Int Cardiovasc Res J.2022;**16**(1):9-13.icrj.119268

International Cardiovascular Research Journal

www.ircrj.com

# Noninvasive Index of Microvascular Resistance as a Predictor of Left Ventricular Performance Recovery in Patients with STEMI Undergoing Primary PCI

Mohammad Javad Alemzadeh-Ansari [1], MD; Seifollah Abdi [1], MD, Bahram Mohebbi [1], MD; Saman Rostambeigi [1], MD; Azin Alizadehasl [1, *], MD; Mohammad Mehdi Peyghambari [1], MD; Zahra Hosseini [1], MD; Yasaman Khalili [1], MD

[1] Cardiovascular Intervention Research Center, Rajaie Cardiovascular Medical and Research Center, Iran University of Medical Sciences, Tehran, IR Iran

ARTICLE INFO

*Article Type:*
Research Article

*Article History:*
Received: 1 Sep 2021
Revised: 1 Jan 2022
Accepted: 18 Jan 2022

*Keywords:*
Percutaneous Coronary Intervention
Left Ventricular Dysfunction
Function
Microvascular Function

ABSTRACT

**Background:** Coronary microvascular function can predict the infarct size and Left Ventricular (LV) functional recovery in patients diagnosed with ST-Elevation Myocardial Infarction (STEMI). Multiple invasive and non-invasive methods are used to evaluate coronary microvascular function. The Non-invasive Index of Microvascular Resistance (NiMR) is a method to evaluate microvascular resistance.

**Objectives:** This study aimed to assess the relationship between NiMR and Left Ventricular Ejection Fraction (LVEF) measured by Transthoracic Echocardiography (TTE) in patients with acute STEMI undergoing primary Percutaneous Coronary Intervention (PCI).

**Methods:** This prospective observational study was conducted on 39 patients with STEMI. NiMR was measured instantly after primary PCI. After that, the patients were divided into two groups based on their NiMR: Group 1 (n = 20) with slighter microvascular dysfunction (NiMR < 24) and Group 2 (n = 19) with more severe microvascular dysfunction (NiMR ≥ 24). In the first 24 hours (Echo1) and one month after primary PCI (Echo2), LVEF and the Global Longitudinal Strain (GLS) were measured by TTE.

**Results:** The mean age of the patients was 58.0 ± 11.3 years, and 34 ones (87.1%) were male. In Echo1, there were no significant differences between the two groups regarding LVEF (39.6 ± 7.8% vs. 38.8 ± 8.6%; P = 0.761) and GLS (–10.2 ± 2.5 vs. –10.9 ± 3.2; P = 0.487). However, LVEF improvement was higher in Group 1 than in Group 2 (Δ LVEF = 5.8 ± 7.3% in Group 1 vs. Δ LVEF = 1.3 ± 8% in Group 2; P = 0.073), but the difference was not statistically significant (OR: 2.8, 95% CI: 0.72 - 10.7; P = 0.13). GLS also exhibited an improvement in both study groups after a month (Δ GLS = 5.4 ± 3.1 in Group 1 vs. Δ GLS = 2.4±3.2 in Group 2; P = 0.005), but this improvement was statistically significant only in Group 1 (OR: 5.5, 95% CI: 1.32 - 22.8; P = 0.01).

**Conclusions:** In patients with lower NiMR values, LV systolic function recovery (defined by improvement in GLS) was significantly higher one month after STEMI. Thus, NiMR can be used as an early marker of LV performance recovery after acute STEMI.

## 1. Introduction

Primary Percutaneous Coronary Intervention (PCI) is an accepted strategy for reperfusion in ST-Elevation Myocardial Infarction (STEMI) (1). Primary PCI can improve clinical outcomes in patients with STEMI. Nonetheless, it may be followed by impaired microvascular perfusion, leading to persistent myocardial non-viability. The target of the current strategies for the treatment of STEMI is to reach total revascularization at the myocardial tissue level. Up to now, several invasive and non-invasive techniques have been used to evaluate microvascular circulation (2-6). Previous studies have shown that the Index of Microvascular Resistance (IMR) measured at the time of STEMI demonstrates coronary microvascular

*Corresponding author: Azin Alizadehasl, Cardio-Oncology Department and Research Center, Rajaie Cardiovascular Medical and Research Center, Tehran, Iran. Tel: +98-2123922190,
Email:alizadeasl@gmail.com.

function, correlates with infarct size, and predicts Left Ventricular (LV) functional recovery (7-11).

