

Efficiency of orbital atherectomy for nodular calcium in bending vessels: *in vitro* vessel models



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ABSTRACT

BACKGROUND: Orbital atherectomy (OA) operates via high-speed elliptical crown rotation, enabling focal plaque modification through controlled forward and backward movement.

AIMS: This study aimed to identify the anatomical conditions that optimise OA effectiveness on nodular calcium within curved lesions, using *in vitro* models to allow quantitative assessment of the debulked volume.

METHODS: Forty stenotic vessel models containing nodular calcium were created with varying anatomical parameters: two calcium positions (inner vs outer curve), two curvature radii (CR: 10 mm or 20 mm), and two bending angles (BA: 100° or 60°). Each model underwent OA with the Diamondback 360 Coronary OA System, using two 30-second low-speed passes and one 30-second high-speed pass. Microcomputed tomography was performed pre- and post-ablation to measure the calcium volume reduction, maximum depth, and width.

RESULTS: Ablation was significantly greater for nodular calcium on the inner curve compared to that on the outer curve (6.6 ± 0.4 mm³ vs 2.7 ± 0.4 mm³; $p < 0.0001$). Among models with calcium on the inner curve, CR20/BA60 showed the highest volume reduction (8.3 ± 1.4 mm³). For models with calcium on the outer curve, CR20/BA100 resulted in the greatest ablation (5.2 ± 0.9 mm³). Ablation depth, more than width, correlated with the total ablated volume.

CONCLUSIONS: Nodular calcium located on the inner curve is more effectively treated with OA. The combination of curvature radius and the bending angle significantly influences procedural efficiency, underscoring the importance of lesion anatomy in OA planning.

KEYWORDS: calcified plaque; *in vitro* vessel model; orbital atherectomy; percutaneous coronary intervention

Orbital atherectomy (OA) is an alternative atherectomy for calcified coronary lesions, with acceptable outcomes¹. OA is characterised by a drive shaft with an eccentrically mounted diamond-coated crown, which allows the combination of orbital and rotational motions and removes a layer of calcified plaque with antegrade and retrograde passes of the crown².

Recently, imaging-based algorithms have been proposed for atherectomy and lithotripsy³⁻⁵; however, the optimal device selection remains unclear. The burr of rotational atherectomy moves directly along the wire and shaves off calcified plaque by utilising wire bias; however, the movement of the OA crown can be unpredictable, particularly in cases of bending lesions.

The objective of this study was to elucidate the anatomical setting for efficient OA on nodular calcium in bending lesions using *in vitro* experimental models in which the debulked volume can be measured quantitatively.

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Methods

MODEL CONSTRUCTION

In vitro vessel models were developed to evaluate atherectomy efficiency. The models consisted of two components: a bent coronary artery model – with a reference diameter of 3.5 mm and a 10 mm long calcified lesion causing 80% stenosis, located on the inner or the outer curve – and an aorta model (Figure 1A).

In total, 40 *in vitro* stenotic coronary artery models with nodular calcium were developed, using two curvature radii (CR: 10 mm or 20 mm), two bending angles (BA: 100° or 60°), and five models with a combination of two different calcium positions (inner or outer curve) (Figure 1B). The calcium model was fabricated using a mixture of calcium sulphate hemihydrate powder, cement powder, and polyurethane resin. The concentrations of the mixture were adjusted to replicate the mechanical properties of *in vivo* calcification fractures. Each coronary artery model was connected to a whole aorta model.

SIMULATION PROTOCOL

The procedures were performed using the Diamondback 360 Coronary Orbital Atherectomy System (Cardiovascular Systems, Inc. [now Abbott]) through a 6 Fr short-tip Amplatz 1.0 guiding catheter. A ViperWire Advance with Flex Tip Coronary Guide Wire (Cardiovascular Systems, Inc. [now Abbott]) was deployed within the vessel. The protocol encompassed two 30-second low-speed (80,000 rpm) ablations, followed by one 30-second high-speed (120,000 rpm) ablation. The OA technique principally involved gradual retraction of the crown and subsequent forward movement of the crown for models with calcium on the inner curve or direct forward movement of the crown for models with calcium on the outer curve. The crown was then manipulated back and forth in the lesion until frictional resistance was no longer perceived. During

Impact on daily practice

Orbital atherectomy (OA) is a unique device characterised by the combination of orbital and rotational movements of an eccentrically mounted diamond-coated crown. The process of bidirectional ablation enhances the contact between the crown and the calcium on the inner curve, thereby leading to substantial calcium removal. This study quantitatively clarifies that OA more effectively ablates nodular calcium on an inner curve with a large radius and a small bending angle.

the experiments, the crown movement was recorded using a high-speed camera (FASTCAM-1024PCI [Photron]) (Moving image 1, Moving image 2).

