

ORIGINAL ARTICLE

Impact of Coronary Artery Calcium Score on Procedural Success and Long-Term Outcomes Following Complex Percutaneous Coronary Intervention

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ABSTRACT

Objective: To assess the effect of coronary artery calcium (CAC) score on outcomes and procedural success after complex PCI.**Methods:** This is a retrospective observational cohort study of 86 patients who underwent complex PCI from September 2022 to March 2023 at the Punjab Institute of Cardiology in Lahore. Patients were separated into two groups based on their CAC score: <300 and ≥300. Demographic, clinical, angiographic, and procedural data were analyzed. SPSS 26 was used for analysis. Logistic and Cox regression analyses were used to identify independent factors.**Results:** Patients with CAC ≥300 had lower procedural success than those with CAC <300 ($p=0.021$). Longer procedures, higher contrast, increased radiation exposure, and higher frequency of rotational atherectomy were associated with higher CAC. MACE was considerably greater in patients with CAC ≥300 ($p=0.009$). CAC ≥300 independently predicted procedural failure ($p=0.049$), complications ($p=0.048$), and MACE ($p=0.027$).**Conclusion:** CAC burden was linked to worse procedural success and long-term outcomes following complicated PCI. The use of CAC scoring can enhance preprocedural risk stratification and procedural planning.**Keywords:** Coronary artery calcium score; Complex percutaneous coronary intervention; Coronary artery calcification.

INTRODUCTION

Percutaneous coronary intervention (PCI) is a well-established therapy option for myocardial revascularization, while coronary artery disease (CAD) is a primary cause of cardiovascular morbidity and mortality worldwide.^[1] As interventional techniques have advanced, PCI can now be performed in patients with extremely difficult coronary anatomy, including chronic complete blockage, bifurcation lesions, left main coronary disease, lengthy diffuse lesions, and severely calcified veins.^[2] A recent review of over 20,000 PCI procedures revealed that complex PCI accounted for roughly 28% of interventions and was linked with higher 1-year mortality and major adverse cardiovascular events (MACE) than non-complex PCI.^[3]

An important criterion used to determine complexity of PCI is coronary artery calcification (CAC).^[4] Atherosclerotic plaques cause a decrease in arterial compliance and can cause problems with lesion crossing, balloon dilatation, stent delivery, and deployment.^[5] In a large pooled analysis of 19,833 patients from 18 randomized trials, 31.3% of PCI patients had moderate or severe CAC.^[6] Patients with moderate or severe CAC had significantly increased 5-year probabilities of patient-oriented adverse outcomes and target-lesion failure (1.12 and 1.21, respectively) compared to those without significant CAC.^[7] CAC was also associated with an increased risk of death, myocardial infarction, and ischemia-driven target-lesion revascularization.^[7]

In another study, the relationship between coronary calcification and poor prognosis has also been demonstrated. In a prospective analysis of 10,068 patients who had PCI, those with moderate-to-severe CAC had a higher 5-year MACE rate than those with none/mild CAC (20.7% vs. 17.9%). Moderate to severe calcification remained independently related with 2-year MACE and target-vessel revascularization.^[8]

High levels of calcium along with severe calcification also require some special plaque modification techniques. Intravascular lithotripsy (IVL) and atherectomy performed by cutting or scoring balloons have been more widely employed in the past few years to aid in the delivery of stents and ensure full stent expansion in heavily calcified lesions. IVL was successful in 92.4% of patients with severely calcified lesions (30-day TLFF 7.2%) in the 2021 patient-level pooled analysis of the Disrupt CAD studies (N=628). The

results of this study indicate that, although patients with extensive calcium are a clinically high-risk group, contemporary calcium-modification technologies can enhance procedural feasibility.^[9]

Coronary calcification serves a prognostic role in addition to the index procedure. Patients with at least one heavily calcified lesion had a significantly higher 10-year all-cause mortality rate (36.4% vs. 22.3%) than those without heavy calcification, according to the SYNTAXES analysis. After controlling for pertinent variables, heavy calcification remained an independent predictor of death. More anatomical complexity and less complete revascularization were also discovered to be related to the presence of significant calcification, especially in PCI patients.^[10]

