# 2025 TSCI Expert Consensus Statement on the Management of Heavily Calcified Coronary Lesions

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## Introduction

Coronary artery calcification (CAC) refers to the deposition of calcium phosphate crystals within the coronary arteries, leading to the progressive hardening and narrowing of these vessels. The prevalence of CAC varies significantly with demographic factors such as age, gender, ethnicity and the presence of other cardiovascular risk factors. In the MESA study, CAC was observed in 30% of participants aged 45-54, 50% of those aged 55-64, 65% of those aged 65-74, and in over 75% of those aged 75-84.[1] In the 45-54-year-old age group, approximately 25% of men had detectable CAC, whereas the prevalence among women was about 10%. In older age groups, such as 75-84 years, the prevalence rose to approximately 85% in men and 65% in

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women.[1] The prevalence of CAC among different ethnic groups also varied; among men aged 45-54, 60% of Whites, 55% of Hispanics, 40% of Chinese, and 30% of African Americans had detectable CAC.[2] The treatment of severe calcified coronary lesions presents significant challenges, necessitating the use of advanced techniques and technologies. These lesions are rigid and resistant to conventional balloon angioplasty, posing risks such as trapped devices, balloon rupture, and vessel perforation. This consensus document aims to assess and consolidate the available evidence to aid interventional teams in developing optimal management strategies for patients with challenging calcified coronary lesions. While it is intended to support healthcare professionals in their clinical decision-making processes, final decisions regarding individual patients should be made by interventional cardiologists in consultation with their patients, as appropriate.

## Invasive Image Assessment

### Angiography

Coronary angiography is an essential tool for evaluating coronary artery disease, including the assessment of calcified lesions. Calcification may be either focal (isolated spots) or diffuse (extensive areas) along the artery and can present in linear or circumferential patterns. In contrast to the diffuse and often more stable calcifications found in atherosclerotic plaques, calcified nodules are characterized by protruding, nodular masses of calcium that can disrupt the fibrous cap of the plaque.[3] These nodules often appear as irregular, spiculated projections into the lumen of the coronary artery. It is crucial to capture images from multiple angles to visualize calcifications that might be missed in a single view. On coronary angiography, moderate or severe calcified lesions are identified as radiopaque densities within the coronary arterial wall, observable with or without cardiac motion, and visible prior to contrast injection.[4,5]

### Intravascular Ultrasound

In the evaluation and management of calcified coronary lesions intravascular ultrasound (IVUS) is a crucial imaging modality. It provides high-resolution, cross-sectional images of the coronary arteries, enabling detailed visualization of plaque morphology, extent, and degree of calcification. IVUS is highly sensitive to the presence of calcium, detecting even small and superficial calcified deposits that may not be visible on angiography.[6] It can precisely locate calcified segments within the coronary artery, distinguishing between superficial and deep calcification. Calcified plaques cause shadowing, blocking the ultrasound waves from penetrating deeper structures, resulting in a dark shadow beyond the calcified area. IVUS detects thin calcified layers as smooth, highly echogenic surfaces with characteristic reverberations (multiple echo reflections).[7,8] With thicker calcium deposits, however, IVUS shows a highly echogenic, irregular surface without reverberations. This means that while IVUS cannot show calcium thickness behind the leading edge, it can quantify calcification by the size of the circumferential arc and by the length of the calcified segment. The following IVUS-derived scoring system is known to predict stent under-expansion under 70%: (1) full arc (360°) of calcium deposits; (2) arc of $>270°$ of calcium deposits, with a length of deposit $\geq 5.0$ mm; (3) calcified lesions in a vessel of diameter $< 3.5$ mm; and (4) the presence of a calcified nodule.[9] (Table 1) If the IVUS-derived calcium score is $\geq 2$, adjunctive calcium modification devices are recommended; if used before stent implantation, calcium fractures and good stent expansion will be mostly achieved.

### Optical Coherence Tomography

Optical Coherence Tomography (OCT) is an advanced intravascular imaging technique that provides high-resolution, cross-sectional images of coronary arteries. OCT works on the principle of near-infrared light reflection and

**Table 1.** Scoring systems for calcified lesions on intravascular imaging

| **IVUS criteria** | | Point | | |
|---|---|---|---|---|
| Calcium arc | < 360° | 0 | | |
| | 360° | 1 | | |
| Length of calcium arc > 270° | ≤ 5 mm | 0 | | |
| | > 5 mm | 1 | | |
| Lesion diameter (EEL) | > 3.5 mm | 0 | | |
| | ≤ 3.5 mm | 1 | | |
| Calcified nodule | Absent | 0 | | |
| | Present | 1 | | |
| **OCT criteria** | Fujino's model | | Sato's model | |
| Calcium thickness | Max. calcium | | Min. calcium | |
| | ≤ 500 um | 0 | ≤ 0.3 mm | 0 |
| | > 500 um | 1 | > 0.3 mm | 1 |
| Calcium arc | ≤ 90° | 0 | < 360° | 0 |
| | 90 - 180° | 1 | 360° | 1 |
| | > 180° | 2 | | |
| Calcium length | ≤ 5 mm | 0 | ≤ 3 mm | 0 |
| | > 5 mm | 1 | > 3 mm | 1 |

EEL: external elastic lamina
If the IVUS-derived calcium score is ≥ 2, Fujino's OCT-derived calcium score is 4 or Sato OCT-derived calcium score is ≥ 2, adjunctive calcium modification devices are recommended.

