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Impact of Plaque Calcification and Stent Oversizing on Clinical Outcomes of Atherosclerotic Femoropopliteal Arterial Occlusive Disease Following Stent Angioplasty

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WHAT THIS PAPER ADDS

Plaque calcification and stent oversizing have been confirmed as two key factors for in stent restenosis in atherosclerotic peripheral artery occlusive disease. An effective plaque scoring system and specific stent oversizing standard have been well established in the coronary artery. However, there are still no similar assessment methods for the femoropopliteal artery. In this study, automatic computer software was used to analyse the pre-operative computed tomography angiography (CTA) images of patients receiving femoropopliteal artery stenting for atherosclerotic occlusive disease. Plaque calcification and stent oversizing were assessed by several quantitative parameters. Stent oversizing and plaque calcification were linked with adverse clinical outcomes. The results suggest potential cut off values of plaque calcification and stent oversizing, which may be useful for clinical intervention, and also imply the feasibility of quantitatively assessing plaques in the femoropopliteal artery on pre-operative CTA.

Objective: Plaque calcification and stent oversizing are two key factors contributing to in stent restenosis (ISR) following femoropopliteal stent angioplasty. This study aimed to explore a pre-operative quantitative assessment method of plaque calcification and rational parameters of stent oversizing in the femoropopliteal artery.

Methods: A total of 115 patients with atherosclerotic femoropopliteal arterial occlusive disease treated from January 2013 to January 2016 were included retrospectively. Computed tomography angiography (CTA) imaging was performed to analyse calcified plaque parameters (calcified plaque volume [CV], standard CV [SCV], burden of calcified plaque) and stent oversizing parameters at different vessel segments (distal oversizing, maximum oversizing, plaque oversizing). Optimal cut offs for the six parameters were determined by the maximum Youden's index. The relationship between calcified plaque, stent oversizing, and clinical outcomes were assessed by correlation analysis and multivariable Cox regression models.

Results: The one year primary patency rate was 77.4%; the rates of ISR, major amputation, target lesion revascularisation, and mortality were 40.9%, 8.7%, 17.4%, and 12.2%, respectively. For all six parameters, patients with values greater than the cut offs had a significantly higher incidence of ISR than those with values below the cut offs. ISR was positively correlated with all six calcification and oversizing parameters. Amputation and mortality were positively correlated with calcification parameters. Multivariable Cox regression analysis demonstrated that all six parameters were independent risk factors for ISR. All calcification parameters were identified as independent risk factors for amputation, while only CV and SCV were independent risk factors for mortality.

Conclusion: Calcified plaque in the femoropopliteal artery can be quantitatively analysed on pre-operative CTA images. High calcified plaque burden and excessive stent oversizing were associated with unfavourable outcomes following stent angioplasty.

Keywords: Atherosclerosis, Calcified plaque, Femoropopliteal artery, Stent angioplasty, Stent oversizing
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INTRODUCTION

Endovascular stent angioplasty has become the first line management for peripheral artery disease (PAD).[1,2] However, the long-term efficacy is greatly impaired by the high incidence of in stent restenosis (ISR).[3–6] ISR occurs in 18–40% of patients within the first year following femoropopliteal artery stenting,[4,7] and is most frequently observed in long, severely stenotic, or totally occlusive lesions where the plaque burden is high and calcified plaques usually exist.[3,4,8] Furthermore, another important negative element, excessive stent oversizing, has been confirmed and has attracted increasing attention in recent years.[9–11]

Though the roles of calcified plaque and stent oversizing in the development of ISR have been extensively investigated,[9,10,12,13] no distinct quantitative method is available to evaluate these two factors and guide clinical practice in femoropopliteal artery. Therefore, this preliminary pilot study was conducted to quantitatively assess plaque calcification and stent oversizing, and their influence on clinical outcomes following femoropopliteal stent angioplasty.

