QUANTIFICATION OF REGIONAL MYOCARDIAL FUNCTION FOLLOWING ACUTE MYOCARDIAL INFARCTION BY ULTRASONIC STRAIN RATE AND STRAIN IMAGING

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Keywords: Doppler myocardial imaging, strain rate, strain, regional myocardial function.

Summary

Objectives: The rapid diagnosis and early risk stratification of patients presenting with acute myocardial infarction (AMI) is important. In experimental setting ultrasonic strain rate (SR) and strain (S) have been shown to identify changes in deformation predictive of ischemia. We sought to evaluate and compare regional myocardial function at “the risk zone” (ARZ) supplied by the culprit coronary artery (CCA) and at the remote (R) area during AMI (25 patients) and control zone (10 healthy subjects) using SR/S.

Design and Methods: Longitudinal deformation (LD) was from the apical views to assess function in the septum (SW) and inferior (IW) walls. Both SW mid and apical segments were considered ARZ segment if the CCA was left anterior descending artery. IW and basal segments of the SW were ARZ, if CCA was the right coronary artery or left circumflex branch.

Results: Segments were scored according to the standard wall motion score (WMS) and compared to the findings of SR/S imaging. The amplitude of peak systolic SR (pSR), maximal systolic S (pS), and overall maximal S (OS) were decreased in infarcted segments (p < 0.05 vs R, vs control (C)). The pS was lower than OS indicating that in many infarcted segments, maximal shortening was delayed and occurred during early diastole. Infarcted segments evaluated as having a WMS = 3 had a tendency to lower values of pS and OS (p < 0.05).

Conclusions: The strain rate/strain magnitude and changes in time interval values reliably identify infarcted segments and differentiating those from remote zone segments. Longitudinal deformation parameters provided statistically significant additional information and allowed a rapid diagnosis of area and extent of myocardial infarction in this high risk group.
rameters are available. Thus, the aim of our study is to evaluate regional myocardial function using SR/S measurements in patients with AMI. To evaluate the range of changes in regional myocardial function at “the risk zone” of the culprit artery and remote area during AMI using Doppler myocardial imaging (DMI) indices strain rate and strain.

**Design and Methods**

**Study group**

The study group consisted from the patients admitted to the Coronary Care Unit with the diagnosis of the first AMI in whom coronary angiography and revascularization using either fibrinolysis or primary percutaneous coronary intervention was performed. Twenty five patients (mean age 68 ± 9.5, 12 females) were studied during the first myocardial infarction (MI). The infarct location was assessed from the 12-lead resting electrocardiogram (ECG). All of them had prolonged chest pain (>30 minutes) with evolving ECG changes indicating acute myocardial ischemia (ST-segment elevation >2 mm and/or Q waves >3 mm in 2 adjacent leads) and a significant rise in serum-specific cardiac enzymes. Patients with a history of MI, arrhythmia, pacemaker implantation, bundle branch blocks, dilated cardiomyopathy, myocardial hypertrophy, pulmonary hypertension, significant valvular heart diseases, poor acoustic window, coronary artery bypass grafting and were excluded from the study.

Ten asymptomatic age-matched subjects (27–48 years old, mean age 37 ± 8.0, 2 females) served as a control group. All of them had a normal rest ECG, echocardiogram, up-right bicycle stress test and no history of coronary artery disease, angina, hypertension or diabetes.

The study protocol has been approved by the local ethics committee.

**Coronary angiography and revascularization**

Coronary angiograms of the right and left coronary arteries were obtained. Data were acquired immediately after the patient had been admitted to Cardiac Care Unit. The coronary angiography and angioplasty procedures were performed using standard techniques. Coronary angiographic data were available in 24 patients (Table 2). Coronary occlusion or significant coronary stenosis was defined as an artery lumen narrowing (more than 75%) in 2 orthogonal angiograms. Two patients had a coronary artery bypass grafting and were excluded from further examination.

**Echocardiographic data acquisition**

Echocardiographic studies were performed using a GE Vingmed ultrasound scanner (System VII) with a 2.5 MHz transducer. All the patients were scanned in the left lateral decubitus position using B mode and color Doppler myocardial imaging (CDMI). All 2D studies were performed using second harmonic imaging. Aliasing was eliminated from the color Doppler data sets by setting appropriately high pulse repetition frequency (PRF) values (range 16 to 21 cm/sec) for data acquisition. The imaging depth and the sector angle in each view were adjusted to obtain the highest possible frame rates for myocardial color Doppler acquisition, while keeping the separate wall of the left ventricle in view. All echocardiographic images were recorded at passive end-expiration to minimize global cardiac movement. Scanning had been performed just before the patient was transferred for the catheterization.

