The Egyptian Heart Journal 70 (2018) 83–88

Contents lists available at ScienceDirect

The Egyptian Heart Journal

journal homepage: www.elsevier.com/locate/ehj

Original Article

Effect of elective percutaneous coronary intervention of left anterior descending coronary artery on regional myocardial function using strain imaging

Gehan Magdy *, Mohammed Sadaka, Tarek Elzawawy, Abdallah Elmaghraby

Department of Cardiology, Alexandria University, Egypt

ARTICLE INFO

Article history:
Received 2 August 2017
Accepted 3 December 2017
Available online 24 December 2017

Keywords:
Percutaneous coronary intervention
Regional myocardial function
Strain imaging

ABSTRACT

Background: Percutaneous coronary intervention (PCI) is a commonly used procedure for revascularization, however the impairment of regional myocardial function in patients with stable coronary artery disease (CAD) has not been well characterized, our study aimed to assess the improvement of left ventricular (LV) systolic function after elective PCI of the left anterior descending artery (LAD) using strain and strain rate imaging techniques.

Materials and methods: The study included 30 patients (aged 56.8 ± 6.6 years, 66.7% males) presented with stable CAD on optimal medical therapy, and recommended for elective PCI to LAD, all patients included in the study had a normal LV wall motions, and normal LV systolic function. Tissue Doppler imaging (TDI) was done before PCI, immediately, and three months post PCI. The peak systolic longitudinal strain (PSLS), and peak systolic strain rate (PSSR) were measured and averaged for the 6 LAD segments (the basal, mid, and apical segments of the anterior wall, the basal, mid anteroseptal, and the apicoseptal segments), 15 healthy control subjects were included as a control group.

Results: The average PSLS and PSSR of the ischemic segments were significantly lower in patients compared to control in the ischemic segments, and significantly increased 3 months post PCI but not immediately post PCI. Using the ROC curve a cutoff value of −13.69% for PSLS can detect regional ischemia with a sensitivity 93.3% and a specificity of 80%.

Conclusions: TDI derived strain and strain rate can detect resting regional myocardial dysfunction in presence of preserved LV systolic function, and can assess the improvement of regional myocardial function after successful elective PCI in patients with stable CAD.

1. Introduction

Left ventricular systolic function is a major predictor of long-term survival in patients with coronary artery disease (CAD),[1,2] evaluation of regional and global subclinical left ventricular (LV) systolic dysfunction could be a good strategy to identify myocardial regions with impaired coronary artery flow and reduced myocardial perfusion. Tissue Doppler imaging (TDI) has been introduced in an attempt to provide a more objective assessment of myocardial contractility but it had confounding effects of cardiac translational motion and passive pathological tethering,[3] These limitations may be overcome by the measurement of myocardial deformation with strain and strain rate (SR) echocardiography which are a variation of TDI that provides a high-resolution evaluation of regional myocardial function. SR is defined as the rate of deformation in response to an applied force and is determined from the spatial gradient of local myocardial tissue velocities between two points. Strain is calculated from the time integral of SR and reflects the magnitude of deformation.[4] Percutaneous coronary intervention (PCI) in patients with preserved LV function and on optimal medical therapy doesn't reduce the cardiac death and myocardial infarction, but it also decreases the need for other procedure and the degree of angina.[5–7] In most of the studies, the effect of primary PCI on cardiac function is well investigated, however result of previous studies about elective PCI and its effect on LV systolic or diastolic function is not clear.[5,8–10] Our study aimed to assess the improvement of left ventricular systolic function after elective PCI of the left anterior descending (LAD) artery using tissue Doppler strain and SR imaging techniques.

Peer review under responsibility of Egyptian Society of Cardiology.

* Corresponding author at: Cardiology Department, Faculty of Medicine, Alexandria University, Egypt.

E-mail address: gehanmagdy@hotmail.com (G. Magdy).

https://doi.org/10.1016/j.ehj.2017.12.003
1110-2608/© 2017 Egyptian Society of Cardiology. Production and hosting by Elsevier B.V.

