Outcomes of coronary rotational atherectomy in patients with reduced left ventricular ejection fraction

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Abstract

Objective: We evaluated the safety and efficacy of rotational atherectomy (RA) in patients with a reduced left ventricular ejection fraction (LVEF).

Methods: In total, 140 consecutive patients with severe coronary artery calcification (CAC) who underwent RA were retrospectively enrolled. Patients were grouped based on LVEF: ≤35% (n = 10), 36% to 50% (n = 11), and >50% (n = 119). We assessed procedural success and periprocedural complication rates as well as the incidences of in-hospital and 2-year major adverse cardiac events (MACEs), defined as hospitalization for myocardial infarction and worsening heart failure, target vessel revascularization, and cardiac death.

Results: Procedural success was achieved in nearly all patients in each group. Most periprocedural complications were minor, and major complications were uncommon. The 2-year MACE rate was significantly higher in the LVEF ≤35% than LVEF >50% group (40.0% vs. 6.7%, respectively). Multivariable regression analysis revealed that the LVEF was the only independent predictor of 2-year MACEs in patients who underwent RA.

Conclusions: Patients with a reduced LVEF who underwent RA had procedural success rates similar to those of patients with preserved left ventricular systolic function. The LVEF might be an independent predictor of 2-year MACEs in patients with severe CAC after percutaneous coronary intervention following RA.

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Introduction

Coronary artery calcification (CAC) is a risk factor for advanced coronary artery disease and is a predictor of adverse outcomes in patients undergoing percutaneous coronary intervention (PCI).[1–3] PCI in patients with severe CAC is technically challenging because of the difficulty of balloon or stent delivery and optimal stent expansion, which may decrease the risk of stent thrombosis and stent restenosis.[4] In addition, repetitive high-pressure balloon inflations to enlarge a suboptimally expanded stent might increase the risk of coronary dissection or perforation.[5]

Coronary rotational atherectomy (RA) is an effective way to treat coronary calcified lesions and can modify calcified plaques to facilitate balloon or stent delivery and optimize stent expansion.[6–8] Current PCI guidelines indicate that RA is a reasonable approach for the treatment of fibrotic or heavily calcified plaques that cannot be crossed by a balloon catheter or adequately dilated before stent implantation.[9] Patients with a reduced left ventricular ejection fraction (LVEF) account for one-fourth to one-third of those undergoing RA.[10,11] A reduced LVEF is reportedly an independent predictor of adverse clinical events in patients undergoing PCI.[12] This population represents a high-risk group because such patients are more often faced with the threats of periprocedural complications of RA, including procedural hypotension that may require hemodynamic support.[11] The outcomes of patients with an impaired LVEF who undergo orbital atherectomy have been previously described,[13] but data on the safety and efficacy of RA in patients with a severely reduced LVEF remain limited. Therefore, we analyzed the in-hospital and 2-year clinical outcomes in patients with a reduced LVEF who underwent RA in this retrospective investigation.

Methods

Study patients

This retrospective analysis included consecutive patients with severe CAC lesions and significant stenosis (stenosis of $\geq 75\%$ of the vessel diameter) who underwent RA from April 2012 to December 2017. Severe CAC was defined visually by fluoroscopy as the presence of radio-opacities within the vessel wall without cardiac motion before contrast injection, and the radio-opacities generally affected both sides of the vessel wall.[14,15] On intravascular ultrasound (IVUS), severe CAC was defined as the presence of $\geq 270°$ of high-intensity echoes with acoustic shadowing at one cross section. Patients were grouped based on the LVEF: $\leq 35\%$, 36% to 50%, and >50%. The institutional ethics committee approved the review of the data.

Device description

All patients underwent coronary RA using the Rotablator Rotational Atherectomy System (Boston Scientific, Marlborough, MA, USA). This coronary rotational atherectomy device has been previously described.[16] An olive-shaped burr coated

with 2,000 to 3,000 microscopic diamonds is bonded to a drive shaft and advances over a 0.009-inch RotaWire (Boston Scientific). The other rotational components include the console, a nitrogen tank, and a turbine that is activated by a foot pedal. When the burr is rotated, a flush solution is infused continuously through the drive shaft to minimize the heat and friction between the device and the RotaWire and to avoid coronary spasm and slow flow.

