ORIGINAL ARTICLE

Residual cardiovascular risk after successful percutaneous coronary intervention: an integrated approach to prognosis

A.A. Olimov[1*], G.A. Nagaeva[1]

[1]*Research Center of Military Medicine, Military Medical Institute, University of Military Security and Defense of the Republic of Uzbekistan, Tashkent, Republic of Uzbekistan*

*Corresponding author: A.A. Olimov; e-mail: nagaeva.gulnora@mail.ru

Abstract

Background. Although percutaneous coronary intervention (PCI) effectively restores coronary blood flow, many patients continue to experience major adverse cardiovascular events (MACE), indicating that procedural success alone does not eliminate residual cardiovascular risk. Identifying patients at greatest risk remains a major challenge in contemporary secondary prevention.

Aim. To evaluate the combined prognostic value of coronary anatomical complexity, left ventricular systolic function, and metabolic status for predicting adverse cardiovascular outcomes after PCI.

Methods. A prospective observational study included 120 patients with coronary artery disease who underwent successful PCI and were followed for 12 months. Baseline clinical characteristics, coronary angiography, echocardiography, and metabolic parameters were analyzed. Coronary lesion complexity was assessed using the SYNTAX Score, left ventricular systolic function by echocardiographic ejection fraction (LVEF), and metabolic status by the presence of diabetes mellitus and glycated hemoglobin (HbA1c). The primary endpoint was the occurrence of major adverse cardiovascular events.

Results. Residual cardiovascular risk remained substantial despite technically successful coronary revascularization. Patients with a SYNTAX Score >32 demonstrated a more than fourfold higher incidence of MACE compared with those with low anatomical complexity. Left ventricular dysfunction (LVEF <40%) and poor glycemic control (HbA1c >8%) were also strongly associated with adverse outcomes. The highest event rates were observed in patients in whom anatomical complexity, myocardial dysfunction, and metabolic impairment coexisted, suggesting that these domains provide complementary rather than competing prognostic information.

Conclusion. Long-term prognosis after PCI is determined not only by procedural success but also by the interaction between coronary anatomy, myocardial function, and metabolic health. An integrated multidimensional assessment may improve individualized risk stratification and support more effective secondary prevention strategies.

Keywords: *coronary artery disease; percutaneous coronary intervention; residual cardiovascular risk; major adverse cardiovascular events; SYNTAX Score; left ventricular ejection fraction; diabetes mellitus.*

MAIN TEXT

Introduction

Percutaneous coronary intervention has transformed the management of coronary artery disease by rapidly restoring myocardial perfusion and reducing ischemic symptoms. Nevertheless, successful coronary revascularization does not necessarily translate into favorable long-term outcomes. A considerable proportion of patients experience recurrent ischemic events, heart failure, repeat revascularization, or cardiovascular death despite technically successful PCI [1–4]. This apparent discrepancy highlights an important concept in modern cardiology: restoration of coronary blood flow does not eliminate the biological mechanisms responsible for disease progression [5, 6].

Current clinical practice has gradually shifted from evaluating procedural success alone toward comprehensive assessment of **residual cardiovascular risk**. Increasing evidence indicates that adverse outcomes after PCI result from the interaction of multiple pathophysiological processes rather than from residual coronary stenosis alone. Coronary anatomical complexity reflects the burden and distribution of atherosclerosis, left ventricular dysfunction represents the cumulative consequences of ischemic myocardial injury, whereas diabetes mellitus and inadequate metabolic control accelerate vascular inflammation, endothelial dysfunction, and progression of atherosclerosis [1–4, 7–13]. Together, these factors may provide a more complete representation of patient vulnerability than any individual parameter [14, 15].

Although the prognostic importance of the SYNTAX Score, left ventricular ejection fraction, and diabetes has been demonstrated separately, their combined clinical significance in routine post-PCI risk stratification remains insufficiently characterized. Most contemporary prediction models continue to emphasize isolated variables instead of considering the cumulative effect of anatomical, functional, and metabolic abnormalities [7, 10, 11, 16–18].

