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# Association of coronary microvascular dysfunction and cardiac muscle injury in acute myocardial infarction: results of comparison of dynamic SPECT and cardiac MRI

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| *Aim* | To study the interrelation of changes in coronary microcirculation by data of dynamic single photon emission computed tomography (SPECT) and myocardial injury by data of magnetic resonance imaging (MRI) in patients with acute myocardial infarction (AMI). |
| *Material and methods* | The study included patients admitted to the emergency cardiology department with new-onset AMI. Contrast-enhanced cardiac MRI was performed for all patients on day 2-7 of admission. Dynamic SPECT of the myocardium with evaluation of semiquantitative and quantitative parameters of perfusion was performed on day 7-10. |
| *Results* | All patients were divided into two groups based on the type of MR contrast agent accumulation: 1) patients with the ischemic type of contrast enhancement (n=34; 62 %); 2) patients with the non-ischemic type of contrast enhancement (n=21; 38 %). According to data of myocardial perfusion scintigraphy (MPS), the group of ischemic MR pattern had larger perfusion defects at rest and during a stress test. Moreover, this group was characterized by lower global stress-induced blood flow and absolute and relative myocardial flow reserve (MFR). When the study group was divided into patients with transmural (n=32; 58 %) and non-transmural (n=23; 42 %) accumulation of the MR-contrast agent, lower values of global stress-induced blood flow and of absolute and relative MFR were observed in the group of transmural MR-enhancement pattern. A moderate inverse correlation was found between the stress-induced myocardial blood flow and the volume of myocardial edema (r= –0.47), infarct area (r= –0.48) and microvascular obstruction area (r= –0.38). |
| *Conclusion* | The variables of dynamic SPECT characterizing microcirculatory disorders that are independent on or due to injuries of the epicardial coronary vasculature reflect the severity and depth of structural changes of the myocardium in AMI. In this process, quantitative variables of myocardial perfusion are interrelated with the myocardial injury more closely than semiquantitative MPS indexes. The findings of the present study can also contribute to the heterogenicity of a patient group with acute coronary syndrome and AMI. Further study is required for understanding the prognostic significance of dynamic SPECT parameters. |

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| *Keywords* | Acute myocardial infarction; magnetic resonance imaging; dynamic single photon emission computed tomography; myocardial flow reserve; myocardial injury; coronary microcirculatory blood flow |
| *For citations* | Mochula A.V., Mochula O.V., Maltseva A.N., Suleymanova A.S., Tsygikalo A.A., Ryabov V.V. et al. Association of coronary microvascular dysfunction and cardiac muscle injury in acute myocardial infarction: results of comparison of dynamic SPECT and cardiac MRI. Kardiologiia. 2023;63(6):37–44. [Russian: Мочула А.В., Мочула О.В., Мальцева А.Н., Сулейманова А.С., Цыгикало А.А., Рябов В.В. и др. Ассоциация коронарных микроциркуляторных нарушений и повреждения миокарда при остром инфаркте миокарда: результаты сравнения динамической ОФЭКТ и МРТ сердца. Кардиология. 2023;63(6):37–44]. |

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## Introduction

Acute myocardial infarction (AMI) remains a significant cause of death of the working-age population in developing and economically prosper countries, which is 1.8 million cases worldwide annually. In Russia, more than 520 thousand people are hospitalized for AMI every year [1]. There are numerous diagnostic approaches that allow accurate and rapid detection of AMI [2].

Contrast-enhanced magnetic resonance imaging (MRI) is one of the most descriptive imaging techniques for evaluating damage to the heart muscle in AMI. The ESC guidelines recommend this examination for all cases of myocardial infarction without coronary artery (CA) obstruction with non-apparent cause (class of recommendations 1, level of evidence B) [2]. This is due to the fact that the structure of myocardial tissue may change, and coronary microcirculation may be

disturbed as ischemia develops, which causes AMI. Abnormal microcirculation, which may be independent or due to epicardial coronary artery disease (CAD), is considered as a key link in the development of coronary insufficiency [3]. According to several studies, the state of the microvascular system affects the choice of treatment strategy and the prognosis of adverse events in cardiac patients, including those with AMI [3–5].

Positron emission tomography [5, 6] and dynamic single photon emission computed tomography (SPECT) [7, 8] are the techniques that can detect changes in coronary microcirculation. It should be noted that this method is not widely available in Russia, while dynamic SPECT has become more widespread in Europe, the United States and some other countries due to low economic costs.

Despite a sufficient number of works on the use of dynamic SPECT in patients with stable CAD [7, 8], only few studies assess myocardial microcirculation in patients with AMI. Pan et al. [9] showed the correlation between dynamic SPECT parameters – myocardial blood flow and blood levels of troponin I. In our previous study [7–9], a decrease was shown in the quantitative indicators of perfusion in the myocardial areas with MR signs of damage. At the same time, the relationship between microvascular disorders and structural changes in myocardial tissue remains unclear for patients of this group.

In this regard, the objective of this study was to examine the correlations between microcirculatory changes in the coronary blood supply according to dynamic SPECT and myocardial damages as determined by MRI in patients with AMI.