Procedure

All patients provided written informed consent to undergo coronary angiography and the intervention procedure. The LVEF used for analysis was the latest measurement obtained via echocardiography prior to PCI. Standard techniques for PCI were performed by an experienced operator. The choice of artery access site (radial or femoral) and the decision to perform RA were at the discretion of the operator. Planned RA was performed when the target lesion was deemed undilatable by a balloon according to angiography and/or IVUS. Rescue RA was performed when there was an inability to fully expand the target lesion or cross the stents with any devices.

The typical burr-to-artery ratio was 0.5. In general, a 1.25-mm burr was initially used, and larger burrs (1.50 or 1.75 mm) were used thereafter. Before insertion into the guiding catheter, the mounted RA burr was tested at 150,000 to 170,000 rpm over the RotaWire. After entering the guiding catheter, the burr was advanced at a low speed of 60,000 to 70,000 rpm. The rotational working speed of the burr ranged from 130,000 to 150,000 rpm, and higher-speed RA ($\geq$180,000 rpm) was performed if the target lesion could not be fully dilated. Each pass was limited to $\leq$30 seconds. The decision to insert a temporary

pacemaker, use a hemodynamic support device, or use IVUS to assess the lesion morphology and stent expansion was made by the operator. After RA, patients underwent placement of a single or multiple drug-eluting stent (DES) with predilatation with a conventional, scoring, or cutting balloon. The balloon and stent type used were chosen by the operator. Procedural success was defined as final residual stenosis of $\leq$30% in the presence of grade 3 thrombolysis in myocardial infarction (TIMI) flow without in-hospital death, emergency coronary artery bypass graft surgery, and/or repeat PCI during the index hospitalization. Angiographic follow-up at 12 months after DES implantation was not routinely performed in all patients.

Adjunctive pharmacotherapy

All patients received pretreatment with 100 to 300 mg of aspirin and a 300-mg loading dose of clopidogrel before the PCI procedure. During PCI, patients received unfractionated heparin in an initial bolus of 80 to 100 U/kg and additional boluses of 1,000 U/hour. A rota-flush solution contains 12,500 units of unfractionated heparin, 5 mg of verapamil, and 5 mg of nitroglycerin in a 1-L bag of saline solution. The duration of dual antiplatelet therapy was 1 year for patients with a DES. After the intervention procedure, the choice of anticoagulant, including low-molecular-weight heparin or fondaparinux, was at the discretion of the operator and was based on the risk of thrombosis after PCI involving long stents or multiple stents, small vessel stenting, or bifurcation stenting and whether residual dissection was present.

Endpoint and definitions

A dedicated RA database was established to record demographic, angiographic, and

procedural data, including the characteristics of RA and periprocedural complications. All procedure-associated adverse events were regarded as periprocedural complications, including coronary spasm, coronary dissection, coronary slow flow or no flow, bradycardia, burr entrapment, side branch occlusion, peripheral vascular complications, contrast-induced nephropathy, periprocedural myocardial infarction (MI), and in-hospital death. Periprocedural MI was defined as an elevation of the cardiac troponin (cTn) level to >5 times the upper limit of the reference range in patients with a normal baseline level and to >20% of the baseline level in patients with a baseline level above the upper limit; however, the absolute postprocedural cTn level still was >5 times the upper limit of the reference range. The analyses were performed independently by two experienced observers. Clinical outcomes were collected from the medical records. Follow-up data, including information on cardiac medications, were obtained by direct telephone or in-person interviews with the patients. The primary endpoint in this study was the occurrence of 2-year major adverse cardiac events (MACEs), defined as hospitalization for MI and worsening heart failure (HF), target vessel revascularization (TVR) after the index PCI, and cardiac death. MI was defined as elevation of the cTn level to >2 times the upper limit of the reference range and recurrent symptoms with or without new ST-segment changes. TVR was defined as repeated revascularization, either percutaneous or surgical, of the target vessel previously treated by RA. Cardiac death was defined as any death with a proximate cardiac cause and all procedure-related deaths.[17] Unwitnessed death or death of unknown cause were adjudicated as cardiac-related unless an unequivocal noncardiac cause could be documented. The Academic Research Consortium definition of stent thrombosis was used.[17]

Statistical analysis

Continuous variables with a normal distribution are presented as mean ± standard deviation, and those with a non-normal distribution are presented as median (interquartile range), as appropriate. Analysis of variance or the Mann–Whitney rank-sum test was used to test differences among continuous variables. Categorical variables are expressed as number and percentage and were compared using the chi-square test or Fisher's exact test. Kaplan–Meier plots for the cumulative incidence of MACEs were constructed from the index procedure, and differences between groups were assessed using the log-rank test. To identify independent risk factors for MACEs, a backward stepwise Cox proportional hazards regression analysis was performed, expressed as the hazard ratio (HR) with the 95% confidence interval (CI). All clinical, angiographic, and procedural factors that might affect the long-term prognosis were evaluated. Variables entered into the Cox hazard regression model were those that reached statistical significance following the univariate analysis. A P value of <0.05 (two-tailed) was considered statistically significant. All data were processed with IBM SPSS version 19.0 (IBM Corp., Armonk, NY, USA).