MICROCOMPUTED TOMOGRAPHY EVALUATION

Microcomputed tomography (micro-CT) analyses (TDM1300-IS [Yamato Scientific]) of the vessel models were performed before and after ablation to evaluate the treatment efficacy. The ablated calcium volume and maximal depth were analysed to compare the inner and outer curves in each model.

STATISTICAL METHODS

Continuous variables are presented as mean±standard deviation (SD). The differences between the ablated calcium volumes in the models with calcium on the inner and outer curves were evaluated using a two-tailed t-test. Furthermore, the differences in ablated volume between the highly ablated and other models were evaluated across the inner and outer curves using a two-tailed t-test. Statistical analysis was performed using JMP 14.3.0 software (SAS Institute), and $p<0.05$ was considered statistically significant.

Results

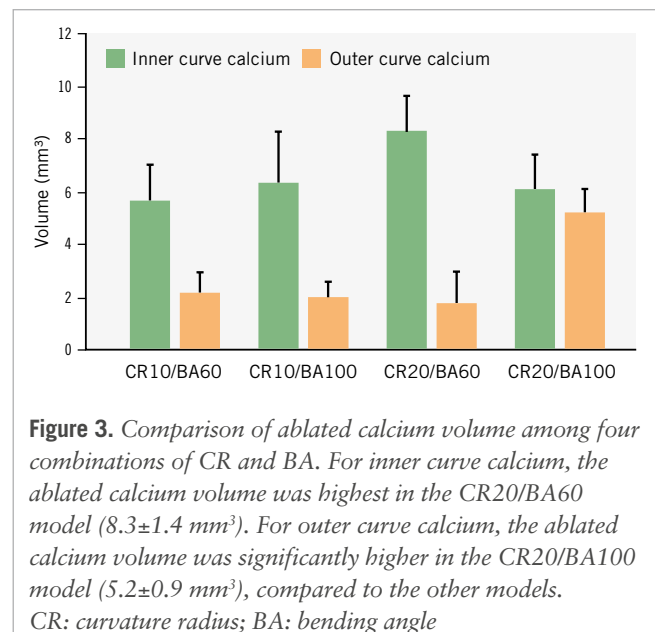
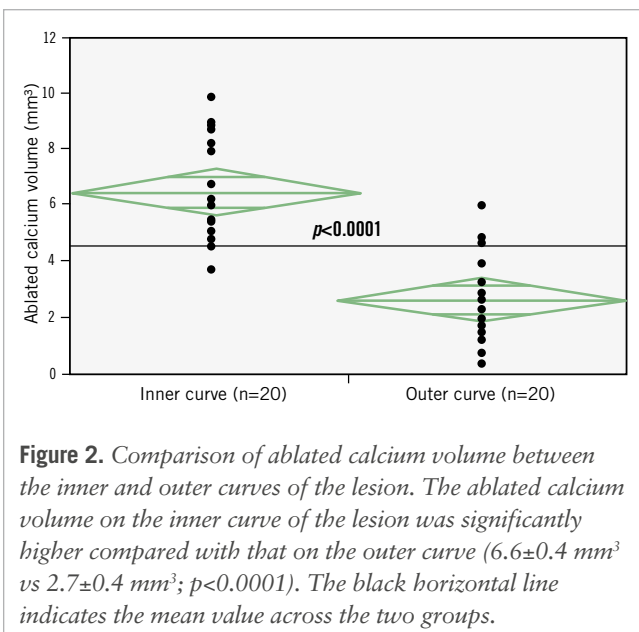
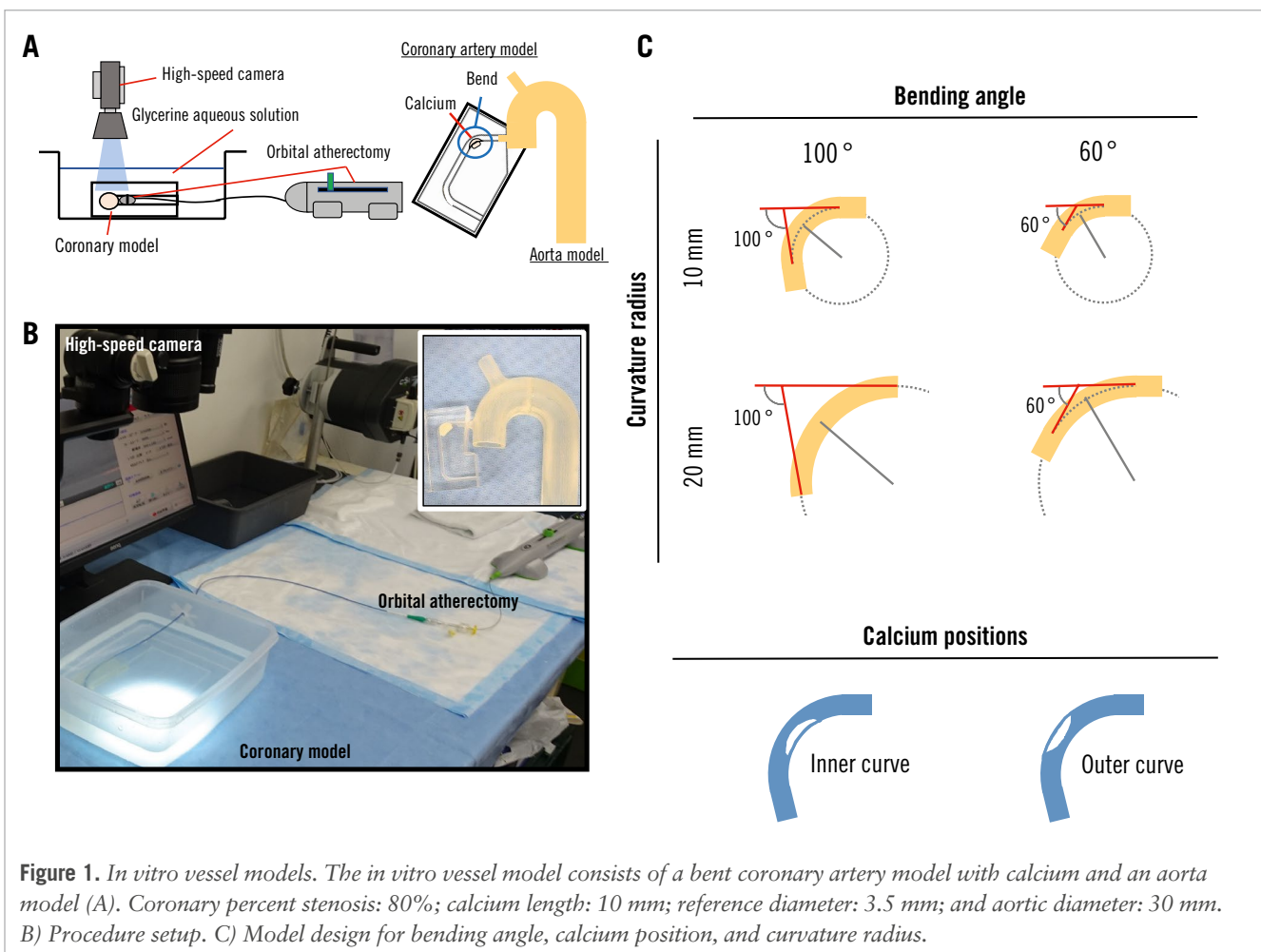
Figure 2 shows the volume of ablated calcium in the inner and outer models. The ablated calcium volume differed depending on the calcium position: the mean ablated volume of nodular calcium on the inner curve of the bend was significantly higher than that on the outer curve of the bend (6.6 ± 0.4 mm³ vs 2.7 ± 0.4 mm³; $p<0.0001$).

