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Original Article

Anatomical and intravascular assessment of coronary arteries in patients with MINOCA: Data from coronary angiography and intravascular ultrasound

Shahin Khalilov[1], Vasadat Azizov[1], Samira Muradova[1], Farah Ibadova[1], Gunay Shiraliyeva[1], Samira Haciyeva[1], Kubra Qaribova[1], Jevgeniy Ploshenkov[2]

[1]Azerbaijan Medical University, Department of Internal Diseases, Baku, Azerbaijan
[2]Sechenov University, City Clinical Hospital, Moscow, Russia

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Corresponding Author: Samira Haciyeva, Azerbaijan Medical University, Department of Internal Diseases, Baku, Azerbaijan
Email: samira_cardio67@mail.ru

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Abstract

Aim: To evaluate the anatomical condition of the coronary arteries using coronary angiography and intravascular ultrasound in patients with myocardial infarction with non-obstructive coronary arteries (MINOCA).

Material and Methods: A prospective study included 94 patients with non-ST-elevation myocardial infarction (NSTEMI) and MINOCA. All patients underwent clinical examination and standard 12-lead electrocardiography (ECG). Coronary angiography (CAG) was performed in all patients, and intravascular ultrasound (IVUS) was performed in 18 patients.

Results: The mean age of the patients was 62.35 ± 10.33 years (range 33–86), with 78.7% males and 21.3% females. The mean admission cardiac troponin level was 0.83 ± 0.30 ng/mL. ST-segment depression was detected in 60.6%, T-wave inversion in 48.9%, and conduction abnormalities in 11.7% of patients. Normal coronary arteries were found in 19.1% of cases. Minimal luminal irregularities were observed in 28.7%, and mild to moderate stenoses in 52.1%. Single-vessel disease was diagnosed in 51.1%, two-vessel disease in 31.9%, and three-vessel disease in 17.0% of patients. Coronary spasm was identified in 8.5%, coronary thrombosis in 2.1%, atherosclerotic plaque disruption in 1.1%, and the coronary slow-flow phenomenon in 16.0% of patients. Among 18 patients with moderate stenosis, plaque rupture was detected in 38.9% of cases. Thrombotic masses were identified in 22.2%, and intimal thickening and signs of intraplaque hemorrhage in 11.1% of patients, respectively. Qualitative assessment of plaque morphology (n=7) revealed fibrous plaques in three cases, calcified plaques in one case, and lipid-rich plaques in one case.

Conclusion: Coronary angiography combined with IVUS enables the detection of subtle morphological changes in the vessel wall that are not visible with standard imaging. The use of intravascular ultrasound improves the accuracy of identifying microanatomical mechanisms underlying ischemic events and may serve as a basis for a personalized approach to patient management.

Keywords: Non-ST-elevation myocardial infarction, myocardial infarction with non-obstructive coronary arteries, coronary angiography, intravascular ultrasound

INTRODUCTION

Myocardial infarction with non-obstructive coronary arteries (MINOCA) is a clinical syndrome in which patients have all the signs and symptoms of a heart attack (including non-ST-segment elevation myocardial infarction (NSTEMI)), but do not have significant blockage (stenosis of 50% or more) of the major coronary arteries detected during angiography (1,2).

MINOCA accounts for approximately 5% to 15% of all cases of acute myocardial infarction (MI). Meta-analyses estimate that it accounts for approximately 6% of all myocardial infarction

cases in various populations (3–6). This heterogeneous condition involves diverse pathophysiological mechanisms leading to myocardial ischemia and necrosis without significant coronary obstruction. MINOCA can be divided into cases with no or minimal atherosclerosis (0–30% stenosis) and cases with moderate atherosclerosis (30–49% stenosis) (7).

Despite growing recognition, MINOCA remains underdiagnosed and often misclassified due to difficulties in identifying its underlying causes. Potential causes can be identified using specialized algorithms, including coronary angiography (CAG) and intravascular ultrasound (IVUS), which are considered valid diagnostic methods for myocardial infarction because they can detect morphological changes in the coronary artery wall that are not always visible with angiography.

As emphasized in the European Society of Cardiology (ESC) position paper, MINOCA should be considered a working diagnosis, serving as the first step in determining the underlying cause (1).

CAG is the initial and primary diagnostic step in the evaluation of MINOCA, as it is used to formally exclude obstructive coronary artery disease (CAD) and establish MINOCA as a "working diagnosis." However, CAG has limitations in fully diagnosing the cause of MINOCA. It primarily visualizes large epicardial arteries and does not effectively assess the microvascular bed. This may lead to missed minor plaque abnormalities, resolved thrombi, or transient vasospasm, which could have caused myocardial infarction. Due to these limitations, clinical guidelines recommend a multimodal imaging approach in addition to initial coronary angiography, including cardiac magnetic resonance imaging (CMR) and IVUS (7–10).