The coronary artery calcium score (CACS) offers a quantitative measure of the total coronary calcium burden, although angiographic assessment is performed routinely for the characterization of coronary calcification. CACS can measure the severity of calcified atherosclerosis in patients and may also be used to select patients who have a high burden of coronary disease before intervention occurs, unlike visual angiographic grading. Although ample angiographic studies have already correlated the presence of preprocedural angiographic calcium with various adverse PCI outcomes, relatively little research has focused on whether a preprocedural quantitative CACS can predict immediate procedural success as well as longer-term outcomes among patients who undergo complex PCI.^[11]

This is an important clinical gap as early detection of a high calcium burden may enable better risk stratification and individualised procedural planning before complex PCI. The more aggressive the preparation of the lesions, the use of specialized calcium-modification devices, intravascular imaging, and greater post-procedural monitoring will be required in patients with higher CACS. Thus, CACS's independent predictive capacity for procedural failure or later unfavorable cardiovascular outcomes may provide a straightforward and clinically meaningful technique for identifying high-risk patients. The current study sought to analyze the connection of CACS with procedural success and clinical outcomes following complex PCI, as well as to determine whether higher CAC load was an independent risk factor for procedural problems and MACE.

MATERIAL & METHODS

A retrospective observational cohort study was conducted at PIC, Lahore for six months' duration from September 2022 to March 2023. Sample size was determined using OpenEpi version 3.01 for

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the single proportion formula. The proportion of procedural complications in patients with high coronary calcium burden was assumed at 17.2%, which was found in another previous study showing a higher incidence of procedure-related complications in patients with a CAC score >300 than in those with lower CAC scores (7.4%). A 95% confidence level and an 8% absolute precision, or margin of error, were applied with an expected population proportion of 17.2%.^[12] The minimum sample size calculated was 86 patients. Thus, 86 patients who met the eligibility criteria were included in the study.

A consecutive sampling technique was used. All patients who were eligible for complex PCI during the study period and met the inclusion criteria described were screened and recruited consecutively until the necessary number of 86 patients was reached.

Patients older than 18 years who had received complex PCI at Punjab Institute of Cardiology during the study period were included. Patients were included if a preprocedural CAC score quantified using the Agatston method was available, and if adequate procedural records were present, patients were included if a preprocedural CAC score quantified using the Agatston method was available, and if adequate procedural records were present. Patients were also needed to have adequate clinical data for evaluation of procedural success and follow-up results. Patients with incomplete coronary calcium scoring data, inadequate angiographic documentation, previous coronary artery bypass graft (CABG) where proper assessment of the relevant coronary anatomy was not available, acute coronary syndromes where the preprocedural CAC assessment was not available, or incomplete follow-up information were excluded. Indeterminate computed tomography (CT) scans and patients with unreliable computed tomography (CT) measurement of atherosclerosis (CAC) were also excluded.

A structured data collection proforma was used to obtain relevant data from the hospital's medical records, catheterization laboratory reports, coronary computed tomography records, and follow-up records. Demographic data such as age and sex were recorded. The clinical variables recorded were diabetes mellitus, hypertension, dyslipidaemia, smoking, family history of coronary artery disease, previous myocardial infarction, previous PCI, chronic kidney disease, and other cardiovascular comorbidities. Hemoglobin, serum creatinine, and lipid profile were recorded in the laboratory.

The coronary artery calcium score was collected before the procedure on non-contrast cardiac computed tomography and was computed using the Agatston scoring system.^[13] Total CAC score was measured as a continuous variable and was also classified by conventional severity categories as appropriate. Coronary calcification was quantified depending on the complexity of the procedure to be performed. The target lesion characteristics, such as vessel involved, location, chronic total occlusion, bifurcation involved, lesion length, number of vessels treated, number and total length of implanted stents, and the use of calcium modification technique (rotational atherectomy or other plaque modification technique) were recorded.

Procedural outcomes were defined as technical/procedural success, which is defined as successful completion of the planned PCI with restoration of adequate coronary blood flow and without major in-hospital adverse events. Procedure-related complications, such as coronary dissection, coronary perforation, acute vessel occlusion, no-reflow/slow-flow phenomenon, periprocedural myocardial infarction, and emergency coronary artery bypass surgery, were recorded. Other factors such as procedure duration, contrast volume, radiation exposure, number of stents, and requirement of adjunctive devices were also documented where available.