Results

Baseline clinical characteristics

In total, 140 patients were included in this study. The patients' baseline clinical characteristics are summarized in Table 1. Patients were grouped by the LVEF as follows: ≤35% (lowest, 25%; mean, 32.6% ±3.5%; n = 10 [7.1%]), 36% to 50% (mean, 45.0%±4.5%; n = 11 [7.9%]), and >50% (mean, 63.8%±4.4%; n = 119 [85.0%]). Patients in the LVEF >50% group were significantly younger than

Table 1. Baseline clinical characteristics of the entire cohort.

Variable	LVEF of ≤35% (n=10)	LVEF of 36%–50% (n=11)	LVEF of >50% (n=119)	P value
LVEF, %	32.6±3.5	45.0±4.5*	63.8±4.4*#	<0.001
Age, years	76.0±9.3	75.9±9.2	69.9±9.1*#	0.021
Male sex	4 (40.0)	5 (45.5)	72 (60.5)	0.310
Hypertension	10 (100.0)	7 (63.6)	90 (75.6)	0.127
Diabetes mellitus	7 (70.0)	6 (54.5)	59 (49.6)	0.452
Previous myocardial infarction	4 (40.0)	4 (36.4)	18 (15.1)	0.068
UAP	6 (60.0)	4 (36.4)	70 (58.8)	0.348
Acute MI	2 (20.0)	4 (36.4)	4 (3.4)#	0.002
STEMI	0 (0.0)	1 (0.9)	0 (0.0)	
NSTEMI	2 (20.0)	3 (27.3)	4 (3.4)	
eGFR (ml/min/1.73 m^2)	63.6±30.1	90.0±25.4*	90.2±25.1*	0.012

Values are presented as n (%) or mean ± standard deviation.
*Significant differences were present when compared with the LVEF ≤35% group.
#Significant differences were present when compared with the LVEF 36%–50% group.
LVEF, left ventricular ejection fraction; UAP, unstable angina pectoris; MI, myocardial infarction; STEMI, ST-elevation myocardial infarction; NSTEMI, non-ST-elevation myocardial infarction; eGFR, estimated glomerular filtration rate.

patients with left ventricular systolic dysfunction (P = 0.021). The prevalence of male sex, hypertension, diabetes mellitus, and unstable angina pectoris was similar among the groups. Patients with an LVEF of ≤50% had a higher prevalence of previous MI, but the difference was not statistically significant. Additionally, significantly more patients in the LVEF 36% to 50% group presented with acute MI than those in the LVEF >50% group (P = 0.002). Patients in the LVEF ≤35% group had a significantly lower estimated glomerular filtration rate (eGFR) than patients in the other two groups (P = 0.012).

Angiographic and procedural characteristics

The detailed angiographic and procedural characteristics are listed in Table 2. There were no significant differences in the volume of contrast or sheath size among all three subgroups. Significantly more RA procedures were performed through transradial access in the LVEF >50% group than

in the LVEF 36% to 50% group (P = 0.024). The proportion of target vessels of the left circumflex artery was significantly lower in the LVEF >50% group (P = 0.001), and the distribution of RA vessels, including the left anterior descending artery and right coronary artery, was similar among the groups. No significant differences in most of the lesion or procedural characteristics were noted among the LVEF subgroups, including the lesion classification of type B2/C, presence of bifurcation lesions, reference vessel diameter, burr size, number of burrs used, maximum rotational speed, number of rotations, number of stents used, or maximum postdilation pressure; the only exception was the maximum predilation pressure, which was larger in the LVEF ≤35% group than in the LVEF >50% group (P = 0.017). A 1.75-mm burr was used in only one patient in the LVEF >50% group. The percentages of IVUS-guided RA procedures were 60.0%, 54.5%, and 47.9% in the LVEF ≤35%, LVEF 36% to 50%, and LVEF >50% groups, respectively, with no significant differences. Procedural success

Table 2. Angiographic and procedural characteristics.