Thus, NSTEMI in the context of MINOCA is a clinical syndrome characterized by features of acute myocardial infarction in the absence of obstructive coronary artery disease as determined by coronary angiography. Despite normal or nearly normal coronary arteries in some patients, ischemic mechanisms may remain undetected by standard angiography. IVUS allows for a detailed assessment of vascular wall morphology, identifying hidden atherosclerotic changes, plaque erosions, or microfractures, and thus clarifying the pathogenetic mechanisms of MINOCA.

The aim of this study was to investigate the anatomical status of the coronary arteries using coronary angiography and intravascular ultrasound in patients with MINOCA.

MATERIAL AND METHODS

Ninety-four patients with NSTEMI and MINOCA were prospectively enrolled in this study. The study protocol was approved by the Azerbaijan Medical University Ethics Committee (Approval No: 3, Date: 15.03.2025), and all participants provided written informed consent prior to inclusion.

NSTEMI was defined according to the third universal definition of myocardial infarction, that is, the presence of signs of myocardial necrosis in a clinical setting consistent with acute myocardial ischemia (typical chest discomfort or angina equivalent) and the absence of ST-segment elevation.

In accordance with contemporary definitions, MINOCA was diagnosed in patients fulfilling the universal criteria for myocardial infarction in the absence of obstructive coronary artery disease (≥50% stenosis). Patients with mild to moderate coronary stenosis (30–49%) were included, as current evidence suggests that plaque rupture, erosion, or thrombosis may occur in non-obstructive lesions and may not be apparent on angiography alone. This approach is consistent with guideline-supported concepts recognizing MINOCA as a heterogeneous entity rather than a purely angiographic diagnosis.

Exclusion criteria included patients with prior myocardial infarction, prior coronary artery bypass grafting (CABG), hemodynamic instability, the need for urgent coronary revascularization, a glomerular filtration rate (GFR) <30 mL/min/1.73 m², and contraindications to CAG and/or cardiac magnetic resonance imaging (CMR). All patients included in the study underwent a detailed medical history, physical examination, and serial troponin measurements using conventional methods. Myocardial necrosis was diagnosed based on elevated and/or decreased troponin (cTn) levels. All patients underwent risk assessment upon admission using the GRACE (Global Registry of Acute Coronary Events) score. The Killip classification was used to assess the severity of heart failure.

Serum troponin T was measured using a microparticle chemiluminescent immunoassay 6 hours after the onset of typical ischemic chest pain. Troponin T concentration was determined using the Roche Diagnostics TNT-HS assay (Germany) with a Cobas 6000 analyzer (e 601, Roche, Switzerland). The measurement range of this assay is 0.1 to 2.0 ng/mL.

All patients underwent a clinical examination and a standard 12-lead electrocardiography (ECG). ST-segment changes, T-wave changes, the presence of pathological Q waves, and rhythm and conduction abnormalities were assessed.

Coronary angiography was performed to rule out obstructive coronary artery disease as the first diagnostic step, usually within 24 hours after admission, using the Optima IGS 330 angiography system (GE, China). Significant coronary artery disease was defined as luminal narrowing ≥50% in at least one major epicardial artery.

In patients without obstructive coronary artery disease, a stepwise diagnostic approach was applied. IVUS was selectively performed in patients with angiographically mild to moderate stenosis (30–49%) when visual assessment suggested possible plaque instability, including irregular lesion contours, haziness, or clinical–angiographic discordance. The decision to perform IVUS was based on predefined angiographic criteria and operator consensus rather than routine use in all patients, reflecting real-world clinical practice. Intravascular ultrasound provides an

internal image of the coronary artery, detailing the vessel wall, plaque, and lumen.

After confirming the diagnosis and selecting the arteries for examination, a specialized ultrasound catheter on a guidewire was inserted through the femoral artery. The ultrasound catheter, a specialized rotating catheter with a miniature ultrasound transducer at the tip, was advanced through the affected segment of the artery, and the device collected data, which were then converted into a two-dimensional image of the coronary artery. Philips (Volcano) catheters were used in the study.

Statistical analysis was performed using Statistica 16 (StatSoft, USA). Data were primarily analyzed using descriptive statistics and are presented as mean ± standard deviation or as absolute numbers and percentages. Given the exploratory and descriptive design of the study, statistical comparisons were limited. The t-test and χ^2 test with Yates' correction were applied where appropriate for descriptive comparisons, without the intention of establishing causal relationships. A p-value ≤0.05 was considered statistically significant.

