

Diagnostic Value of Deformation Imaging in Patients with Suspected Stable Coronary Artery Disease

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ABSTRACT

Background: Deaths from coronary artery disease accounts for more than a half of cardiovascular mortality, hence, early diagnosis and treatment are warranted. Systolic and diastolic myocardial deformation parameters are considered as sensitive markers of ischemia and may be useful in the quantification of haemodynamic significance of coronary artery stenoses. Small previous studies show that speckle tracking derived myocardial deformation parameters aid in the diagnosis of myocardial ischaemia in patients with preserved left ventricular ejection fraction and help to determine the earliest alterations in myocardial function.

Aim: The aim of the study is to determine the diagnostic value of myocardial deformation parameters derived by dobutamine speckle tracking echocardiography at rest, during low and high dobutamine doses for assessment of significant coronary artery stenosis validated by adenosine magnetic resonance imaging in patients with suspected stable coronary artery disease.

Methods: In 91 patients (mean age 65.2 ± 9.25 years) with suspected stable coronary artery disease inducible myocardial ischemia was evaluated by dobutamine stress echocardiography and adenosine magnetic resonance imaging. After these tests all patients underwent invasive coronary artery angiography. Significant coronary artery stenosis was defined as $\geq 70\%$ or greater luminal narrowing of epicardial coronary vessel. Based on adenosine magnetic resonance imaging patients were divided into two groups — non-pathologic (n=51) and pathologic (n=40). Peak longitudinal, circumferential, radial strain, systolic and diastolic longitudinal, circumferential, radial strain rate parameters at rest, low and peak dose were estimated.

Results: There were no significant differences in the clinical characteristics, results of conventional echocardiography and strain, strain rate parameters between the two groups at rest. According to ROC analysis these myocardial deformation parameters had the greatest predictive value of significant stenoses: longitudinal strain (AUC 0.731 sensitivity 77.8%, specificity 50.0% at low doses, 0.731 sensitivity 88.9%, specificity 50.0% at high doses), circumferential strain (AUC 0.769, sensitivity 77.8%, specificity 75.0% at low doses, 0.759 sensitivity 100%, specificity 58.3% at high doses), circumferential SR (AUC 0.722 sensitivity 77.8%, specificity 75.0% at low doses, 0.750 sensitivity 88.9%, specificity 58.3% at high doses). Combination of myocardial deformation parameters— circumferential early diastolic SR at low dobutamine doses, longitudinal strain at low doses and difference of radial systolic SR from low to high doses best classified patients into predefined CAD groups. The accuracy of classifying to non-pathologic group is 92.3 % while classifying to pathologic – 100 %.

Conclusion: Two dimensional speckle tracking echocardiography derived myocardial deformation parameters (peak strain and systolic strain rate) obtained during low, high dobutamine dose and recovery are important markers of validated by perfusion defects hemodynamically significant coronary artery disease.

KEYWORDS: Coronary artery disease, Speckle tracking echocardiography, Dobutamine stress echocardiography, Adenosine stress myocardial perfusion, Deformation imaging.

INTRODUCTION

Coronary artery disease (CAD) is still growing problem. That is why the assesment of CAD using non invasive diagnostic techniques are very important. Dobutamine stress echocardiography (DSE) is an established, cost effective method for detecting the presence, localization and extent of coronary artery disease (CAD) which has advantages over SPECT, including no irradiation, higher resolution, shorter test duration, immediate availability of results at the bedside, and the ability to perform stress and resting images in the same setting [1-3]. Studies comparing DSE with coronary angiography have demonstrated relatively high sensitivity for detecting ischemia with inducible wall motion analysis during DSE, ranging from 73% to 89% [4]. However, achieving the published levels of accuracy is not easy in daily clinical practice, because interpretation of DSE is often subjective and highly dependent on the operator's experience. Various factors can affect the

diagnostic accuracy of DSE in clinical situations, such as left ventricular hypertrophy, the extend of ischemia, the presence of resting WMA [5,6].