Variable	LVEF of ≤35% (n=10)	LVEF of 36%–50% (n=11)	LVEF of >50% (n=119)	P value
Volume of contrast, mL	301.7±105.0	271.9±79.6	264.6±85.6	0.426
Guiding catheter				
6F	9 (90.0)	10 (90.9)	116 (97.5)	0.279
7F	1 (10.0)	1 (9.1)	3 (2.5)	
PCI access				
Transradial	6 (60.0)	6 (54.5)	99 (83.2)#	0.024
Transfemoral	4 (40.0)	5 (45.5)	20 (16.8)	
LM and/or three-vessel coronary disease	8 (80.0)	8 (72.7)	84 (70.6)	0.815
Target vessel				
LAD	7 (70.0)	9 (81.8)	105 (88.2)	0.243
LCX	2 (20.0)	2 (18.2)	2 (1.7)*#	0.001
RCA	1 (10.0)	0 (0.0)	12 (10.1)	0.543
ACC/AHA lesion classification				
B2/C	9 (90.0)	11 (100.0)	116 (97.5)	0.331
Bifurcation lesion	3 (30.0)	6 (54.5)	73 (61.3)	0.148
Reference vessel diameter, mm	2.6±0.2	2.7±0.3	2.8±0.3	0.087
Maximum burr size/Reference vessel diameter	0.50 (0.50–0.50)	0.5 (0.42–0.50)	0.5 (0.43–0.50)	0.507
Number of burrs				
1	9 (90.0)	10 (90.9)	107 (89.9)	0.994
2	1 (10.0)	1 (9.1)	12 (10.1)	
1.25 mm	9 (81.8)	8 (66.7)	80 (61.1)	0.377
1.50 mm	2 (18.2)	4 (33.3)	50 (38.2)	0.406
1.75 mm	0 (0.0)	0 (0.0)	1 (0.8)	0.915
Number of rotational times	4.0 (3.8–6.8)	5.0 (3.0–7.0)	4.0 (3.0–5.0)	0.134
Maximum rotational speed (10,000 rpm)	15.9±1.4	15.0±2.1	15.9±1.3	0.148
Maximum predilation pressure, atm	16.4±4.3	15.4±4.3	13.4±3.5*	0.017
Maximum postdilation pressure, atm	17.2±2.9	18.2±2.9	18.1±3.2	0.672
Number of stents	2.0±0.8	1.9±0.3	2.0±0.7	0.852
IVUS-guided RA	6 (60.0)	6 (54.5)	57 (47.9)	0.714
Procedural success	9 (90.0)	11 (100.0)	118 (99.2)	0.656

Values are presented as n (%), mean ± standard deviation, or median (interquartile range).
*Significant differences were present when compared with the LVEF ≤35% group.
#Significant differences were present when compared with the LVEF 36%–50% group.
LVEF, left ventricular ejection fraction; ACC/AHA, American College of Cardiology/American Heart Association; LM, left main; PCI, percutaneous coronary intervention; LAD, left anterior descending artery; LCX, left circumflex artery; RCA, right coronary artery; IVUS, intravascular ultrasound; RA, rotational atherectomy.

was achieved in nearly all patients in each group.

Complications and 2-year outcomes

No significant differences were observed in the incidence of overall periprocedural complications across all LVEF subgroups. The incidence of each periprocedural complication is documented in Table 3. Most complications were minor, and seriously major complications were uncommon. Burr entrapment occurred in two patients in the LVEF >50% group and was

Table 3. Periprocedural complications and 2-year MACE rates.