On the inner curve, the ablated calcium volume was highest in the CR20/BA60 model (8.3 ± 1.4 mm³) compared with the CR10/BA100 (6.3 ± 1.9 mm³; $p=0.14$), CR10/BA60 (5.6 ± 1.4 mm³; $p=0.04$), and CR20/BA100 (6.1 ± 1.3 mm³; $p=0.09$) models (Figure 3). On the outer curve, the ablated calcium volume was highest in the CR20/BA100 model (5.2 ± 0.9 mm³) compared with the CR10/BA100 (2.0 ± 0.6 mm³; $p<0.001$), CR10/BA60 (2.1 ± 0.8 mm³; $p=0.002$), and CR20/BA60 (1.7 ± 1.2 mm³; $p<0.001$) models (Figure 3). The maximum depth after ablation showed a trend similar to that of the ablated volume (Figure 4). The mean maximum depths were highest for the inner curve in the CR20/BA60 model

Abbreviations

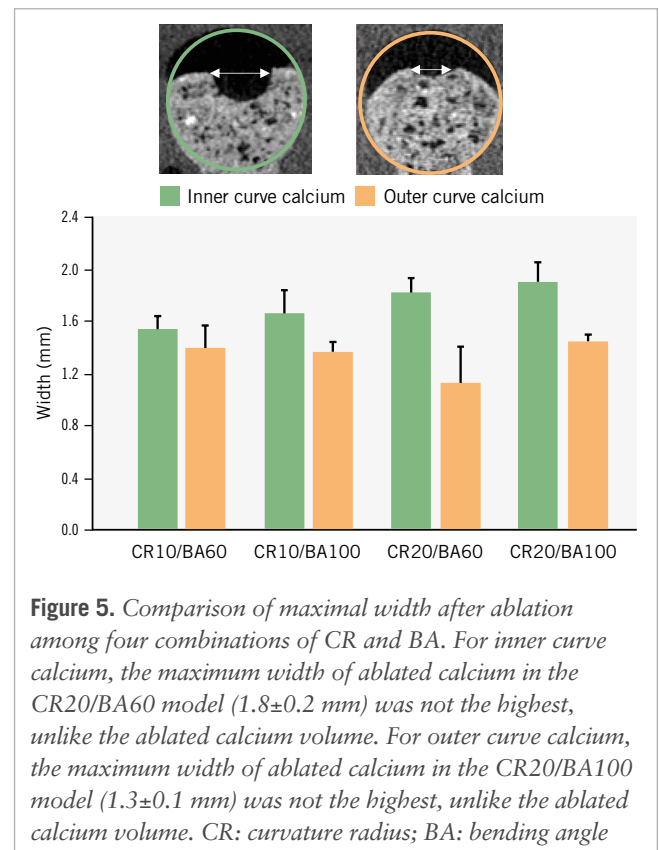
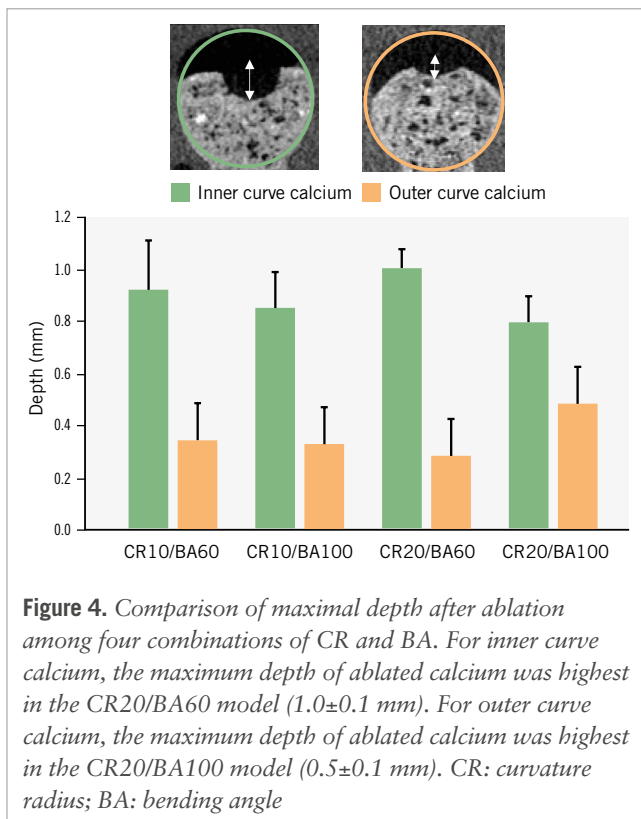
BA bending angle
CR curvature radius

CT computed tomography
OA orbital atherectomy



($1.0 \pm 0.1 \text{ mm}$) and for the outer curve in the CR20/BA100 model ($0.5 \pm 0.1 \text{ mm}$). A comparison of the maximum widths between the models revealed no significant disparities, both in the inner and outer models (Figure 5).