To overcome the limitation of subjective wall motion assessment, a number of imaging modalities have been proposed to quantify myocardial ischaemia by measuring various motion and deformation parameters. Tissue velocity imaging as well as speckle tracking imaging has been shown to be feasible during DSE [7-9]. Tissue Doppler-derived strain echocardiography can assess regional systolic and diastolic patterns and track changes related to regional ischemia [10-12]. However, this technique is limited by variability related to signal noise and influenced by the angle of insonation [13]. Two-dimensional strain analysis techniques overcome these limitations. Speckle tracking is an echocardiographic method based on tracking of characteristic speckle patterns created by interference of ultrasound beams in the myocardium [14]. Amundsen [15] was the first who showed in vivo that STE can provide accurate and angle-independent measurements of regional myocardial strain and has potential to become a clinical bedside tool to quantify regional myocardial function. This technique offer a more reproducible and less time-consuming measurement of global and regional strain, systolic and diastolic strain rate evaluation [16,17]. Myocardial deformation parameters allow to assess myocardial ischaemia when left ventricle ejection fraction (LVEF) is normal and to find the earliest changes of global and regional left ventricle systolic and diastolic function.

Global and Regional Myocardial Deformation parameters Assessed by Tissue Doppler Imaging and Speckle Tracking Echocardiography at Rest

Liang et al. [18] was the first who in small population (61 patient with stable CAD) showed that regional myocardial deformation evaluated by tissue doppler imaging enables detection of significantly diseased coronary arteries at rest with high sensitivity. Choi et al. [19] found that resting peak systolic longitudinal strain (PSLS) is significantly reduced in patients with severe CAD including left main or 3-vessels CAD, even when resting wall motion and LV ejection fraction are normal. This study showed that mid- and basal PSLS could effectively detect patients with severe CAD (area under ROC curve - 0.83, 95% CI 0.75–0.91). The reason for this study was the development of a semi-automated function imaging that can assist PSLS measurements. This method provide quantitative measurements of global and segmental PSLS using a simple bull's eye display. Shimoni et al. [20] were analysing not only stable but also unstable CAD patients. Lowest (least negative) 10th-percentile peak systolic strain (PSS 10%) showed the best accuracy in detecting CAD, with an area under the receiver operating characteristic curve of 0.85 and was better than segmental peak systolic strain in the detection of CAD in each coronary territory. Nucifora et al. [21] studied 182 patients with suspected CAD referred to 64-slice computed tomography for coronary evaluation, because of increased risk profile and/or stable chest pain. Conventional echocardiographic parameters of left ventricle systolic and diastolic function, global and regional strain and strain rate were analysed. They concluded that that only global strain provided significant incremental value over the Duke clinical score for the identification of

patients with obstructive CAD on multislice computed tomography. The cutoff for GS was -17.4%, with sensitivity and specificity of 83% and 77%, respectively. Yang et al. [22] found that global longitudinal deformation parameters were significantly lower in patients with severe coronary artery disease comparing them to control group patients even during intermediate-dose of DSE. These findings suggest that longitudinal impairment occurs early during cardiac ischemia. A possible reason may be the fiber orientation of the left ventricular myocardium, which consists of circumferential fibers in the mid wall and longitudinal fibers in the endocardial and epicardial layers [23,24] and ischemia-induced myocardial changes often begin from the endocardium.

Global and Regional Myocardial Deformation Parameters Assessed by Tissue Doppler And Speckle Tracking Echocardiography Analysis During Dobutamine Stress

Assessment of myocardial ischemia by DSE is well validated and reliable tool, where new or worsening regional wall motion abnormality is developed [25]. This technique requires considerable experience, difficulties with moderate coronary stenosis, potential limitations surrounding image quality, site variability, lack of quantification. On the basis of metaanalysis [26]: DSE sensitivity, specificity and accuracy were 80%, 84% and 81%, respectively. Voight et al. [27] was the first who was looking for myocardial deformation parameters in detecting ischaemia during dobutamine stress. DSE was performed in 44 patients with known or suspected coronary artery disease. Simultaneous perfusion scintigraphy served as a “gold standard” to define regional ischemia. The ratio of postsystolic shortening to maximal segmental deformation was the best quantitative parameter to identify stress-induced ischemia. Weidemann et al. [28] analysed 30 patients with one known intermediate stenosis in a large coronary artery without other CAD. They found the strain rate change from rest to peak doses - the best parameter to detect ischaemia (AUC 0,90; sensitivity 89% and specificity 86%). Celutkienė et al. [29] analysed systolic, post-systolic and diastolic velocities, strain and strain rate parameters which were obtained at rest and at peak dobutamine stress. It was concluded that visual assessment appears to be more accurate than single velocity and strain/strain rate markers in the diagnosis of coronary artery disease. Hwang et al. [30] analysed 44 patients with chest discomfort. They concluded that assessment of global longitudinal strain at recovery of DSE might be a reliable and objective method for detection of significant CAD. This finding may suggest that systolic stunning after a transient ischemic event persists and that assessment by GLS during the recovery period allows this phenomenon to be objectively and quantitatively assessed. According to this study the optimal cutoff of global longitudinal strain (GLS) at recovery for detection of CAD was -19% (sensitivity of 70.6%, specificity of 83.3%).