METHODS

Patients

The medical records of 602 consecutive patients with PAD treated from January 2013 to January 2016 were reviewed retrospectively. The inclusion criteria were as follows: (i) diagnosis of atherosclerotic femoropopliteal arterial occlusive disease; (ii) intermittent claudication or critical limb ischaemia (Rutherford stage 3–6); (iii) received primary stent angioplasty. The exclusion criteria were (i) aorto-iliac lesion stenosis $>$30%; (ii) occlusion of all below knee arteries; (iii) acute lower limb arterial embolism; (iv) secondary stent angioplasty; (v) previous bypass surgery; (vi) Buerger's disease, polyarteritis, malignancy, or rheumatism; and (vii) antiplatelet therapy intolerance. This study was approved by the institutional review board (IRB) of the Eastern Branch of the Third Affiliated Hospital of Sun Yat-sen University. Written informed consent was waived by the IRB owing to the study's retrospective nature.

Stenting procedure

All the procedures were performed under local anaesthesia. Contralateral femoral access was preferred, but ipsilateral antegrade femoral access and retrograde popliteal access were adopted if necessary. Intravenous heparin (1 mg/kg) was administered routinely. A 0.035 inch hydrophilic stiff guidewire was usually used to cross the lesions, and then the lesions were dilated by a plain balloon for 2–3 min under a pressure of 12–14 atm. For patients with residual stenosis $>$30% or flow limiting dissections, stents were selectively implanted and post-dilation was routinely performed. Stent selection was determined by the surgeon based on the size of the target vessel. At least 1 cm overlap was demanded if more than one stent was used. The maximum acceptable residual stenosis was 30%. After the stenting procedure, patients were administered 75 mg clopidogrel and 100 mg aspirin per day for three months. Then clopidogrel was withdrawn and aspirin continued.

Computed tomography angiography and image analysis

All patients underwent pre-operative computed tomography angiography (CTA) examination on admission, using a 320 slice spiral CT (Aquilion ONE; Toshiba, Tokyo, Japan) and iopromide (Ultravist, 370 mg/mL; Bayer Schering Pharma, Berlin, Germany) or iodixanol (Visipaque, 320 mg/mL; GE Healthcare AS, Dublin, Ireland) as the contrast agent.

All CTA image analyses were performed with Vitrea Core software (Version 6.7.1030; Vital Images, Plymouth, MN, USA) by the same investigator blinded to the patients' outcomes. To eliminate measurement error, each patient's images were analysed three times and mean values recorded. The interval between two measurements was $>$ one week.

CTA images were reconstructed in the volume rendering mode with centreline automatically analysed by the software and then manually checked by the investigator. Different types of plaque can be clearly displayed within the region of interest (Fig. 1), according to the suggested CT value of −100 to 49 Hounsfield units (HU) for soft plaque, 50–299 HU for fibrous plaque, and 300–2,000 HU for calcified plaques.[13] Values of calcified plaque were collected and analysed.

Calcified plaque volume (CV, mm^3) was defined as the volume of calcified plaque (CT value = 300–2,000 HU) in the target lesion. Standard calcified plaque volume (SCV, mm^2) was calculated according to the following equation: SCV = CV/length of the lesion. Calcified plaque burden (CB, %) was defined as the volume ratio of calcified plaque to the total plaques, using the following equation: CB = calcified plaque volume/volume of the total plaques. All three parameters indicate the extent of calcification in the target lesions.

The stent oversizing rate (OS, %) was calculated according to the following equation: $OS = (\sqrt{S_{stent}/S_{lumen}} - 1) \times 100\%$, where S_{stent} is defined as the original cross sectional area of the stent graft, S_{lumen} is defined as the pre-stenting cross sectional inner area of the target artery, which was measured on pre-operative CTA transverse sections, including the area occupied by compressible plaques characterised by a HU value $<$ 300.

Oversizing rates at three levels were automatically calculated by Vitrea Core software as follows: oversizing rate of stent distal end (OSdis) was defined as the OS at the distal level of stent; maximum oversizing rate (OSmax) was defined as the OS at the narrowest cross sectional level of the target lesion; oversizing rate of calcified plaque (OSp) was defined as the OS at the level where the maximum calcified plaque existed.