## Material and methods

Patients admitted to the emergency cardiology department for new-onset AMI in 2021–2022 were consecutively included in the study (Figure 1). Exclusion criteria were as follows:

- History of stroke;
- Life-threatening heart arrhythmias;
- Unstable hemodynamics within 7 days after hospitalization;
- Valvular heart pathology;
- Various cardiomyopathies;
- Pulmonary embolism;
- Contraindications to contrast-enhanced MRI of the heart;
- Contraindications to adenosine triphosphate (ATP) stress test;
- Refusal of a patient to participate in the study.

All patients underwent a full range of diagnostic procedures. All patients underwent additional contrast-enhanced cardiac MRI on day 2–7 after the admission. Moreover, dynamic SPECT of the myocardium was performed on day7–10 after hospitalization – at rest and using a pharmacological stress test with an assessment of semi-quantitative and quantitative parameters of perfusion.

The study was conducted following the Declaration of Helsinki and was approval by the local ethics committee. All patients signed the informed consent before being included in the study.

## MRI of the heart

### *MRI protocol*

Cardiac MRI was performed in a Vantage Titan 1.5 T scanner. Gadobutrol 0.1–0.2 mL/kg was injected intravenously to patients to obtain series of contrast-enhanced images.

The MR scan protocol had two parts. At the first stage, non-contrast-enhanced images of the heart were obtained in the following sequences: cine MRI (gradient-recalled echo steady-state free precession, GRE SSFP) in standard views, T2 weighted images (T2WI) and T1 weighted images (T1WI; turbo spin echo) along the short axis of the LV. The second stage, after the administration of the contrast agent, included early contrast-enhanced T1WI scans along the short axis of the LV to determine the presence and localization of LV myocardial hyperemia, delayed contrast-enhanced T1WI images (after 8–15 minutes) in GRE inversion mode with reconstruction and inversion time selection.

### *Analysis and interpretation of cardiac MRI*

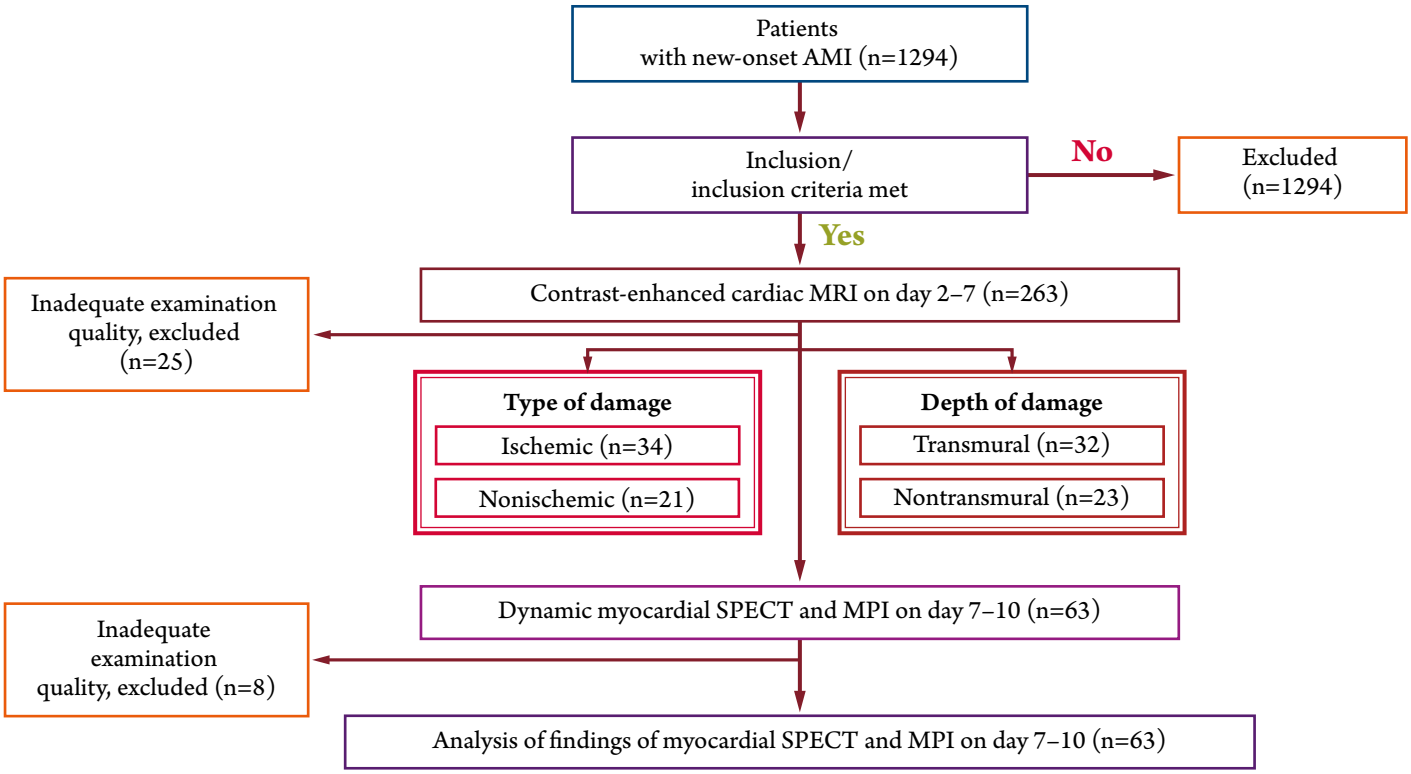
MRI data were evaluated according to the 17 Segment Model of the American Heart Association. The pattern of acute ischemic injury was increased T2WI signal intensity as a sign of myocardial edema and a hyperintense MR signal on delayed images with a typical ischemic pattern of contrast enhancement (subendocardial, transmural). A hypointense signal in the region of increased MR signal intensity was assessed as microvascular obstruction (no-reflow phenomenon).

