Alterations of systolic left ventricular twist after acute myocardial infarction

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Cardiac rotation about a left ventricular (LV) long axis is an important component of normal systolic function, capable of equalizing end-systolic fiber stress across the LV wall (1). LV rotational deformation has been described in animal models (5, 28) and humans (9, 12) in whom strain gauges and radio-opaque markers have been implanted at cardiac surgery or transplantation. Although echocardiography has been used in humans for assessment of cardiac rotation (19), it has been limited to the measurement of the angular deformation of anatomic landmarks such as papillary muscles. Detailed studies (2, 3, 30) of the wringing motion of the normal human LV have been performed using magnetic resonance (MR) myocardial tagging, but routine clinical assessment of LV rotation by tagged MR imaging (MRI) has been difficult to implement. Consequently, the effects of acute myocardial ischemia on LV rotation remain poorly understood, stressing the need for a noninvasive and easily accessible technique capable of assessing such cardiac motion in humans.

Tissue Doppler echocardiography (TDE) provides velocity mapping of myocardial motion (17, 20, 27). On the basis of the physical properties of the Doppler effect and the geometric model represented by the LV parasternal short-axis view, we hypothesized that TDE could represent an accurate tool for the assessment of LV twist. We sought to use color TDE for quantitative assessment of systolic LV rotational deformation and to characterize alterations of LV twist in patients after anterior acute myocardial infarction (MI) in relation to conventional markers of LV contractile performance.

METHODS

All experimentations were conducted in conformity with the “Guiding Principles for Research Involving Human Beings” and with the principles embodied in the Declaration of Helsinki for human investigations. The study protocol was approved by the local ethics committee. The patients gave informed written consent.

Screened Population

Forty-one patients admitted <24 h after the onset of a first Q wave anterior myocardial infarction were screened, regardless of the treatment they received at the acute stage. The diagnosis of acute infarct was confirmed by electrocardiographic features, a rise in creatine kinase (CK-MB) or troponin I >2×, and a marked asynergy on echocardiography. Patients were given aspirin, β-blockers if tolerated, and angiotensin-converting enzyme (ACE) inhibitors when LV ejection fraction was <40%. TDE images of the LV were recorded within the first week after the infarct. Patients with bundle branch block, atrial fibrillation, transient atrioventricular block, cardiac pacemaker, LV hypertrophy, prior cardiomyopathy, or infarction were excluded. The volunteers were hospital employees with normal electrocardiograms and echocardiograms and no cardiovascular risk factors.

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Tissue Doppler Echocardiography

Image acquisition. We used conventional equipment (Acuson, Sequoia; Mountain View, CA; or System 5, GE Vingmed; Horten, Norway) with 2.5–4 MHz phased-array transducer and software modifications allowing the display of myocardial velocities by color TDE (17, 20, 27). Color TDE of the LV parasternal short-axis view at the midpapillary muscle level was performed in all subjects (O. Pascal, P. Guéret, and J. Garot). Image magnification was used while allowing the whole LV to be included in the frame. The grayscale mode power was switched off and the color Doppler gain was adjusted to obtain maximal filling of the myocardium without color degradation. Frame rates of color Doppler images were ~30–40 Hz. The Doppler velocity scale was reduced to the lowest setting at which aliasing did not occur. We acquired at least six cardiac cycles during a single breath hold. Sequences were stored on optical disks.

Systolic LV Wringing Motion

LV endocardial contours were drawn at end diastole (Scion Image; Frederick, MD), while excluding papillary muscles. A circle was superimposed to best fit the endocardial boundary. Its centroid was then chosen as the centroid of the LV cavity and its coordinates \((x, y)\) in the image plane were used to place the fixed centroid on the end-systolic frame. We defined a theoretic black zone located in the septal wall at 90° angle between the direction of the Doppler beam and that of myocardial motion towards the centroid (yielding no Doppler signal) (Fig. 1). The shift between the position of the theoretic and that of the observed black zone at end systole was assumed to provide a measure of LV twist (Fig. 1). Because of the properties of the Doppler effect, the observed black zone corresponded to the transition zone on myocardial Doppler images. The last frame during systole was selected as the one with the smallest LV cavity. The line materializing the Doppler beam was drawn from a virtual and arbitrary point located 10 mm above the top and in the middle of the frame. Its direction was traced from this virtual point to the endocardial border of the transition zone. We then drew the lines between the centroid and the endocardial area of the observed and theoretic black zones and measured systolic LV twist about a long axis. The magnitude of deformation was averaged over three consecutive cardiac cycles (excluding premature and postextrasystolic beats).