The long-term clinical outcomes of patients were then assessed using outpatient data, hospital readmission, telephone follow-up, and cardiology paperwork. The primary long-term objective was MACE, which included all-cause mortality, cardiovascular death, myocardial infarction, target-vessel/target-

lesion revascularization, or hospitalization for heart failure or other serious cardiovascular events, as defined by the study's endpoint criteria. Other clinically relevant adverse events and individual items of MACE were also reported during follow-up.

IBM SPSS Statistics was used to enter data and run analyses. Measured data were provided as mean $\pm$ standard deviation for normally distributed variables, and median (IQR) for non-normally distributed values. Categorical variables were presented as frequencies and percentages. Patients were separated into groups depending on their CAC burden, and baseline characteristics and procedure aspects were compared between them. For continuous variables, the independent-samples t-test and Mann-Whitney U test were employed, while categorical variables were compared using the chi-square test and Fisher's exact test.

Initially, univariable analyses were utilized to determine the relationship between CAC score and operative success, procedural complications, and long-term MACE. Following adjustment for potential confounding factors (age, diabetes mellitus, hypertension, chronic kidney disease, previous PCI, and lesion complexity), a binary logistic regression analysis was performed to determine whether the CAC score was independently associated with procedural failure or complications. The Kaplan-Meier method was used to create survival curves, which were then compared between CAC groups using the log-rank test for long-term time-to-event analyses. Cox proportional-hazards regression analysis was used to generate risk ratios (HRs) and 95% confidence intervals (CIs) for time-dependent outcomes such as MACE. The CAC score was also examined as a continuous variable to see if there was a gradual rise in risk as calcium burden rose. A two-sided p-value <0.05 indicated statistical significance.

RESULTS

Among the 86 patients included, the mean age was 59.8 ± 10.7 years and 74.4% were male. The prevalence of diabetes mellitus, hypertension, dyslipidemia, and chronic kidney disease was 48.8%, 66.3%, 59.3%, and 20.9%, respectively. Patients with CAC ≥ 300 were significantly older and had higher rates of diabetes and chronic kidney disease compared with patients with CAC <300 (Table 1).

The median CAC score was 356 (IQR 182–648), with 16.3% of patients having a score ≥ 1000 . Severe angiographic calcification was significantly more common in the CAC ≥ 300 group, and the number of patients who needed at least three stents, as well as the total stent length >60 mm, was higher in this group (Table 2).

Patients with CAC ≥ 300 had significantly higher CAC, longer procedures, higher contrast usage, and higher radiation doses. Plaque modification (including rotational atherectomy) was also more common in this group. The success of the procedure was high (88.4%), with a significantly lower success rate in patients with CAC ≥ 300 compared to patients with CAC <300 ($p=0.021$) (Table 3).

Over a median follow-up period of 27 months, overall MACE rates were 25.6% and were significantly higher in the groups with CAC ≥ 300 than with lower calcium scores ($p=0.009$). Similarly, patients with greater CAC burden tended to have more target lesion revascularization (Table 4).

In multivariable logistic regression, CAC ≥ 300 was an independent predictor of procedural failure, after adjustment for age, diabetes, chronic kidney disease, previous PCI, and lesion complexity ($p=0.049$). After adjustment, the association of age, diabetes, chronic kidney disease, and prior PCI with procedural failure was not statistically significant (Table 5).

Likewise, patients with CAC ≥ 300 were more likely to experience procedural complications. In multivariable analysis, a CAC score ≥ 300 also provided independent prediction of procedural complications ($p=0.048$) (Table 6).

The Cox regression showed that the higher the burden of CAC, the more significant the association with long-term MACE. The HR of MACE for CAC ≥ 300 was approximately 2.7-fold higher after adjusting for the relevant clinical and procedural characteristics ($p=0.027$) (Table 7).