Variable	LVEF of ≤35% (n=10)	LVEF of 36%–50% (n=11)	LVEF of >50% (n=119)	P value
Peri-procedural complications	1 (10.0)	5 (45.5)	34 (28.6)	0.199
Minor complications	0 (0.0)	3 (27.3)	26 (21.8)	0.224
Coronary spasm	0 (0.0)	0 (0.0)	1 (0.8)	
Coronary dissection	0 (0.0)	0 (0.0)	12 (10.1)	
Coronary slow flow/no flow	0 (0.0)	2 (18.2)	6 (5.0)	
Bradycardia	0 (0.0)	1 (0.9)	8 (6.7)	
Side branch occlusion	0 (0.0)	0 (0.0)	2 (1.7)	
Peripheral vascular complications	0 (0.0)	0 (0.0)	2 (1.7)	
Femoral hematoma	–	–	1 (0.8)	
Mediastinal hematoma	–	–	1 (0.8)	
Contrast-induced nephropathy	0 (0.0)	0 (0.0)	1 (0.8)	
Major complications	1 (10.0)	0 (0.0)	2 (1.7)	0.191
Burr entrapment	0 (0.0)	0 (0.0)	2 (1.7)	
Peri-procedural myocardial infarction	1 (10.0)	2 (18.2)	13 (10.9)	0.761
In-hospital death	1 (10.0)	0 (0.0)	0 (0.0)	
2-year MACE	4 (40.0)	2 (18.2)	8 (6.7)	0.002*
Hospitalization from MI and HF	2 (20.0)	2 (18.2)	2 (1.7)	0.001*#
TVR	1 (10.0)	0 (0.0)	5 (4.2)	0.525
Cardiac death	1 (10.0)	0 (0.0)	1 (0.8)	0.059

Values are presented as n (%).
*Significant differences were present when compared with the LVEF ≤35% group.
#Significant differences were present when compared with the LVEF 36%–50% group.
MACE, major adverse cardiac event; LVEF, left ventricular ejection fraction; MI, myocardial infarction; HF, heart failure; TVR, target vessel revascularization.

successfully relieved by repeat balloon dilation following removal of the whole rotational system. One in-hospital death due to refractory HF occurred after the procedure during hospitalization in the LVEF ≤35% group. The one patient who died in the LVEF >50% group was a 77-year-old man who developed cardiac arrest at home 14 months post-discharge. No coronary perforation or cardiac tamponade occurred, and no definite or probable stent thrombosis was recorded in any patient. The primary endpoint rate of 2-year MACEs in the LVEF ≤35% group was significantly higher than that in the LVEF >50% group (P = 0.002), mainly because of the difference in hospitalization between patients with MI and HF (Table 3).

The Kaplan–Meier estimates of the 2-year MACE rates are shown in Figure 1 (log-rank P<0.001). There were no significant differences in the 2-year rates of TVR and cardiac death.

Predictors of 2-year MACEs

To evaluate the independent predictors of 2-year MACEs in patients who underwent RA, a backward stepwise Cox proportional hazards regression analysis was performed as described above. The significantly different clinical, angiographic, and procedural variables that were entered into the Cox hazard regression model were the LVEF, eGFR, acute MI, and maximum predilation pressure. Table 4 shows the predictors of
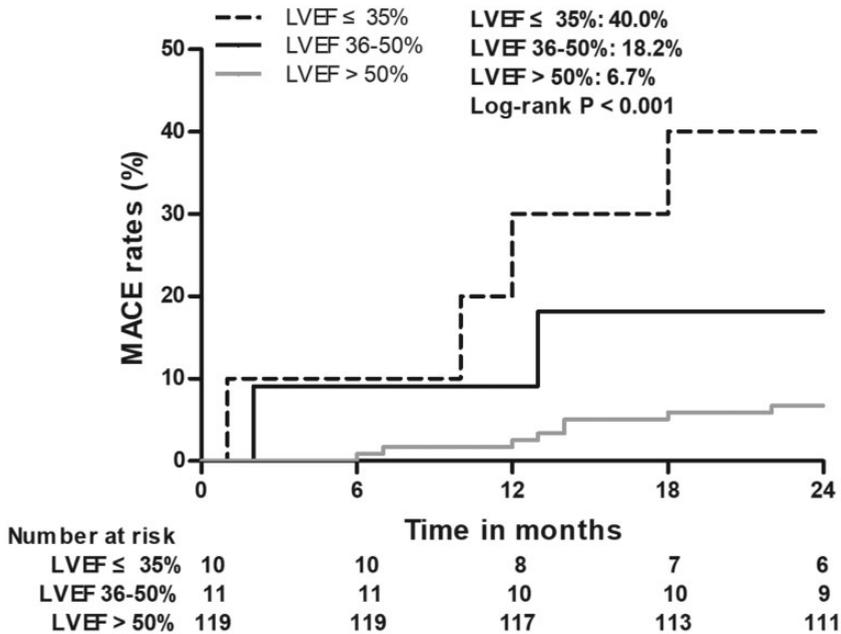
Figure 1. Major adverse cardiac event rates in patients who underwent rotational atherectomy at the 2-year follow-up stratified by the left ventricular ejection fraction. MACE, major adverse cardiac event; LVEF, left ventricular ejection fraction.