The present study was designed to evaluate whether integrating these three complementary domains provides a more clinically meaningful framework for identifying patients at increased risk of major adverse cardiovascular events during the first year after PCI [1, 2, 7, 10]. Rather than focusing exclusively on procedural success, our approach seeks to characterize the residual cardiovascular risk that persists after coronary revascularization and may require intensified secondary prevention.

Material and Methods

Study design and population

This prospective observational study included 120 patients with coronary artery disease (CAD) who underwent percutaneous coronary intervention (PCI) and were followed for 12 months after the procedure. The study population consisted of patients with clinically significant coronary atherosclerosis requiring revascularization.

All patients underwent comprehensive baseline evaluation, including clinical assessment, laboratory testing, transthoracic echocardiography, and coronary angiography. The study was designed to identify clinical, functional, and anatomical characteristics associated with the development of major adverse cardiovascular events (MACE) during follow-up.

The study protocol was conducted in accordance with the principles of the Declaration of Helsinki. All participants provided informed consent for participation and follow-up.

Clinical assessment and cardiovascular risk evaluation

Baseline clinical characteristics included age, body mass index (BMI), history of arterial hypertension, smoking status, dyslipidemia, diabetes mellitus, and previous myocardial infarction. The overall burden of cardiovascular risk was assessed by evaluating the number and combination of established risk factors.

Diabetes mellitus was defined according to contemporary diagnostic criteria. Glycemic control was assessed using glycated hemoglobin (HbA1c), with HbA1c >8% considered an indicator of insufficient metabolic control [19].

The presence of multiple cardiovascular risk factors was analyzed to evaluate the cumulative contribution of metabolic and clinical abnormalities to residual cardiovascular risk after PCI.

Echocardiographic assessment

Transthoracic echocardiography was performed to evaluate left ventricular (LV) structure and function.

Left ventricular systolic function was assessed by measuring left ventricular ejection fraction (LVEF). Patients were categorized according to preserved (LVEF ≥55%), moderately reduced (40–54%), and severely reduced systolic function (LVEF <40%) [20].

Additional echocardiographic parameters included assessment of regional wall motion abnormalities and diastolic function of the left ventricle.

The rationale for including LV functional assessment was based on the concept that myocardial recovery after revascularization depends not only on restoration of coronary flow but also on the extent of previously established ischemic injury.

Coronary angiographic assessment

Coronary anatomy was evaluated using invasive coronary angiography performed before PCI.

The anatomical complexity of coronary artery disease was quantified using the SYNTAX Score, which integrates lesion location, complexity, and distribution of coronary atherosclerotic involvement.

Patients were classified according to SYNTAX Score categories:

- low anatomical complexity: <22 points;
- intermediate complexity: 22–32 points;
- high complexity: >32 points.

The extent of coronary involvement was additionally assessed, including the presence of multivessel disease and involvement of major coronary arteries.

Study endpoint

The primary endpoint was the occurrence of major adverse cardiovascular events (MACE) during the 12-month follow-up period [21, 22].

MACE included clinically significant cardiovascular outcomes occurring after PCI. The analysis focused on identifying baseline characteristics associated with increased probability of adverse events despite successful coronary revascularization.

Statistical analysis

Statistical analysis was performed using standard methods of biomedical statistics.

Continuous variables were expressed as mean ± standard deviation, while categorical variables were presented as absolute values and percentages. Differences between groups were assessed using appropriate comparative statistical methods.

The association between clinical and instrumental parameters and the occurrence of MACE was evaluated by calculating odds ratios (ORs) with 95% confidence intervals (CIs).

A p-value <0.05 was considered statistically significant.

Results

Baseline clinical characteristics and residual cardiovascular risk profile

The study included 120 patients with coronary artery disease who underwent PCI and completed 12 months of follow-up. The mean age of the study population was 44.2±5.4 years, indicating a relatively young cohort with clinically significant coronary atherosclerosis.

