Assessment of the regional myocardial deformation changes and viability in anterior acute myocardial infarction patients by strain and strain rate imaging

Anteriyor akut miyokart enfarktüslü hastalarda bölgesel miyokardiyal deformasyon değişiklikleri ve canlılığın gerilme ve gerilme oranı görüntülemesi ile değerlendirilmesi

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ABSTRACT

Objective: To prospectively evaluate the regional myocardial deformation changes and viability in anterior acute myocardial infarction (AMI) patients before and after primary coronary intervention (PCI) by strain (S)/strain rate (Sr) imaging.

Methods: Twenty-one patients presented during the first six hours of an anterior AMI and twenty controls were included in this study. Echocardiographic recordings were obtained from the apical/parasternal images just before PCI, one week and one month after PCI. The S/Sr and velocity (V) were measured from the basal mid and apical segments of the walls supplied by the left anterior descending artery. Myocardial perfusion scintigraphy was performed in the 1st month after PCI. Mann-Whitney U and Wilcoxon tests were used for statistical analysis.

Results: Acute myocardial infarction resulted in the reduction of deformation indices (S/Sr/V) in all segments. Deformation indices were increased after successful PCI. The S/Sr values of the normal and ischemic segments after PCI were higher compared to the baseline (ischemic Sr:-1.3±0.3 vs. -1.1±0.3, p=0.04). No difference was noted in the S/Sr values of the necrotic segments during the first week (Sr:-1.1±0.3 vs. -1.0±0.3, p=0.054). For V measurements, no difference was observed between the viability types at the follow-up measurements (p>0.05).

Conclusion: The remedial effect of PCI on the deformation values was observed in the first week and continued during the first month. In the early reperfusion period, S/Sr indices have the potential to differentiate necrotic tissue from other viability types. Strain/Strain rate imaging can be used for determination of myocardial deformation changes and parameters of viability. However, V values were insufficient.

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Key words: Acute myocardial infarction, deformation, echocardiography, viability, strain, strain rate

ÖZET

Amaç: Anteriyor akut miyokart enfarktüslü (AMİ) hastalarda primer koroner girişim öncesi ve sonrası bölgesel deformasyon değişimi ile miyokardiyal canlılığın gerilme (S) ve gerilme oranı (Sr) görüntüleme yöntemi ile prospektif olarak değerlendirilmesidir.

Yöntemler: Çalışmaya anteriyor AMİ'nin ilk altı saatinde başvuran, 21 hasta ve kontrol grubu olarak sağlıklı 20 kişi alındı. Ekokardiyografik kayıtlar girişim öncesi, girişimden sonraki birinci hafta ve birinci ayda, apikal/parasternal görüntülerden alındı. Sol ön inen arterin beslediği duvarların bazal, mid ve apikal segmentlerinden S/Sr ve velositeler (V) ölçüldü. Birinci ayda miyokart perfüzyon sintigrafisi çekildi, segmentler normal, iskemik ve nekrotik olarak gruplandırıldı. İstatistiksel değerlendirme için Mann-Whitney U ve Wilcoxon testleri kullanıldı.

Bulgular: Akut miyokart enfarktüsü deformasyon değerlerinin (S/Sr/V) azalması ile sonuçlandı. Deformasyon belirteçleri başarılı girişimden sonra arttı. Normal ve iskemik segmentlerin S/Sr değerleri koroner girişim öncesine göre takip ölçümlerde anlamlı olarak yüksekti (iskemik segmentler için Sr:-1.3±0.3'e karşın -1.1±0.3, p=0.04). Nekrotik segmentlerin S/Sr değerlerinde ise ilk hafta değişim yoktu (Sr:-1.1±0.3'e karşın -1.0±0.3, p=0.054). V için segmentlerin çoğunda takip ölçümlerinde canlılık tipleri arasında fark yoktu (p>0.05).

Sonuç: Primer koroner girişimin deformasyon değerlerini düzeltici etkisi birinci haftada gözlenip birinci ayda değişmeden devam etmektedir. Reperfüzyonun erken döneminde S/Sr değerleri nekrotik dokuyu diğer canlılık durumlarından ayırt etme potansiyeline sahiptir. Gerilme/gerilme

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oranı görüntüleme miyokardiyal deformasyon değişiminin belirlenmesinde ve canlılığın belirteci olarak kullanılabilir. Ancak V verileri bu durumlar için yetersizdir. *(Anadolu Kardiyol Derg 2010 December 1; 10(6): 479-87)*
Anahtar kelimeler: Akut miyokart enfarktüsü, deformasyon, ekokardiyografi, canlılık, gerilme, gerilme oranı

Introduction

The presence and size of the viable myocardial tissue following an acute myocardial infarction (AMI) is closely associated with both the general improvement in the left ventricular (LV) functions and prognosis (1). Therefore, the assessment of LV function following an ischemic coronary event and determination of viability is crucial.