All patients had well-defined regional wall motion abnormalities. Color Doppler velocity mapping of the infarcted segment was then performed in appropriate gain: velocity settings and the resulting images were compared with two-dimensional images in attempt to assess the ability of this technique to detect and differentiate between normal and hypocontractile myocardium.

B-mode CDMI myocardial velocity data was acquired at the frame rate of 140–190 frames/sec using the imaging sector angle of 45–60 degrees. The 2D grey scale images were assessed visually. The color Doppler velocity data was processed off-line to derive velocity and regional SR/S curves for longitudinal deformation. Apical 4-chamber and 2-chamber view was used for the assessment of either septum or inferior wall longitudinal function respectively. Each wall was subdivided into three segments (basal, mid ventricular and apical). Both septal mid and apical segments, imaged in apical 4-chamber view, were considered “at-risk” segment, if a culprit artery was the left anterior descending coronary artery. All inferior wall segments and the basal segment of septum were considered “at-risk”, if a culprit artery was the right or circumflex coronary artery.

In total, data were obtained from 150 segments for patients with AMI; and 60 segments were analyzed as a control group. All acquired images were stored in a digital memory of the machine and downloaded to the workstation for off-line analysis.

**Echocardiographic data analysis**

The CDMI data sets were analysed off-line using dedicated software (TVI 6.0, GE Vingmed, Horten, Norway). Regional peak systolic velocities were measured for longitudinal motion in each of the 3 segments of the septal and inferior left ventricular walls. Regional SR was estimated during off-line analysis (Speqle – Software Package for Echocardiographic Quantification, University of Leuven) and using the same methodology previously described [7]. To describe regional deformation in longitudinal direction the following parameters from the mean velocity and SR profiles respectively were...
calculated: the peak systolic SR and S, overall maximal S (OS), time interval from the beginning of the Q wave on ECG to the OS (tOM) (Figure 1).

**Statistical analysis**
Statistical analysis was performed by STAT view software (SAS Institute, Cary North Carolina). Continuous values were expressed as mean values ± SD. All values measured were grouped segment wise and their means compared. Qualitative values were compared using two sample t-test. A p value of <0.05 was considered as statistically significant.

**Results**
In total 150 myocardial segments recorded from 25 patients treated in Coronary Care Unit were included for analysis. Clinical and hemodynamic data of patients are presented in Table 1. Coronary angiography data are presented in Table 2.

**Control segments**
This group includes 10 healthy volunteers mean age 37 ± 8.0 years. In total 60 segments were analyzed as control segments. For each cardiac cycle, the normal longitudinal systolic shortening of myocardium was characterized by negative strain rate and strain values. Maximal longitudinal shortening expressed as maximal overall strain occurred during the systole or just after aortic valve closure. The amplitude and time interval value of OS was similar to maximal systolic strain in almost all segments of the normal myocardium.

**Infarcted segments**
Coronary artery supplying infarcted segments was occluded or severe stenosis was found by angiography. Prolonged ischemia resulted in myocardial wall motion abnormalities on two-dimensional imaging. Color Doppler velocity mapping of the infarcted segment was performed. We had subdivided infarcted segments according to the wall motion index (Table 3). Infarcted segments data set consisted from analysis of 64 segments (42.7%). Characteristic findings recorded from infarcted segment using SR/S are shown in (Table 3). As it was expected, the amplitude of peak systolic strain rate (pSR), maximal systolic S (pS), and OS were decreased in infarcted segments (p < 0.05 vs remote (R), vs control (C)). The pS was lower than OS indicating that in many infarcted segments, maximal shortening was
Table 1. Baseline characteristics of patients

<table>
<thead>
<tr>
<th>Number of patients</th>
<th>n = 25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (mean age ± SD)</td>
<td>68 ± 9.5</td>
</tr>
<tr>
<td>Hypertension</td>
<td>12</td>
</tr>
<tr>
<td>Dyslipidemia</td>
<td>17</td>
</tr>
<tr>
<td>Diabetes</td>
<td>4</td>
</tr>
<tr>
<td>CK</td>
<td>904 ± 631</td>
</tr>
<tr>
<td>CK-MB</td>
<td>94 ± 89</td>
</tr>
<tr>
<td>Troponin I</td>
<td>55.7 ± 99.4</td>
</tr>
</tbody>
</table>

CK – creatine kinase; CK-MB – creatine kinase MB isoenzyme; SD – standard deviation

Table 2. Patients (n = 24) coronary angiography and treatment data

| 1 vessel disease | n = 14 (LAD n = 7; RCA n = 6; LCx n = 1) |
| 2 vessel disease | n = 7 |
| 3 vessel disease | n = 3 |
| Primary PCI      | n = 16 (LAD n = 6; RCA n = 8; LCx n = 2) |
| Fibrinolysis     | n = 3 (LAD n = 2; RCA n = 1) |
| Rescue PCI       | n = 3 (LAD n = 2; RCA n = 1) |
| Conservative treatment | n = 2 |
| CABG             | n = 2 |