The pattern of non-ischemic (non-coronary) myocardial damage was determined as a hyperintense signal on delayed MR images with typical intramyocardial, focal, subepicardial accumulation of the contrast agent.

The depth of myocardial damage was transmural and non-transmural – if the contrast agent accumulation in delayed images was more and less than 50% of the myocardial segment thickness, respectively.


ISSN 0022-9040. Kardiologiia. 2023;63(6). DOI: 10.18087/cardio.2023.6.n2439

**Figure 1.** Study design




SPECT, single-photon emission computed tomography; MPI, myocardial perfusion imaging.

## Dynamic cardiac SPECT and myocardial perfusion imaging

### *Radionuclide imaging protocol*

Dynamic SPECT of the heart was performed using a two-day rest-stress protocol. $^{99m}$ Tc-MIBI 3 MBq/kg was used as a radiopharmaceutical. The stress test protocol included intravenous administration of ATP 160 μg/g/min for 4 minutes [7, 8].

Electrocardiogram (ECG) – synchronized myocardial perfusion imaging (MPI) was included in the dynamic SPECT protocol and performed 60 minutes after obtaining a series of dynamic scintigraphic images.

### *Analysis of radionuclide findings*

The Net Retention model with attenuation correction was used to calculate the quantitative indicators of perfusion – myocardial blood flow (MBF) at rest and during pharmacological stress test, the absolute and relative reserve of myocardial blood flow (MFR).

The analysis of MPI data included the assessment of standard indicators: the perfusion defect size during stress test and at rest – summed stress score (SSS) and summed rest score (SRS), respectively, and summed difference score (SDS). Moreover, scintigraphic indicators of LV hemodynamics were obtained during stress test and at rest: left ventricular end-diastolic volume (LVEDV), left ventricular end-systolic volume (LVESV), left ventricular ejection fraction (LVEF), peak ejection rate (PER), peak filling rate (MCR), mean filling rate over the first third of diastole (1/3MFR), time to peak ejection (TTPE), and time to peak filling (TTPF).

The protocol and subsequent processing of native data of dynamic SPECT and MPI were described in previous works [7, 8].

Statistical analysis of data was performed using Statistica 10.0 (Stat Soft Inc). The Shapiro-Wilk test was used to verify the normality of variable distribution. Normally distributed continuous quantitative data are presented as the mean ± standard deviation and non-normally distributed continuous quantitative data are expressed as the median and interquartile range. Categorical data are presented as absolute rates and percentages. A two-tailed Fisher's exact test was used to compare groups with categorical data. The Mann – Whitney U-test was used to evaluate the significance of differences between the groups. The correlations between the indicators were evaluated using the Spearman's correlation coefficient. The differences were considered statistically significant at $p<0.05$.

## Results

### *Characteristics of the study population*

The study included 55 patients with AMI (72.3% were male), mean age was 61.79 ± 11.19. History of

angina pectoris was established in 38% of cases, and dyslipidemia was detected in 76%. ST-segment elevation was observed in 65.5% of patients. At admission, patients had elevated levels of creatine phosphokinase (CPK), CPK-MB, and troponin I – 322.5 [175; 603] U/L, 34 [24; 87] U/L, and 10.33 [1.09; 54.05] ng/mL, respectively. Invasive coronary angiography revealed obstruction in 71% of cases. At the same time, atherosclerotic stenosis was most often observed in the anterior descending artery and the right coronary artery systems. Infarct-related coronary artery was stented in 52.5% of patients (Table 1 and Table 2).

### *State of myocardial blood flow depending on the type of delayed contrast enhancement*

To analyze myocardial damage, several MR patterns are distinguished, which include the nature of the contrast accumulation and the type of contrast enhancement.

All included patients with AMI were divided into two subgroups depending on the nature of paramagnetic contrast agent accumulation: patients with ischemic type of contrast accumulation (n=34; 62%) and patients with non-ischemic contrast accumulation (n=21; 38%).