Table 1. Baseline Demographic and Clinical Characteristics of Study Participants According to Coronary Artery Calcium Score (n=86)

Variable	Overall (n=86) n(%) / mean $\pm$ SD	CAC <300 (n=48) n(%) / mean $\pm$ SD	CAC $\geq$ 300 (n=38) n(%) / mean $\pm$ SD	p-value
Age, years	59.8 $\pm$ 10.7	56.7 $\pm$ 9.8	63.7 $\pm$ 10.2	0.002 ^a
Male sex	64 (74.4)	33 (68.8)	31 (81.6)	0.187 ^b
Diabetes mellitus	42 (48.8)	19 (39.6)	23 (60.5)	0.049 ^b
Hypertension	57 (66.3)	28 (58.3)	29 (76.3)	0.084 ^b
Dyslipidemia	51 (59.3)	25 (52.1)	26 (68.4)	0.129 ^b
Current smoking	29 (33.7)	18 (37.5)	11 (28.9)	0.410 ^b
Family history of CAD	34 (39.5)	19 (39.6)	15 (39.5)	0.992 ^b
Previous myocardial infarction	31 (36.0)	14 (29.2)	17 (44.7)	0.146 ^b
Previous PCI	27 (31.4)	11 (22.9)	16 (42.1)	0.061 ^b
Chronic kidney disease	18 (20.9)	6 (12.5)	12 (31.6)	0.036 ^b
Hemoglobin, g/dL	12.7 $\pm$ 1.6	12.9 $\pm$ 1.5	12.4 $\pm$ 1.7	0.151 ^a
Serum creatinine, mg/dL, median (IQR)	1.18 (0.91–1.52)	1.05 (0.84–1.34)	1.35 (1.02–1.68)	0.008 ^c
LDL cholesterol, mg/dL	108.6 $\pm$ 32.4	106.1 $\pm$ 31.2	111.8 $\pm$ 33.8	0.424 ^a

^aIndependent-samples t-test; ^bChi-square test; ^cMann-Whitney U test.

Table 2. Coronary Artery Calcium Burden and Angiographic Characteristics

Variable	Overall (n=86) n(%) / mean $\pm$ SD	CAC <300 (n=48) n(%) / mean $\pm$ SD	CAC $\geq$ 300 (n=38) n(%) / mean $\pm$ SD	p-value
CAC score, median (IQR)	356 (182–648)	176 (96–238)	648 (438–914)	<0.001 ^c
CAC score $\geq$ 1000	14 (16.3)	0 (0)	14 (36.8)	<0.001 ^b
Chronic total occlusion	29 (33.7)	12 (25.0)	17 (44.7)	0.065 ^b
Bifurcation lesion	32 (37.2)	16 (33.3)	16 (42.1)	0.412 ^b
Left main intervention	18 (20.9)	7 (14.6)	11 (28.9)	0.106 ^b
Saphenous vein graft PCI	9 (10.5)	4 (8.3)	5 (13.2)	0.493 ^b
$\geq$ 3 stents implanted	35 (40.7)	15 (31.3)	20 (52.6)	0.049 ^b
Total stent length >60 mm	41 (47.7)	18 (37.5)	23 (60.5)	0.037 ^b
Multivessel PCI	38 (44.2)	17 (35.4)	21 (55.3)	0.068 ^b
Severe angiographic calcification	37 (43.0)	11 (22.9)	26 (68.4)	<0.001 ^b

^bChi-square test; ^cMann-Whitney U test.

Table 3. Procedural Characteristics and Outcomes

Variable	Overall (n=86) n(%) / mean $\pm$ SD	CAC <300 (n=48) n(%) / mean $\pm$ SD	CAC $\geq$ 300 (n=38) n(%) / mean $\pm$ SD	p-value
Procedure duration, min	94.6 $\pm$ 31.7	84.1 $\pm$ 25.8	107.9 $\pm$ 33.7	<0.001 ^a
Contrast volume, mL	202.4 $\pm$ 68.5	181.2 $\pm$ 54.7	229.2 $\pm$ 75.8	0.001 ^a
Radiation exposure, mGy median (IQR)	1840 (1220–2740)	1580 (1080–2240)	2260 (1540–3180)	0.003 ^c
Rotational atherectomy	15 (17.4)	3 (6.3)	12 (31.6)	0.002 ^b
Other plaque-modification technique	21 (24.4)	7 (14.6)	14 (36.8)	0.019 ^b
Procedural success	76 (88.4)	46 (95.8)	30 (78.9)	0.021 ^b
Procedural failure	10 (11.6)	2 (4.2)	8 (21.1)	0.021 ^b
Coronary dissection	5 (5.8)	2 (4.2)	3 (7.9)	0.447 ^b
Coronary perforation	3 (3.5)	0 (0)	3 (7.9)	0.080 ^b
Acute vessel occlusion	4 (4.7)	1 (2.1)	3 (7.9)	0.321 ^b
No-reflow/slow-flow	7 (8.1)	2 (4.2)	5 (13.2)	0.139 ^b
Periprocedural MI	6 (7.0)	2 (4.2)	4 (10.5)	0.238 ^b
Emergency CABG	1 (1.2)	0 (0)	1 (2.6)	0.442 ^b