Table 4. Predictors of 2-year MACEs in patients who underwent RA.

Variable	HR	95% CI	P value
LVEF	0.952	0.913–0.993	0.022
eGFR	0.979	0.960–1.000	0.050
AMI	1.688	0.440–6.476	0.445
Maximum predilation pressure	1.077	0.957–1.213	0.218

MACE, major adverse cardiac event; RA, rotational atherectomy; HR, hazard ratio; CI, confidence interval; LVEF, left ventricular ejection fraction; eGFR, estimated glomerular filtration rate; AMI, acute myocardial infarction.

2-year MACEs in patients who underwent RA. After adjusting for possible confounders, the eGFR (HR, 0.979; 95% CI, 0.960–1.000), AMI (HR, 1.688; 95% CI, 0.440–6.476), and maximum predilation pressure (HR, 1.077; 95% CI, 0.957–1.213) were not significant independent predictors of 2-year MACEs. The only independent predictor of 2-year MACEs in patients who underwent RA was the LVEF (HR, 0.952; 95% CI, 0.913–0.993, P = 0.022).

Discussion

In the present study, we evaluated the safety and long-term clinical outcomes of RA in patients with a reduced LVEF. The four main findings were as follows. First, patients with severe CAC and a reduced LVEF who underwent RA had a procedural success rate similar to that of patients with preserved left ventricular systolic function. Second, periprocedural complications

of RA were not rare, but severely major complications were not common across all LVEF subgroups. Third, a higher 2-year MACE rate was observed in patients with a severely reduced LVEF who underwent RA than in patients with preserved left ventricular systolic function. Finally, among patients who underwent RA, those with a reduced LVEF had a worse long-term prognosis.

The ORBOT II study demonstrated that the 1-year cardiac mortality rate was higher in patients with left ventricular systolic dysfunction who underwent orbital atherectomy, suggesting an association between reduced left ventricular function and increased mortality after orbital atherectomy.[13] However, limited data concerning RA in patients with left ventricular dysfunction have been reported.[18,19] In the present study of RA, patients with a severely reduced LVEF who underwent RA had a higher 2-year MACE rate than patients with preserved left ventricular systolic function, and the LVEF was an independent predictor of 2-year MACEs in patients who underwent RA. There are several possible explanations for why a reduced LVEF adversely affects the prognosis in patients who have undergone RA. First, in general, patients with impaired left ventricular systolic function have a poorer prognosis than patients with preserved left ventricular systolic function.[20] In patients who have undergone PCI, a significant relationship reportedly exists between left ventricular function and mortality, with worsening left ventricular function associated with worse short-term and long-term clinical outcomes.[21] Second, patients with a reduced LVEF are more likely to have a greater risk profile, which might influence clinical outcomes.[19] In the present study, compared with patients who had a preserved LVEF, more patients in the LVEF 36% to 50% group presented with acute MI, and patients with a severely reduced LVEF (LVEF of ≤35%) had a significantly lower eGFR. Third, in patients with a decreased LVEF, a compensation mechanism cannot be established in time when faced with abrupt coronary atherectomy. Thermal injury and platelet activation may also be involved during this process.[22] In addition, coronary microvascular dysfunction resulting from distal embolization of the released microparticulate debris during the procedure might worsen the left ventricular function, even leading to instant hemodynamic instability. For some patients with a severely reduced LVEF, in-hospital outcomes are more unfavorable even though the RA procedure is tolerated. In the present study, one in-hospital death occurred because of refractory decompensated HF during hospitalization in the LVEF ≤35% group despite the rescue intra-aortic balloon pump being inserted after the procedure.