Several markers (wall thickness, ejection fraction, and wall motion score index) have been used to determine LV functions by various echocardiographic methods. However, these markers are easily influenced by the variability of observers, hemodynamic factors and technical problems. Strain (S) and strain rate (Sr) techniques, which is a novel quantitative technique used for the assessment of LV functions, and for determination of viability, were, originated from the tissue Doppler imaging (TDI) technique (2, 3).

Strain defines the direct myocardial contractile pattern and reflects the dimensional changes (deformation) as a percentage. Shortening or contraction is reflected as a negative value and lengthening or relaxation is reflected as a positive value (4-6). Sr defines the rate of deformation which is the change in S value within a certain period of time. Sr is calculated from the velocity gradients between the two points in the direction of the ultrasound beam with a unit of 1/second (s^{-1}) (4-6). The superiority of S/Sr over the TDI technique is that S/Sr is not influenced from neighboring tissue effects (tethering) and the rotation motion of the heart (2-6).

In several studies, it has been demonstrated that S/Sr values can be successfully used for the assessment of myocardial functions (6-10). However, in the literature there are no studies investigating the alteration in S/Sr/V parameters before and after primary percutaneous coronary intervention (PCI) in AMI patients.

In this study, we investigated the regional deformation changes before and after a successful PCI in anterior AMI patients by peak systolic S and Sr techniques, and the utility of this technique in the determination of myocardial viability. Tl-201 myocardial perfusion scintigraphy (MPS) was used as a reference method to determine the degree of myocardial tissue viability.

Methods

We designed a prospective, observational study to investigate the impact of PCI on the myocardial deformation changes and viability in anterior AMI patients.

Study population

Twenty-one consecutive patients (20 men and 1 woman; mean age, 61±11 years) who were diagnosed as an acute ST segment elevation AMI according to ESC/ACC criteria (11), presented to our clinic within the first six hours of their first anterior AMI, and who had indication for PCI were included in this study. The exclusion criteria included the following: a history of an ischemic coronary event, late admission (>6 hours), history of coronary artery disease, cardiac muscle disease, excessive LV hypertrophy (interventricular septum thickness >14 mm), significant valvular disease, bundle branch block or atrial fibrillation, any mechanical complications, inadequate echogenicity, and those patients, in whom the first echocardiographic recording revealed the possibility of delaying the PCI. The control group consisted of 20 healthy volunteers (15 men and 5 women; mean age, 49±9 years) with normal electrocardiographic, echocardiographic and coronary angiographic findings.

The study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the local Ethics Committee. All the patients and the healthy controls were informed about the study and their written consent forms were obtained.

During the follow-up period, 8 new patients fulfilling the study criteria were included and 2 patients with poor image quality and the 6 patients without Tl-201 MPS results were excluded from the study.

Echocardiography

The first echocardiographic recordings of all the patients were obtained just before PCI in the angiography laboratory. The echocardiographic evaluation was performed by a Vingmed System Five (GE Vingmed Ultrasound, Horten, Norway) echocardiography machine using a 2.5 MHz probe. All of the recordings were stored in digital media for later measurements (Echopac, GE). Following echocardiographic recordings were obtained one week and one month after the PCI: LV dimensions and volumes, fractional shortening (FS), ejection fraction (EF) according to Teicholz method and Simpson rule. Measurements were performed by two observers. Arithmetic mean of three consecutive measurements was taken into consideration. Only one measurement was performed in the control group. An echocardiographic examination was performed according to the recommendations of the American Society of Echocardiography (12). Recordings were obtained after the expirium and involving three consecutive cycles.

Color Doppler myocardial imaging

For the measurement of deformation indices, color tissue Doppler recordings from the septum, anterior and anteroseptal walls were used. During this procedure, the evaluated wall was narrowed down by reducing the angle to approximately 30 degrees in a way that it would be in the center of the image window and the frame rate was maintained to be >100/seconds. By using the semi-automatic software program of the apparatus, longitudinal peak systolic S, Sr, mean systolic V, and the mean diastolic early and late V were measured from the S/Sr/V curves

obtained from the basal, mid, and apical segments. The distance between the two points was designated as 10 mm during the calculation of the deformation values.

Coronary angiography

Conventional coronary angiography was performed with Philips Integris 5000 equipment (Philips Medical Systems, Best, Netherlands). After obtaining images by standard approaches, intervention (balloon angioplasty and/or stent) to the suitable lesions was performed on the artery responsible for the infarction, in line with the operator's demand.