Figure 6 shows representative photographs during ablation. In the CR20/BA60 model for the inner curve calcium, the proximal and the distal portions of the wire were firmly anchored to the vessel wall, and the crown exhibited a greater



degree of linearity at the lesion site than in the other models. Conversely, in the CR20/BA100 model designed for the outer curve calcium, the wire exhibited a substantial arc, and the crown was correctly aligned with the lesion.

Discussion

In this study, we developed *in vitro* vessel models with eight different anatomies and quantitatively evaluated the ablated volume following OA. The results of this study provided quantitative evidence that (1) nodular calcium on the inner curve was ablated more effectively than that on the outer curve; (2) the volume of calcium ablation differed depending on the anatomical combination of CR and BA; (3) on the inner curve, the CR20/BA60 group exhibited the greatest ablated calcium volume and depth compared with the other groups; and (4) on the outer curve, the CR20/BA100 group showed the highest calcium ablation volume and depth among all groups.

The unique nature of OA is characterised by the combination of orbital and rotational movements of an eccentrically mounted diamond-coated crown⁶. As the crown rotates, its orbital diameter expands radially via a centrifugal force to modify the calcified plaque and increase the luminal size⁷. However, this is not the case with the treatment of a bending vessel. Notably, a ViperWire Advance with Flex Tip Coronary Guide Wire and its driveshaft with crown caused vessel straightening and “wire bias” at the bend, facilitating enhanced contact with the wall. The crown can ablate the focal plaque bidirectionally as it advances back and forth through a target lesion, depending on the degree of wire bias.

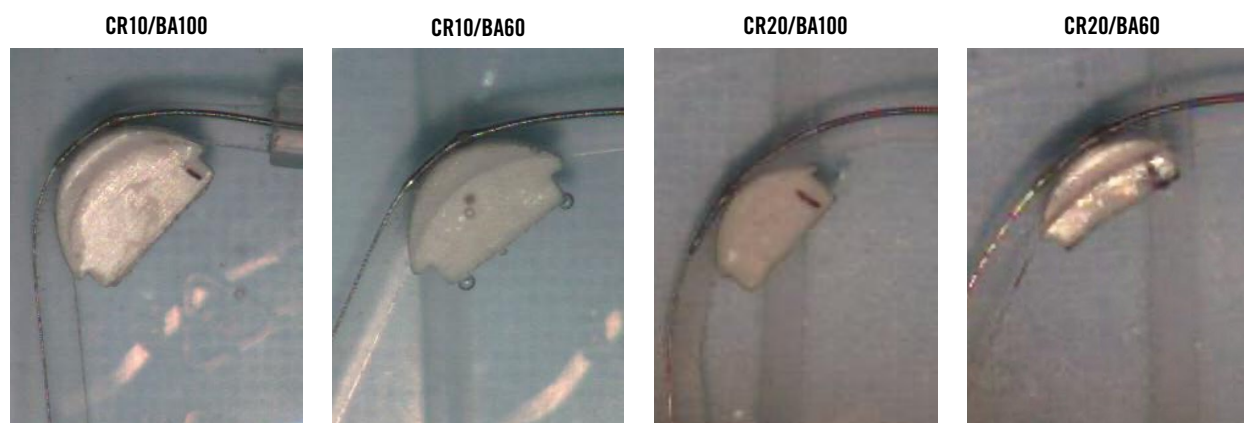
The experimental data demonstrated that significantly more calcium could be ablated from the inner curve of the vessel than from the outer curve. One potential explanation

for this result is the enhanced contact of the crown with the inner curve when the crown is pulled back. This is a feature of OA that is absent in rotational atherectomy. A previous case report has discussed the successful treatment of tortuous lesions with pullback OA, rather than rotational atherectomy, although the mechanism has not been clarified⁸.