Despite successful coronary revascularization, the majority of patients demonstrated a substantial burden of cardiovascular risk factors. Arterial hypertension was present in 70 patients (58.3%), dyslipidemia in 82 patients (68.3%), and active smoking in 76 patients (63.3%). Type 2

diabetes mellitus was identified in 42 patients (35.0%), while a previous myocardial infarction was documented in 36 patients (30.0%).

Multiple cardiovascular risk factors were common: two or more risk factors were present in 96 patients (80.0%), whereas three or more concomitant risk factors were observed in 58 patients (48.3%). The combination of dyslipidemia, smoking, and arterial hypertension represented the most frequent risk profile and was observed in 42 patients (35.0%).

These findings demonstrate that PCI was performed in patients with a significant residual cardiovascular risk burden, emphasizing that anatomical restoration of coronary blood flow does not necessarily reflect complete elimination of disease activity.

Table 1. Baseline clinical characteristics of the study population (n=120)

Parameter	Value
Age, years	44.2±5.4
BMI, kg/m²	27.8±3.1
Arterial hypertension, n (%)	70 (58.3%)
Dyslipidemia, n (%)	82 (68.3%)
Smoking, n (%)	76 (63.3%)
Type 2 diabetes mellitus, n (%)	42 (35.0%)
Previous myocardial infarction, n (%)	36 (30.0%)
Multivessel coronary artery disease, n (%)	67 (55.8%)

Coronary anatomical complexity as a marker of residual risk

Although PCI successfully restores epicardial coronary patency, the underlying extent and complexity of coronary atherosclerosis may determine long-term prognosis. Therefore, the anatomical characteristics of coronary artery disease were assessed using the SYNTAX Score.

The mean SYNTAX Score in the study population was 24.6±9.2 points, reflecting a broad spectrum of coronary anatomical complexity.

Low anatomical complexity (SYNTAX Score <22) was observed in 52 patients (43.3%), intermediate complexity (22–32 points) in 45 patients (37.5%), and high anatomical complexity (>32 points) in 23 patients (19.2%).

The distribution of patients by SYNTAX Score category is shown in Figure 1.

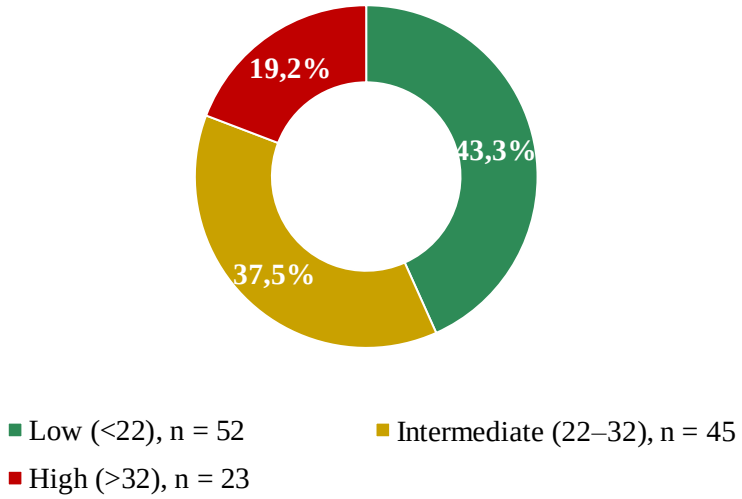


Figure 1. Distribution of patients by SYNTAX Score category of coronary anatomical complexity (n = 120), %.

Multivessel coronary disease was present in 67 patients (55.8%). The most frequently affected vessel was the left anterior descending artery, involved in 78 cases (65.0%), followed by the right coronary artery in 64 cases (53.3%) and the left circumflex artery in 49 cases (40.8%). Left main coronary artery involvement was identified in 14 patients (11.7%).

Importantly, high anatomical complexity was associated with a greater prevalence of metabolic and functional abnormalities. Among patients with SYNTAX Score >32, diabetes mellitus was observed in 13 patients (56.5%) compared with 29 patients (29.9%) among those with lower SYNTAX values (p=0.018).