Previous studies have shown that PCI of severely calcified lesions is associated with adverse clinical outcomes.[23,24] RA is a useful tool with which to reduce severely calcified plaques prior to stent deployment, and it helps to remarkably improve the procedural success rate.[25] In our study, procedural success was achieved in 138 of 140 (98.6%) patients who underwent RA. It was not rare to encounter patients with a reduced LVEF among those undergoing RA. In the present study, patients with an impaired LVEF accounted for nearly one-sixth of those who underwent RA. Higher rates of periprocedural complications have been reported with the use of atherectomy devices during PCI, and the safety of RA in patients with a lower LVEF has raised more concerns.[26] Our study demonstrated a similar success rate with insignificantly different complication rates among patients in different LVEF subgroups. The operation of the RA device appears to be more complicated when using a 0.009-inch-diameter RotaWire with a crown-shaped burr

attachment, which is easier to fold incautiously. The burr only ablates in the antegrade direction because of the lack of a diamond coating on the proximal portion of the burr; this gives rise to the possibility of burr entrapment, especially when faced with heavily calcified lesions. In the present study, no burr entrapment occurred in patients with a reduced LVEF, which seems irrelevant to the status of cardiac function. With the exception of a greater maximum predilation pressure, which was applied in patients with a severely reduced LVEF without an increased coronary dissection rate, no significant differences were observed in the characteristics of the RA procedure among the LVEF subgroups. In daily practice, RA is performed more often in patients with complex and diffuse coronary lesions to avoid periprocedural complications and to successfully treat the calcified lesion; experience performing the technique and skilled assistance are absolutely needed. Notably, periprocedural complications were not a predictor of MACEs in patients who underwent RA in the present study.

Study limitations

This study had several limitations. First, it was a small, retrospective, observational study conducted at a single center, and the multivariable regression model might have been over-fitted. The lack of a control group made it impossible to prove the superiority of RA over techniques employing other special devices used to treat calcified lesions, such as scoring balloons, cutting balloons, or orbital atherectomy devices. Hence, the results of our study are limited to patients who have undergone RA. To our knowledge, however, the clinical outcomes of PCI following RA in patients with impaired left ventricular systolic function have rarely been reported. Second, the percentage of patients with an impaired LVEF who underwent RA in our study was lower than that reported in a previous study (one-sixth compared with one-fourth to one-third of patients).[10,11] This implies that the study population might have been selective, with possibly biased results. Furthermore, patients with severe left ventricular dysfunction (LVEF of ≤25%) were not included in the present study; therefore, the outcomes in these patients remain unclear. Third, we did not evaluate the possible myocardial injury resulting from RA, and periprocedural myocardial injury might have manifested as changes in the LVEF. Fourth, the complete revascularization rate across all groups was not analyzed. Previous studies have shown that the complete revascularization achieved by PCI was significantly associated with a survival benefit.[27,28] Fifth, IVUS was used in only half of the patients in our study. Many patients underwent rescue RA when the routine intervention procedure failed and heavily calcified lesions were revealed by IVUS. IVUS used before the PCI procedure may aid in achieving a more comprehensive understanding of the characteristics of the calcified lesions, and the outcomes of planned RA might differ from those of rescue RA. Sixth, objectively, an undeniable learning curve was present in performance of RA across all patients in this study. The strategy and technique for treatment of calcified lesions in a single center might not adequately reflect the treatment in patients with impaired left ventricular systolic function. Finally, routine angiographic follow-up in patients who underwent RA was not absolute in our daily practice, which might have induced bias in the TVR rate.

Conclusions

In this assessment of patients with a reduced LVEF who underwent RA for severe CAC, although the procedural

success rate was similar to that of patients with preserved left ventricular systolic function and there was no significantly increased incidence of major complications, a higher 2-year MACE rate was observed. The multivariate analysis revealed that the LVEF was the only independent predictor of 2-year MACEs in patients who underwent RA for severe CAC. With regard to the feasibility of RA in patients with impaired left ventricular systolic function and the adverse effect of a reduced LVEF on the prognosis, future studies should be carried out to help confirm the role of the LVEF in risk stratification of patients undergoing RA. Prospective, randomized studies with larger populations are warranted in the future.

Availability of data and materials

All data analyzed during the current study are available from the corresponding author upon reasonable request.

Authors' contributions

Study conception and design: F-CS, H-PZ
Acquisition of data: H-PZ, HA, YZ, HL, G-DT, N-XZ
Analysis and interpretation of data (e.g., statistical analysis, computational analysis): H-PZ, HA, YZ, F-CS, HL
Writing, review, and/or revision of the manuscript: H-PZ, YZ, F-CS
Study supervision: F-CS

Declaration of conflicting interest

The authors declare that there is no conflict of interest.

Ethics approval and consent to participate

The study was approved by the institutional ethics committee, and all patients provided written informed consent to undergo coronary angiography and the intervention procedure. Because the study was retrospective, we were unable to obtain informed consent from those patients in whom MACEs occurred.

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