Previous studies indicated a relationship between IMR and post-STEMI recovery in myocardial function, as expressed by myocardial strain (2, 11-14). Nevertheless, the correlation between the Non-invasive Index of Microvascular Resistance (NiMR) and the Global Longitudinal Strain (GLS) after STEMI has yet to be elucidated.

## 2. Objectives

the present study aims to evaluate the relationship between NiMR and LV functional recovery according to systolic and diastolic echocardiographic parameters in patients with STEMI undergoing primary PCI.

## 3. Methods

This prospective observational study was conducted on 39 patients with the first STEMI treated by primary PCI within 12 hours from the onset of symptoms. The first STEMI was diagnosed based on acute chest pain lasting for at least 20 minutes, ST-segment elevation of at least 1 mm in two or more contiguous leads in electrocardiography, and Thrombolysis In Myocardial Infarction (TIMI) flow grade of 0 or 1 at the initial coronary angiography. Patients with cardiogenic shock, renal insufficiency (defined as serum creatinine > 1.5 mg/dL), contraindications to adenosine, pregnancy, previous STEMI, and previous coronary artery bypass surgery were excluded. The patients with severe valvular heart disease and those with more than one culprit lesion were excluded, as well. Primary PCI was used as the standard method of treatment of patients with STEMI. The study protocol was approved by the Institutional Ethics Committee and written informed consent was obtained from all the patients.

Primary PCI was successfully performed in patients aged 18 years or above on the culprit lesion of a native coronary artery based on the current international guidelines. All the patients received oral aspirin (162 mg) and a bolus of heparin (100 U/kg) before the procedure. If the procedure lasted for more than 90 minutes, additional heparin was given to maintain a minimum activated clotting time of 250 seconds.

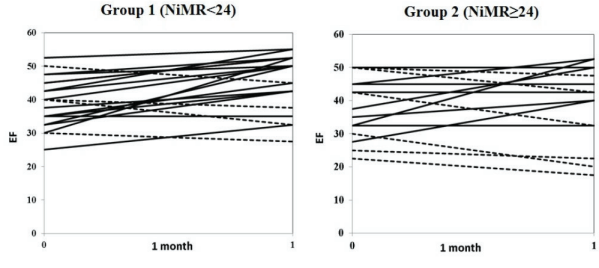
All medical decisions were made blinded to the NiMR measurements. Transthoracic echocardiography and 2D speckle-tracking imaging were performed within the first 24 hours (Echo1) and after one month (Echo2) to obtain the Left Ventricular Ejection Fraction (LVEF) and GLS (Figure 1). All the patients were discharged successfully without any complications, and medical therapy based on the current international guidelines was started.

### *3.1. NiMR Calculation*

Previously, a study by Babakhani et al. (15) showed that the calculated non-invasive 2D Fractional Flow Reserve (FFR) yielded comparable results to those derived from invasive FFR. In the present study, NiMR was computed immediately after successful primary PCI. One projection of patient-specific X-ray angiography was selected to obtain coronary stenosis size. A contrast-filled catheter (5F or 6F) was used as the calibration standard for the right and left coronary arteries. The projection demonstrating the stenosis with the least foreshortening, stenosis diameter, lesion length, distal diameter, and proximal diameter in the end-diastolic frame was manually selected using the MicroDicom software (Figure 2). For the conversion of pixel size into millimeters, a scaling factor was determined. Angiography was performed using a manual injection of contrast dye, and images were acquired digitally at a speed of 15 frames per second.

The TIMI Frame Count (TFC) was used to assess the flow across the stenotic region based on the angiographic images. TFC, which can be applied inexpensively, counts the number of frames needed for the dye to reach a distal landmark (7, 8). Subsequently, the contrast transport time was calculated in the target branch of the coronary artery on rest projections via TFC. The mean flow rate at rest state was derived using the mean length of the coronary artery divided by the contrast transport time multiplied by the cross-sectional reference area. Intracoronary adenosine injection was performed to obtain maximum hyperemia through the effect of adenosine on reducing resistance in the downstream coronary arteries. Adjedj et al. (16) reported that maximum coronary hyperemia could be achieved with 100 μg in the right coronary artery and 200 μg in the left coronary artery. The same doses were applied to reach maximum coronary hyperemia in the current study.