Similarly, reduced left ventricular systolic function (LVEF <55%) was more frequent in patients with high anatomical complexity compared with those with lower SYNTAX Scores (65.2% vs. 29.9%, p=0.003).

These findings indicate that anatomical complexity should not be interpreted as an isolated angiographic characteristic but rather as a marker reflecting a broader disease phenotype characterized by advanced atherosclerotic burden, metabolic impairment, and myocardial vulnerability.

Left ventricular dysfunction identifies persistent myocardial vulnerability after PCI

Assessment of myocardial function revealed substantial heterogeneity in ventricular recovery after coronary revascularization.

The mean LVEF in the overall population was 54.8±8.6%. Preserved systolic function (LVEF ≥55%) was observed in 76 patients (63.3%), whereas reduced LVEF was identified in 44 patients (36.7%).

Among patients with impaired systolic function, 31 patients (25.8%) demonstrated moderate reduction of LVEF (40–54%), while severe left ventricular dysfunction (LVEF <40%) was present in 13 patients (10.9%).

Patients with reduced LVEF more frequently had evidence of previous myocardial injury and metabolic disturbances. A history of myocardial infarction was present in 23 patients (52.3%) with reduced LVEF compared with 13 patients (17.1%) among those with preserved systolic function ($p<0.001$).

Diabetes mellitus was also significantly more frequent in patients with impaired ventricular function: 22 cases (50.0%) versus 20 cases (26.3%) in patients with preserved LVEF ($p=0.009$).

Furthermore, reduced LVEF was associated with a higher prevalence of regional wall motion abnormalities (77.3% vs. 23.7%, $p<0.001$) and left ventricular diastolic dysfunction (70.5% vs. 38.2%, $p<0.001$).

Thus, impaired ventricular function after PCI represents a marker of persistent myocardial vulnerability and identifies patients in whom restoration of coronary flow does not fully reverse the consequences of previous ischemic injury.

Association of anatomical, functional, and metabolic factors with MACE

During the 12-month follow-up period, 30 patients experienced major adverse cardiovascular events.

The strongest association with adverse outcomes was observed for coronary anatomical complexity. Patients with SYNTAX Score >32 had a MACE incidence of 52.2%, compared with 11.5% among patients with SYNTAX Score <22.

Diabetes mellitus was also associated with substantially higher event rates. MACE occurred in 18 patients (42.9%) with diabetes compared with 12 patients (15.4%) without diabetes.

The degree of metabolic control demonstrated additional prognostic importance. Among patients with HbA1c >8%, the incidence of MACE reached 77.8%, indicating that inadequate glycemic control represents a particularly high-risk phenotype.

The incidence of MACE across anatomical, metabolic and functional subgroups is summarised in Figure 2.