Follow up

All patients were followed up at one, three, six and twelve months post stenting and yearly thereafter. Color Doppler ultrasonography was routinely performed to measure the

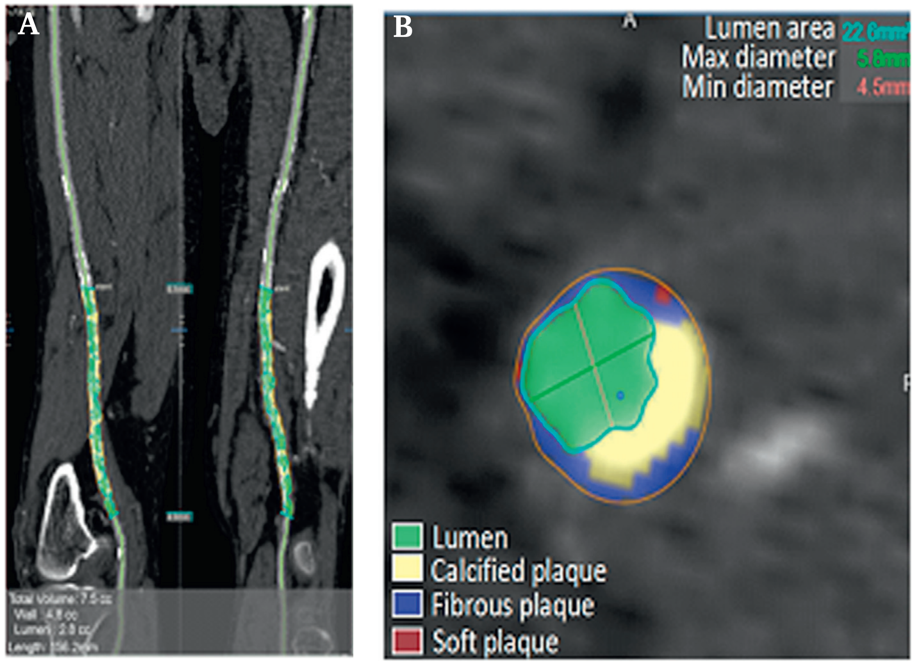

Figure 1. Computed tomography angiography (CTA) imaging analysis. (A) CTA images were reconstructed in the volume rendering mode. (B) The volume of calcified plaque was then calculated automatically within the region of interest.

peak systolic velocity ratio (PSVR). ISR was confirmed by post-operative CTA when PSVR was >2.0.[4] The primary measurement outcome was the one year primary patency rate. The second measurement outcome included ISR, major amputation, target lesion revascularisation, and mortality.

Statistical analysis

Continuous data are presented as mean ± SD and compared by the Student independent *t* test or Mann—Whitney U test (if normality was not assumed). Categorical data are presented as *n* (%) and tested by the chi-square test or Fisher's exact test (if an expected value < 5 was found). The optimal cut off for the six calcification and oversizing parameters (all were continuous variables), including CV, SCV, CB, OSdis, OSmax, and OSp were determined by the maximum Youden's index in receiver operating characteristic curve (ROC) analysis (Appendix S1; see Supplementary Material). Patients were divided into dichotomous subgroups based on these cut offs. Spearman's correlation coefficient analysis was used to assess the correlations among variables. Univariable and multivariable Cox regression models were carried out to investigate the associations between independent variables and clinical outcomes. The statistical significance level was set at a $p < .05$ (two tailed). All analyses were performed using SPSS Version 20 (IBM, Armonk, NY, USA).

RESULTS

Patients characteristics

A total of 115 patients (84 men, 31 women; age 71.11 ± 9.10 years [range 47—89 years]) were included. The demographic and clinical characteristics of the patients are summarised in Table 1. Based on the Trans-Atlantic Inter-Society Consensus (TASC) II classification system, there were 1, 18, 55, and 41 patients classified as A, B, C, and D, respectively. The mean length of the treated lesion was 242.47 ± 89.50 mm.

Stenting procedure

All patients received stent therapy (mean stenting length 24.0 ± 10.5 cm) and 28 patients needed pre-stenting percutaneous transluminal angioplasty (PTA) below the knee to keep at least one runoff vessel. Surgery was successful in all the patients (success rate 100%).

Follow up

The median follow up was 18 months (range 12—36 months). No patient was lost in the first 12 months after operation. The one year primary patency rate was 77.4%. The rates of ISR, major amputation, target lesion revascularisation, and mortality were 40.9%, 8.7%, 17.4%, and 12.2%, respectively.