MATERIALS AND METHODS

We examined 91 subjects (mean age 65,2±9,25 years, 45 men) with symptoms suggesting stable angina and scheduled for myocardial ischemia testing, without wall motion abnormalities

at rest. Exclusion criteria were: 1) contraindications to dobutamine or atropine, 2) history of cardiovascular or valvular heart disease, 3) left ventricular ejection fraction <55% on echocardiography, 4) known hypersensitivity to contrast agents, 5) mental diseases, 6) pregnancy or breast-feeding, 7) severe renal impairment (eGFR ≤ 30 ml/min/1.73m²). All subjects gave written informed consent to participate in the study and the protocol was approved by local Ethical Committee.

Evaluation of Myocardial Ischemia

In all patients myocardial ischemia was evaluated using two imaging techniques: echocardiography (at rest and during dobutamine stress) and cardiac magnetic resonance imaging (myocardial perfusion at rest and adenosine stress myocardial perfusion, AMRI).

Echocardiography at Rest and During Dobutamine Stress

The conventional echocardiography system (Vivid 7, GE Healthcare, Horten, Norway) with 1.5 – 4.6 MHz transducer was used. Range of frame rate per second was from 64 to 112 with mean value 83. Beta-blockers and nitrates were discontinued at least 48 hours prior to the study. DSE was performed using the standard protocol according to the recommendations of the EACVI (formerly EAE) [25]. Intravenous dobutamine was initiated at 10 mg/kg/min and the dose increased every 3 min to 20, 30, and finally 40 mg/kg/min. If target heart rate was not achieved, atropine was given. A 12-lead electrocardiogram, blood pressure, and standard two-dimensional echocardiograms were taken at baseline, low-dose, peak dobutamine dose and during recovery. The dobutamine infusion was terminated once 85% of the maximal predicted heart rate was achieved. Stress test was terminated prematurely in the presence of severe chest pain or other intolerable symptoms, severe arrhythmia, >2 mm ST-segment elevation or depression, systolic blood pressure >230 mm Hg, diastolic blood pressure >120 mm Hg, or a drop in systolic blood pressure >20 mm Hg.

Standard Echocardiographic Measurements

Ejection fraction, visual wall motion score index, and number of dysfunctional segments were determined by an experienced observer blinded to clinical and strain data. LV ejection fraction was calculated using the modified Simpson's biplane method with manual tracing of the endocardial borders at end-diastole and end-systole in the apical four- and two-chamber views. All segmental analyses were based on the conventional American Society of Echocardiography 16-segment LV model. Each segment was assigned a wall motion score of 1 to 4, where 1 = normal, 2 = hypokinetic, 3 = akinetic and 4 = dyskinetic or aneurysmal. Wall motion score index was derived as the sum of individual segment scores divided by the number of segments visualized.

The assessment of myocardial deformation

Off-line speckle-tracking analysis (EchoPac, GE Healthcare) was performed using images obtained at rest and during DSE. Conventional 2D, colour tissue Doppler images of the apical

four-, three-, two-chamber and papillary muscle views over three heart cycles at baseline and low stress and peak stress were analysed. Cardiac cycles associated with atrial or ventricular extrasystolic beats were excluded. Five consecutive beats were averaged for each of these measurements to improve the signal to noise ratio of the derived curves. For each LV segment the value of peak systolic longitudinal strain was measured at baseline and low and peak level of dobutamine stress test. Segments that were unsuitable for myocardial strain analysis because of limited image quality or poor tracking were excluded. The quality of tissue tracking was verified by the software's own quality control function, as well as visual assessment of the reader. In case of poor-tracking quality, the reference points were manually readjusted until satisfactory tracking was achieved.