**Table 1.** Clinical characteristics of patients

| Parameter | Total (n=55) | Patient disposition | | | | | |
|---|---|---|---|---|---|---|---|
| | | Type of paramagnetic contrast accumulation | | | Depth of myocardial damage | | |
| | | Ischemic (n=34) | Nonischemic (n=21) | p | Transmural (n=32) | Nontransmural (n=23) | p |
| Age, years | 61.79 ± 11.19 | 61.1 ± 10.4 | 63.6 ± 13.2 | 0.28 | 62 ± 11.3 | 61.9 ± 11.5 | 0.9 |
| SBP at admission, mm Hg | 130 [120; 150] | 130 [119; 138] | 143.5 [130; 169.5] | 0.144 | 130 [120; 138] | 130 [109.5; 166.5] | 0.859 |
| DBP at admission, mm Hg | 79 [73; 90] | 76 [70; 86] | 89 [82; 90] | 0.143 | 78 [74; 87] | 81 [64; 89] | 0.750 |
| ST-segment elevation, n (%) | 36 (65.5) | 31 (91) | 5 (23) | < 0.0001 | 27 (84) | 9 (39) | 0.001 |
| **Killip class, n (%)** | | | | | | | |
| 0 | 8 (14.5) | 4 (12) | 4 (19) | 0.46 | 4 (12.5) | 4 (17) | 0.7 |
| 1 | 43 (69.1) | 27 (79) | 11 (52) | 0.07 | 26 (81) | 12 (52) | 0.03 |
| 2 | 9 (16.4) | 6 (17.5) | 3 (14) | 0.52 | 4 (12.5) | 5 (22) | 0.006 |
| GRACE risk score, % | 2 [2; 4] | 2 [2; 4] | 2 [2; 3] | 0.96 | 2 [2; 4] | 2.5 [2; 5] | 0.62 |
| **Time to hospitalization, n (%)** | | | | | | | |
| • Less than 3 hours | 26 (47.3) | 19 (56) | 7 (33) | 0.16 | 16 (50) | 10 (43.5) | 0.78 |
| • 3 to 6 hours | 14 (25.5) | 9 (26.5) | 5 (24) | 0.54 | 8 (25) | 6 (26) | 0.58 |
| • 6 to 24 hours | 15 (27.2) | 9 (26.5) | 6 (28.5) | 0.55 | 8 (25) | 7 (30) | 0.76 |
| Body mass index, kg/m2 | 28.85 [25.7; 31.2] | 28.35 [25.36; 30.3] | 29.3 [27; 35.9] | 0.19 | 27.5 [25.4; 30] | 29.9 [27; 35.6] | 0.12 |
| Smoking, n (%) | 25 (45.5) | 19 (56) | 6 (26) | 0.06 | 16 (50) | 9 (39) | 0.58 |
| Hypertensive heart disease, n (%) | 37 (67) | 24 (70.5) | 13 (62) | 0.56 | 23 (71.8) | 14 (60.8) | 0.56 |
| History of exertional angina, n (%) | 21 (38) | 13 (38) | 8 (38) | 0.61 | 12 (37.5) | 9 (39) | 0.56 |
| Dyspnea, n (%) | 45 (82) | 29 (85.3) | 16 (76) | 0.56 | 27 (84) | 18 (78) | 0.72 |
| Diabetes mellitus type 2, n (%) | 8 (14.5) | 2 (5.9) | 6 (28.5) | 0.04 | 2 (6) | 6 (26) | 0.73 |
| CVA, n (%) | 3 (5.5) | 3 (8.8) | 0 | 0.001 | 1 (3) | 2 (8.5) | 0.56 |
| History of COVID-19, n (%) | 2 (3.5) | 0 | 2 (9.5) | 0.003 | 0 | 2 (8.5) | 0.02 |
| Glomerular filtration rate (CKD-EPI), mL/min/1.73m2 | 75 [63; 88] | 76.9 [64; 89] | 72 [58; 84] | 0.54 | 76.9 [64; 89] | 72 [58; 83.9] | 0.24 |
| Heart rate, bpm | 69 [60; 87] | 72 [64; 87] | 60.5 [59; 75.5] | 0.38 | 65.5 [58; 75] | 75 [60.5; 96] | 0.36 |
| Respiratory rate, brpm | 16 [16; 17] | 16.5 [16; 17] | 16 [15.5; 18] | 0.79 | 16 [16; 17] | 16.5 [16; 17] | 0.57 |
| SpO2, % | 96 [95; 98] | 96 [95; 97] | 97 [96; 98] | 0.19 | 96.5 [95; 98] | 96 [95.5; 97] | 0.83 |

CVA, cerebrovascular accident; SPO2, blood oxygen saturation.


ISSN 0022-9040. Kardiologiia. 2023;63(6). DOI: 10.18087/cardio.2023.6.n2439

According to MPI, patients with an ischemic MR pattern had significantly (p<0.05) greater stress-induced perfusion defect that patients with typical clinical signs of AMI and non-ischemic type of contrast enhancement. It should also be noted that MPI with pharmacological stress test showed that patients with ischemic accumulation had significantly lower LVEF. The same indicators calculated at functional rest did not differ between the study groups.

Moreover, patients with an ischemic pattern had lower stress-induced PER and 1/3MFR, and higher TTPE. Dynamic SPECT of the myocardium also showed that patients with ischemic damage were characterized by reduced global stress-induced blood flow, and absolute and relative MFR (Table 3).

### *State of myocardial blood flow depending on the depth of paramagnetic contrast enhancement*

In the analysis of data depending on the depth of myocardial damage according to contrast-enhanced cardiac MRI, all patients were divided into two groups:

Patients with transmural LV damage (n=32, 58%);

Patients with non-transmural LV damage (n=23, 42%).

The MPI findings did not differ significantly between the two groups. However, scintigraphic indicators reflecting LV function during pharmacological load showed a significantly lower LVEF and higher LVESV, decreased PER, 1/3MFR and increased in TTPE in patients with transmural damage. The same indicators calculated at functional rest did not differ between the study groups.

Despite the absence of differences between the groups in the MPI indicators, dynamic SPECT showed that patients with transmural accumulation of the MR contrast agent had significantly lower global stress-induced MBF and absolute and relative global MFR (Table 3).

