of myocardium and 0.8 is the correction factor, all measurements were made at end-diastole).
Tissue Doppler echocardiography and two-dimensional strain imaging

For TD-SE and 2D-SE, narrow sector, high frame rates (~200 Hz) were used to image single left ventricle walls of 4- and 2-chamber apical views at end-expiratory apnea. The analysis was performed offline using the EchoPAC program with custom two-dimensional strain rate imaging software. For purposes of this study only the infero-septal and lateral walls of the left ventricle were analyzed at three levels (basal, medial, and apical) in the apical 4-chamber projection.  

Statistics

Results were expressed as mean values ± SD. Data were analyzed with the use of JMP software (SAS Institute Inc., NC). Differences between the groups (cardiomyopathy vs. healthy volunteers) were analyzed by Student’s t test. The correlations between the two methods (2D-SE and TD-SE) were performed using kappa-statistic. The intraobserver and interobserver variability and the intrainstitutional correlation for strain and strain rate was performed using Bland Altman method. A p value of <0.05 was considered statistically significant.

Results

Clinical and conventional echocardiographic characteristics are summarized in Table 1. The subjects in the cardiomyopathy group had a significant increase in wall thickness and in left ventricle mass when compared to the control group.

Acceptable quality data by both techniques was available in 92% of segments (150 of 162 segments). Sample 2D-SE and TD-SE tracings are available in 92% of segments (150 of 162 segments). Results are expressed as mean values ± SD. Data were analyzed with the use of JMP software (SAS Institute Inc., NC). Differences between the groups (cardiomyopathy vs. healthy volunteers) were analyzed by Student’s t test. The correlations between the two methods (2D-SE and TD-SE) were performed using kappa-statistic. The intraobserver and interobserver variability and the intrainstitutional correlation for strain and strain rate was performed using Bland Altman method. A p value of <0.05 was considered statistically significant.

Table 1. Clinical and echocardiographic features

<table>
<thead>
<tr>
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<th>Infiltrative cardiomyopathy (n = 17)</th>
<th>Healthy volunteers (n = 10)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>61 ± 7</td>
<td>61 ± 10</td>
<td>0.96</td>
</tr>
<tr>
<td>BSA (cm²/m²)</td>
<td>1.8 ± 0.2</td>
<td>1.9 ± 0.2</td>
<td>0.59</td>
</tr>
<tr>
<td>Male gender (%)</td>
<td>9 (54)</td>
<td>4 (43)</td>
<td>0.25</td>
</tr>
<tr>
<td>Heart failure symptoms (%)</td>
<td>17 (100)</td>
<td>0</td>
<td>0.001</td>
</tr>
<tr>
<td>HR (bpm)</td>
<td>76 ± 15</td>
<td>70 ± 10</td>
<td>0.08</td>
</tr>
<tr>
<td>SBP (mmHg)</td>
<td>114 ± 17</td>
<td>128 ± 10</td>
<td>0.41</td>
</tr>
<tr>
<td>LVDd (mm)</td>
<td>44.5 ± 6.1</td>
<td>48.1 ± 5.1</td>
<td>0.02</td>
</tr>
<tr>
<td>LVsd (mm)</td>
<td>29.5 ± 5.6</td>
<td>29.1 ± 4.5</td>
<td>0.75</td>
</tr>
<tr>
<td>Wall thickness (mm)</td>
<td>15.5 ± 3.4</td>
<td>11.6 ± 1.7</td>
<td>0.0001</td>
</tr>
<tr>
<td>LV mass index (g/cm³)</td>
<td>131.6 ± 58.8</td>
<td>24.8 ± 23.6</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

BSA = body surface area; HR = heart rate; LVDd = left ventricular end-diastolic dimension; LVsd = left ventricular end-systolic dimension; SBP = systolic blood pressure.

Intraobserver and interobserver variability for 2D-SE was tested by independent analysis of segments by two blinded reviewers. Mean interobserver difference (U.S. site) for strain rate and strain was 0.1 ± 0.25 s⁻¹ and 1 ± 2%, respectively (Fig. 3). Mean intraobserver (Israeli operator) difference for strain rate and strain was 0.1 ± 0.2 s⁻¹ and 1 ± 2%, respectively. Mean inter-institutional difference for strain rate and strain (U.S. vs. Israeli operators) was 0.2 ± 0.3 s⁻¹ and 3 ± 2%, respectively. The number of segments scored as analyzable by all three operators was higher in 2D-SE vs. TD-SE (92 vs. 85%, p = 0.02).

Discussion

Our study demonstrates that strain analysis using the novel 2D-SE technique is feasible in a clinical setting. We also demonstrate that 2D-SE values of regional myocardial deformation correlate closely with TD-SE measurements with minimal systematic bias over a wide range of global systolic function.

Tissue Doppler derived strain echocardiography has been validated as an accurate measure of global and regional ventricular function. However, Doppler angle dependence and signal noise inherent to the calculation of strain rate have limited its clinical application. Two-dimensional strain echocardiography utilizes the unique acoustic
Figure 1  Sample tracings of 2D-SE (solid line) and TD-SE (dashed line) derived strain rates (A) and strain (B). 
AVC = aortic valve closure determined by pulsed Doppler through the LV outflow tract.
Figure 2  Correlation between 2D-SE and TD-SE derived strain rates (A) and strain (B).
patterns seen within the image to determine regional tissue velocities. These patterns are relatively stable over time and can be tracked over several frames. New image processing algorithms allow semi-automated identification and tracking of these acoustic patterns. Once a unique acoustic pattern is identified within a frame, its new location in subsequent frames is tracked using image correlation techniques. The geometric shift over time in these acoustic patterns or markers is assumed to represent local tissue movement. Local tissue velocity is then calculated as the distance moved by the acoustic marker from one frame to the next divided by the time between the two sequential frames. The change in distance between two acoustic markers represents strain and the rate of change of inter-marker distance represents strain rate.

Since there are multiple acoustic markers in a single frame, the potential for averaging and increasing signal to noise ratio is improved thereby enhancing strain rate and strain signal quality. The new software also allows semi-automated determination of strain rate and strain, thus reducing the image processing time.

In a recent publication, Leitman et al. demonstrated that 2D-SE reliably detected reduced strain rates in infarcted segments. These authors also showed that in normal patients, 2D-SE correlated with TD-SE. Our findings are concordant with those reported by Leitman et al. In addition, we report the close correlation between 2D-SE and TD-SE in global LV dysfunction over a wide range of systolic function. Our findings also suggest that there is close agreement between the two techniques with no systematic bias. Finally, intraobserver, interobserver and interinstitutional correlation was high.

**Limitations**

Lower frame rates allow maximal line density and increased recognition of acoustic markers. This setting will, however, reduce temporal resolution. The semi-automated software reduces the opportunity to determine strain parameters in a specific location via manual placement of a region of interest. Tracking of myocardial borders and acoustic patterns may be challenging when image quality is poor. Strain rates by either TD-SE or 2D-SE techniques were not validated by an independent technique such as magnetic resonance. Our study was not intended as a validation study but was meant to determine whether there was a close correlation between the two techniques.

**Conclusion**

Strain echocardiography analysis using novel 2D-SE software is feasible in a clinical setting. Semi-automated estimation of 2D-SE values of regional myocardial deformation correlates closely with manual TD-SE measurements and demonstrates no systematic bias over a wide range of global systolic function. High intraobserver, interobserver and interinstitutional correlation of 2D-SE values suggests that this novel technique may help to facilitate the implementation of strain echocardiography in a clinical setting.

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References