CABG – coronary artery bypass grafting; LAD – left anterior descending artery; LCx – left circumflex branch; PCI – percutaneous coronary intervention; RCA – right coronary artery

Table 3. Quantitative segmental analysis. Characteristical findings recorded from infarcted, remote and control segment using strain rate/strain

<table>
<thead>
<tr>
<th>Controls</th>
<th>Patients (n = 25)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WMS1(C)</td>
<td>WMS1(P)</td>
</tr>
<tr>
<td>Number of segments</td>
<td>n = 60</td>
</tr>
<tr>
<td>OS (%)</td>
<td>−22 ± 4.8\textsuperscript{a}</td>
</tr>
<tr>
<td>Ot (msec)</td>
<td>366 ± 22\textsuperscript{a}</td>
</tr>
<tr>
<td>pS (%)</td>
<td>−21 ± 5.4\textsuperscript{a}</td>
</tr>
<tr>
<td>pSR (1/sec)</td>
<td>−1.46 ± 0.4\textsuperscript{a}</td>
</tr>
</tbody>
</table>

\textsuperscript{a}<0.05 vs WMS2; \textsuperscript{b}<0.001 vs WMS3; \textsuperscript{c}<0.05 vs WMS2;3; values are mean ± standard deviation

Discussion

Our study shows that we are able to differentiate between the normal contracting segment and infarcted segment using ultrasonic deformation parameter amplitude and time interval values. We suggest that segmental analysis provides additional and

delayed and occurred during early diastole. Infarcted segments evaluated as having a wall motion score (WMS) = 3 had a tendency to lower values of pS and OS (p < 0.05). Time interval to OS (tOM) had been prolonged and maximal overall strain occurred during isovolumetric relaxation or early diastolic phase (Figure 2).

Remote zone segments

Remote zone segments were supplied by a non-infarcted coronary artery. In total 86 segments (57.3% (WMS-1)) contributed to the remote zone data set. Normokinetic segments had a comparable systolic SR and strain values in patients and in controls. Descriptive analysis using SR/S of the remote segment is shown in Table 3.
Figure 2. A typical example of strain measurements performed in the septum supplied by occluded left anterior descendens coronary artery. The longitudinal function of the apical segment is severely altered: the maximal systolic value is positive, time interval to maximal overall strain is prolonged (>500 ms). In contrast, a basal segment supplied by a normal coronary artery has a normal systolic amplitude and time interval value.

IVRT – isovolumic relaxation time

valuable information to visual motion scoring in the quantification and identification of ischemia-induced changes in regional contractility. As we know, rapid diagnosis and early risk stratification of patients with acute chest pain are important in identifying patients to whom early interventions may result the better outcome [8].

As it was expected, longitudinal shortening had altered in ischemic segments. The amplitude of maximal systolic shortening was reduced in acute ischemia. In some segments supplied by occluded coronary artery, systolic shortening was completely abolished and replaced by lengthening (positive systolic strain). This is in agreement with previous works [9,10]. Moreover, we evaluated the timing interval for peak deformation. It is interesting to note that shortening of the ischemic segment was delayed and occurred after aortic valve closure what was early or even late diastole for the non-ischemic myocardial surrounding segments. This phenomenon was found by other authors [11,12] and named postsystolic shortening (PSS). Experimental animal models suggest that PSS relates to ischemic alterations of the systolic and diastolic function. Timely onset of diastolic relaxation requires the uptake of cytoplasmic calcium by sarcoplasmic reticulum, which is an energy demanding process. Alteration of this active process is the established predictor of myocardial dysfunction at the level of myocyte metabolism [13,14].

The SR and S values in normal and dyssynergic segments in this study are comparable with those, published by Voigt et al [10].

Our study shows that CDMI parameters SR/S can provide information in localizing myocardial infarct territory and identifying culprit artery location. It is important to differentiate infarcted segments from remote ones in order to predict prognosis, left ventricular recovery and myocardial area under the risk, to identify patients at high risk of further events such, as reinfarction or death, and hopefully to intervene in order to prevent these events.

Limitations

Data post-processing was time consuming taking up to 1 to 2 hours per study. The usual limitations inherent in the angle dependency of all echocardiographic Doppler techniques apply equally to SR and ε derived by ultrasonic auto-correlation.

Conclusions

Strain rate and strain imaging can identify, localize and quantify acutely induced segmental changes in acute ischemia. We suggest that quantitative lon-
longitudinal deformation parameters provide additional information to visual motion scoring in the quantification and identification of ischemia-induced changes in regional contractility in the clinical setting. It could add a new and important parameter for the measurement of myocardial segmental function, being relatively independent of both overall heart motion and motion direction.

References