### *Correlation between dynamic SPECT and cardiac MRI*

Comparative analysis of quantitative indicators of myocardial perfusion with cardiac MRI findings characterizing the degree of LV myocardial damage showed moderate inverse correlation (p<0.05) between stress-induced MBF and myocardial edema (r= –0.47), the infarction area (r= –0.48), and the microvascular obstruction area (r= –0.38), and between MBF at rest and myocardial tissue edema (r= –0.42) and the infarction volume (r= –0.38).

## Discussion

This study shows for the first time the correlation between the type and depth of myocardial damage as determined by MRI and microcirculatory disorders identified by dynamic SPECT of the heart in patients with subacute AMI. Patients with deeper – transmural –

**Table 2.** Findings of invasive coronary angiography

| Parameter | Total (n=55) | Patient disposition: Type of paramagnetic contrast accumulation | | | Patient disposition: Depth of myocardial damage | | |
|---|---|---|---|---|---|---|---|
| | | Ischemic (n=34) | Nonischemic (n=21) | p | Transmural (n=32) | Nontransmural (n=23) | p |
| Nonobstructive coronary artery disease, n (%) | 16 (29) | 7 (20.5) | 9 (43) | 0.13 | 6 (19) | 10 (43.5) | 0.07 |
| Obstructive coronary artery disease, n (%) | 39 (71) | 31 (91) | 8 (38) | 0.00001 | 26 (81) | 13 (56.5) | 0.071 |
| LMCA, n (%) | 1 (2) | 1 (3) | 0 (0) | 1.0 | 0 (0) | 1 (4) | 0.42 |
| LAD, n (%) | 25 (45.5) | 21 (62) | 4 (19) | 0.0024 | 16 (50) | 9 (39) | 0.58 |
| LCX, n (%) | 15 (2) | 10 (29) | 5 (23) | 0.761 | 9 (28) | 6 (26) | 1.0 |
| RCA, n (%) | 22 (40) | 18 (53) | 4 (19) | 0.0224 | 14 (44) | 8 (35) | 0.58 |
| Stenting, n (%) | 29 (52.5) | 25 (73.5) | 4 (19) | 0.0001 | 19 (59) | 10 (43) | 0.28 |
| **TIMI at baseline, n (%)** | | | | | | | |
| 0 | 15 (27) | 13 (38) | 4 (19) | 0.23 | 12 (37.5) | 3 (14) | 0.07 |
| 1 | 8 (14.5) | 7 (20.5) | 1 (5) | 0.14 | 6 (19) | 1 (4) | 0.22 |
| 2 | 6 (11) | 3 (9.5) | 3 (14) | 0.66 | 5 (15.5) | 1 (4) | 0.38 |
| 3 | 26 (47.5) | 11 (32) | 13 (62) | 0.05 | 9 (28) | 18 (78) | 0.0003 |
| **TIMI after stenting, n (%)** | | | | | | | |
| 1 | 2 (3.5) | 2 (6) | 1 (5) | 0.67 | 2 (6) | 1 (4) | 0.62 |
| 2 | 3 (5.5) | 3 (9) | 1 (5) | 0.51 | 3 (9) | 1 (4) | 0.63 |
| 3 | 50 (91) | 29 (85) | 19 (90) | 0.69 | 27 (85) | 21 (92) | 0.68 |

TIMI, thrombolysis in myocardial infarction score.