Tl-201 MPS Imaging

Tl-201 MPS imaging was performed on all patients one month after the intervention. MPS images were acquired 15 min, 4 h, and 24h after the intravenous injection of 111 MBq (3 mCi) of Tl-201 using a dual-head gamma camera (Siemens E.CAM, Siemens Medical Systems, Inc. Hoffman Estates, IL 60195, USA) equipped with a low-energy, high-resolution, parallel-hole collimator. Thirty-two frames were acquired over a 180° arc (45° left posterior oblique to 45° right anterior oblique view). The images were reconstructed using a filtered back projection algorithm using a Butterworth filter with a cutoff frequency of 0.40 Nyquist and an order of 5. Reconstructed tomograms were then reoriented in the standard short, horizontal long and vertical long axes for interpretation and quantitation of Tl-201 uptake.

Tl-201 MPS images were analyzed quantitatively by two experienced nuclear medicine physicians who were blind to the patient's clinical, echocardiographic and angiographic data. Computerized two-dimensional polar maps of the three-dimensional myocardial radioactivity were generated. A 17-segment model comparable to that of echocardiography was used. Segment Tl-201 uptake was calculated as the total of the normalized counts of the pixels divided by the number of pixels included within the segments. The segment with maximal Tl-201 uptake was normalized to 100 and Tl-201 uptake of the other segments was expressed as a percentage of Tl-201 up take of the peak segment. A Tl-201 defect was defined when Tl-201 uptake was <80%. Redistribution was defined when relative Tl-201 uptake at 4-h or 24-h imaging increased ≥12% above the initial value (13). Segments were considered viable when Tl-201 uptake was ≥50% of maximal uptake and nonviable when Tl-201 uptake was <50% of maximal uptake at 4- and 24-hour imaging (13).

Statistical analysis

Statistical evaluation was performed using SPSS 10.0 (Statistical Package for the Social Sciences, Chicago, IL, USA). Continuous numeric variables were expressed as the arithmetic mean±standard deviation. Fisher and chi-square tests were used for the comparison of ratios. The normal distribution of continuous variables was tested with Shapiro-Wilk test (n=20 for controls, n=21 for patients). The Mann-Whitney U test was used for the comparison of non-parametric independent groups and initially Friedman test was used for comparison of consecutive measurements, if there was a significant difference then Wilcoxon test was used to find the statistical differences in the patient groups. P values <0.05 were considered statistically significant.

Results

Clinical characteristics

The clinical and laboratory features of the study population are summarized in Table 1. Patient and control groups were similar in blood pressure, hypertension, smoking status, family history, and lipid levels (p>0.05). The mean duration of pain in the patient group was 220.2±113.2 min and the mean door-to-needle time was 41±4.2 min. Seven patients (33%) had primary stent implantation and 14 (67%) underwent balloon angioplasty procedure in addition to stent implantation. No re-occlusions, ischemic coronary events, or deaths were observed at the end of one-month follow-up period.

Among the conventional echocardiographic parameters, there was a significant increase in the Teicholz and Simpson's EF in the patient group at the end of the first month compared before PCI (p=0.011 and p=0.009, respectively) (Table 2).

Effects of PCI on the strain, strain rate and velocities

Acute ischemia was characterized by the loss of the homogenous distribution of S/Sr from basal to apical segments and decrease in these indices. S/Sr values increased after the successful PCI. The effect of PCI was as an improvement in S/Sr values in one week and absence of any change during one month (p>0.05 for first month vs. first week). Significant increases, especially in the apical segments, were noted in S/Sr values during the follow-up period (p<0.05 for first month vs. before PCI) (Table 3A, B).

Table 1. Clinical and laboratory parameters of the groups

Variables	Controls (n=20)	Patients (n=21)	p*
Gender, Male/Female, n	15/5	20/1	0.130
Age, years	49±9	61±11	0.002
Systolic BP, mmHg	115±15	121±21	0.405
Diastolic BP, mmHg	69±8	73±12	0.209
Hypertension, %	10	33	0.130
Smoker, %	45	57	0.437
Family History, %	35	34	0.910
TC, mg/dl	198±35	211±43	0.188
LDL, mg/dl	122±32	131±40	0.411
HDL, mg/dl	42±11	41±7	0.648
TG, mg/dl	146±67	146±68	0.990
Echocardiographic recording time, min	6±2	7±2	0.910

Results are shown as mean ± standard deviation and numbers/percentages
*Pearson Chi -square and Mann-Whitney U tests
BP - blood pressure, HDL - high-density lipoprotein, LDL - low-density lipoprotein, min - minute, TC - total cholesterol, TG - triglyceride

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Table 2. Changes in conventional echocardiographic data in anterior AMI patients