Nomenclature

A	late transmitral inflow velocity
Aa	late diastolic annular velocity
ACEI	angiotensin converting enzyme inhibitors
BP	blood pressure
ASA	acetyl salicylic acid
CAD	coronary artery disease
E	early transmitral inflow velocity
Ea	early diastolic annular velocity
EF	ejection fraction
LAD	left anterior descending coronary artery
LV	left ventricle
PCI	percutaneous coronary intervention
PSLS	peak systolic longitudinal strain
PSSR	peak systolic strain rate
Sa	systolic annular velocity
TDI	Tissue Doppler imaging
SR	strain rate

2. Methods

2.1. Study population

An informed consent was obtained from all patients. And the study was approved by the ethical committee. The study was conducted on 30 patients presented with stable CAD on optimal medical therapy, and with angiographically significant lesion (≥50% luminal narrowing) in LAD recommended for PCI, all the patients had objective evidence of ischemia before coronary angiography and PCI (15(50%) had a positive exercise stress test, 10(33.3%) had positive myocardial perfusion scan, 5(16.7%) had a multisclice computed tomography coronary angiography), all patients included in the study had a normal resting LV wall motions, and normal LV systolic function with ejection fraction (EF) ≥ 50%, patients with diabetes mellitus, paced rhythm, atrial fibrillation, left bundle branch block, conduction delay in their electrocardiogram, or those with previous PCI or coronary artery bypass graft were excluded from the study.

2.2. Clinical evaluation

All the patients were subjected to full history taking, clinical examination, laboratory investigations including (hemoglobin %, creatinine level).

2.3. Coronary angiography and PCI

Coronary angiography was done and only patients with LAD significant stenosis (≥50% luminal narrowing) were included, the site of occlusion in LAD where divided into, ostial, proximal, mid and distal (ostial LAD is from the origin of the vessel and or within 3 mm from the origin, Proximal LAD is the segment 3 mm from LAD origin to the first diagonal branch (D1), mid LAD from D1 to second diagonal branch (D2) and distal LAD segment was beyond D2 elective PCI was done to all patients, acetyl salicylic acid (ASA) 325 mg as well as clopidogrel 600 mg were administered before PCI. After the PCI, they were maintained on a regimen of a low dose ASA (75–100 mg) and clopidogrel 75 mg daily.

2.4. Conventional transthoracic echocardiography[11]

It was done to all patients before PCI (within 24 h), immediately post PCI (within 24 h), and three months post PCI. The following parameters were calculated using (HD11 XE, Philips) machine, EF was calculated by modified Simpson method, pulsed wave Doppler mitral inflow velocities were obtained from the apical 4-chamber view to measure diastolic early filling velocity (E) wave, late diastolic velocity (A) wave, and Pulsed wave TDI was obtained after placement of the sample volume at the level of the septal and lateral mitral annuli. From these recordings, myocardial systolic (Sa), early diastolic (Ea), late diastolic velocities (Aa), and E/Ea ratio were measured and averaged.

2.5. Strain and strain rate imaging[12]

It was done by acquiring color TDI in apical 4,3,and 2 chambers views, sector adjusted to keep frame rates of at least higher than 200 frames and cine images were stored for offline analysis, then the peak systolic longitudinal strain (PSLS), and peak systolic strain rate (PSSR) were measured and averaged for the 6 segments supplied by LAD territory from the16 LV segments model (the basal, mid, and apical segments of the anterior wall, the basal, mid anteroseptal segments, and the apicoseptal segment). It was done to all patients before PCI (within 24 hour), immediately post PCI (within 24hour), and three months post PCI (Fig. 1).

2.6. Statistical analysis

Statistical analyses were performed by using SPSS system for Windows (version 20 Chicago, IL, USA), Continuous variables were presented as mean ± SD and were compared by Student's t-test or Mann-Whitney U test for variables with or without normal distribution, respectively. Categorical variables were expressed as percentages and evaluated with a Chi square test or Fisher's exact test. Wilcoxon signed ranks test for comparing between results before and after PCI. The receiver operational characteristic (ROC) analyses was performed and best cut off value was determined and at that point sensitivity and specificity were determined, the results were considered significant when the p value was less than 0.05.

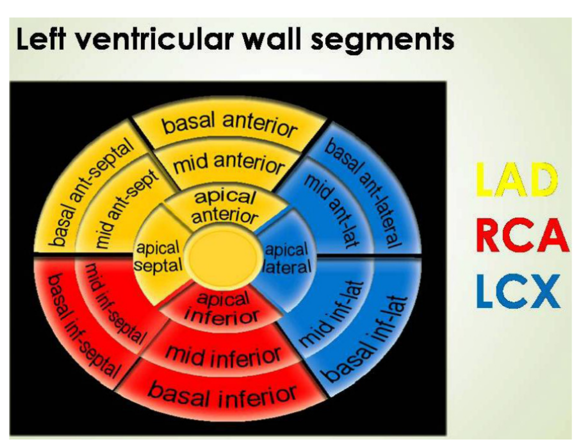

Fig. 1. Left ventricular wall segments in the 16 LV segment model, LAD: left anterior descending artery, LCX: left circumflex artery, RCA: right coronary artery.