**Table 3.** Findings of MPI and dynamic SPECT

| Parameter | Total (n=55) | Patient disposition | | | | | |
|---|---|---|---|---|---|---|---|
| | | Type of paramagnetic contrast accumulation | | | Depth of myocardial damage | | |
| | | Ischemic (n=34) | Nonischemic (n=21) | p | Transmural (n=32) | Nontransmural (n=23) | p |
| **MPI** | | | | | | | |
| SSS | 3 [1; 6.5] | 6 [3; 9] | 1.5 [0; 3] | 0.042 | 6 [3; 9] | 3 [0; 3] | 0.11 |
| SRS | 0.5 [0; 6.5] | 4 [0; 7] | 0 [0; 0] | 0.055 | 6 [0; 7] | 0 [0; 2] | 0.21 |
| SDS | 0 [0; 3] | 1 [0; 3] | 0 [0; 3] | 0.79 | 0 [0; 2] | 0 [0; 3] | 0.84 |
| LVEDV, stress, mL | 132.5 [116; 157.5] | 136 [123; 178] | 126.5 [70; 148] | 0.26 | 139 [111; 178] | 129 [121; 148] | 0.26 |
| LVESV, stress, mL | 50.5 [36; 66.5] | 63 [43; 111] | 37.5 [18; 52] | 0.056 | 62 [39; 111] | 43 [33; 64] | 0.0559 |
| LVEF, stress, % | 65 [51.5; 71] | 54 [43; 65] | 71 [65; 75] | 0.016 | 55 [43; 65] | 65 [57; 74] | 0.016 |
| LVEDV, rest, mL | 134 [104; 152] | 135.5 [106; 178] | 120 [97; 149] | 0.37 | 139 [104; 178] | 124 [104; 149] | 0.54 |
| LVESV, rest, mL | 50 [39; 63.5] | 56.5 [43; 110] | 43.5 [30; 54] | 0.18 | 59 [37; 110] | 45 [41; 54] | 0.35 |
| LVEF, rest, % | 60 [55; 67] | 58 [43; 64] | 66.5 [61; 70] | 0.09 | 58 [43; 64] | 64 [58; 69] | 0.299 |
| PFR, stress, LVEDV/s | 1.87 [1.705; 2.68] | 1.76 [1.69; 2.15] | 2.345 [1.84; 4.21] | 0.15 | 1.9 [1.69; 2.61] | 1.84 [1.72; 2.75] | 0.15 |
| PER, stress, LVEDV/s | 2.695 [2.275; 3.275] | 2.395 [2.01; 2.63] | 3.865 [2.88; 5.42] | 0.003 | 2.55 [2.01; 3.1] | 2.88 [2.49; 4.29] | 0.003 |
| 1/3MFR, stress, LVEDV/s | 1.275 [0.985; 1.41] | 1.175 [0.96; 1.29] | 1.395 [1.3; 2.1] | 0.055 | 1.26 [0.96; 1.36] | 1.3 [1.15; 1.46] | 0.0559 |
| TTPF, stress, ms | 168.5 [136; 241.5] | 168.5 [135; 232] | 178 [137; 251] | 1.00 | 168 [135; 232] | 169 [137; 251] | 1.00 |
| TTPE, stress, ms | 174.5 [149; 320] | 294.5 [183; 355] | 148 [107; 165] | 0.005 | 311 [203; 355] | 159 [137; 165] | 0.005 |
| PFR, rest, LVEDV/s | 2.115 [1.6; 2.55] | 2.02 [1.52; 2.42] | 2.24 [1.68; 2.62] | 0.71 | 2.23 [1.5; 2.81] | 2 [1.79; 2.48] | 0.92 |
| PER, rest, LVEDV/s | 2.43 [2.06; 2.89] | 2.285 [1.86; 2.54] | 2.78 [2.41; 4.05] | 0.07 | 2.49 [1.89; 2.79] | 2.41 [2.23; 3.11] | 1.00 |
| 1/3MFR, rest, LVEDV/s | 1.185 [1.02; 1.47] | 1.185 [0.99; 1.32] | 1.29 [1.05; 1.56] | 0.635 | 1.19 [0.99; 1.53] | 1.18 [1.14; 1.41] | 0.76 |
| TTPF, rest, ms | 160 [126; 194.5] | 159 [125; 190] | 161 [135; 199] | 0.635 | 160 [127; 190] | 160 [125; 199] | 0.84 |
| TTPE, rest, ms | 271.5 [229.5; 308.5] | 272 [225; 324] | 258.5 [234; 293] | 0.79 | 268 [225; 278] | 275 [234; 324] | 0.76 |
| **Dynamic SPECT** | | | | | | | |
| MBF, stress, mL/min/g | 0.86 [0.63; 1.45] | 0.76 [0.62; 1.39] | 1.41 [0.85; 1.74] | 0.006 | 0.78 [0.62; 1.255] | 1.2 [0.68; 1.74] | 0.045 |
| MBF, rest, mL/min/g | 0.51 [0.32; 0.8] | 0.465 [0.32; 0.71] | 0.69 [0.4; 1.08] | 0.115 | 0.55 [0.32; 0.81] | 0.47 [0.34; 0.77] | 0.84 |
| MFR rel. | 1.78 [1.19; 2.38] | 1.75 [1.16; 2.34] | 2.1 [1.61; 2.42] | 0.037 | 1.75 [1.08; 2.185] | 2.1 [1.61; 2.9] | 0.04 |
| MFR abs., mL/min/g | 0.37 [0.11; 0.76] | 0.255 [0.1; 0.57] | 0.66 [0.3; 1.12] | 0.032 | 0.225 [0.07; 0.48] | 0.59 [0.2; 1.12] | 0.0075 |

MPI, myocardial perfusion imaging; SPECT, single photon emission computed tomography; SSS, summed stress score; SRS, summed rest score; SDS, summed difference score; LVEDV, left ventricular end-diastolic volume; PFR, peak filling rate; PER, peak ejection rate; 1/3MFR, filling rate over the first third of diastole; TTPF, time to peak filling; TTPE, time to peak ejection; MBF, myocardial blood flow; MFR, myocardial flow reserve.

myocardial damage and the ischemic type of contrast agent accumulation have more severe microcirculatory disorders as shown by dynamic SPECT of the heart.

Cardiac MRI has exceptional characteristics for visualizing myocardial wall damage [10, 11]. This technique allows not only identifying myocardial damage but also determining the substrate of this damage [12], its cause [13], and further prognosis of the disease course [14]. Our study showed that patients with ischemic contrast agent accumulation and deeper myocardial damage are characterized by reduced and stress-induced MBF and absolute and relative MFR. This is most likely due to the severity of microcirculatory abnormalities, the volume of which determines the size of myocardial damage in patients with acute coronary complications, which was shown in several studies in patients with stable CAD [6]. At the same time, non-transmural myocardial damage may occupy a significant area but not extend deeper. This explains the lack of differences in the MPI findings between the groups. At the same time, changes in resting MPI detected in the subacute period of AMI do not fully correspond to the formed scar [14]. This may explain the discrepancy between the MPI and MRI data. However, patients with the ischemic pattern and transmural wall damage as shown by MRI had LV systolic dysfunction during stress test, which was absent at rest. Thus, it may be useful to assess not only standard indices but also additional MPI indicators.