Adenosine stress myocardial perfusion

Prior to AMRI all patients were asked to refrain from caffeine-containing beverages or drugs for 24 hours. Images were acquired using a dedicated 1.5 T scanner with a eighteen-channel phased-array receiver coil (Siemens Magnetom Aera, Siemens AG Healthcare Sector, Erlangen, Germany). ECG and breathing motion were detected continuously. A retrospectively-gated balanced steady-state free-precession (bSSFP) sequence was used to obtain cine images in three long-axis (two-, three- and four-chamber) views, followed by contiguous stack of short-axis slices. Perfusion imaging was planned using end-systolic frames of the long-axis cine images and performed in three short-axis slices corresponding basal, midventricular and apical segments of the left ventricle. For stress perfusion Adenosine was infused at 140 mcg/kg/min for a minimum 3 minutes to achieve hyperemia. In cases of inadequate hemodynamic response Adenosine dose was increased up to 210 mcg/kg/min. Heart rate and blood pressure were monitored before and continuously during Adenosine infusion. At peak stress gadolinium contrast (Gadovist, Bayer-Schering, Berlin, Germany, 0.1 mmol/kg) was rapidly injected at 4.0 ml/s, followed by 20 ml saline flush using a power injector (Medrad UK, Ely, Cambridgeshire, UK). After 10 minutes late gadolinium enhancement (LGE) images were acquired. Ventricular volumes, function, myocardial mass and ejection fraction were calculated using a manufacturer dedicated software (Syngo.via, Siemens AG Healthcare Sector, Erlangen, Germany). The rest and stress perfusion images were assessed by visual analysis. The true stress-induced perfusion defect was defined as a persistent hypoenhancement in subendocardial or transmural appearance with normal first-pass perfusion at rest.

After DSE and AMRI all patients underwent invasive coronary artery angiography. Significant coronary artery stenosis was defined as 70% or greater luminal narrowing of epicardial coronary vessel. DSE and AMRI investigators were blinded to coronary artery angiography results.

RESULTS

A total of 91 patients (mean age 65,2±9,25 years, 45 men) with stable coronary artery disease (CAD) were included into the study. Based on coronary artery (CA) angiography, two groups

were formed— pathologic (n=40) (when significant coronary artery stenoses were detected ($\geq 70\%$) and non-pathologic (n=51) (when non-significant stenoses ($< 70\%$) were found). Clinical characteristics of study population are provided in Table 1. There were no differences in conventional echocardiography (Table 2) and myocardial deformation parameters (Table 4) between groups at rest. A half of pathologic group had one damaged vessel, mostly – left anterior descending artery (Table 3).

Table 1: Clinical characteristics of study population.

Characteristics	CAD (-)	CAD (+)	p value
Gender male, n(%)	23 (56.1%)	22 (55.0%)	0.26
Age (year)	63.0 $\pm$ 8.9	65.9 $\pm$ 7,5	0.41
History of hypertension, n (%)	21 (51.2%)	20 (50.0%)	0.10
History of smoking, n (%)	15 (36.5%)	15 (37.5)	0.10
Obesity, n (%)	22 (53.6%)	19 (47.5%)	0.20
Diabetes, n (%)	7 (17.0%)	4 (10%)	0.32
Family history of CAD, n (%)	12 (29.2%)	112 (27.5%)	0.57

Table 2: Conventional echocardiography parameters.

Characteristics	CAD (-)	CAD (+)	p value
LVEDD (mm)	46.4 $\pm$ 5.9	46.8 $\pm$ 6.7	0.84
VESD (mm)*	33.4 $\pm$ 6.2	30.8 $\pm$ 8.7	0.17
LVEF (%)	59.7 $\pm$ 6.5	60.7 $\pm$ 6.9	0.80
E/A ratio*	0.9 $\pm$ 0.2	0.8 $\pm$ 0.2	0.68
E peak rate (m/s)	59.8 $\pm$ 14.5	64.9 $\pm$ 18.5	0.40
e' lateral (m/sec)	9.2 $\pm$ 1.8	9.2 $\pm$ 2.2	0.68
e' septal (m/sec)	7.7 $\pm$ 1.7	9.1 $\pm$ 5.6	0.86
E/E'	3.4 $\pm$ 1.1	4.2 $\pm$ 2.6	0.12

Table 3: Data of coronary artery angiography.