3. Results

3.1. Baseline clinical and demographic assessment

The study included 30 patients with mean age 56.8 ± 6.6, and 67.6% were males, with non significant difference between patient and control group. The CAD risk factors and laboratory results of the studied groups are listed in Table 1.

3.2. Coronary angiography and PCI

All patients included in the study had a single vessel CAD which is the LAD with a significant stenosis (28 patients were with >70% stenosis, and only two patients with 50% borderline LAD lesion which had a myocardial perfusion imaging that proved myocardial ischemia), regarding the site of occlusion in LAD (12 (40%) had proximal stenosis, 10(33.3%) had a mid stenosis, 8(26.7%) had a distal stenosis. All patients underwent PCI for LAD with successful result in all patients, 26(86.7%) had one stent, 4(13.3%) had 2stents, 28(93.3%) had bare metal stent, 2(6.6%) had drug eluting stent.

Table 1
Baseline clinical and demographic characteristics of the patients and control group.

	Patients (No = 30)	Control group (No = 20)	P value
Age (mean ± SD)	56.8 ± 6.6	51.73 ± 8.2	.088
Male gender (No, %)	20(67.7)	14(70%)	.092
Angina class (No, %)			
I	1(3.3)	–	<.0001
II	17(56.7)	–	<.0001
III	12(40.0)	–	<.0001
Hypertension (No, %)	14(46.7)	–	<.0001
Smoking (No, %)	10(33.3)	4(26.6)	<.001
Diabetes (No, %)	0(0)	–	<.0001
Dyslipidemia (No, %)	20(67.7)	–	<.0001
Family history of CAD (No, %)	4(13.3)	–	<.0001
Medical treatment (No, %)			
Acetyl salicylic acid	30(100)	–	<.0001
Statins	30(100)	–	<.0001
B Blockers	30(100)	–	<.0001
ACEI	10(33.3)	–	<.0001
Nitrates	30(100)	–	<.0001
Clopedogrel (post PCI)	30(100)	–	<.0001
Systolic BP (mmHg)	123.0 ± 14.66	122 ± 12.33	.952
Diastolic BP (mmHg)	76.67 ± 8.02	75.55 ± 5.23	.856
Heart rate (bpm)	70.0 ± 7.15	72 ± 5.56	.845
Creatinine level (mg/dl)	0.84 ± 0.19	0.85 ± 0.01	.923
Hemoglobin level (gm/dl)	13.52 ± 1.60	13.45 ± 1.3	.953

ACEI: angiotensin converting enzyme inhibitor, **BP:** blood pressure.

3.3. Conventional transthoracic echocardiography

The EF did not show any significant changes whether immediate or 3 months post PCI, the mitral inflow velocities and mitral annular tissue Doppler systolic and diastolic velocities did not show significant improvement immediate post PCI with significant improvement 3 month post PCI (Table 2).

3.4. Strain and strain rate imaging

By comparing the PSLS and PSSR in the 6 ischemic (LAD) segments between control group and patient before PCI, we found a significant reduction in all segments in patients compared to control ($P < .001$ in all segments), and by comparing the PSLS and PSSR before PCI to that immediately done after PCI, there was no significant improvement for both values. Meanwhile when comparing the values before PCI and immediately after PCI to that measured 3 months later after PCI, there was significant improvement of both PSLS and PSSR values (Table 3, Figs. 2 and 3).

Also we had studied the relationship of PSLS and PSSR and the site of stenosis in LAD, and found that patient with proximal LAD stenosis had a significantly lower PSLS and PSSR when compared to those with mid and distal LAD lesions, however there was no significant difference in PSLS and PSSR when patients with mid lesions compared to distal LAD lesions (Table 4).

Furthermore, using the ROC curve the PSLS and PSSR demonstrated a high diagnostic accuracy (AUC of 0.88 & 0.83 respectively) to detect resting regional ischemia using a cutoff value of −13.69% for PSLS with a high sensitivity 93.3% and a specificity of 80%, and a cutoff value of $-0.92\ S^{-1}$ for PSSR with a sensitivity of 90% and a specificity of 66.7% (Figs. 4 and 5).