CTA data analysis

The mean post-processing time was 51.5 ± 22.7 min. The intra-observer variabilities for the three CTA measurements in each patient were all <5%. The cut offs, determined by the maximum Youden index in ROC analysis, were 145 mm^3 for CV, 7 mm^2 for SCV, 12% for CB, 8% for OS_{dis}, 40% for OS_{max}, and 35% for OS_p.

Table 1. Baseline characteristics and clinical outcomes of 115 patients with atherosclerotic femoropopliteal arterial occlusive disease undergoing stent angioplasty

Sex	
Female patients	31 (27.0)
Age, years	71.11 ± 9.10
Length of lesion (mm)	242.47 ± 89.50
Calcified plaque volume (mm^3)	736.09 ± 1282.23
Standardised calcified plaque volume (mm^3/cm)	27.99 ± 44.46
Burden of calcified plaque (%)	10.67 ± 9.56
Distal oversizing (%)	12.40 ± 14.07
Maximum oversizing (%)	50.56 ± 29.44
Oversizing at plaque (%)	36.61 ± 23.38
Critical limb ischaemia	87 (75.7)
Pathological length (mm)	194.43 ± 87.03
ABI before intervention	0.30 ± 0.18
ABI after intervention	0.76 ± 0.15
Rutherford stage	
2	5 (4.3)
3	22 (19.1)
4	39 (33.9)
5	40 (34.8)
6	9 (7.8)
Hypertension	79 (68.7)
Coronary artery disease	43 (37.4)
Cerebrovascular disease	17 (14.8)
Diabetes	39 (33.9)
Smoking	54 (47.0)
Dyslipidaemia	51 (44.3)
Renal insufficiency	22 (19.1)
Occlusion	78 (67.8)
TASC II type	
A	1 (0.9)
B	18 (15.7)
C	55 (47.8)
D	41 (35.6)
Number of outflow vessels below the knee	
1	48 (41.7)
2	42 (36.5)
3	25 (21.7)
Multi-lesion	28 (24.3)
Subintimal angioplasty	10 (8.7)
Pre-expansion prior to stenting	18 (15.7)
Improvement of clinical symptom stage	
0	5 (4.3)
1	26 (22.6)
2	80 (69.6)
3	4 (3.5)
Restenosis	47 (40.9)
Amputation	10 (8.7)
Target lesion revascularisation	20 (17.4)
Death	14 (12.2)
Adverse event in follow up	13 (11.3)

Data are *n* (%) or mean ± standard deviation. ABI = ankle brachial index; TASC = Trans-Atlantic Inter-Society Consensus.

Stratified subgroup analysis by calcification parameters

Clinical outcomes were compared between dichotomous subgroups divided by CV, SCV, and CB (Table 2). Patients with more serious symptoms presented higher calcification metric values. The treated lesion was longer in the groups with CV and CB greater than the cut offs (both $p < .01$). The rates of dissection after plain PTA were higher in the groups that had values greater than the cut offs (all $p < .05$). Subintimal angioplasty was more often seen in the groups with CV and SCV values greater than the cut offs (both $p < .05$). Of all three calcification variables, the groups with values greater than the cut offs had significantly higher incidences of ISR, major amputation, target lesion revascularisation, and mortality compared with their corresponding comparison groups (all $p < .05$).

Stratified subgroup analysis by stent oversizing parameters

Patients were also divided into dichotomous subgroups based on the cut offs of stent oversizing parameters. As shown in Table 3, the group with an $OS_{dis} > 8\%$ had significantly higher incidences of ISR and target lesion revascularisation compared with the group with an $OS_{dis} \leq 8\%$ (both $p < .05$). The group with an $OS_{max} > 40\%$ had a higher restenosis rate than those with an $OS_{max} \leq 40\%$ ($p < .05$). The group with an $OS_p > 35\%$ had a significantly longer length of treated lesion, more patients underwent subintimal angioplasty, and more had a higher ISR rate than those with an $OS_p \leq 35\%$ (all $p < .05$).