Characteristics	CAD (+)
Single vessel disease, n (%)	20 (50%)
Two vessel disease, n (%)	8 (20%)
Three vessel disease, n (%)	12 (30%)
Diseased vessel -left main coronary artery, n (%)	7 (17.5%)
Diseased vessel - right coronary artery, n (%)	20 (50%)
Diseased vessel - left circumflex artery, n (%)	14 (35.5%)
Diseased vessel - left anterior descending artery, n (%)	30 (75.0%)

Table 4: Peak strain and strain rate (SR) parameters in non-pathologic and pathologic groups at rest.

Miocardial deformation parameter	Non-pathologic group	Pathologic group	p value
Strain, %			
Longitudinal	-19.7±2.2	-18.8±3.2	0.35
Circumferential	-18.8±5.8	-19.7±8.6	0.81
Radial	43.8±29.3	29.6±18.0	0.11
Systolic strain rate (SR), s⁻¹			
Longitudinal	-1.3±0.2	-1.3±0.2	0.41
Circumferential	-1.8±0.6	-1.9±0.6	0.71
Radial	2.4±0.7	2.2±0.9	0.59
Early diastolic strain rate (SR) s⁻¹			
Longitudinal	1.4±0.2	1.3±0.3	0.64
Circumferential	1.9±0.8	1.6±0.8	0.44
Radial	-2.1±1.2	-1.8±1.2	0.73
Late diastolic strain rate (SR) s⁻¹			
Longitudinal	1.3±0.2	1.3±0.2	0.12
Circumferential	1.4±0.4	1.3±0.6	0.44
Radial	-1.9±0.7	-2.0±0.9	0.76

Miocardial Deformation Parameters (Strain, Strain Rate) in Non-Pathologic and Pathologic Groups from Rest to Low Dobutamine Dose

Longitudinal, circumferential and radial myocardial strain

In non-pathologic group longitudinal and circumferential strain increased significantly from the baseline to low dobutamine dose, while in pathologic group circumferential strain had tendency to decrease. At low dobutamine dose circumferential strain was significantly lower in pathologic group (-23.4% vs -18.9%, $p=0.04$). (Table 5). These results confirms the statement that without ischaemia myocardial strain significantly increases, while it does not change or even decreases when ischaemia affects myocardium [21]. According to our findings, not only longitudinal but also circumferential strain had the same tendency from the baseline to low dobutamine doses.

Table 5: Peak longitudinal and circumferential strain parameters in non-pathologic and pathologic groups from rest to low dose.

Strain, %	Non-pathologic group		
	Rest	Low dose	P value
Longitudinal	-19.7±2.2	-22.6±2.6	0.05
Circumferential	-18.8±5.8	-23.4±6.6	0.04
Strain, %	Pathologic group		
	Rest	Low dose	P value
Longitudinal	-18.8±3.2	-20.1±3.7	0.11
Circumferential	-19.7±8.6	-18.9±4.2	0.74

Longitudinal, radial and circumferential myocardial strain rate

Circumferential strain rate was significantly lower in pathologic group at low dobutamine doses (-3.1 s^{-1} vs -2.5 s^{-1} , $p=0.04$) (Table 6). According to our findings at low dobutamine doses circumferential strain and systolic circumferential strain rate were significantly lower in pathologic group. This confirms experimental research with animals results [31] that not only longitudinal strain but also circumferential strain and systolic circumferential strain rate are important for detecting significant coronary artery stenoses.

Table 6: Peak longitudinal and circumferential strain rate parameters in non-pathologic and pathologic groups from rest to low dose.

Systolic strain rate, s^{-1}	Non-pathologic group		
	Rest	Low dose	P value
Longitudinal	-1.3±0.2	-1.9±0.3	0.01
Circumferential	-1.8±0.6	-3.1±0.9	0.01
Radial	2.4±0.7	2.9±1.9	0.33
Systolic strain rate, s^{-1}	Pathologic group		
	Rest	Low dose	P value
Longitudinal	-1.3±0.2	-1.7±0.4	0.01
Circumferential	-1.9±0.6	-2.5±0.7	0.02
Radial	2.2±0.9	3.7±2.3	0.10