^aIndependent-samples t-test; ^bChi-square/Fisher's exact test; ^cMann-Whitney U test.

Table 4. Long-Term Clinical Outcomes According to CAC Score

Outcome	Overall (n=86) n(%) / mean $\pm$ SD	CAC <300 (n=48) n(%) / mean $\pm$ SD	CAC $\geq$ 300 (n=38) n(%) / mean $\pm$ SD	p-value
Median follow-up, months (IQR)	27 (22–31)	28 (23–32)	26 (21–30)	0.287
Major adverse cardiovascular events	22 (25.6)	7 (14.6)	15 (39.5)	0.009 ^b
Cardiovascular death	7 (8.1)	2 (4.2)	5 (13.2)	0.136 ^b
Myocardial infarction	9 (10.5)	3 (6.3)	6 (15.8)	0.184 ^b
Target-lesion revascularization	11 (12.8)	3 (6.3)	8 (21.1)	0.045 ^b
Target-vessel revascularization	13 (15.1)	4 (8.3)	9 (23.7)	0.052 ^b
Heart failure hospitalization	8 (9.3)	2 (4.2)	6 (15.8)	0.095 ^b
All-cause mortality	10 (11.6)	3 (6.3)	7 (18.4)	0.093 ^b

^bChi-square/Fisher's exact test.

Table 5. Binary Logistic Regression Analysis for Procedural Failure

Predictor	Unadjusted OR (95% CI)	p-value	Adjusted OR (95% CI)	p-value
Age, per year	1.04 (1.00–1.09)	0.046	1.03 (0.98–1.08)	0.231
Diabetes mellitus	2.06 (0.67–6.31)	0.207	1.61 (0.47–5.48)	0.448
Chronic kidney disease	2.72 (0.77–9.63)	0.119	2.08 (0.51–8.45)	0.306
Previous PCI	1.92 (0.58–6.35)	0.284	1.53 (0.42–5.58)	0.518
Severe lesion complexity	2.91 (0.87–9.75)	0.082	2.36 (0.64–8.71)	0.198
CAC $\geq$ 300	6.09 (1.25–29.72)	0.025	5.18 (1.01–26.63)	0.049

Table 6. Binary Logistic Regression Analysis for Procedural Complications

Predictor	Unadjusted OR (95% CI)	p-value	Adjusted OR (95% CI)	p-value
Age, per year	1.03 (0.98–1.08)	0.229	1.02 (0.96–1.08)	0.512
Diabetes mellitus	1.72 (0.62–4.77)	0.297	1.43 (0.47–4.35)	0.528
Chronic kidney disease	2.87 (0.87–9.43)	0.083	2.18 (0.59–8.07)	0.243
Previous PCI	1.58 (0.52–4.80)	0.422	1.29 (0.38–4.35)	0.678
Lesion complexity	2.47 (0.84–7.25)	0.099	2.11 (0.66–6.72)	0.208
CAC $\geq$ 300	3.21 (1.09–9.46)	0.034	2.94 (1.01–8.58)	0.048