A decrease in myocardial microcirculation has been previously shown in areas with MR signs of


ISSN 0022-9040. Kardiologiia. 2023;63(6). DOI: 10.18087/cardio.2023.6.n2439

damage in patients with AMI [15]. More severe changes were observed in the group of patients with obstructive CAD. A decrease in quantitative indicators of microcirculation was also detected in areas of myocardial fibrosis [16] and segments with impaired wall motion [4]. The authors of the presented works confirm that microcirculatory disorders play significant roles in the development of coronary insufficiency and that these changes should be assessed in patients with various cardiological diseases, which once again confirms the findings of this study.

It should be noted that the degree and volume of microcirculatory disorders largely depend on their causes. Microcirculatory dysfunction can be the result of functional or structural abnormalities and their combinations. Functional mechanisms include vasodilation disorders and/or more pronounced vasoconstrictor phenomena, which are common in endothelial dysfunction, mast cell hyperactivity, and epicardial vasospasm. Structural causes of microvascular abnormalities may be remodeling of the vascular wall as a result of mast cell proliferation and activation, perivascular fibrosis, or inflammatory changes; reduction of the capillary network; external compression of vessels; infiltration of the vascular wall; coronary artery obstructions [3]. However, in reality, the two mechanisms work together to cause microvascular disorders. In patients with acute coronary syndrome (ACS), microcirculatory abnormalities may be due to coronary embolism or occlusion at both the macrocirculatory and microcirculatory levels, inflammatory changes in the myocardium, artery spasm, etc. [3]. Thus, microcirculatory abnormalities in patients with ACS can be both a cause and a consequence of myocardial tissue damage, which is indirectly confirmed by the relation between these pathogenetic links in this study and several other studies [3, 16].

### *Limitations*

This work is limited by the small sample size and single-center design of the study. Nevertheless, we obtained statistically significant differences between the study groups. Moreover, dynamic myocardial SPECT was performed 7–10 days after hospitalization, and revascularization by stenting was performed in selected patients. This could also affect the results of semiquantitative and quantitative assessment of myocardial perfusion.

## Conclusion

Indicators of dynamic single photon emission computed tomography, which characterize microcirculation disorders that occur independently or as a result of epicardial coronary damage, reflect the severity and depth of structural changes in the myocardium in acute myocardial infarction. At the same time, the quantitative indicators of myocardial perfusion are correlated with myocardial tissue damage more closely than the semi-quantitative indices of myocardial perfusion imaging. The facts revealed in this study can make a separate contribution to heterogeneity of the group of patients with acute coronary syndrome and acute myocardial infarction. Additional studies are required to understand the prognostic significance of dynamic single photon emission computed tomography – myocardial blood flow and myocardial flow reserve.

***Funding***

*The study was supported by a grant of the Russian Science Foundation (project N 21-75-00051, https://rscf.ru/project/21-75-00051/).*

*No conflict of interest is reported.*

**The article was received on 09/03/2023**

REFERENCES

1. Staroverov I.I., Shakhnovich R.M., Gilyarov M.Yu., Komarov A.L., Konstantinova E.V., Panchenko E.P. et al. Eurasian clinical guidelines on diagnosis and treatment of acute coronary syndrome with st segment elevation (STEMI). Eurasian heart journal. 2020;1(30):4–77. [Russian: Староверов И.И., Шахнович Р.М., Гиляров М.Ю., Комаров А.Л., Константинова Е.В., Панченко Е.П. и др. Евразийские клинические рекомендации по диагностике и лечению острого коронарного синдрома с подъемом сегмента ST (ОКСпST). Евразийский кардиологический журнал. 2020;1(30):4-77]. DOI: 10.38109/2225-1685-2020-1-4-77
2. Collet J-P, Thiele H, Barbato E, Barthélémy O, Bauersachs J, Bhatt DL et al. 2020 ESC Guidelines for the management of acute coronary syndromes in patients presenting without persistent ST-segment elevation. European Heart Journal. 2021;42(14):1289–367. DOI: 10.1093/eurheartj/ehaa575
3. Del Buono MG, Montone RA, Camilli M, Carbone S, Narula J, Lavie CJ et al. Coronary Microvascular Dysfunction Across the Spectrum of Cardiovascular Diseases. Journal of the American College of Cardiology. 2021;78(13):1352–71. DOI: 10.1016/j.jacc.2021.07.042
4. Rigo F, Sicari R, Gherardi S, Djordjevic-Dikic A, Cortigiani L, Picano E. The additive prognostic value of wall motion abnormalities and coronary flow reserve during dipyridamole stress echo. European Heart Journal. 2007;29(1):79–88. DOI: 10.1093/eurheartj/ehm527
5. Fukuoka Y, Nakano A, Tama N, Hasegawa K, Ikeda H, Morishita T et al. Impaired myocardial microcirculation in the flow-glucose metabolism mismatch regions in revascularized acute myocardial infarction. Journal of Nuclear Cardiology. 2017;24(5):1641–50. DOI: 10.1007/s12350-016-0526-z
6. Xu J, Cai F, Geng C, Wang Z, Tang X. Diagnostic Performance of CMR, SPECT, and PET Imaging for the Identification of Coronary Artery Disease: A Meta-Analysis. Frontiers in Cardiovascular Medicine. 2021;8:621389. DOI: 10.3389/fcvm.2021.621389