4. Discussion

The development of ischemia is associated with a progressive reduction in systolic contraction, the diagnosis of chronic stable angina is based on the presence of angina, a positive exercise test for myocardial ischemia, and confirmation of coronary artery atherosclerosis by coronary angiography, as the availability of non-invasive methods of diagnosing CAD steadily increases,[13] strain and strain rate echocardiography are a promising techniques for quantification of systolic and diastolic functions in patients with chronic stable angina in presence of preserved systolic func-

Table 2
Comparison of some conventional echocardiographic parameters between control and patients before and after PCI.

Parameter Mean ± SD	Control group (No = 15)	Before PCI (No = 30)	Immediately post PCI (No = 30)	3 months post PCI (No = 30)
EF (%)	66.56 ± 6.03	67.73 ± 6.03	68.73 ± 7.03	68.73 ± 7.03
$P = 0.951$, $P_1 = 0.852$, $P_2 = 0.850$, $P_3 = 0.845$				
E (cm/s)	0.88 ± 0.17	0.63 ± 0.11	0.65 ± 0.13	0.82 ± 0.10
$P < .001^*$, $P_1 = .949$, $P_2 < .001^*$, $P_3 < .001^*$				
A (cm/s)	0.67 ± 0.15	0.89 ± 0.12	0.88 ± 0.11	0.66 ± 0.11
$P = .002$, $P_1 = .148$, $P_2 < .001^*$, $P_3 = .003^*$				
Ea (cm/s)	0.12 ± 0.01	0.06 ± 0.01	0.07 ± 0.02	0.12 ± 0.02
$P < .001^*$, $P_1 = .321$, $P_2 < .001$, $P_3 < .001^*$				
Aa (cm/s)	0.07 ± 0.03	0.10 ± 0.01	0.11 ± 0.03	0.08 ± 0.02
$P < .001^*$, $P_1 = .162$, $P_2 = .004^*$, $P_3 < .001^*$				
Sa (cm/s)	0.12 ± 0.03	0.07 ± 0.01	0.08 ± 0.01	0.11 ± 0.01
$P < .001^*$, $P_1 = .080$, $P_2 = .001^*$, $P_3 < .001^*$				
E/Ea ratio	4.55 ± 1.1	8.13 ± 1.78	7.18 ± 0.88	5.69 ± 1.0
$P < .001^*$, $P_1 < .06$, $P_2 < .001^*$, $P_3 = .003^*$				

P: comparing control group and patients before PCI, P_1: comparing before PCI and immediately post PCI, P_2: comparing before PCI and 3 months post PCI, P_3: comparing immediately post PCI and 3 months post PCI.

* Statistically significant at $P \leq .05$.

Table 3
Comparison of strain and strain rate between control group and patients before and after PCI.