MR Myocardial Tagging

A subset of five randomly selected healthy volunteers and eight infarct patients were also studied with the use of MR tagging by independent investigators (B. L. Gerber, J. A. C. Lima, and J. Garot) within 2 days of TDE acquisitions. MR images were acquired during multiple breath holds on a 1.5-T whole body magnet (Signa, General Electric Medical Systems; Milwaukee, WI). Anterior and posterior phased-array coils were used for signal acquisition. We utilized an electrocardiogram-triggered segmented k-space fast gradient-echo imaging pulse sequence (18). The tagging pulse sequence consisted of nonselective radio frequency pulses separated by spatial modulation of magnetization encoding gradients to achieve tag separation of 7 mm. After scout images were completed, contiguous stacks of four base-to-apex short-axis cross sections were prescribed, along with six radially oriented (every 30°) long-axis slices. Two sets of identical short-axis views were acquired (the second set rotated by 90°). This imaging sequence allowed us to image each slice within 1 breath hold (~14–20 s each). Scanner settings were the following: 36-cm field of view, 7-mm tag separation, 8-mm slice thickness, 6.5-ms repetition time, 2.3-ms echo time, 15° tip angle, 256 × 160 image matrix, 5–7 phase-encoded views per movie frame, and cardiac cycle. Myocardial strains were assessed offline using an established technique (8), as previously described (6). Images were processed by a blinded observer with the use of a custom-developed software program (Findtags; Baltimore, MD) that requires interactive detection of myocardial contours and tag lines, and which is based on the tracking of tag planes throughout systole. Maximum systolic mid-LV twist was determined in the subendocardium of the septal wall by tracking local myocardial motion over time. The method defines a central axis of the LV and relates wringing motion of an individual segment to the centroid. It generates a detailed motion map of myocardial shear strain in the circumferential-radial direction \((\varepsilon_{cr})\), which represents local twist (29) (Fig. 2). Coordinates of the posterior right ventricle-LV insertion point were calculated on the most basal slice and were used as reference landmarks for segmentation of the LV. Proper cross registration between TDE and MRI was obtained by using midpapillary muscles as an anatomic landmark.

Coronary and LV Cineangiography

All patients underwent a coronary and LV angiogram within the first week after the infarct. Global LV function was evaluated on 30° right- and 60° left-anterior oblique positions. LV contours were traced by an independent observer and digitized (TSI; Paris, France). End-diastolic and end-systolic volume indexes (ml/m²), and LV ejection fraction

Fig. 1. Schematic representations of color Doppler left ventricular tomograms (T) in the short-axis view at the mid-papillary muscle level. A: position of the theoretic black zone located at 90° between the direction of the Doppler beam and that of radial wall motion. B: location of the observed black zone at end systole. The angle \(\beta\) represents the magnitude of the wringing motion assessed in the septal wall. Both lines were drawn from the left ventricular (LV) centroid to the endocardial area of the corresponding black zone. The direction of the Doppler beam was materialized by drawing a line between an arbitrary point located 10 mm above the top and exactly in the middle of the frame.

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were calculated by the area-length method (4, 24). Segmental wall motion was expressed as radial shortening fraction [(end-diastolic radius – end-systolic radius/end-diastolic radius] of 16 anatomic wall segments by the center gravity method in the right and left anterior oblique positions (7, 25). The normal range for LV ejection fraction and radial shortening of each segment was determined from ventriculograms obtained from 40 matched subjects with atypical chest pain and no evidence of coronary stenosis or other cardiovascular disease. We used a standardized motion index expressed in units of standard deviation from the normal mean (% shortening of a patient’s segment mean of the same normal segment/SD of the normal segment)). The wall motion for an individual segment was considered normal if the value lay within 2 SDs of the mean value in controls and asynergic when ≥2 SDs below the normal range. The number of asynergic segments was used to determine the size of the area at risk.

**Statistics**

Data are shown as means ± SD. An unpaired Student’s t-test was used for comparisons of continuous variables between controls and patients. Regressions were calculated by the linear regression method. Tests were two tailed and considered significant at P < 0.05.

**RESULTS**

**Study Population**

Twenty volunteers (6 females, 49 ± 10 yr) and 34 infarct patients (11 females, age 61 ± 11 yr) were included in the study. Patients’ characteristics are summarized in Table 1. TDE was acquired 3 ± 2 days after the infarct and 2 ± 1 days apart from angiography and from MRI. No significant clinical event occurred between TDE and MRI. The medications were kept constant throughout the study period. Seven patients could not be included: two had left bundle branch block, two had atrial fibrillation, and the other three had poor echogenicity. Twenty-six patients were treated by primary angioplasty (n = 18) or thrombolysis (n = 8) 5 ± 3 h after the onset of acute MI. The eight remaining patients were admitted >12 h after the onset of chest pain and were treated medically.