Early and late diastolic longitudinal, circumferential and radial strain rate

From the baseline to low dobutamine dose early diastolic longitudinal strain rate significantly increased at both groups (in non-pathologic: from 1.4 s^{-1} to 1.6 s^{-1} , $p=0.030$, in pathologic: from 1.3 s^{-1} to 1.6 s^{-1} , $p=0.025$), however, early diastolic circumferential strain rate significantly increased only in non-pathologic group (respectively, in non-pathologic group from 1.9 s^{-1} to 2.5 s^{-1} , $p=0.020$, in pathologic group from 1.6 s^{-1} to 1.6 s^{-1} , $p=0.957$). At low dobutamine dose early diastolic circumferential strain rate and late diastolic radial strain rate were significantly higher in non-pathologic group (respectively, 2.5 s^{-1} vs 1.6 s^{-1} , $p=0.00$; 1.6 s^{-1} vs 1.4 s^{-1} , $p=0.071$). Moreover there is confirmed that diastolic myocardial strain rate parameters are more sensitive

than systolic parameters [32]. According to our research, late diastolic strain rate are increasing at all planes (longitudinal, radial and circumferential) only when there is no significant coronary artery stenosis.

Miocardial Deformation Parameters (Strain, Strain Rate) in Non-Pathologic And Pathologic Groups from Low to High Dobutamine Dose

Longitudinal, circumferential and radial myocardial strain

From low to high dobutamine doses myocardial strain decreased in all planes, but only longitudinal strain changed significantly at both groups (Table 7). This matches with earlier studies results that myocardial strain increases at low dobutamine doses and later, when heart rate is increasing, it doesn't change or even decreases. Therefore, at this dobutamine phase myocardial strain is not very important prediction of significant coronary artery stenosis.

Table 7: Peak longitudinal and circumferential strain parameters in non-pathologic and pathologic groups from low to high dobutamine dose.

Strain, %	Non-pathologic group		
	Low dose	High dose	P-value
Longitudinal	-22.6±2.6	-18.6±4.1	0.01
Circumferential	-23.4±6.6	-23.0±10.0	0.67
Radial	26.0±15.4	28.6±14.8	0.48
Strain, %	Pathologic group		
	Low dose	High dose	P-value
Longitudinal	-20.1±3.7	-16.2±3.8	0.01
Circumferential	-18.9±4.2	-16.9±5.8	0.68
Radial	20.9±21.9	16.6±15.2	0.52

Longitudinal, radial and circumferential strain rate

From low to high dobutamine dose longitudinal systolic strain rate significantly increased only in non-pathologic group, while circumferential strain rate increased non-significantly at both groups. In pathologic group radial strain rate had tendency to decrease from low to high dobutamine dose. (Table 8)

Table 8: Peak longitudinal, circumferential and radial strain rate parameters in non-pathologic and pathologic groups from low to high dobutamine dose.

Systolic strain rate (SR), s ⁻¹	Non-pathologic		
	Low dose	High dose	P-value
Longitudinal	-1.9±0.3	-2.3±0.3	0.01
Circumferential	-3.1±0.9	-3.3±0.8	0.70
Radial	-3.1±0.9	-3.3±0.8	0.70
Systolic strain rate (SR), s ⁻¹	Pathologic group		
	Low dose	High dose	P-value
Longitudinal	-1.7±0.4	-1.9±0.4	0.01
Circumferential	-2.5±0.7	-2.9±1.0	0.15
Radial	-2.5±0.7	-2.9±1.0	0.15

Early and late diastolic myocardial longitudinal, circumferential and radial strain rate

Early diastolic myocardial strain rate had not significant differences from low to high dobutamine dose. At high dobutamine dose late diastolic radial strain rate was significantly higher in non-pathologic group (-3.1 s⁻¹ vs -2.0 s⁻¹, p=0.047).

Miocardial Deformation Parameters (Strain, Strain Rate) in Non-Pathologic and Pathologic Groups from High Dobutamine Dose to Recovery

Longitudinal, circumferential and radial myocardial strain

Longitudinal and radial strain non-significantly increased from high dobutamine dose to recovery in both groups. However, circumferential strain had tendency to increase in non-pathologic group, while it decreased in pathologic group (Table 9). There is no earlier researches for confirming this tendency.

Table 9: Peak longitudinal, circumferential and radial strain parameters in non-pathologic and pathologic groups from high dobutamine dose to recovery.