Parameter Mean ± SD	Control group (No = 15)	Before PCI (No = 30)	Immediately post PCI (No = 30)	3 months post PCI (No = 30)
Peak longitudinal systolic strain (%)				
Apicoseptal	−15.01 ± 6.60	−7.96 ± 6.67	−8.23 ± 5.78	−10.14 ± 5.40
P < .001*, P1 = .417, P2 = .044*, P3 = .004*				
Basal anterior	−21.58 ± 6.75	−12.22 ± 8.51	−14.33 ± 9.92	−16.11 ± 8.08
P < .001*, P1 = .271, P2 = .019*, P3 = .004*				
Mid anterior	−17.53 ± 10.60	−7.19 ± 6.41	−6.79 ± 5.35	−10.58 ± 5.58
P < .001*, P1 = .688, P2 = .036*, P3 = .036*				
Apico-anterior	−15.94 ± 9.12	−2.80 ± 2.73	−4.25 ± 4.49	−6.75 ± 3.44
P < .001*, P1 = .185, P2 < .001*, P3 < .001*				
Basal anteroseptum	12.58 ± 7.52	−8.23 ± 7.86	−10.81 ± 6.68	−12.05 ± 7.43
P < .001*, P1 = .058, P2 = .033*, P3 = .016*				
Mid anteroseptum	−15.43 ± 4.64	−7.47 ± 4.89	−8.34 ± 6.53	−11.48 ± 6.24
P < .001*, P1 = .465, P2 = .022*, p3 = .005*				
Average PSLS of all LAD segments	−16.66 ± 5.26	−8.11 ± 3.3	−8.95 ± 4.33	−12.81 ± 3.27
P < .001*, P1 = .199, P2 < .001*, P3 < .001*				
Peak systolic strain rate (S^{-1})				
Apicoseptal	−0.95 ± 0.42	−0.60 ± 0.44	−0.65 ± 0.43	−0.78 ± 0.53
P < .001*, P1 = .393, P2 = .055, P3 = .021*				
Basal anterior	−1.81 ± 0.86	−1.05 ± 0.78	−1.12 ± 0.66	−1.25 ± 0.78
P < .001*, P1 = .299, P2 = .055, P3 = .013*				
Mid anterior	−1.28 ± 0.71	−0.59 ± 0.50	−0.62 ± 0.41	−0.74 ± 0.48
P < .001*, P1 = .102, P2 = .061, P3 = .010*				
Apico-anterior	−1.14 ± 0.73	−0.29 ± 0.23	−0.38 ± 0.31	−0.45 ± 0.26
P < .001*, P1 = .056, P2 = .066, P3 = .035*				
Basal anteroseptum	−1.29 ± 0.68	−0.89 ± 0.47	−0.96 ± 0.54	−1.02 ± 0.59
P < .001*, P1 = .172, P2 = .066, P3 = .050*				
Mid anteroseptum	−1.11 ± 0.64	−0.63 ± 0.36	−0.74 ± 0.45	−0.99 ± 0.45
P < .001*, P1 = .497, P2 = .055, P3 = .035*				
Average PSSR of all LAD segments	−1.15 ± 0.60	−0.66 ± 0.27	−0.69 ± 0.18	−0.90 ± 0.29
P < .001*, P1 = .251, P2 < .001*, P3 < .001*				

LAD:left anterior descending artery, PSLS: peak systolic longitudinal strain, PSSR: peak systolic strain rate P: comparing between control and patients before PCI, P_1: comparing before PCI and immediately post PCI, P2: comparing before PCI and 3 months post PCI, P3: comparing immediately post PCI and 3 months post PCI.
* Statistically significant at P ≤ .05.

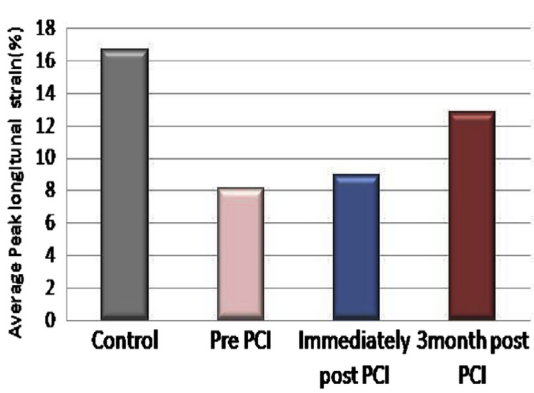

Fig. 2. Comparison of the average peak systolic longitudinal strain of the ischemic region in control group and patients before and after PCI.

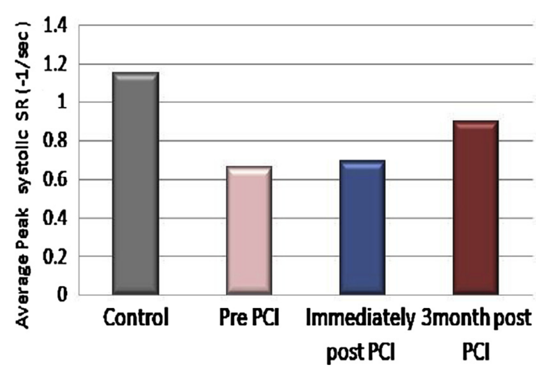

Fig. 3. Comparison of the average peak systolic longitudinal strain rate of the ischemic region in control and patients before and after PCI.

tion.[14] The optimum treatment of these patients has been a controversial issue in recent years. Recent studies have still not fully determined the usefulness of invasive treatment of the coronary arteries with PCI in patients with chronic stable angina,[15–17] so our study aimed to assess the improvement of LV systolic function after elective PCI using tissue Doppler strain imaging techniques, and we found a significant improvement in the PSLS and PSSR measured in the ischemic segments of LAD territory before PCI to after PCI by 3 months, but no significant improvement in the values measured immediately after PCI. Several studies have demonstrated that this method is an appropriate tool for evaluating regional myocardial systolic function and this is in agreement with our study.[18–21]