Correlations between independent variables and clinical outcomes

Correlation analysis revealed that ISR was positively correlated with all the calcification (CV, SCV, CB) and oversizing (OS_{dis}, OS_{max}, OS_p) variables (all $p < .05$), while mortality and major amputation were only positively correlated with three calcification parameters (all $p < .05$; Table 4)

Multivariable Cox regression analysis

Adjusted multivariable Cox regression analysis showed that all the six calcification and oversizing variables were associated with ISR (all $p < .05$; Table 5). Meanwhile, all three calcification parameters were associated with major amputation, and two calcification parameters (CV and SCV) were associated with mortality (all $p < .05$). All the groups with parameter values higher than the cut offs had higher incidences of ISR, major amputation, and mortality (all estimated hazard ratios > 1).

DISCUSSION

The adverse effect of calcified plaque on peripheral artery occlusive disease has been well recognised. A study by Patel et al. has reported that it was the burden of calcified plaque, but not soft or fibrocalcific plaque, which was associated with ISR, re-intervention, and amputation free survival.[13] Different atherectomy devices have been used to eliminate the negative influence of calcified plaque and achieve a higher long-term patency rate.[14–19] However, unlike the well established scoring system for the coronary artery,[20] there are still no reliable assessment methods to help decide which patients should receive atherectomy alone, direct stent angioplasty, or atherectomy prior to stent angioplasty.

Table 2. Characteristics stratified by calcified level

	Calcified plaque volume			Standardised calcified plaque volume			Burden of calcified plaque		
	≤145 mm^3 (*n* = 57)	>145 mm^3 (*n* = 58)	*p* value	≤7 mm^2 (*n* = 57)	>7 mm^2 (*n* = 58)	*p* value	≤12% (*n* = 82)	>12% (*n* = 33)	*p* value
Lesion length (mm)	214 ± 89	271 ± 81	<.001	230 ± 88	255 ± 90	0.087	230 ± 86	275 ± 91	0.007
Pre-expansion	4 (7.0)	14 (24.1)	0.012	4 (7.0)	14 (24.1)	0.012	8 (9.8)	10 (30.3)	0.006
Subintimal angioplasty	1 (1.8)	9 (15.5)	0.009	2 (3.5)	8 (13.8)	0.05	6 (7.3)	4 (12.1)	0.408
Improvement of clinical symptom stage			<.001			<.001			<.001
0	0 (0.0)	5 (8.6)		0 (0.0)	5 (8.6)		0 (0.0)	5 (15.2)	
1	6 (10.5)	20 (34.5)		6 (10.5)	20 (34.5)		14 (17.1)	12 (36.4)	
2	49 (86.0)	31 (53.4)		49 (86.0)	31 (53.4)		64 (78.0)	16 (48.5)	
3	2 (3.5)	2 (3.4)		2 (3.5)	2 (3.4)		4 (4.9)	0 (0.0)	
In stent restenosis	9 (15.8)	38 (65.5)	<.001	12 (21.1)	35 (60.3)	<.001	20 (24.4)	27 (81.8)	<.001
Major amputation	1 (1.8)	9 (15.5)	0.009	1 (1.8)	9 (15.5)	0.009	2 (2.4)	8 (24.2)	<.001
Target lesion revascularisation	3 (5.3)	17 (29.3)	<.001	5 (8.8)	15 (25.9)	0.016	8 (9.8)	12 (36.4)	<.001
Mortality	2 (3.5)	12 (20.7)	0.005	1 (1.8)	13 (22.4)	<.001	6 (7.3)	8 (24.2)	0.012

Data are *n* (%) or mean ± standard deviation.

Rocha et al. proposed the Peripheral Arterial Calcium Scoring System, based on the length and distribution of calcified plaques observed on angiography, to classify plaque calcification in the femoral artery.[21] However, the comprehensive nature of calcified plaque in the extensive femoropopliteal artery may not be precisely reflected on two dimensional angiography. In addition, their scoring grades are somewhat rough to direct a clinical intervention strategy. Aware of the weakness of two dimensional evaluation of calcified plaque, Ohana et al. raised a quantitative assessment method for plaque calcification based on cross sectional analysis of CTA and magnetic resonance angiography images.[22] Cross sectional imaging analysis can provide more information of plaque calcification.