**Figure 1.** The Images Illustrate the Changes in the Left Ventricular Ejection Fraction Based on the Non-Invasive Index of Microvascular Resistance (Group 1: 39.6 ± 7.8% to 45.5 ± 7.8%, Group 2: 38.8 ± 8.6% to 40.1 ± 10.7%; Δ LVEF = 5.8 ± 7.3% in Group 1 vs. Δ LVEF = 1.3 ± 8% in Group 2; P = 0.073).




Abbreviations: LVEF, left ventricular ejection fraction; NiMR, non-invasive index of microvascular resistance.

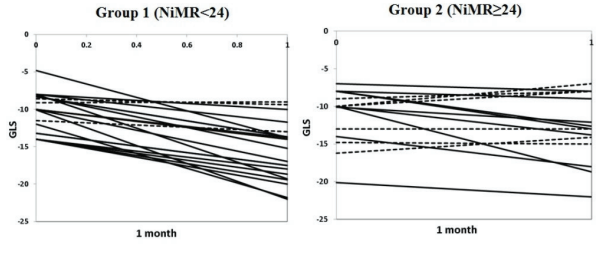



**Figure 2.** The Images Depict Changes in the Global Longitudinal Strain Based on the Non-Invasive Index of Microvascular Resistance (Group 1: −10.2 ± 2.5 to −15.7 ± 3.7 and Group 2: −10.9 ± 3.2 to −13.4 ± 4; Δ GLS = 5.4 ± 3.1 in Group 1 vs. Δ GLS = 2.4 ± 3.2 in Group 2; P = 0.005). GLS, global longitudinal strain; NiMR, non-invasive index of microvascular resistance.

*3.2. Echocardiographic Study*

Transthoracic echocardiography was performed using a Philips Epiq 7 system blinded to the NiMR results of the patients. LV volumes and LVEF were obtained from the 4- and 2-chamber views. In order to assess GLS, gray-scale 4-chamber, 2-chamber, and long-axis views were obtained and speckle-tracking analysis was performed via automated function imaging. Change in the length of the myocardium from end-diastole to end-systole was defined as the peak longitudinal strain (as a percentage):

Longitudinal strain (%) ¼ (L end-systole—L end-diastole)/L end-diastole 100%

Where L was the length of the region of interest.

Additionally, LVGLS was calculated by estimating the mean of the peak systolic longitudinal strain values from 17 LV segments.

*3.3. Statistical Analysis*

Statistical analyses were performed using the SPSS 16.0 software (SPSS, Inc., Chicago, IL, USA). The data were assessed by descriptive statistics, namely frequency, percentage, mean, and standard deviation. Student t-test was used to evaluate the quantitative variables, while chi-square test was utilized to analyze the categorical ones. Correlation analyses (Pearson method) were also employed to assess the relationship between the parameters. $P < 0.05$ was considered statistically significant. All p-values were two-sided, and 95% Confidence Interval (CI) was reported for each variable.

## 4. Results

The mean age of the patients was 58.0 ± 11.3 years, and males comprised 87.1% of the study population (n = 34). The patients were divided into two groups based on their median NiMR: Group 1 with a lower degree of microvascular dysfunction (NiMR < 24) and Group 2 with a higher degree of microvascular dysfunction (NiMR ≥ 24). The baseline characteristics of these groups have been summarized in Table 1.

On the initial echocardiography (within the first 24 hours), there were no significant differences between the two groups in terms of LVEF (39.6 ± 7.8% vs. 38.8 ± 8.6%; P = 0.761) and GLS (−10.2 ± 2.5 vs. −10.9 ± 3.2; P = 0.487) (Table 1). In the follow-up echocardiography (after one month), LVEF improvement was higher in Group 1 than in Group 2 (Δ LVEF = 5.8 ± 7.3% in Group 1 vs. Δ LVEF = 1.3 ± 8% in Group 2; P = 0.073). However, this difference was not statistically significant (OR = 2.8, 95% CI: 0.72 - 10.7; P = 0.13) (Table 2). GLS also exhibited an improvement in