Sang Jin Ha et al.[22] studied 22 patients with chronic stable angina and follow up for 6 months after PCI, the peak systolic strain of the ischemic segments improved significantly from −10.9 ± 5% to −15.9 ± 6.8% (P < .01), and they concluded that in patients with significant coronary artery stenosis but normal LV function, strain imaging demonstrated the regional LV dysfunction in the ischemic segments and improvement in regional LV dysfunction after PCI and that proved the effectiveness of the new modality of strain imaging in detection of ischemia even when the 2D resting echocardiography is not conclusive and this in agreement to our study findings.

And in another study by Jin-Oh Choiet al.[23] studied global PSLS of LV to 100 patients without regional wall motion abnormality and with preserved EF, patients were grouped according to the results of coronary angiogram as following; left main or 3 vessel disease as high risk group, 1- or 2-vessel disease as low risk group, and normal group, the global and segmental PSLS was significantly

Table 4
PSLS and PSSR according to the site of stenosis in LAD coronary artery.

Parameter	Proximal LAD (No = 12)	Mid LAD (No = 10)	Distal LAD (No = 8)	P value
Average PSLS of LAD segments (%)	−7.55 ± 3.31	−9.12 ± 3.42	−10.61 ± 3.52	P_1 = .017*, P_2 = .011*, P_3 = .119
Average PSSR of LAD segments (%)	−0.58 ± 0.27	−0.66 ± 0.22	−0.75 ± 0.21	P_1 = .011*, P_2 = .001*, P_3 = .161

PSLS:peak systolic longitudinal strain, PSSR: peak systolic strain rate, LAD:left anterior descending artery, P_1: comparing proximal to mid LAD, P2: comparing proximal to distal LAD, P3: comparing mid to distal LAD.
* Statistically significant at P ≤ .05.

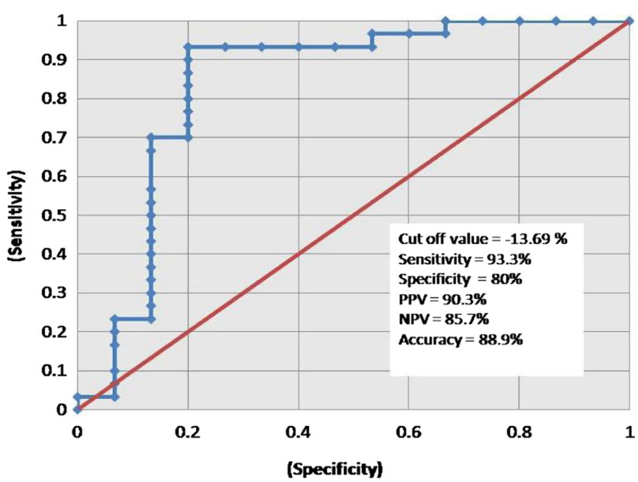

Fig. 4. ROC curve showing the sensitivity and specificity of the peak systolic strain to detect regional ischemia in LAD territory.

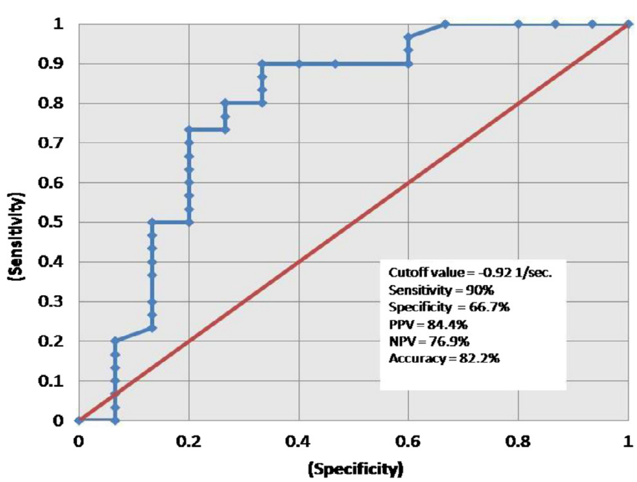

Fig. 5. ROC curve showing the sensitivity and specificity of the peak systolic strain rate to detect regional ischemia in LAD territory.