7. Zavadovsky KV, Mochula AV, Maltseva AN, Boshchenko AA, Baev AE, Andreev SL et al. The diagnostic value of SPECT CZT quantitative myocardial blood flow in high-risk patients. Journal of Nuclear Cardiology. 2022;29(3):1051–63. DOI: 10.1007/s12350-020-02395-8
8. Maltseva A.N., Mochula A.V., Kopyeva K.V., Grakova E.V., Zavadovsky K.V. Radionuclide imaging methods in the diagnosis of microvascular dysfunction in non-obstructive coronary artery disease. Russian Journal of Cardiology. 2021;26(12):181–8. [Russian: Мальцева А.Н., Мочула А.В., Копьева К.В., Гракова Е.В., Завадовский К.В. Радионуклидные методы исследования в диагностике микроваскулярной дисфункции при необструктивном атеросклеротическом поражении коронарных артерий. Российский кардиологический журнал. 2021;26(12):181-8]. DOI: 10.15829/1560-4071-2021-4746
9. Pan J, Yuan M, Yu M, Gao Y, Shen C, Wang Y et al. Myocardial Blood Flow Quantified by Low-Dose Dynamic CT Myocardial Perfusion Imaging Is Associated with Peak Troponin Level and Impaired Left Ventricle Function in Patients with ST-Elevated Myocardial Infarction. Korean Journal of Radiology. 2019;20(5):709–18. DOI: 10.3348/kjr.2018.0729
10. Terenicheva M.A., Shakhnovich R.M., Stukalova O.V., Pevzner D.V., Arutyunyan G.K., Demchenkova A.Yu. et al. Correlations between clinical and laboratory findings and prognostically unfavorable CMR-based characteristics of acute ST-elevation myocardial infarction. Kardiologiia. 2021;61(1):44–51. [Russian: Тереничева М.А., Шахнович Р.М., Стукалова О.В., Певзнер Д.В., Арутюнян Г.К., Демченкова А.Ю. и др. Взаимосвязь клинических и лабораторных показателей с развитием прогностически неблагоприятных характеристик инфаркта миокарда с подъемом сегмента ST по данным магнитно-резонансной томографии сердца с контрастированием. Кардиология. 2021;61(1):44-51]. DOI: 10.18087/cardio.2021.1.n1373
11. Mochula O.V., Sulejmanova A.S., Sukhareva A.E., Ryabov V.V., Zavadovsky K.V. Relationship between the degree of myocardial damage according to contrast-enhanced cardiac magnetic resonance imaging and laboratory data in patients with acute myocardial infarction. Russian Journal of Cardiology. 2022;27(11):30–8. [Russian: Мочула О.В., Сулейманова А.С., Сухарева А.Е., Рябов В.В., Завадовский К.В. Взаимосвязь степени повреждения миокарда по данным магнитно-резонансной томографии сердца с контрастированием и лабораторных данных у пациентов с острым инфарктом миокарда. Российский кардиологический журнал. 2022;27(11):30-8]. DOI: 10.15829/1560-4071-2022-5226
12. Stukalova O.V., Gupalo E.M., Chumachenko P.V., Samko A.N., Butorova E.A., Shakhnovich R.M. et al. The value of cardiovascular magnetic resonance in myocarditis with different clinical presentation. Therapeutic Archive. 2019;91(4):28–36. [Russian: Стукалова О.В., Гупало Е.М., Чумаченко П.В., Самко А.Н., Буторова Е.А., Шахнович Р.М. и др. Возможности магнитно-резонансной томографии сердца с контрастированием в диагностике миокардита различного клинического течения. Терапевтический архив. 2019;91(4):28-36]. DOI: 10.26442/00403660.2019.04.000078
13. Pershina E.S., Shchekochikhin D.Yu., Shaginyan G.M., Shilova A.S., Sherashov A.V., Poltavskaya M.G. et al. Cardiovascular magnetic resonance in myocardial infarction with non-obstructive coronary arteries. Therapeutic Archive. 2021;93(4):376–80. [Russian: Першина Е.С., Щекочихин Д.Ю., Шагинян Г.М., Шилова А.С., Шерашов А.В., Полтавская М.Г. и др. Значение магнитно-резонансной томографии в диагностике инфаркта миокарда без обструктивного поражения коронарных артерий. Терапевтический архив. 2021;93(4):376-80]. DOI: 10.26442/00403660.2021.04.200676
14. Kim HW, Farzaneh-Far A, Kim RJ. Cardiovascular Magnetic Resonance in Patients With Myocardial Infarction. Journal of the American College of Cardiology. 2009;55(1):1–16. DOI: 10.1016/j.jacc.2009.06.059
15. Zavadovsky KV, Vorobyeva DA, Mochula OV, Mochula AV, Maltseva AN, Bayev AE et al. Myocardial Blood Flow and Flow Reserve in Patients With Acute Myocardial Infarction and Obstructive and Non-Obstructive Coronary Arteries: CZT SPECT Study. Frontiers in Nuclear Medicine. 2022;2:935539. DOI: 10.3389/fnume.2022.935539
16. Everaars H, van Diemen PA, Biesbroek PS, Hopman LHGA, Bom MJ, Schumacher SP et al. Comparison between cardiac magnetic resonance stress T1 mapping and [15O]H2O positron emission tomography in patients with suspected obstructive coronary artery disease. European Heart Journal - Cardiovascular Imaging. 2022;23(2):229–37. DOI: 10.1093/ehjci/jeab073




ISSN 0022-9040. Kardiologiia. 2023;63(6). DOI: 10.18087/cardio.2023.6.n2439