**Table 1.** Baseline Characteristics of the Patients

| Parameter | | Group 1 (NiMR < 24) (n = 20) | Group 2 (NiMR ≥ 24) (n = 19) | P-value | Total |
|---|---|---|---|---|---|
| Age (y) | | 56.4 ± 10.2 | 59.6 ± 12.5 | 0.382 | 58.0 ± 11.3 |
| Sex | Male (n, %) | 18 (90%) | 16 (84%) | 0.661 | 34 (87.1%) |
| | Female (n, %) | 2 (10%) | 3 (15%) | | 5 (12.8%) |
| Diabetes mellitus (n, %) | | 1 (5%) | 5 (26%) | 0.091 | 6 (15.3%) |
| Hypertension (n, %) | | 10 (50%) | 7 (36%) | 0.408 | 17 (43.5%) |
| Smoking (n, %) | | 11 (55%) | 7 (36%) | 0.256 | 18 (46.1%) |
| Dyslipidemia (n, %) | | 5 (25%) | 3 (15%) | 0.695 | 8 (20.5%) |
| FH (n, %) | | 3 (15%) | 2 (10%) | 1.000 | 5 (12.8%) |
| Hemoglobin (mg/dL) | | 14.3 ± 1.6 | 14.3 ± 2 | 0.975 | 14.3 ± 1.7 |
| Serum creatinine (mg/dL) | | 1 ± 0.1 | 1.1 ± 0.5 | 0.566 | 1.1 ± 0.3 |
| LAD-diagonal (n,%) | | 13 (65%) | 12 (63%) | 0.174 | 25 (64.1%) |
| LCX-OM | | 5 (25%) | 2 (10%) | | 7 (17.9%) |
| RCA-PDA-PLV | | 1 (5%) | 5 (26%) | | 6 (15.3%) |
| Ramus | | 1 (5%) | 0 (0%) | | 1 (2.5%) |
| NiMR (mean ± SD) | | 20.5 ± 2.5 | 30.5 ± 7.3 | 0.000 | 25.4 ± 7.3 |
| EF1 (%) | | 39.6 ± 7.8 | 38.8 ± 8.6 | 0.761 | 39.2 ± 8.1 |
| EF2 | | 45.5 ± 7.8 | 40.1 ± 10.7 | 0.082 | 42.8 ± 9.6 |
| GLS1 | | −10.2 ± 2.5 | −10.9 ± 3.2 | 0.487 | -10.6 ± 2.9 |
| GLS2 | | −15.7 ± 3.7 | −13.4 ± 4 | 0.064 | -14.6 ± 4 |

Abbreviations: NiMR, noninvasive index of microvascular resistance; FH, family history; LAD, left anterior descending coronary artery; LCX, left circumflex artery; OM, obtuse marginal; RCA, right coronary artery; PDA, patent ductus arteriosus; PLV, posterior left ventricular artery; EF, ejection fraction; GLS, global longitudinal strain.

**Table 2.** Echocardiography Findings at Baseline and One Month Later

| Parameter | | Group 1 (NiMR < 24) (n = 20) | Group 2 (NiMR ≥ 24) (n = 19) | P-value |
|---|---|---|---|---|
| Left ventricular ejection fraction (%) | Baseline | 39.6 ± 7.8 | 38.8 ± 8.6 | 0.761 |
| | One month later | 45.5 ± 7.8 | 40.1 ± 10.7 | 0.082 |
| | Δ Ejection fraction | 5.8 ± 7.3 | 1.3 ± 8 | 0.073 |
| Global longitudinal strain | Baseline | −10.2 ± 2.5 | −10.9 ± 3.2 | 0.487 |
| | One month later | −15.7 ± 3.7 | −13.4 ± 4 | 0.064 |
| | Δ Global longitudinal strain | 5.4 ± 3.1 | 2.4 ± 3.2 | 0.005 |

Abbreviations: NiMR, noninvasive index of microvascular resistance

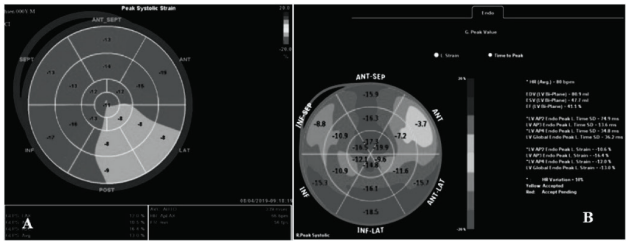



**Figure 3**. A 69-Year-Old Woman Presented with Anterior ST-Segment-Elevation Myocardial Infarction. The Patient Underwent Primary Percutaneous Coronary Intervention. The Non-Invasive Index of Microvascular Resistance Was 19.57, Indicating a Lower Degree of Microvascular Dysfunction. The Baseline Global Longitudinal Strain Was −13.2 (A). Fortunately, The Global Longitudinal Strain Exhibited a Significant Improvement After One Month (−17.5) (B).