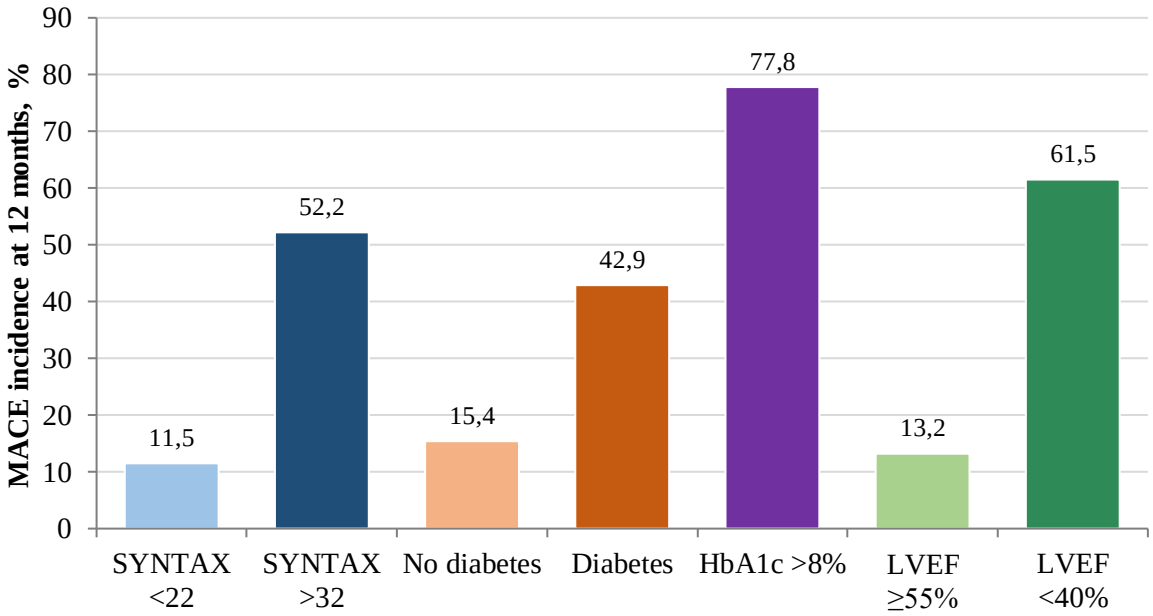


Figure 2. Incidence of major adverse cardiovascular events (MACE) within 12 months after PCI according to coronary anatomical complexity (SYNTAX Score), diabetes mellitus, glycated haemoglobin and left ventricular ejection fraction.

Left ventricular systolic function showed a progressive relationship with adverse outcomes. The incidence of MACE increased from 13.2% in patients with preserved LVEF (≥55%) to 61.5% in patients with severe LV dysfunction (LVEF <40%).

Multivariable risk assessment demonstrated that several parameters retained strong associations with adverse outcomes:

Table 2. Factors associated with MACE after PCI

Factor	OR	95% CI	p-value
SYNTAX Score >32	8.4	2.7–25.9	<0.001
Type 2 diabetes mellitus	4.1	1.8–9.5	0.003
HbA1c >8%	12.2	2.1–70.5	0.006
LVEF <40%	10.6	2.8–39.5	<0.001

Overall, these results demonstrate that adverse outcomes after PCI are not determined by a single parameter. Instead, the highest-risk phenotype is characterized by the convergence of complex coronary anatomy, impaired myocardial function, and metabolic dysfunction.

Discussion

The present study demonstrates that successful percutaneous coronary intervention does not represent the end of cardiovascular risk management. Although PCI effectively restores epicardial coronary blood flow and reduces ischemic burden, the underlying biological processes responsible for atherosclerotic progression, myocardial injury, and metabolic deterioration may persist. Therefore, long-term prognosis after revascularization depends not only on procedural

characteristics but also on the interaction between coronary anatomy, myocardial function, and systemic cardiovascular risk factors [1–3].

The concept of residual cardiovascular risk has become increasingly important in contemporary cardiology [1, 2]. Traditional assessment after PCI has historically focused on technical success, stent patency, and the degree of anatomical revascularization. However, clinical outcomes are influenced by a much broader spectrum of factors, including the extent of coronary atherosclerosis, incomplete recovery of myocardial function, and persistent metabolic abnormalities. Our findings support the transition from a procedure-centered approach toward a patient-centered strategy based on multidimensional risk assessment.

In the present cohort, coronary anatomical complexity remained one of the strongest determinants of adverse outcomes. A SYNTAX Score >32 was associated with a markedly increased risk of MACE, confirming that the anatomical burden of coronary disease retains prognostic significance even after successful PCI [4, 7]. These findings are consistent with previous studies demonstrating that complex coronary anatomy reflects not only the number and location of lesions but also the diffuse nature of atherosclerotic disease and the probability of future cardiovascular events.

Nevertheless, our results indicate that anatomical assessment alone is insufficient for accurate risk stratification. Patients with high SYNTAX Scores frequently demonstrated concomitant metabolic abnormalities and impaired left ventricular function, suggesting that anatomical complexity represents only one component of a broader high-risk phenotype. The coronary lesion treated during PCI may therefore be considered a visible manifestation of a systemic disease process rather than an isolated pathological target.