**Validation of TDE for Assessment of LV Twist**

In five randomly selected controls, mid-LV twist by MR tagging and TDE occurred counterclockwise when viewed from the base [11.8 ± 3.1° and 13.2 ± 3.4°, respectively, P = not significant (NS)]. In eight random patients, LV twist by MR tagging and TDE occurred in the same direction (6.9 ± 2.5 and 8.0 ± 3.1°, respectively, NS). For the 13 subjects, serial measurements were correlated [y = 0.87x + 2.1, r = 0.83, standard error of the estimate = 1.6°, P < 0.001].

**LV Twist in Healthy Volunteers and Infarct Patients**

In 20 healthy volunteers (6 females, age 49 ± 10 yr), systolic mid-LV wringing motion as assessed by TDE occurred counterclockwise when viewed from the base.

**Table 1. Patient characteristics**

<table>
<thead>
<tr>
<th>Patients</th>
<th>n = 34</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean age, yr</td>
<td>61 ± 11</td>
</tr>
<tr>
<td>Male, %</td>
<td>68</td>
</tr>
<tr>
<td>Diabetes, %</td>
<td>15</td>
</tr>
<tr>
<td>Hypertension, %</td>
<td>29</td>
</tr>
<tr>
<td>Smoker, %</td>
<td>44</td>
</tr>
<tr>
<td>Hypercholesterolemia, &gt;220 mg/dl, %</td>
<td>50</td>
</tr>
<tr>
<td>Thrombolytics or angioplasty n, %</td>
<td>26(76)</td>
</tr>
<tr>
<td>Peak CK, IU/l</td>
<td>2,630 ± 610</td>
</tr>
<tr>
<td>Left anterior descending, %</td>
<td>100</td>
</tr>
<tr>
<td>TIMI 3 score n, %</td>
<td>20(59)</td>
</tr>
<tr>
<td>TIMI 0–1 score n, %</td>
<td>7(21)</td>
</tr>
<tr>
<td>1-vessel disease, %</td>
<td>68</td>
</tr>
<tr>
<td>LV ejection fraction, %</td>
<td>48 ± 8</td>
</tr>
<tr>
<td>Aspirin, %</td>
<td>97</td>
</tr>
<tr>
<td>β-Blockers, %</td>
<td>88</td>
</tr>
<tr>
<td>ACE inhibitors, %</td>
<td>59</td>
</tr>
</tbody>
</table>

Values are means ± SD; n, no. of subjects. Numbers in parentheses are percentages. ACE, angiotensin-converting enzyme; CK, creatine kinase; LV, left ventricular; TIMI, thrombolitics in myocardial infarction flow score.
Fig. 3. Side-by-side diastolic and systolic myocardial Doppler images from a healthy volunteer (top) and a patient with anterior myocardial infarction (MI) (bottom) are displayed. Systolic wringing deformation about a LV long axis was decreased in the setting of anterior infarct. Image magnification of the whole LV myocardium was used.

(14.8 ± 3.4°, range 11–20°) (Fig. 3). The reproducibility of measurement was assessed in eight randomly selected volunteers by two independent investigators. The mean difference between the two analyses was 1.9 ± 1.0° (12.8%), and serial measurements were correlated (y = 0.91x + 2.8, r = 0.95, P = 0.0003). In patients, TDE-derived LV twist occurred in the same direction but was significantly lower than in controls (9.8 ± 3.1°, range 6–18°, P < 0.01) (Fig. 3). Interobserver reproducibility was also assessed in eight randomly selected patients with good agreement between two observers (mean difference 1.2 ± 0.9°, coefficient of variability 12.2%, y = 0.92x + 1.5, r = 0.93, P < 0.001).

Decrease in LV Twist and Contractile Function

In patients, mean angiographic LV ejection fraction was 48 ± 8%, and the mean number of asynergic segments was 3.5 ± 1.6. Systolic LV wringing deformation was significantly lower in patients with impaired compared with patients with preserved LV function (7.3 ± 2.3 vs. 12.3 ± 3.9°, P < 0.01; the median ejection fraction of 48% was chosen as a cutoff). There was a good correlation between LV rotational motion and postinfarct angiographic LV ejection fraction (Fig. 4A), and between the decrease in LV wringing motion and the number of asynergic segments (Fig. 4B).

DISCUSSION

We described the use of color TDE for the quantitative assessment of systolic LV wringing motion in humans and characterized alterations of LV twist in patients after acute MI. LV twist was significantly decreased after acute myocardial ischemia, and there was a close relationship between the decrease in LV twist and that in global LV function. As with other imaging techniques capable of assessing LV twist, the TDE method defines a central axis of the LV and relates wringing motion of an individual segment to the centroid. The measurements of LV twist by TDE were reproducible and validated against an established MR tagging technique. So far, TDE has been used to measure myocardial radial velocities by short-axis interrogation and longitudinal velocities by long-axis interrogation (20, 27). Our study shows that LV wringing motion can also be determined from myocardial Doppler images and therefore may have direct implications for straightforward clinical assessment of LV twist.