lower in high risk group compared with normal group. According to the ROC curve, −17.9% may be an optimal operational cut-off level to discriminate high risk group from others (specificity 79%, sensitivity 83%), and concluded that longitudinal strain of LV at rest is significantly reduced in high risk CAD without regional wall motion abnormality and it might be useful for prediction of high risk before stress test. Also another study prove that elective PCI in patients with CAD improves LV systolic function was carried by Nozari et al.[24] studied the effect of PCI on LV systolic and diastolic function, they studied 115 patients with CAD, and echocardiography was performed before PCI, the day after and 3–6 months later, and they found that PCI improved LV systolic function in patients with CAD, as the mean EF was (%40.52 ± 6.36) before, (% 41.83 ± 7.14) the day after, and (%44.0 ± 7.89) 3–6 months after PCI (*P* < .0001), and concluded that PCI improved LV ejection fraction, and LV diastolic function in his patient's population.

A study done in 2013 by Hossain et al.[25] on 40 patients with chronic stable angina, follow up was 48 h and 6 weeks later only, they found that strain and SR significantly increased at both 48 h and 6 weeks after PCI (P < .001) which means significant improvement of systolic function, and they concluded that strain and SR imaging can detect the early changes of improvement of the left ventricular myocardium in patients with chronic stable angina undergoing PCI even as early as 48 h after PCI but this conclusion is not in agreement with our study as we found no significant improvement in strain and SR values early after PCI up to 24 h and only the significant improvement was found in follow up after 3 months.

Most of the studies were in agreement with our study that strain and SR imaging could diagnose resting regional ischemia in patient with stable CAD in spite of normal wall motion and EF and also can detect improvement of regional function after elective PCI to significant stable CAD.

5. Conclusions

TDI derived strain and strain rate can detect resting regional myocardial dysfunction in presence of preserved LV systolic function, and can assess the improvement of regional myocardial function after successful elective PCI in patients with stable CAD.

Study limitations

One of the limitations in this study was the small sample size, we study only the systolic function, a study of diastolic function by strain and strain rate imaging should be considered in further studies, another limitation is that we study only longitudinal LV function because TDI is angle dependant and further study of circumferential and radial myocardial functions by speckle tracking echocardiography is to be considered. A patient outcomes were not investigated and this is a point that can be added to further studies.

Conflict of interest

None to be declared.

References

1. Cassar Andrew, Holmes Jr David R, Rihal Charanjit S, Gersh Bernard J. Chronic coronary artery disease: diagnosis and management. *Mayo Clin Proc*. 2009;84 (12):1130–1146.
2. Lloyd-Jones Donald, Carnethon Mercedes, Flegal Katherine, Greenlund Kurt, Howard Virginia, Lisabeth Lynda, et al.. American Heart Association Statistics Committee and Stroke Statistics Subcommittee. Heart disease and stroke statistics–2009 update: a report from the American Heart Association Statistics Committee and Stroke Statistics Subcommittee [published correction appears in Circulation. 2009; 119(3):e182]. *Circulation*. 2009;119(3):480–486.