CTA is a non-invasive and efficient diagnostic imaging that has been considered as a first line diagnostic procedure for

Table 3. Characteristics stratified by stent oversizing

	Distal oversizing			Maximum oversizing			Oversizing at plaque		
	≤8% (*n* = 58)	>8% (*n* = 57)	*p* value	≤40% (*n* = 50)	>40% (*n* = 65)	*p* value	≤35% (*n* = 70)	>35% (*n* = 45)	*p* value
Lesion length (mm)	228 ± 75	257 ± 101	0.086	239 ± 78	245 ± 98	0.629	221 ± 83	276 ± 89	<.001
Subintimal angioplasty	5 (8.6)	5 (8.8)	0.977	3 (6.0)	7 (10.8)	0.368	2 (2.9)	8 (17.8)	0.006
In stent restenosis	13 (22.4)	34 (59.6)	<.001	11 (22.0)	36 (55.4)	<.001	17 (24.3)	30 (66.7)	<.001
Major amputation	5 (8.6)	5 (8.8)	0.977	3 (6.0)	7 (10.8)	0.368	6 (8.6)	4 (8.9)	0.953
Target lesion revascularisation	6 (10.3)	14 (24.6)	0.044	6 (12.0)	14 (21.5)	0.181	9 (12.9)	11 (24.4)	0.110
Mortality	7 (12.1)	7 (12.3)	0.972	6 (12.0)	8 (12.3)	0.96	8 (11.4)	6 (13.3)	0.76

Data are *n* (%) or mean ± standard deviation.

Table 4. Correlation analyses between independent variables and clinical outcomes

Parameters	Median (IQR)	Restenosis	Death	Amputation
Calcified plaque volume (mm^3)	840 (60–900)	.48**	.29**	.20*
Standardised calcified plaque volume (mm^2)	32.40 (2.60–35.00)	.41**	.27**	.23*
Burden of calcified plaque (%)	9.80 (5.00–14.80)	.46**	.30**	.25**
Distal oversizing (%)	15.51 (3.38–18.89)	.38**	−.001	.007
Maximum oversizing (%)	28.33 (31.98–60.31)	.27**	.07	.040
Oversizing at plaque (%)	22.14 (25.32–47.47)	.40**	−.001	−.008

Spearman's correlation coefficient: $*p < .05$; $**p < .01$. IQR = interquartile range.

Table 5. Multivariable Cox regression results

Predictor	In stent restenosis		Major amputation		Mortality	
	HR (95% CI)	*p* value	HR (95% CI)	*p* value	HR (95% CI)	*p* value
Calcified plaque volume (mm^3)		<.001		0.008		0.046
≤145	Ref		Ref		Ref	
>145	5.12 (2.11–12.43)		52.27 (2.76–990.32)		9.73 (1.04–90.85)	
Standardised calcified plaque volume (mm^2)		0.002		0.018		0.026
≤7	Ref		Ref		Ref	
>7	3.64 (1.60–8.25)		36.47 (1.86–716.00)		13.54 (1.36–134.99)	
Burden of calcified plaque (%)		<.001		0.002		0.392
≤12	Ref		Ref		Ref	
>12	5.88 (2.45–14.12)		53.79 (4.16–696.24)		2.10 (0.38–11.41)	
Distal oversizing (%)		0.007		Not significant (NS)		NS
≤8	Ref		Ref		Ref	
>8	2.53 (1.30–4.93)		–		–	
Maximum oversizing (%)		0.001		NS		NS
≤40	Ref		Ref		Ref	
>40	3.42 (1.62–7.22)		–		–	
Oversizing at plaque (%)		<.001		NS		NS
≤35	Ref		Ref		Ref	
>35	4.09 (2.08–8.03)		–		–	

All parameters in these multivariable models were also significant in univariable Cox regression models. The covariates controlled in multivariable models were sex, age, history of hypertension, coronary artery disease, cerebral vascular accidents, diabetes, smoking, dyslipidaemia, and renal insufficiency. HR = hazard ratio; CI = confidence interval; NS = not significant in multivariable Cox regression model.

patients with PAD.[23,24] Different plaque components can be defined clearly on the transverse CT images.[13] With the assistance of professional automatic software, detailed features, including plaque length, distribution, component, and artery lumen area, can be measured precisely on CTA images. This has been verified in the iliac and carotid arteries, respectively, by Krishnaswamy et al. and Marquering et al.[25,26]