RESULTS

The average patient age was 62.35 ± 10.33 years (range 33–86 years); 78.7% (n=74) were men and 21.3% (n=20) were women. No statistically significant differences were found in the age distribution of patients between men and women ($p > 0.05$).

Patient characteristics are presented in Table 1.

Table 1. Characteristics of the examined patients

Parameter	Group of patients with NSTEMI MINOCA (n=94)
Average body mass index (BMI), kg/m²	23.6 ± 2.2
Smoking, n (%)	42 (44.7%)
Average troponin T, ng/mL	0.83 ± 0.30
Hypertension, n (%)	47 (50.0%)
Systolic blood pressure (SBP), mmHg	132.4 ± 18.2
Diastolic blood pressure (DBP), mmHg	84.4 ± 10.8
Diabetes mellitus, n (%)	21 (22.3%)
Dyslipidemia, n (%)	19 (20.2%)
Family history of coronary heart disease, n (%)	6 (6.4%)

The ECG revealed the following changes: ST-segment depression in 57 patients (60.6%), T-wave inversion in 46 (48.9%), and conduction disturbances in 11 patients (11.7%). ST-segment depression was detected primarily in leads V4–V6. Pathological Q waves were absent in all cases. Conduction disturbances were most often expressed as intraventricular conduction slowing. Heart rate ranged from 68 to 104 bpm, with an average of 83 ± 9 bpm.

The clinical condition of the majority of patients—77 (81.9%)—on admission was assessed as satisfactory. However, signs of left ventricular failure (Killip class II) were observed in 17 patients (18.1%). All patients were assessed for risk on admission using the GRACE score, which averaged 130 ± 20 points, indicating a moderate risk of adverse outcomes.

According to CAG, the patients had normal or nearly normal coronary arteries (Table 2).

Table 2. Cardiac angiographic characteristics of the examined patients

Characteristics	Group of patients with NSTEMI MINOCA (n=94)	
	n	%
Normal coronary arteries	18	19.1%
Minimal luminal irregularities	27	28.7%
Mild to moderate stenosis	49	52.1%
Vessels with any stenosis		
Single-vessel disease	48	51.1%
Two-vessel disease	30	31.9%
Triple-vessel disease	16	17.0%
Others		
Coronary thrombosis	2	2.1%
Atherosclerotic plaque rupture	1	1.1%
Coronary spasm	8	8.5%
Coronary slow flow	15	16.0%

Table 2 presents the results of coronary angiography in 94 patients with NSTEMI and no obstructive coronary artery disease (MINOCA). It was found that some patients had completely normal coronary arteries—such changes were observed in 18 patients (19.1%). Twenty-seven patients (28.7%) had minimal luminal irregularities, which are considered early or minor structural changes without significant stenosis. The largest group of patients—49 (52.1%)—had mild to moderate stenosis, highlighting the heterogeneity of morphological findings in patients with MINOCA.

An analysis of the prevalence of vascular lesions revealed that any stenosis was detected in the majority of patients examined. Single-vessel disease was diagnosed in 48 patients (51.1%), two-vessel disease in 30 patients (31.9%), and three-vessel disease in 16 patients (17.0%), indicating significant variability in the angiographic pattern and the potential role of subclinical atherosclerosis in the pathogenesis of MINOCA.

Among other identified changes, rare but clinically significant findings were noted: coronary thrombosis in two patients (2.1%) and signs of atherosclerotic plaque rupture in one patient (1.1%). Functional disturbances were also frequently observed:

coronary spasm in eight patients (8.5%) and coronary slow-flow phenomenon in 15 patients (16.0%). These data highlight the multifactorial nature of MINOCA and the importance of assessing not only anatomical but also functional parameters of coronary blood flow.

Following coronary angiography, IVUS was performed in 18 patients with moderate stenosis to identify occult causes not visible with standard angiography, such as plaque rupture or erosion, intracoronary thrombus, or spontaneous coronary artery dissection (Table 3).

Table 3. Intracoronary ultrasound parameters in patients with moderate stenosis

Characteristics	Group of patients with NSTEMI MINOCA (n=18)	
	n	%
Plaque rupture	7	38.9%
Plaque presence in the vessel wall	3	16.7%
Thrombotic masses	4	22.2%
Intimal thickening	2	11.1%
Intraplaque hemorrhage	2	11.1%

According to the results of intravascular ultrasound examination in patients with NSTEMI and MINOCA with moderate stenosis (n=18), the most common finding was plaque rupture, detected in 38.9% of patients. Thrombotic masses were detected in one in five patients (22.2%), confirming the presence of subclinical thrombogenic activity even in the absence of significant coronary obstruction. Intimal thickening and signs of intraplaque hemorrhage were equally common (11.1% each), indicating possible elements of inflammatory remodeling of the vascular wall in some cases.