Effects of Acute MI on LV Rotational Motion

The assessment of systolic LV wringing motion by TDE provided a valuable index of myocardial ischemia in the LAD territory. A few experimental (2, 14) and clinical (22) studies have demonstrated a decrease in LV rotation induced by acute ischemia. Animal models have suggested a marked reduction in rotational rigid-body motion in nonreperfused transmural infarcts after experimental coronary occlusion (15). Our study indicates that LV twist remains decreased well beyond reflow in humans, reflecting the persistence of postischemic dysfunctional myocardium. Although alterations of LV twist may be secondary to subtle changes in usual parameters of LV function, these findings support the hypothesis that LV twist may represent a sensitive indicator of LV function (10, 11, 13).

Relation of LV Twist to Global Contractile Function

TDE measurements of LV rotational motion correlated closely with angiographic parameters of global contractile LV function in the setting of acute myocar-
dial ischemia. Previous studies using intramyocardial markers (9, 10), or magnetic resonance tagging (2), have suggested a dependence of LV rotation on LV contractile strength, and a significant increase in LV rotation under inotropic stimulation (10, 21). LV fiber angles vary gradually from the endocardial to the epicardial surface by as much as 160° with the subepicardial and subendocardial fibers oriented obliquely to the LV long axis and with fibers in the midwall oriented circumferentially (26). This spiral transmural distribution of fibers and the extent of shortening among obliquely oriented fibers are likely to be major determinants of LV rotation. As such, measurements of LV twist may provide useful information about LV contractile performance.

**Limitations**

The inability to measure more complex features of rotation represents the main drawback of the technique. LV twist was not measured in the lateral wall because signal-to-noise and lateral resolutions are too low. Moreover, TDE did not allow for separate assessment of LV wringing motion in the subendocardial and subepicardial layers. In contrast to the interface between the blood pool and the myocardium, the lack of accurate delineation of the subepicardium is a current limitation of TDE (17, 20, 27). Second, the relatively low signal-to-noise of B-mode TDE makes the precise delineation of the transition zone within the wall sometimes mistaken. Therefore, measurements of myocardial shear strain were not performed. Although cardiac twist was only assessed at mid-LV, this method has the potential for its assessment at different cross-sectional levels along the LV long axis. Because frame rates of B-mode TDE are relatively low, the method did not provide accurate analysis of the time course of LV rotational deformation throughout systole. However, it offers the possibility of wide applicability at the bedside and may be useful for obtaining serial studies in individuals.

The impact of regional wall motion abnormalities on the position of the observed transition zone has not been systematically addressed. In the parasternal short-axis view, the kinetics of the septal wall in the direction of wall thickening or thinning occurs at ∼90° angle with the direction of the Doppler beam, and therefore may be overlooked when considering the overall motion that the wall experiences. Conversely, the Doppler beam is aligned on rotational components of septal deformation and therefore well suited for measurement of LV twist. As with any echocardiographic technique, the method does not compensate for cardiac translation during systole (19, 23). Cardiac translation occurs through plane in the short-axis view and therefore is unlikely to significantly affect the measurements of LV twist. Also, two-dimensional measurements of myocardial strain, which do not compensate for through-plane translation of the heart, are sufficiently powerful to precisely index myocardial ischemia (16).

TDE slightly overestimates LV twist compared with MRI. However, the absolute difference between the two techniques is as low as 1.4° in normal subjects (11.9%) and 1.1° among infarct patients (15.9%), which is unlikely to impact on routine clinical assessment of LV twist. The interobserver reproducibility of the technique is ∼12%. As with any other echocardiographic measurement, it is recommended to perform the evaluation by the same observer when serial measurements over time are needed. Potential sources of mistake for the assessment of LV twist by TDE include a bad delineation of the transition zone in the subendocardium, a misplacement of the centroid at end systole, a bundle branch block, or any condition that implies abnormal septal motion such as cardiac pacemaker or tamponade, and a marked deformation of the LV at end systole (LV aneurysm). The validity of the method has not been demonstrated in patients with atrial fibrillation, transient atrioventricular block, LV hypertrophy, prior cardiomyopathy, or prior infarction.
Color TDE has potential for quantitative assessment of LV wringing motion during cardiac contraction and is capable of analyzing ischemia-induced alterations of LV twist, which are related to global contractile function. Although clinical applications remain to be determined, B-mode color TDE appears as a widely accessible technique that enables straightforward assessment of LV twist in humans.

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REFERENCES