Variables	Controls	Patients			p1*	p2*	p3*	p4**	p5**	p6**
		Before PCI	1st week	1st month						
LVDD, mm	47.8±4.2	51.4±5.3	53.1±5.3	54.0±6.7	0.058	0.004	0.003	0.108	0.076	0.458
LVSD, mm	34.3±4.5	41.1±6.0	42.2±6.7	42±7.7	0.001	0.001	0.002	0.411	0.821	0.862
LVEFt, %	59.9±5.1	43.7±9.3 (21-65)	48.1±11.4 (34-70)	51.7±10.5 (35-70)	<0.001	<0.001	<0.001	0.304	0.011	0.117
LVEFs, %	67.0±6.0	45.0±7.1 (30-60)	47.5±9.8 (32-67)	51.1±9.3 (31-65)	<0.001	<0.001	<0.001	0.478	0.009	0.023
FS	26.2±3.0	19.9±8.1	20.5±6.7	22.1±5.9	<0.001	<0.001	<0.001	0.602	0.099	0.322

Results are shown as mean ± standard deviation, rank (min-max) values

* Mann-Whitney U test, ** Wilcoxon test

P1 - before PCI vs. control, P2 - 1st week vs. control, P3 - 1st month vs. control, P4 - 1st week vs. before PCI, P5 - 1st month vs. before PCI, P6 - 1st month vs. 1st week

AMI – acute myocardial infarction, FS - fractional shortening, LVDD - left ventricular end-diastolic diameter, LVEF - left ventricular ejection fraction, LVSD - left ventricular end-systolic diameter, PCI - primary coronary intervention, t - Teicholz rule, s - Simpson's rule

Table 3. Changes in strain rate (A) and strain (B) indices before and after PCI in anterior AMI patients

A	Controls	Patients			p1*	p2*	p3*	p4**	p5**	p6**
Strain rate, s^{-1}		Before PCI	1st week	1st month						
Mid Septal Sr	-1.5±0.2	-1.1±0.3	-1.3±0.3	-1.3±0.3	<0.001	0.070	0.072	0.012	0.012	0.357
Apical Septal Sr	-1.5±0.2	-0.8±0.2	-1.1±0.3	-1.1±0.3	<0.001	<0.001	<0.001	0.003	0.004	0.767
Basal Anterior Sr	-1.6± 0.2	-1.5±0.2	-1.6±0.3	-1.6±0.2	0.179	0.539	0.666	0.322	0.185	0.765
Mid Anterior Sr	-1.7±0.2	-1.3±0.2	-1.4±0.2	-1.5±0.3	<0.001	0.001	0.019	0.082	0.037	0.244
Apical Anterior Sr	-1.7±0.2	-1.0±0.3	-1.2±0.4	-1.2±0.3	<0.001	<0.001	<0.001	0.046	0.082	0.370
Basal AS Sr	-1.5±0.2	-1.3±0.3	-1.3±0.3	-1.3±0.2	0.012	0.006	0.006	0.903	0.411	0.498
Mid AS Sr	-1.6±0.2	-1.1±0.3	-1.2±0.3	-1.3±0.3	<0.001	0.001	0.002	0.100	0.022	0.198
Apical AS Sr	-1.5±0.2	-1.0±0.3	-1.1±0.3	-1.3±0.3	<0.001	<0.001	0.001	0.048	0.011	0.036
B	**Controls**	**Patients**			**p1***	**p2***	**p3***	**p4****	**p5****	**p6****
Strain, %		**Before PCI**	**1st week**	**1st month**						
Mid Septal S	-21±3.6	-14.6±4.2	-15.7±3.8	-17.2±4.1	<0.001	<0.001	0.005	0.114	0.013	0.076
Apical Septal S	-23±3.4	-9.7±2.3	-13.2±4.7	-15.1±4.5	<0.001	<0.001	<0.001	0.005	0.001	0.012
Basal Anterior S	-20.9±2.9	-19.3±4.8	-19±3.5	-19.4±3.3	0.183	0.108	0.162	0.821	0.955	1.000
Mid Anterior S	-21.9±2.9	-15.9±3.2	-16.4±2.9	-17.4±3.7	<0.001	<0.001	<0.001	0.289	0.117	0.121
Apical Anterior S	-21.8±2.5	-11.4±4.4	-14±4.5	-14.8±5.2	<0.001	<0.001	<0.001	0.060	0.013	0.341
Basal AS S	-19.7±2.7	-16.6±4.7	-17.5±4.4	-17.7±3.7	0.033	0.060	0.004	0.254	0.944	0.242
Mid AS S	-21.8±3.2	-14.7±3.3	-15.2±4.1	-16.3±3.6	<0.001	<0.001	<0.001	0.601	0.184	0.061
Apical AS S	-20.6±3.5	-10.5±4.0	-12.6±3.7	-14.4±4.2	<0.001	<0.001	<0.001	0.024	0.021	0.192

Results are shown as mean±standard deviation

* Mann-Whitney U test, ** Wilcoxon test

P1 - before PCI vs. control, P2 - 1st week vs. control, P3 - 1st month vs. control, P4 - 1st week vs. before PCI,