Strain, %	Non-pathologic group		
	High dose	Recovery	P-value
Longitudinal	-18.6±4.1	-18,7±2,5	0,75
Circumferential	-23.0±10.0	-37,8±23,4	0,82
Radial	-28.6±14.8	-29,9±4,2	0,07
Strain	Pathologic group		
	High dose	Recovery	P-value
Longitudinal		-19,7±2,9	0,49
Circumferential		- 37,3±25,3	0,07
Radial		-16,9±4,3	0,57

Systolic longitudinal and circumferential strain rate. Systolic circumferential strain rate non-significantly decreased in pathologic group, while it decreased significantly in non-pathologic group. Longitudinal strain rate significantly decreased in both groups. (Table 10)

Table 10: Peak longitudinal, circumferential and radial strain rate parameters in non-pathologic and pathologic groups from high dobutamine dose to recovery.

Myocardial deformation parameter	Non-pathologic group		
	High dose	Recovery	P-value
Systolic strain rate (SR), s-1			
Longitudinal	-2.3±0.3	-1,5±0,3	0,02
Circumferential	-3.3±0.8	-1,7±0,4	0,01
Systolic strain rate (SR), s-1	Pathologic group		
	High dose	Recovery	P-value
Longitudinal	-2.1±0.4	-1,5± 0,4	0,02
Circumferential	-2.9±1.0	-2,1±0,7	0,28

Diastolic myocardial strain rate after high dobutamine dose decreased at all planes, however, changes were not significant.

According to our findings myocardial strain and systolic and diastolic strain rate parameters could sensitively and specifically set haemodynamically significant coronary artery stenoses. Marginal values of myocardial deformation parameters are listed in Table 11. Myocardial strain and systolic myocardial strain rate parameters had similar predictive value as early and late diastolic strain rate parameters. Low and high dobutamine doses circumferential strain, low and high dobutamine doses longitudinal strain, low and high dobutmaine doses systolic circumferential strain rate had the highest sensitivity and specificity for prognosing haemodynamically significant coronary artery stenoses for moderate and high CAD risk patients.

Table 11: 2D speckle tracking echocardiography (STE) derived myocardial deformation parameters predictive value in detecting hemodynamically significant coronary artery stenoses in patients with suspected stable coronary artery disease (CAD).

Miocardial deformation parameter	Cut-off value	Sensitivity	Specificity	AUC	p-value
Circumferential strain at low dose	-18.6	77.8%	75.0%	0.769	0.039
Circumferential strain at high dose	-25.2	100%	58.3%	0.759	0.047
Low dose longitudinal strain	-21.7	77.8%	50.0%	0.731	0.046
High dose longitudinal strain	-19.6	88.9%	50.0%	0.731	0.046
Systolic circumferential SR at low dose	-2.8	77.8%	75.0%	0.722	0.038
Systolic circumferential SR at high dose	-3.2	88.9%	58.3%	0.750	0.050

Because no one of analysed myocardial deformation parameters alone was not enough able to determine haemodynamically significant coronary artery stenoses by 100% sensitivity, the value of parameters combinations were analysed for prognosing significant coronary artery stenoses. According to discriminant analysis, the combination of three myocardial deformation parameters distinguishes patients to pathologic and non-pathologic groups with 92.3% and 100%, respectively. These myocardial deformation parameters were used for discriminant analysis: low dobutamine dose early diastolic circumferential strain rate, low dobutamine dose longitudinal strain and the change of systolic radial strain rate form low to high dobutamine dose.

According to our research results, myocardial deformation parameters obtained by noninvasive speckle tracking method can be used for assessing myocardial ichaemia for patients with moderate and high CAD risk. Therefore left ventricle longitudinal, circumferential, radial myocardial strain and systolic, diastolic (early and late) circumferential, radial and longitudinal strain rate and their changes during dobutamine stress can be used as sensitive and specific markers of ischaemia for patients with moderate and high CAD risk.

CONCLUSION

The highest diagnostic value to detect hemodynamically significant coronary artery stenoses have these strain and strain rate parameters:

Strain, Strain Rate (SR)

longitudinal strain at low and high dose, circumferential systolic SR at low and high doses.

Combination of Miocardial Deformation Parameters

Circumferential early diastolic SR at low dobutamine doses, longitudinal strain at low doses and difference of radial systolic SR from low to high doses best classify patients into predefined CAD groups. The accuracy of classifying to non-pathologic group is 92.3 % while classifying to pathologic – 100 %.

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