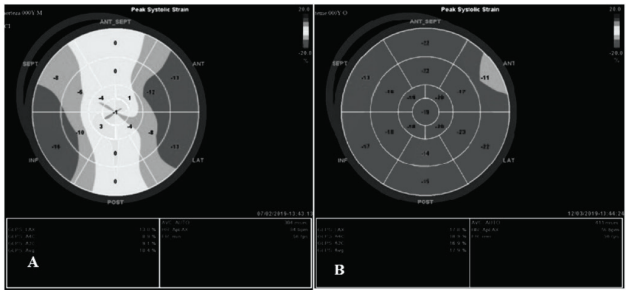



**Figure 4**. A 41-Year-Old Man Presented with Anterior St-Segment-Elevation Myocardial Infarction. The Patient Underwent Primary Percutaneous Coronary Intervention. The Non-Invasive Index of Microvascular Resistance Was 37.03, Indicating a Higher Degree of Microvascular Dysfunction. The Baseline Global Longitudinal Strain Was −13 (A). Unfortunately, The Global Longitudinal Strain Did Not Differ After One Month (B).

both groups after one month (Δ GLS = 5.4 ± 3.1 in Group 1 vs. Δ GLS = 2.4 ± 3.2 in Group 2; P = 0.005), but this improvement was statistically significant only in Group 1 (OR: 5.5, 95% CI: 1.32 - 22.8; P = 0.01) (Figures 1 and 2). The findings vis-à-vis strain values in two cases from each group have been illustrated in Figures 3 and 4.

## 5. Discussion

Previous studies demonstrated that microvascular dysfunction after STEMI could predict LV dysfunction (17-20). Evidence indicated that patients with more severe microvascular dysfunction had larger infarcts, more significant long-term LV wall motion abnormalities, and lower LV function (21-23). Thus, the present study aimed to determine the correlation between the severity of microvascular dysfunction after primary PCI, as expressed by NiMR, and LV functional recovery evaluated through LVEF and GLS.

A previous study confirmed that calculated non-invasive 2D-based FFR yielded comparable results to those derived from invasive FFR (15). In the current investigation, there was no statistically significant difference between the two groups in terms of LVEF changes, which might result from the need for a longer time for LVEF improvement. In contrast, the increase in GLS was significantly higher in the group with less severe microvascular disorders than in the group with severe microvascular dysfunction. Prolonged follow-up of patients may also show the difference in the improved LV function in the form of increased LVEF.

The present study results yielded supporting evidence on the importance of microvascular dysfunction after primary PCI. Accordingly, less severe microvascular dysfunction (NiMR < 24) was associated with improved GLS, reflecting better recovery in LV systolic function assessed one month after primary PCI. The results also indicated that myocardial ischemic changes due to microvascular injury after STEMI could be reversible, which was consistent with a previous research carried out by Borlotti et al. (21).

Generally, coronary vascular resistance is modulated through changes in vascular tone. This process is under metabolic, endothelial, myogenic, and neurohumoral control. Nonetheless, it is not clear which of these mechanisms exerts a more pronounced effect on IMR-measured values in patients with STEMI (24). Additionally, no clear cutoff value for IMR has thus far been described for the assessment of microvascular dysfunction. Yet, this value was higher in patients with higher microvascular dysfunction. It is worthy of note that most of the published studies using this technique in the treatment of patients with STEMI have been conducted on small populations and have used median values to define the severity of microvascular dysfunction. In the current research, the patients who had a lower NiMR value enjoyed better LV functional recovery, as expressed by GLS, one month after primary PCI. The findings also showed that a minimum NiMR value of 24 predicted myocardial dysfunction. Overall, NiMR measured immediately and one month after STEMI is a very sensitive method for evaluating the infarction extension and LV functional recovery.

### *5.1. Study Limitations*

The small number of patients and limitations in evaluating echocardiographic parameters in all the patients were the weaknesses of the current investigation. Moreover, considering the power of 80%, an 84-subject sample size was needed to show improvements in GLS amongst patients with NiMR < 24 and a 208-subject sample size was required to indicate GLS improvement in patients with NiMR > 24. Thus, the results are recommended to be confirmed in larger studies.