P5 - 1st month vs. before PCI, P6 - 1st month vs. 1st week

AMI - acute myocardial infarction, AS - anteroseptal, PCI - primary coronary intervention, S - strain, Sr - strain rate

It was observed that none of V values in the patient and control groups were distributed homogeneously throughout the wall and they decreased from the basal to apical segments. In the patient group, lower systolic V values were measured in most of the segments compared to the control group ($p<0.05$). Systolic V values increased during the first week ($p>0.05$ for first week vs. before PCI, in most of the segments) and then decreased during the first month in most of the segments ($p<0.05$ for first month vs. before PCI, in most of the segments) (Table 4A). In the patient group, during the acute ischemic

period, early and late diastolic V values which were obtained from some of anterior and anteroseptal wall segments were lower than those of the controls (p<0.05), the other segments were similar with those of the controls (p>0.05). As to the follow-up measurements, there were no significant differences in most of the segments compared to the controls (p>0.05) (Table 4B, C).

Deformation indices and viability

Segments were divided into three groups according to their viability status assessed by Tl-201 MPS: normal, ischemic, and necrotic. One hundred eighty-nine segments from all three assessment periods were included in the study. While 147 segments supplied by the left anterior descending artery (LAD) were evaluated, the basal septum, which is also supplied by

Table 4. Changes in systolic (A), early diastolic (B) and late diastolic (C) velocity indices before and after PCI in anterior AMI patients

A	**Controls**	**Patients**			**p1***	**p2***	**p3***	**p4****	**p5****	**p6****
Systolic velocities, cm/s		**Before PCI**	**1st week**	**1st month**						
Mid Septal	3.5±0.9	2.3±1.1	3.2±1.1	3.5±1.2	<0.001	0.311	0.927	0.003	0.002	0.313
Apical Septal	1.7±0.9	2.0±1.3	2.1±1.1	2.4±1.4	0.554	0.450	0.172	0.681	0.348	0.251
Basal Anterior	5.9±0.8	3.9±1.3	4.5±1.3	4.4±1.3	<0.001	<0.001	<0.001	0.104	0.117	0.654
Mid Anterior	4.3±1.4	2.1±1.0	3.4±1.5	2.7±1.2	<0.001	0.066	0.001	<0.001	0.062	0.009
Apical Anterior	1.9±1.1	1.1±0.8	1.9±1.4	1.4±1.2	0.003	0.643	0.023	0.005	0.210	0.102
Basal AS	4.8±1.0	2.8±0.9	4.0±1.2	4.0±1.3	<0.001	0.018	0.020	0.001	0.005	0.840
Mid AS	3.4±1.0	2.1±1.0	3.5±1.5	3.8±1.7	0.001	0.813	0.289	0.001	0.001	0.197
Apical AS	1.6±1.1	1.7±0.9	1.9±1.4	2.3±1.1	0.529	0.638	0.038	0.667	0.019	0.322
B	**Controls**	**Patients**			**p1***	**p2***	**p3***	**p4****	**p5****	**p6****
Early diastolic velocities, cm/s		**Before PCI**	**1st week**	**1st month**						
Mid Septal	5.0±1.6	4.1±1.8	4.2±1.6	3.9±1.4*	0.129	0.150	0.039	0.879	0.737	0.456
Apical Septal	2.3±1.3	2.0±1.2	2.3±1.2	2.7±1.2	0.504	0.886	0.228	0.093	0.073	0.316
Basal Anterior	6.2±1.0	4.0±1.9	4.9±1.9*	4.6±1.6*	<0.001	0.030	0.001	0.024	0.126	0.601
Mid Anterior	4.5±1.7	2.4±1.6	3.7±1.6	3.3±1.9	<0.001	0.191	0.054	0.002	0.009	0.185
Apical Anterior	1.9±1.2	1.1±0.8	1.7±1.6	1.3±0.6	0.008	0.282	0.074	0.016	0.093	0.201
Basal AS	4.6±1.4	3.4±0.8	3.8±1.5	3.9±1.7	0.021	0.086	0.135	0.145	0.145	1.000
Mid AS	4.0±1.8	3.0±1.8	4.1±1.7	3.9±1.6	0.114	0.784	0.958	0.024	0.048	0.350
Apical AS	1.8±1.0	2.3±1.8	1.7±1.8	2.1±0.8	0.185	0.723	0.187	0.161	0.454	0.305
C	**Controls**	**Patients**			**p1***	**p2***	**p3***	**p4****	**p5****	**p6****
Late diastolic velocities, cm/s		**Before PCI**	**1st week**	**1st month**						
Mid Septal	4.4±1.2	4.3±1.8	4.5±1.6	4.1±1.4	0.824	0.834	0.497	0.651	0.681	0.232
Apical Septal	1.9±1.3	1.3±1.2	1.4±1.0	2.6±1.5	0.069	0.253	0.133	0.421	0.007	0.002
Basal Anterior	5.5±1.3	5.1±1.6	5.0±1.4	5.0±1.5	0.401	0.217	0.358	0.845	0.809	0.943
Mid Anterior	4.2±1.6	3.1±1.8	3.2±1.8	2.8±1.6	0.028	0.078	0.012	0.955	0.588	0.287
Apical Anterior	1.9±1.5	1.0± 0.9	1.6±1.5	1.3±1.2	0.018	0.276	0.123	0.106	0.357	0.444
Basal AS	5.3±1.3	4.6±1.3	4.8±1.8	4.5±1.5	0.154	0.334	0.091	0.811	0.778	0.409
Mid AS	4.2±1.6	3.0±1.3	3.1±1.7	3.3±1.8	0.006	0.028	0.089	0.781	0.490	0.728
Apical AS	1.7±1.2	1.1±0.7	1.0±0.7	1.3±1.2	0.064	0.020	0.148	0.694	0.751	0.153