Additionally, a qualitative assessment of the morphology of the visualized plaques (n=7) was conducted: fibrous structures were detected in three cases, and calcified and lipid-rich plaques were detected in one case each. This profile highlights the heterogeneity of plaque composition in patients with MINOCA and emphasizes the importance of IVUS in identifying coronary event substrates not detected by standard angiography.

Thus, intravascular ultrasound helped identify that a “moderate” stenosis on angiography may, in fact, represent an unstable, high-risk plaque that caused myocardial infarction, thereby facilitating appropriate treatment decisions.

DISCUSSION

In the present study, coronary angiography revealed that patients with NSTEMI and MINOCA most frequently exhibited mild to moderate coronary stenosis, predominantly affecting a single vessel, as well as functional abnormalities such as coronary spasm and slow flow. These findings are consistent with existing literature emphasizing the heterogeneous and multifactorial nature of MINOCA, in which ischemic myocardial injury may occur in the absence of angiographically significant obstruction (7).

IVUS provided additional insights into the underlying coronary pathology in a selected subgroup of patients with moderate stenosis. Notably, IVUS identified features of plaque instability, including plaque rupture and thrombotic masses, in a substantial proportion of examined vessels. These observations support previous reports indicating that vulnerable plaque characteristics may be present even in angiographically non-obstructive lesions and may contribute to the development of myocardial infarction (11,12). Importantly, such pathological substrates are frequently beyond the resolution of conventional angiography and require intravascular imaging for detection.

Nevertheless, the IVUS findings should be interpreted with caution. The imaging was performed in a limited and selectively chosen subgroup of patients, and the results primarily reflect descriptive morphological observations rather than definitive causal mechanisms. While plaque rupture and thrombosis are well-recognized triggers of acute coronary syndromes (13,14), their identification in this study should be regarded as indicative of potential pathogenic pathways rather than conclusive evidence of causality in the broader MINOCA population.

The observed heterogeneity in plaque morphology, including fibrous, lipid-rich, and calcified components, further underscores the complexity of coronary pathology in MINOCA. Although fibrous plaques are traditionally considered less vulnerable, their presence does not preclude instability, particularly when microstructural alterations are present. These findings align with contemporary concepts recognizing plaque rupture, erosion, and calcified nodules as distinct but overlapping mechanisms that may underlie myocardial infarction without obstructive coronary disease (13,15).

The detection of thrombotic material in a subset of patients suggests that transient or partially resolved thrombosis may play a role in MINOCA pathophysiology. This phenomenon may explain the absence of significant luminal obstruction at the time of angiography and highlights the dynamic nature of coronary events in this clinical entity. However, given the exploratory design of the study, therapeutic implications should be interpreted cautiously and within the context of existing clinical guidelines.

Overall, the present findings reinforce the concept that MINOCA is not a benign or uniform condition but rather a spectrum of pathophysiological processes involving both structural and functional coronary abnormalities. Intravascular imaging techniques such as IVUS can contribute valuable information by uncovering concealed coronary pathology and improving mechanistic understanding. Future large-scale, multicenter studies incorporating systematic intravascular imaging and cardiac magnetic resonance imaging are required to validate these observations and refine diagnostic and therapeutic strategies.

Limitations

Several limitations of this study should be acknowledged. First, IVUS was performed in only a subset of patients (n=18), which may introduce selection bias and limits the statistical power of the analysis. Second, the absence of optical coherence tomography (OCT) may have resulted in underestimation of certain microstructural plaque features. Third, the cross-sectional design does not allow assessment of vascular remodeling dynamics over time. In addition, the study was conducted at a single center, which may limit the generalizability of the findings. Finally, systematic cardiac magnetic resonance imaging was not performed in all patients, although it is recommended in contemporary diagnostic algorithms for MINOCA.

CONCLUSION

Coronary angiography combined with selective intravascular ultrasound enables the detection of subtle morphological abnormalities of the coronary vessel wall that are not apparent on conventional imaging. In patients with NSTEMI and MINOCA, IVUS may reveal features of plaque instability and thrombosis, supporting the concept that clinically significant myocardial infarction can arise from angiographically mild lesions. These findings highlight the heterogeneity of MINOCA and underscore the potential role of intravascular imaging as a complementary diagnostic tool. Further prospective studies are warranted to clarify the clinical implications of these observations and to define the optimal diagnostic approach for patients with MINOCA.

Conflict of Interest: The authors declare that there is no conflict of interest.

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Ethics Committee Approval: This study was approved by the Azerbaijan Medical University Ethics Committee (Approval No: 3, Date: 15.03.2025).

Informed Consent: Written informed consent was obtained from all participants prior to inclusion in the study.

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