3. Miyatake K, Yamagishi M, Tanaka N, Uematsu M, Yamazaki N, Mine Y, et al.. New method for evaluating left ventricular wall motion by color-coded tissue Doppler imaging: in vitro and in vivo studies. *J Am Coll Cardiol*. 1995;25:717–724.
4. Heimdal A, Stoylen A, Torp H, Skjaerpe T. Real-time strain rate imaging of the left ventricle by ultrasound. *J Am Soc Echocardiogr*. 1998;11:1013–1019.
5. Agirbasli M, Guler N. Recovery of left ventricular systolic function after left anterior descending coronary artery stenting. *J Interv Cardiol*. 2005;18(2):83–88.
6. Ioannidis JP, Katritsis DG. Percutaneous coronary intervention for late reperfusion after myocardial infarction in stable patients. *Am Heart J*. 2007;154(6):1065–1071.
7. Silva JC, Rochitte CE, Júnior JS, Tsutsui J, Andrade J, Martinez EE, et al.. Late coronary artery recanalization effects on left ventricular remodelling and contractility by magnetic resonance imaging. *Eur Heart J*. 2005;26(1):36–43.
8. Remmelink M, Sjauw KD, Henriques JP, Vis MM, van der Schaaf RJ, Koch KT, et al.. Acute left ventricular dynamic effects of primary percutaneous coronary intervention from occlusion to reperfusion. *J Am Coll Cardiol*. 2009;53 (17):1498–1502.
9. Buszman P, Szkróbka I, Gruszka A, Parma R, Tendera Z, Leśko B, et al.. Comparison of effectiveness of coronary artery bypass grafting versus Percutaneous coronary intervention in patients with ischemic cardiomyopathy. *Am J Cardiol*. 2007;99(1):36–41.
10. Nechvatal L, Hlinomaz O, Groch L, Hornacek I, Sitar J, Orban M, et al.. Serial echocardiographic assessment of the left ventricular function after direct PCI. *Kardiol Pol*. 2003;59(11):397–401.
11. Lang RM, Badano LP, Mor-Avi V, Afilalo J, Armstrong A, Ernande L, et al.. Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. *J Am Soc Echocardiogr*. 2015;28:1–39.
12. Bayat F, Farahani E, Saadat H. The effect of percutaneous coronary intervention on isolated left ventricular diastolic dysfunction in patients with coronary artery disease assessed by using strain rate imaging. *J Cardiol Clin Res*. 2014;2 (4):1037.
13. Maragiannis D, Lazaros G, Vavuranakis M, Chrysohoou C, Athanassopoulou S, Patialiakas A, et al.. Chronic stable angina: percutaneous coronary intervention or medication? *Hellenic J Cardiol*. 2011;52:246–252.
14. Tanaka H, Kawai H, Tatsumi K, et al.. Improved regional myocardial diastolic function assessed by strain rate imaging in patients with coronary artery disease undergoing percutaneous coronary intervention. *J Am Soc Echocardiogr*. 2006;19:756–762.
15. Opie LH, Commerfold PJ, Gersh BJ. Controversies in stable coronary artery disease. *Lancet*. 2006;367:69–78.
16. Abrams J. Clinical practice. Chronic stable angina. *N Engl J Med*. 2005;352:2524–2533.
17. Vaina S, Stefanadis C. Treatment of multi-vessel coronary arterydisease. What is the optimal revascularization approach?What do we know, what will we learn? *Hellenic J Cardiol*. 2007;48:1–4.
18. Thambyrajah J, Vijayalakshmi K, Graham RJ, Turley AJ, de Belder MA, Stewart MJ. Strain rate imaging pre- and post-percutaneous coronary intervention: a potential role in the objective detection of ischaemia in exercise stress echocardiography. *Eur J Echocardiogr*. 2008;9:646–654.
19. Voigt JU, Exner B, Schmiedehausen K, Huchzermeyer C, Reulbach U, Nixdorff U, et al.. Strain-rate imaging during dobutamine stress echocardiography provides objective evidence of inducible ischemia. *Circulation*. 2003;107:2120–2126.
20. Jamal F, Kukulski T, Strotmann J, Szilard M, D'Hooge J, Bijnens B, et al.. Quantification of the spectrum of changes in regional myocardial function during acute ischemia in closed chest pigs: an ultrasonic strain rate and strain study. *J Am Soc Echocardiogr*. 2001;14:874–884.
21. Williams RI, Payne N, Phillips T, D'Hooge J, Fraser AG. Strain rate imaging after dynamic stress provides objective evidence of persistent regional myocardial dysfunction in ischaemic myocardium: regional stunning identified? *Heart*. 2005;91:152–160.
22. Sang Jin HA, Kim SH, Kim JB, Kim SJ, Kim W, Kim W. Improvement in regional myocardial function assessed by strain rate imaging in patients who had coronary artery disease but normal wall motion undergoing percutaneous coronary intervention. *Circulation*. 2012;126:A17807.
23. Choi Jin-Oh, Park Seung Woo, Yang Jeong Hoon, Cho Sung Won, Cho Soo Jin, Lee Sang Yeub, et al.. Abstract 1581: Longitudinal 2-dimensional strain of left ventricle at rest predicts high risk coronary artery disease without regional wall motion abnormality. *Circulation*. 2007;116:II_329–II_330.
24. Nozari Y, Oskouei NJ, Khazaeipour Z. Effect of elective percutaneous coronary intervention on left ventricular function in patients with coronary artery disease. *Acta Medica Iranica*. 2012;50:26–30.
25. Hossain M, Fazlur A, Siddique A, Krishna S, Meskat C, Hoque H, et al.. Study of changes in various echocardiographic parameters in patients with chronic stable angina undergoing percutaneous coronary intervention. *Univ Heart J*. 2013;9:2.