The most noteworthy outcome derived from the data was that the combination of curve and angle was associated with the efficiency of OA for calcium on both the inner and outer curves of the bend. The maximum depth after ablation, rather than the maximum width, was comparable to the ablated volume. In the inner curve calcium models, the volume of calcium ablated in the CR20/BA60 model was the highest among the models. Conversely, in the outer curve calcium models, the volume of calcium ablated in the CR20/BA100 model was the highest among the models. These differences may be attributed to the fixed wire bias, which is affected by the CR and BA of the vessel. For lesions located on the outer curve with a large CR and BA, the outward force remains stable. This is because the guidewire’s low bending moment reduces the restoring force that would otherwise straighten the wire.

The *in vitro* transparent bending models and micro-CT accurately demonstrated the effectiveness of OA. To evaluate the debulking effect of OA for calcified nodules (CNs), Shin et al quantified ablation volume using optical coherence tomography imaging⁹. The authors demonstrated that OA may be preferable for CNs with smaller baseline lumen areas. However, the analysis was based exclusively on the lumen area, and the effect of anatomy-related wire bias was not

A For inner curve calcium



B For outer curve calcium

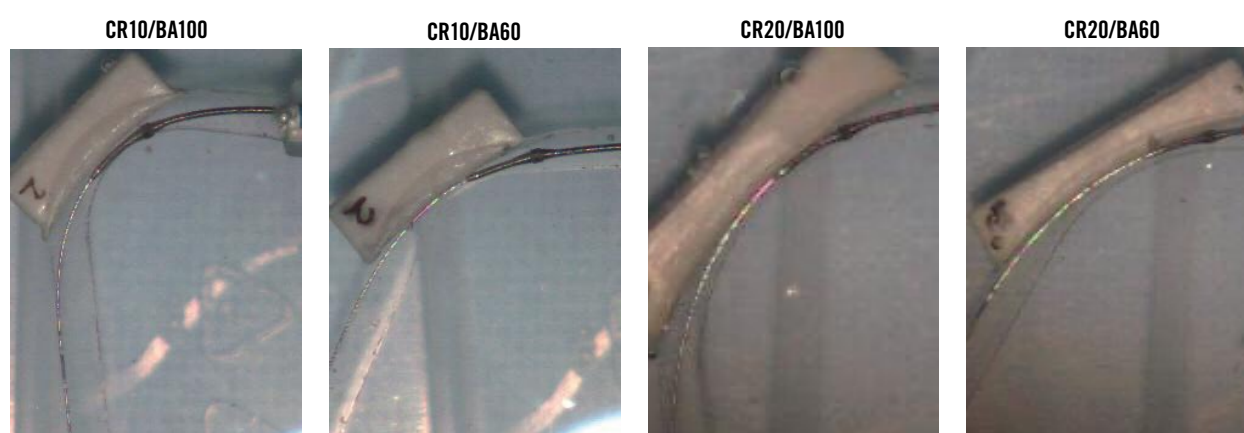


Figure 6. Representative images during ablation. Representative images illustrating how the crown on the guidewire touched the lesion in each of the inner curve calcium models (A), and representative images illustrating how the crown on the guidewire touched the lesion in each of the outer curve calcium models (B). CR: curvature radius; BA: bending angle

considered. The present study revealed that the efficacy of OA was enhanced when employed on a lesion located on the inner curve, characterised by a large radius of curvature and a small BA. The most significant indication for OA may be the presence of CNs on the inner curve. The utilisation of bidirectional ablation, involving a gradual retraction followed by a subsequent forward movement of the crown, resulted in significant removal of thick calcium.

Limitations

This study highlights the role of anatomical features in determining the efficacy of OA. However, the evaluation was conducted using simplified two-dimensional coronary artery models to analyse the effects of curvature radius, bending angle, and calcium position. Consequently, the findings may not fully reflect the complexity of real patient anatomies. Further studies using three-dimensional vessel models that more accurately represent the anatomical diversity of coronary curves would be more clinically relevant. To better assess the risk of injury to healthy vessel walls – especially in patients with more intricate vascular structures – intracoronary imaging should be employed in clinical practice.

Conclusions

The anatomical setting for efficient OA is the nodular calcium on the inner curve of the vessel. The volume of calcium ablation, predominantly determined by depth, varies depending on the anatomical combination of the CR and BA.

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Conflict of interest statement

The authors have no conflicts of interest to declare.

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Supplementary data

Moving image 1. Representative high-speed video recording of calcium ablation on the inner surface of the CR20/BA60 model.

Moving image 2. Representative high-speed video recording of calcium ablation on the outer surface of the CR20/BA100 model.

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