Results are shown as mean±standard deviation

*Mann-Whitney U test, **Wilcoxon test

P1 - before PCI vs. control, P2 - 1st week vs. control, P3 - 1st month vs. control, P4 - 1st week vs. before PCI,

P5 - 1st month vs. before PCI, P6 - 1st month vs. 1st week

AMI - acute myocardial infarction, AS - anteroseptal, PCI - primary coronary intervention

Anadolu Kardiyol Derg 2010 Aralık 1; 10(6): 479-87
doi:10.5152/akd.2010.166

other arteries and mid-septum segments that cannot be accurately defined by Tl-201 MPS, were not evaluated (42 segments in total).

Significant increases in S/Sr were found in normal and ischemic segments in the follow up period (Table 5). There was no significant difference in S/Sr values after one week in the necrotic segments (p=0.069 for S and p=0.054 for Sr) (Table 5).

No significant change was noted among the three assessment periods for the systolic V values in the apical segments of any of the viability groups (p>0.05). The systolic V values of the mid segments were increased in the first week compared to initial values, for all viability types (p=0.001, p=0.021, p=0.012, for normal, ischemic and necrotic tissue, respectively) (Table 6). Since the basal segments were often normal (35 of 42 segments), the viability comparison for systolic V was not conducted at this level.

Discussion

In our study, we detected that S, Sr and V values were significantly decreased within the first six hours of AMI; S and Sr values were distributed heterogeneously among the segments throughout the wall and V values were distributed as a descending order from the basal to apical segments. Moreover, we also demonstrated that S and Sr values were increased in parallel to other systolic markers (such as, EF) during the first week period following a successful PCI and continued to increase afterwards. However, it was noted that V values did not change in parallel to these values. A significant increase in the apical segments both in the first week and in the first month were interpreted as these segments benefited more from the PCI. These finding may show that S and Sr values may be used as a marker for follow-up improvements. The significant improvement noted in the mid segments on the first month might be the indicator of a later recovery in these segments. Low levels of deformation indices in the 1st week and an increase in these indices in the 1st month in the patient group reflects that contractile functions recover later despite the reperfusion.

Similar results were reported in several experimental and clinical investigations. In an experimental study, it was reported that in dogs after 15 minutes of complete coronary occlusion, S and Sr were reduced to zero S was increased again in parallel with the post-ischemic hyperemia following reperfusion in the subendocardial layer and returned to normal earlier than the global wall thickness in M-mode echocardiography (14). In another study, coronary hypoperfusion without complete coro-

Table 5. Changes in Sr/S in the viability groups in anterior AMI patients

Viability Group	n	Sr/S	Before PCI	1st week	1st month	p1*	p2*	p3*
Normal	63	Sr, sn^{-1}	-1.3±0.3	-1.4±0.3	-1.5±0.2	<0.001	<0.001	0.232
		S, %	-16.7±4.8	-18.0±3.8	-18.5±3.1	0.009	0.017	0.361
Ischemic	23	Sr, sn^{-1}	-1.1±0.3	-1.3±0.3	-1.3±0.2	0.004	0.009	0.584
		S, %	-12.3±3.7	-14.9±3.6	-15.7±3.5	0.012	0.005	0.205
Necrotic	61	Sr, sn^{-1}	-1.0±0.3	-1.1±0.3	-1.2±0.3	0.054	0.001	0.024
		S, %	-11.8±4.3	-12.9±4.0	-14.1±4.6	0.069	0.004	0.005

Results are shown as numbers and mean ± standard deviation
* Wilcoxon test
P1 - 1st week vs. before PCI, P2 - 1st month vs. before PCI, P3 - 1st month vs. 1st week
AMI - acute myocardial infarction, n - number of segment, PCI - primary coronary intervention, S - % strain, Sr - strain rate