### *5.2. Conclusions*

The results of the present study on patients with STEMI who underwent primary PCI showed that less severe microvascular dysfunction, which was evaluated noninvasively and was described as NiMR < 24, was associated with better recovery in LV function, as expressed by GLS. Accordingly, NiMR can be used as an early marker of LV functional recovery after acute STEMI.

### *5.3. Clinical Trial Registration Code*

This study was not a randomized clinical trial.

### *5.4. Ethical Approval*

IR.RHC.REC.1398.065.

**Acknowledgements**

There is no acknowledgement.

## Authors' Contribution

M.A.A. and A.A. conceived and designed the evaluation and drafted the manuscript. S.A. and S.R. participated in designing the evaluation, performed parts of the statistical analysis, and helped to draft the manuscript. M.P. and Z.H. re-evaluated the clinical data, performed the statistical analysis, and revised the manuscript. S.R. and Y.K. collected the clinical data, interpreted them, and revised the manuscript. M.A.A. re-analyzed the clinical and statistical data and revised the manuscript. All authors read and approved the final manuscript.

## Funding/Support

The authors received no financial support for the research (code: 98003).

## Financial Disclosure

The authors have no financial interests related to the material in the manuscript.

## References

1. Levine GN, Bates ER, Blankenship JC, Bailey SR, Bittl JA, Cercek B, et al. 2015 ACC/AHA/SCAI focused update on primary percutaneous coronary intervention for patients with ST-elevation myocardial infarction: an update of the 2011 ACCF/AHA/SCAI guideline for percutaneous coronary intervention and the 2013 ACCF/AHA guideline for the management of ST-elevation myocardial infarction. Journal of the American College of Cardiology. 2016;67(10):1235-50.
2. Park S-M, Hong S-J, Kim Y-H, Ahn C-M, Lim D-S, Shim W-J. Predicting myocardial functional recovery after acute myocardial infarction: relationship between myocardial strain and coronary flow reserve. Korean circulation journal. 2010;40(12):639.
3. Wu KC, Zerhouni EA, Judd RM, Lugo-Olivieri CH, Barouch LA, Schulman SP, et al. Prognostic significance of microvascular obstruction by magnetic resonance imaging in patients with acute myocardial infarction. Circulation. 1998;97(8):765-72.
4. Bière L, Donal E, Terrien G, Kervio G, Willoteaux S, Furber A, et al. Longitudinal strain is a marker of microvascular obstruction and infarct size in patients with acute ST-segment elevation myocardial infarction. PloS one. 2014;9(1):e86959.
5. Johnson NP, Gould KL, Di Carli MF, Taqueti VR. Invasive FFR and noninvasive CFR in the evaluation of ischemia: what is the future? Journal of the American College of Cardiology. 2016;67(23):2772-88.
6. Bae YG, Hwang ST, Han H, Kim SM, Kim H-Y, Park I, et al. Non-invasive coronary physiology based on computational analysis of intracoronary transluminal attenuation gradient. Scientific reports. 2018;8(1):1-10.
7. McGeoch R, Watkins S, Berry C, Steedman T, Davie A, Byrne J, et al. The index of microcirculatory resistance measured acutely predicts the extent and severity of myocardial infarction in patients with ST-segment elevation myocardial infarction. JACC: Cardiovascular Interventions. 2010;3(7):715-22.
8. Lim H-S, Yoon M-H, Tahk S-J, Yang H-M, Choi B-J, Choi S-Y, et al. Usefulness of the index of microcirculatory resistance for invasively assessing myocardial viability immediately after primary angioplasty for anterior myocardial infarction. European heart journal. 2009;30(23):2854-60.
9. Løgstrup BB, Høfsten DE, Christophersen TB, Møller JE, Bøtker HE, Pellikka PA, et al. Association between coronary flow reserve, left ventricular systolic function, and myocardial viability in acute myocardial infarction. European Journal of Echocardiography. 2010;11(8):665-70.
10. Zaliaduonyte□Peksiene D, Vaskelyte JJ, Mizariene V, Jurkevicius R, Zaliunas R. Does longitudinal strain predict left ventricular remodeling after myocardial infarction? Echocardiography. 2012;29(4):419-27.