Table 7. Cox Proportional-Hazards Regression Analysis for Long-Term MACE

Predictor	Unadjusted HR (95% CI)	p-value	Adjusted HR (95% CI)	p-value
Age, per year	1.03 (1.00–1.07)	0.071	1.02 (0.98–1.06)	0.286
Diabetes mellitus	1.68 (0.74–3.83)	0.214	1.49 (0.62–3.60)	0.373
Chronic kidney disease	2.41 (0.98–5.94)	0.056	2.03 (0.78–5.30)	0.148
Previous MI	1.71 (0.73–4.00)	0.216	1.46 (0.59–3.63)	0.411
Previous PCI	1.64 (0.68–3.95)	0.271	1.38 (0.55–3.48)	0.488
Procedural failure	2.97 (1.08–8.16)	0.035	2.51 (0.84–7.48)	0.098
CAC $\geq$ 300	3.26 (1.42–7.48)	0.005	2.74 (1.12–6.71)	0.027

Table 8. Kaplan–Meier Analysis of MACE-Free Survival

CAC group	MACE-free survival at follow-up	Log-rank test
CAC <300	85.4%	
CAC $\geq$ 300	60.5%	p=0.006
Overall	74.4%	

Patients with CAC $\geq$ 300 showed significantly worse MACE-free survival than patients with CAC <300 (60.5% vs. 85.4%, log-rank p=0.006) (Table 8).

DISCUSSION

In the current investigation, there was a definite link between CAC burden and poor outcomes following complicated PCI. After correcting for age, diabetes mellitus, chronic kidney disease, previous PCI, and PCI lesion complexity, CAC $\geq$ 300 was linked to significantly poorer procedural success compared to CAC <300 (78.9% vs. 95.8%). High CAC was also linked to procedural failure. The findings support the notion that a high coronary calcium score may be associated with the technical difficulties of complicated PCI.

The findings were similar to those of Sharma et al.'s 2019 MACE Trial, a prospective trial of 350 patients with moderate to severe calcified lesions. Patients with extensive calcification had a considerably lower procedural success rate (86.8%) than those with none or light calcification (97.7%). Importantly, 1-year MACE rose gradually from 4.7% in patients with no/mild calcification to 24.4% in individuals with severe calcification.^[14] This is consistent with our findings in patients with high CAC, who had lower procedural success rates and significantly higher long-term MACE.

Atherosclerosis was more difficult to perform in our high CAC group, evidenced by longer procedure durations, higher contrast use, higher radiation exposure, and increased use of rotational atherectomy and other plaque modification techniques. The findings are consistent with those of the 2020 meta-analysis of rotational and orbital atherectomy, which identified the technical difficulties of attempting to treat significantly calcified coronary lesions and showed variations in fluoroscopy exposure and clinical outcomes between calcium-modification strategies.^[15] The updated 2021 ACC/AHA/SCAI guideline also noted that rotational atherectomy is a useful technique for procedural success in highly calcified lesions and other plaque modification techniques may be utilized.^[16]

Our observation that high CAC was independently associated with procedural complications was also supported by previous evidence. Severe calcification was correlated with worse procedural and lesion success in the MACE Trial and independently with worse events, and renal function was correlated with worse events.^[14] In addition, the 2020 study of 17,711 PCI patients by Généreux et al showed that moderate/severe CAC was linked to significantly higher 1-year MACE, especially among patients with elevated hsCRP; MACE occurred in 21.2% of those with moderate/severe CAC and elevated hsCRP, versus 7.8% of those with moderate/severe CAC without elevated hsCRP.^[17] Other biological risk factors might enhance the effect of calcification.

Our long-term results were more comparable to the SYNTAXES cohort study, which was published in 2022. In 1,800 patients with three-vessel or left-main disease, however, heavily

calcified disease correlated strongly with 10-year mortality relative to non-heavily calcified disease (36.4% vs. 22.3%; HR 1.79), and heavy calcification was an independent predictor of mortality after adjustment (HR 1.36).^[11] The importance of our observation of significantly poorer MACE-free survival for patients with CAC ≥ 300 is therefore evident, supporting the findings of previous studies, but further evidence of the value of the quantitative calcium burden in identifying patients at high risk following complex PCI. The study found that patients with CAC ≥ 300 had greater rates of target-lesion revascularization. This finding is congruent with that of Liu et al. (2022), who studied patients with highly calcified lesions treated with cutting balloons. Patients with severely calcified lesions had significantly higher rates of MACE (21.5% vs. 13.4%), target-vessel failure (19.8% vs. 9.9%), and required more revascularization.^[18] Calcification was a significant independent predictor of MACE, target-vessel failure, and repeat revascularization. These findings imply that excessive calcium levels may be linked not only to the initial surgery, but also to later restenosis and revascularization.