Left ventricular systolic function emerged as another major determinant of prognosis. Reduced LVEF, particularly values below 40%, was strongly associated with subsequent adverse events. This observation highlights an important clinical principle: restoration of coronary perfusion does not always translate into complete myocardial recovery[23]. Persistent ventricular dysfunction may reflect previous ischemic injury, myocardial fibrosis, adverse remodeling, and limited functional reserve. Consequently, echocardiographic evaluation remains essential even after apparently successful revascularization [24, 25].

The relationship between diabetes mellitus and adverse outcomes observed in this study further emphasizes the importance of metabolic factors in post-PCI management. Diabetes is not merely an additional cardiovascular risk factor but represents a complex metabolic condition associated with endothelial dysfunction, inflammation, accelerated atherosclerosis, and impaired vascular repair mechanisms. Importantly, our findings suggest that the degree of metabolic control may be more informative than the presence of diabetes alone. The markedly increased incidence of

MACE among patients with HbA1c >8% indicates that persistent hyperglycemia identifies a particularly vulnerable subgroup requiring intensified preventive strategies [26].

An important implication of this study is that the most accurate assessment of prognosis after PCI may require integration of complementary domains rather than reliance on isolated markers. Coronary anatomy provides information regarding disease burden, LVEF reflects myocardial consequences of ischemic injury, and metabolic parameters characterize ongoing systemic drivers of atherosclerosis [27]. Together, these variables create a more comprehensive representation of individual cardiovascular vulnerability.

From a clinical perspective, this integrated approach may help identify patients who require closer surveillance and more aggressive secondary prevention after PCI. Such patients may benefit from intensified lipid-lowering therapy, optimized glycemic management, structured lifestyle interventions, and careful monitoring of ventricular function. Future risk models should therefore consider moving beyond traditional single-factor prediction toward multidimensional algorithms incorporating anatomical, functional, and metabolic characteristics [28–30].

Several limitations should be acknowledged. The study was conducted in a relatively limited patient population and included a 12-month follow-up period, which restricts assessment of long-term outcomes. In addition, the observational design does not allow direct determination of causality between identified factors and cardiovascular events. Further multicenter studies with larger populations and longer follow-up are required to validate these findings and determine their applicability across broader clinical settings.

Despite these limitations, the present study provides additional evidence that PCI should be regarded as one stage in the management of coronary artery disease rather than a definitive solution. The future of post-revascularization care lies in identifying residual cardiovascular risk through integrated assessment and applying personalized preventive strategies tailored to the individual patient profile [31].

Conclusion

Successful percutaneous coronary intervention restores coronary blood flow but does not completely eliminate the risk of future cardiovascular events. The present study demonstrates that long-term outcomes after PCI are determined by the interaction of anatomical disease complexity, myocardial functional status, and metabolic abnormalities rather than by procedural success alone.

High coronary anatomical complexity (SYNTAX Score >32), severe left ventricular systolic dysfunction (LVEF <40%), and inadequate glycemic control (HbA1c >8%) were the strongest markers associated with adverse cardiovascular outcomes. These findings emphasize that residual

cardiovascular risk after PCI represents a multidimensional phenomenon requiring integrated clinical assessment.

A personalized follow-up strategy incorporating coronary anatomy, ventricular function, and metabolic status may allow earlier identification of high-risk patients and optimization of secondary prevention measures. Future approaches to post-PCI care should focus not only on successful revascularization but also on controlling the biological processes that continue to drive cardiovascular disease progression.

Additional information

Ethical approval. The study protocol was conducted in accordance with the principles of the Declaration of Helsinki.

Consent. All participants provided informed consent for participation and follow-up.

Author contributions. All authors contributed to the compilation and layout of this material.

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Information about the authors

A.A. Olimov — Research Center of Military Medicine, Military Medical Institute, University of Military Security and Defense of the Republic of Uzbekistan, Tashkent, Republic of Uzbekistan

G.A. Nagaeva — Research Center of Military Medicine, Military Medical Institute, University of Military Security and Defense of the Republic of Uzbekistan, Tashkent, Republic of Uzbekistan