11. De Maria GL, Scarsini R, Shanmuganathan M, Kotronias RA, Terentes-Printzios D, Borlotti A, et al. Angiography-derived index of microcirculatory resistance as a novel, pressure-wire-free tool to assess coronary microcirculation in ST elevatioyoon myocardial infarction. The international journal of cardiovascular imaging. 2020;36(8):1395.
12. Løgstrup BB, Høfsten DE, Christophersen TB, Møller JE, Bøtker HE, Pellikka PA, et al. Correlation between left ventricular global and regional longitudinal systolic strain and impaired microcirculation in patients with acute myocardial infarction. Echocardiography. 2012;29(10):1181-90.
13. Ersbøll M, Valeur N, Mogensen UM, Andersen M, Greibe R, Møller JE, et al. Global left ventricular longitudinal strain is closely associated with increased neurohormonal activation after acute myocardial infarction in patients with both reduced and preserved ejection fraction: a two□dimensional speckle tracking study. European journal of heart failure. 2012;14(10):1121-9.
14. Zhang M, Yang J, Ma C, Liu M. Longitudinal strain measured by two□dimensional speckle tracking echocardiography to evaluate left ventricular function in patients with myocardial bridging of the left anterior descending coronary artery. Echocardiography. 2019;36(6):1066-73.
15. Babakhani H, Sadeghipour P, Tashakori Beheshti A, Ghasemi M, Moosavi J, Sadeghian M, et al. Diagnostic accuracy of two□dimensional coronary angiographic□derived fractional flow reserve—Preliminary results. Catheterization and Cardiovascular Interventions. 2021;97(4):E484-E94.
16. Adjedj J, Toth GG, Johnson NP, Pellicano M, Ferrara A, Floré V, et al. Intracoronary adenosine: dose–response relationship with hyperemia. JACC: Cardiovascular Interventions. 2015;8(11):1422-30.
17. Bolognese L, Carrabba N, Parodi G, Santoro GM, Buonamici P, Cerisano G, et al. Impact of microvascular dysfunction on left ventricular remodeling and long-term clinical outcome after primary coronary angioplasty for acute myocardial infarction. Circulation. 2004;109(9):1121-6.
18. Araszkiewicz A, Grajek S, Lesiak M, Prech M, Pyda M, Janus M, et al. Effect of impaired myocardial reperfusion on left ventricular remodeling in patients with anterior wall acute myocardial infarction treated with primary coronary intervention. The American journal of cardiology. 2006;98(6):725-8.
19. Sheng X, Qiao Z, Ge H, Sun J, He J, Li Z, et al. Novel application of quantitative flow ratio for predicting microvascular dysfunction after ST□segment□elevation myocardial infarction. Catheterization and Cardiovascular Interventions. 2020;95:624-32.
20. Yoon G-S, Ahn SG, Woo S-I, Yoon MH, Lee M-J, Choi SH, et al. The Index of Microcirculatory Resistance after Primary Percutaneous Coronary Intervention Predicts Long-Term Clinical Outcomes in Patients with ST-Segment Elevation Myocardial Infarction. Journal of Clinical Medicine. 2021;10(20):4752.
21. Borlotti A, Jerosch-Herold M, Liu D, Viliani D, Bracco A, Alkhalil M, et al. Acute microvascular impairment post-reperfused STEMI is reversible and has additional clinical predictive value: a CMR OxAMI study. JACC: Cardiovascular Imaging. 2019;12(9):1783-93.
22. Hassell M, Bax M, van Lavieren M, Nijveldt R, Hirsch A, Robbers L, et al. Microvascular dysfunction following ST-elevation myocardial infarction and. EuroIntervention. 2017;13:e578-e84.
23. Rodríguez-Palomares JF, Alonso A, Martí G, Aguadé-Bruix S, González-Alujas M, Romero-Farina G, et al. Quantification of myocardial area at risk in the absence of collateral flow: the validation of angiographic scores by myocardial perfusion single-photon emission computed tomography. Journal of Nuclear Cardiology. 2013;20(1):99-110.
24. Kitabata H, Kubo T, Ishibashi K, Komukai K, Tanimoto T, Ino Y, et al. Prognostic value of microvascular resistance index immediately after primary percutaneous coronary intervention on left ventricular remodeling in patients with reperfused anterior acute ST-segment elevation myocardial infarction. JACC: Cardiovascular Interventions. 2013;6(10):1046-54.