In this study, automatic computer software was used to analyse the calcified plaques in the femoropopliteal artery. All calcified plaques in the target lesion were reflected by the metrics (i.e., CV, SCV, and CB), which could be measured or calculated. High values for these metrics were associated with more severe clinical symptoms and higher ISR, major amputation, and target vessel revascularisation rates. The findings confirmed that calcified plaque in the femoropopliteal artery could be assessed quantitatively on pre-intervention CTA images. Moreover, high calcification metrics could predict unfavourable clinical outcomes after stent angioplasty. All metrics were identified as independent risk factors for restenosis. Further determination of the most crucial of these metrics is necessary, as shown in previous studies.[13,27]

In the subgroup analysis stratified by CB cut off, the difference in the adverse event rates (including ISR, major amputation, and target vessel revascularisation) between the two subgroups was the greatest among the three calcification metrics. However, whether CB is the most important parameter for plaque calcification needs further investigation.

Excessive stent oversizing is regarded as another important contributor to unfavourable outcomes after femoropopliteal stent angioplasty. The purpose of stent oversizing in peripheral arteries is to prevent elastic recoil or to repair flow limiting intimal dissection. Nevertheless, accumulating evidence has suggested that greater stent oversizing will cause more mid-tunica and arterial intimal injury, and a higher degree of haemodynamic change, which will induce more smooth muscle cell proliferation, eventually causing restenosis.[28–32]

In an animal experiment by Zhao et al., the oversized stent increased the artery lumen in the first six months. However, the in stent lumen was gradually reduced owing to gradually worsening neointimal hyperplasia.[28] In a clinical study of a covered stent with a bioactive heparin surface, the stent patency rate decreased markedly when stent oversizing exceeded 20%.[11] Thus, the authors stated that careful stent oversizing was essential for achieving optimal outcomes. However, no clear stent oversizing standard is available for the femoropopliteal artery, while a similar stenting scale has already been established in coronary artery intervention.[33,34]

In the present study, stent oversizing was measured at the three levels where ISR most often occurs.[35] It was found that ISR incidence significantly increased when stent oversizing exceeded the cut off values at all three levels ($OS_{dis} > 8\%$, $OS_{max} > 40\%$, $OS_p > 35\%$), indicating that excessive stent oversizing would result in low stent patency. These results are consistent with previous studies.[28–32] In the subgroup analysis stratified by OS_p cut off, the difference in the adverse event rates between the two subgroups was the largest among the three metrics for oversizing, indicating that OS_p might be the most important metric among three oversizing parameters in determining stent size.

Bausback and Madhavan observed that the stent could not expand fully when implanted in a heavily calcified lesion, which would alter the blood flow shear stress, increase chronic outward forces, and promote smooth muscle cells proliferation.[12,36]

Furthermore, the cut off of OS_{dis} in the present study was only 8%, which is easy to exceed. For the distal femoral or proximal popliteal artery (usually 5—6 mm in diameter), one mm increase in stent diameter means nearly 20% increase in oversizing. Thus, the parameter of OS_{dis} also needs to be paid extra attention.

Though clinical values of these proposed calcification and stent oversizing parameters need further validation, they may be useful for determining intervention strategy and stent size. For instance, when the plaque calcification parameters are higher than the cut offs, atherectomy is suggested prior to stenting. If primary stenting is planned, the stent oversize should not exceed the suggested cut offs. For patients with a high calcified plaque burden, if atherectomy devices are unavailable, great saphenous vein or prosthetic bypass might be adopted rather than endovascular stenting.[37]

The current study was limited by the small sample size, short-term follow up, and its retrospective nature. The heterogeneity of the stents inevitably influenced the outcome. Therefore, these plaque calcification and stent oversizing metrics need to be comprehensively evaluated by a prospective clinical trial with a large sample size using a uniform stent. In addition, the post-processing time for CTA data analysis was long, which would be a limitation to translate this procedure into clinical routine. Therefore, the analysis procedure should be further optimised and simplified.

CONCLUSION

This study proposes special metrics and corresponding cut off values for plaque calcification and stent oversizing, which may be used to guide clinical practice in femoropopliteal arterial occlusive disease.

CONFLICT OF INTEREST

None.

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None.

APPENDIX A. SUPPLEMENTARY DATA

Supplementary data related to this article can be found at https://doi.org/10.1016/j.ejvs.2019.01.025.

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