Table 6. Changes in systolic velocities in the viability groups in anterior AMI patients

Segments	Viability Group	n	Velocities, cm/s			p1*	p2*	p3*
			Before PCI	1st week	1st month			
Apical	Normal	11	1.9±1.1	2.5±1.6	2.1±0.9	0.563	0.656	0.760
	Ischemic	12	1.8±1.0	23±1.0	3.0±1.8	0.099	0.025	0.169
	Necrotic	40	1.4±1.1	1.7±1.3	1.7±1.1	0.178	0.095	0.908
Mid	Normal	17	2.5±1.1	4.3±1.3	3.7±1.6	0.001	0.012	0.333
	Ischemic	10	1.9±0.8	2.8±1.2	2.8±1.4	0.021	0.063	0.893
	Necrotic	16	1.8±0.7	2.9±1.3	2.9±1.5	0.012	0.023	0.798
Basal	Normal	35	3.5±1.3	4.3±1.2	4.3±1.2	0.001	0.002	0.925

Results are shown as numbers and mean ± standard deviation
* Wilcoxon test
P1 - 1st week vs. before PCI, P2 - 1st month vs. before PCI, P3 - 1st month vs. 1st week
AMI - acute myocardial infarction, n - number of segment, PCI - primary coronary intervention

nary occlusion was performed for 60 minutes in pigs. Regional S and Sr reduced and remained so for more than 60 minutes after the perfusion returned to normal (15). The return of S to its previous level following removal of very prolonged (90-120 minutes) coronary occlusion was shown to be a marker for residual myocardial viability in dogs. Although no improvement was observed in the S values of the transmural infarcts, an improvement in non-transmural infarcts was detected (16).

Kukulski et al. (17) have demonstrated that in stable angina patients, S values in normal, hypokinetic, and akinetic segments were decreased by balloon-induced occlusion during elective angioplasty and reached pre-occlusion values via reperfusion. In this study, a significant difference was observed in the dysfunctional segments within both themselves and the normal neighboring segments, and also with normal control groups segments, thus it has been demonstrated that during the acute ischemic period, with the help of S values, dysfunctional segments could be identified from normal segments. Similarly Edvardsen et al. (4) has been reported that S and Sr values are changed in the mid and apical septum during elective angioplasty of LAD. The results of our study are similar with aforementioned studies. However the mean duration of total coronary occlusion or hypoperfusion (220.2±113.2 min) in our study is longer than these studies. Therefore, LV contractile functions and deformation indices are significantly depressed in our patients at pre-interventional period. Although PCI was performed successfully, low levels of deformation indices in the first week and an increase in these indices in the first month in the patient group, compared to the controls, reflects that contractile functions recovered later than the reperfusion. Lower S/Sr indices in the first week may also reflect the stunned myocardium. The increase in these indices in the first month may show that contractile myocardial reserve was preserved by reperfusion. Similarly Derumeaux et al. (14) showed that despite persistent stunning, the peak systolic Sr recovers significantly after reperfusion in comparison with totally ischemic myocardium.

In the present study, the decrease in systolic V values was similar to S and Sr in the beginning; however at follow ups, V values increased in the first week and then decreased in the first month. These changes were thought to be due to the effects of neighboring segments of the same wall, regarded as the passive dragging effect (tethering) of the intact segment on the neighboring ischemic or scarred segment. In the first month systolic V values of the anterior wall, which is most affected from ischemia, were lower than the first week values. This finding was an indicator of this hypothesis. Also in our study, we were unable to show positive changes in ischemic segments in V values after reperfusion. Edvardsen et al. (4) has been demonstrated that V values are changes in the basal septum values which were not supplied by LAD during elective angioplasty of LAD. Heimdal et al. (18) have demonstrated that positive V values could dissonantly be measured by the S/Sr technique, even in akinetic segments without any deformation changes. Similar to the other studies in the literature (4-10), our study gave rise to the thought that systolic V is inadequate to evaluate the successful PCI effects because of the inconsistent variation in systolic V due to tethering and/or adjacent effects of the neighboring segments.

We saw that during AMI, there was a reduction in early diastolic V values. After a successful PCI, these values became similar with the control in the first week and remained so in the first month. Also late diastolic V values were less influenced and there were no difference with the controls during the follow-up. All these findings suggested that diastolic functions were recovered early and were maintained by successful PCI. Furthermore, we have found that diastolic V values exhibited more consistent changes differently from the systolic V values. Therefore, we believe that diastolic V values can be used for the assessment of diastolic functions in anterior AMI patients undergoing successful PCI. The fact that there are no major changes in both systolic and diastolic V indices within the apical segments arises from the limited evaluation of apical motions by V indices. Thus, Sutherland et al. (19) have reported that the velocities are angle-dependent and are affected by the movement and rotation of the heart, as well as the contraction of adjacent tissues, and are insufficient for the assessment of the apical segments.