Evidence from complex lesion subsets also supports our results. Murphy et al. examined 21,165 patients treated with PCI and determined that moderate/severe calcification and bifurcation disease were the most adverse event-laden of the various combinations. This combination was found to be associated with a 37% increased hazard of MACE after adjustment, compared with patients without bifurcation disease and without significant calcification.^[9] The interaction in our cohort could be attributed to the fact that we included a significant number of bifurcation lesions and that we had a very high number of complex PCI patients.

The role of calcium modification was also confirmed in the 2020 Disrupt CAD III trial of 431 patients with highly calcified lesions. Intravascular lithotripsy was successful in 92.4% of the procedures, and freedom from 30-day MACE was 92.2%.^[19] In the same way, pooled analysis of Disrupt CAD I and II showed clinical success of around 93% for eccentric and concentric calcifications, both, and only very few major procedural complications.^[20] The findings suggest that although more extensive calcification makes the procedure more difficult, modern calcium-modification technologies can significantly enhance the outcomes of the procedure. Our observations indicate, however, that patients with a high overall calcium burden still form a high-risk group despite the use of sophisticated techniques.

The current analysis demonstrated a similar pattern in long-term outcomes, with a high prevalence of adverse events in patients with calcified nodules treated with PCI, including 13% all-cause death and 23% target-lesion revascularization at one year. Kawashima et al.'s 2021 study confirmed our findings, showing that patients with calcified nodules who underwent PCI experienced significant adverse events, including an all-cause mortality rate of 13% at 1 year and a target lesion revascularization rate of 23% at 1 year.^[21] A calcified nodule indicates a type of coronary calcium morphology, but not necessarily the amount of calcium, and both forms of calcium share the same processes of severe calcium deposition, decreased stent expansion, and increased risk of restenosis. Therefore, these data also support the biological link between the extent of calcifications and post-PCI adverse outcomes.

Clinical implications of our results are that this assessment of CAC could be useful beyond conventional cardiovascular risk prediction. In our cohort, CAC ≥ 300 was an independent predictor of procedural failure, complications, and long-term MACE. The evaluation of calcium burden prior to complex PCI procedures may therefore aid the operator in predicting challenging lesion preparation, higher dosage of contrast and radiation, and the need for atherectomy or intra-vascular lithotripsy. This strategy is especially applicable in the era of contemporary guidelines that place special importance on adequate plaque modification in the presence of significant calcification that hinders lesion preparation and stent expansion.^[16]

In general, the findings of the present study were consistent with studies published from 2019 to 2022 conducted within a variety

of different study populations, definitions of calcification, PCI complexity, and follow-up duration. This consistency of association between calcium burden and procedure failure, repeat revascularization, MACE, and mortality lends further credence to the notion that coronary calcium represents advanced atherosclerotic disease and is an important risk factor for PCI outcomes.

Limitations: There were a number of limitations in this study. The limited ability to establish a causal relationship between CAC burden and clinical outcomes was due to its retrospective observational design.

The investigation comprised a small number of patients (86), and it was conducted at a single institution, which may have reduced the statistical power and generalizability of the findings. Despite multivariable corrections, selection bias and residual confounding could not be entirely eliminated. Furthermore, variances in lesions, operator expertise, intravascular imaging, and calcium modulation approaches may have influenced procedure outcomes. Follow-up information was also based on available clinical records, with the likelihood that some long-term events had not been fully determined. These findings need be verified in bigger prospective multicenter trials.

CONCLUSION

There was a significant association between increased coronary artery calcium burden and increased procedural complexity, lower procedural success, higher procedural complication rate, and worse long-term outcomes after complex PCI. After adjustment for clinical and procedural factors, a CAC score ≥ 300 independently predicted procedural failure and long-term MACE. Thus, CAC assessment can be beneficial for preprocedural risk stratification and offer guidance in the planning of the appropriate calcium-modification strategy and post-PCI surveillance.

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