In our study, deformation indices were lower in ischemic and necrotic tissues, and for S/Sr measurements, a normal>ischemic> necrotic distribution was observed. An increase in the first week S/Sr values in the normal and ischemic segments compared to the pre-PCI period and a persistence of this significant increase during the first month was regarded as the consequence of a successful PCI. Observation of this result in ischemic segments similar to the normal segments is the positive effect of successful PCI on the recovery period. Our results are in agreement with the experimental models and clinical studies with a shorter ischemic duration. Similarly, Zhang et al. (2) have used contrast magnetic resonance imaging to determine tissue viability in patients within 2-6 days of their first AMI and demonstrated that ischemia which does not cover the whole wall and scar tissue could be differentiated by the peak systolic Sr value. Sachdev et al. (20) have detected that the S value decreased by an enhancement on the scar tissue rate throughout the wall thickness. Urheim et al. (21) have reported that acute and chronic ischemia and infarction could be differentiated by the S/Sr technique. Hoffmann et al. (22) have reported that stress-induced increase in S, Sr and V was an indicator for a functional reserve in viable myocardium, while the increase in deformation indices in nonviable tissue was inadequate. However, in our study, it is important that we detected the segments as necrotic by the end of the first month, even though there was no significant change in the first week S/Sr values, when compared to the acute ischemic period, which reflects the difference of these segments from the normal and ischemic segments. This data has a significant contribution to the literature for the use of S/Sr technique in viability determination.

In the present study, for systolic velocities in the assessment of viability, although the distribution was observed as normal>ischemic>necrotic during acute ischemic period, the deterioration of this sequence during the post-intervention

Anadolu Kardiyol Derg 2010 Aralık 1; 10(6): 479-87
doi:10.5152/akd.2010.166

period were connected to the tethering effects of neighboring segments with varying viability characteristics. In all three viability sub-groups, there was no significant change in the apical level before and after the PCI. Similar changes were observed in V values in normal and necrotic tissues at mid-level. These suggested that in accordance with the previous studies, V values were not reliable and efficient in the determination of myocardial viability. Similarly, Edvardsen et al. (23) have reported that the V values were not suitable for the assessment of myocardial viability and that the longitudinal Sr was superior and stronger. Park SM. et al. (24) have investigated clinical importance of determine the viability of akinetic segments by TDI in anterior AMI patients who underwent PCI. Compared with persistent akinetic segments with no myocardial viability, akinetic viable myocardium demonstrated better diastolic function, better SR of early diastolic filling and increased presence of isovolumic contraction reported in this study. Strain rate imaging has been found to be a better method than tissue velocity imaging in patients with ST elevation AMI patients who underwent PCI in this study. But wall motion improvement, used a reference method for assessment of myocardial viability instead of MPS or cardiac magnetic resonance imaging, decreased that impact of that study.

Finally, accuracy and superiority of S/Sr technique in the detection of acute myocardial ischemia have been demonstrated in many experimental studies and in a fewer number of clinical studies. Our study is important because regional myocardial functions can be determined quantitatively in patients with AMI in acute ischemic period and in post PCI period. Our results demonstrate the potential clinical advantages of using S/Sr imaging in the detection of regional myocardial deformation changes and viability in AMI patients at early reperfusion period.

Study limitations

The most important limitation was that the S/Sr technique is angle-dependent and deformation can only be assessed longitudinally. We attempted to overcome this problem by reaching high frame rates by narrowing the image window and centralizing the assessed image. The second limitation was the image quality and the artifacts, which led to exclusion of two patients from the study during the follow-up period, and new patients, were recruited instead of these patients. Third, the collaterals that were formed in patients during acute ischemia were not included in the evaluation; however, there is insufficient data concerning this issue in the literature. The fourth limitation was that unlike the control group, the patient group used several other drugs (beta- blockers and angiotensin converting enzyme blockers) affecting hemodynamics and myocardial functions from the beginning of the study. The last limitation of our study was that the selection of the control group from the individuals with normal coronary anatomy resulted in a lower mean age; however, the effect of age on S/Sr is unclear (25). In the near future, technique-related limitations can be overcome by the development of 2- and 3- dimensional or intra-cardiac strain echocardiography methods.

Conclusion

In conclusion, the remedial effect of PCI on the deformation values was observed in the first week and there was no major change during the first month. In the early reperfusion period, S and Sr indices have the potential to differentiate necrotic tissue from other viability types. The serial low levels of S/Sr would be a signal of necrosis in the anterior AMI patients. S/Sr imaging can be used for determination of myocardial deformation changes and reflectors of viability. However, velocity values are insufficient in this condition.

Conflict of interest: None declared.

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