offers a resolution of 10-20 micrometers, which is significantly higher than that of IVUS. This makes it particularly effective for visualizing the details of calcified plaques. Since the tissue penetration of low-coherence light is less affected by calcium deposit material, the entire layer of the calcified plaque can be quite well visualized and quantified.[10,11] Fujino et al. proposed one OCT-based calcium scoring system which is known to predict stent under-expansion.[12] It assigns a calcium score of 2 points for more than 180° of calcium deposit arc, 1 point for maximum calcified thickness greater than 0.5 mm, and 1 point for calcified length greater than 5 mm. Such lesions with a score of 4 show significantly poorer stent expansion (96% vs. 78%, $p < 0.01$). Sato et al introduced a point-based OCT-derived calcium scoring system tailored for severely calcified lesions — specifically those with a calcium angle > 270° which can serve as a reliable tool for identifying severely calcified lesions at risk for stent under-expansion.[13] The scoring assigns 1 point each for the following morphologic features: calcium arc > 270° and length > 3 mm; calcium arc = 360°; minimum calcium thickness > 0.30 mm. Total score ranges from 0 to 3 points and lesions with a score of 2 and 3 had significantly poorer stent expansion. Fujino's system is best for mild-to-moderate calcification, whereas Sato's revision is specifically aimed at severely calcified lesions (angle > 270°). Sato's newer system has lower thresholds for thickness (> 0.30 mm vs. > 0.5 mm) and length (> 3 mm vs. > 5 mm), reflecting adaptation to more severe lesion morphology. The revised scoring model offers a more tailored, sensitive tool to guide decisions like plaque modification strategy before stenting.

Scoring systems for calcified lesions on IVUS or OCT offer quantitative and qualitative assessments that assist in clinical decision-making

(Table 1). These scores help estimate procedural difficulty, inform the selection of interventional tools, and enhance the success rate of PCI and patient long-term outcomes.

## Treatment Modalities for Calcified CAD

### Non-compliance Balloon

Non-compliance balloons (NCBs) are commonly used to modify coronary artery lesions. However, in concentric calcified lesions, even with the use of an NCB under high pressure, there may be uneven balloon expansion, with under-expansion of the calcified segments of the calcified lesion, often referred to as a dog-bone appearance. This feature indicates inadequate lesion preparation and may also lead to balloon rupture, vessel dissection, or perforation.[14] Although standard NCBs can be inflated to high pressures (rated pressure is usually 16 atmospheres), the single-layer structure of the balloon makes it susceptible to rupture in the presence of calcium, especially with uneven lumen surface. High-pressure NCB expansion can lead to severe dissection of less-calcified lesions due to easy slippage.

### Specialty Balloons - Cutting Balloon, Scoring Balloon, Ultra-High-Pressure Balloon

The cutting balloon is a non-compliant balloon equipped with three to four micro surgical blades longitudinally aligned on its surface. These devices are compatible with a 6 Fr system and should be utilized in a 1:1 ratio to the vessel reference diameter. They function by creating minor calcium fractures that minimize elastic recoil post-predilatation, thus yielding superior outcomes, compared to conventional noncompliant balloon angioplasty.[15] Additionally, the blades help prevent balloon slippage during inflation. The Wolverine Cutting Balloon (Boston Scientific) features a low-profile design that enhances delivery capacity compared to previous models. Cutting balloons are primarily employed to create fissures in calcifications rather than to optimally dilate the lesion. To mitigate the risk of perforation, it is advised to reduce the size of the cutting balloon by 0.5 mm relative to the reference vessel diameter, and use a noncompliant balloon sized 1:1 after inflating the cutting balloon. Experts recommend multiple inflations of the cutting balloon, moving it slightly proximally or distally to achieve cuts in different areas. The cutting balloon is suitable for proximal lesions, aortic ostial lesions, in-stent re-stenosis lesions, and adjunctive use after rotational atherectomy (RA), orbital atherectomy (OA), or intravascular lithotripsy (IVL).[16,17]

The scoring balloon is a semi-compliant balloon featuring nickel-titanium alloy scoring elements on its surface. The distinctive characteristic of the Scoreflex (Orbus Neich) balloon is its very short rapid-exchange section, which uses a conventional guidewire as the scoring element along with an additional nitinol guidewire extending from the distal to the proximal end of the balloon. The NSE Alpha (B Braun) balloon is distinguished by three triangular scoring elements at the proximal and distal ends, ensuring a low penetration profile and good tracking while reducing slippage during inflation. The Angiosculpt (Philips) balloon is covered with three spiral nickel-titanium wires that slide and rotate during inflation, creating a scoring effect on the plaque. The Wolverine Cutting Balloon has demonstrated smoother lesion penetration than the Lacrosse NSE ALPHA Scoring Balloon (Nipro), while providing similar acute lumen gain. However, the delivery success rate of the Wolverine cutting balloon was significantly higher than that of the Lacrosse NSE ALPHA scoring balloon (90.8%, compared to 79.5%).[18] The technical advantage of cutting and scoring balloons over conventional balloons lies in reduced slippage, which is particularly beneficial in ostial lesions.

The ultra-high-pressure non-compliant balloon (OPN NC, Sis-Medical) is a newly designed device with a double-layer structure capable of inflating to 35-40 atmospheres. These balloons are compatible with 6 F systems and have superior penetration curves, compared to cutting and scoring balloons. In calcified lesions, the OPN balloon should be 0.5 mm smaller than the reference vessel diameter due to its expansion at higher pressures. Early studies have indicated that they are safe for lesion dilation and avoid the risk of vessel perforation, compared to traditional non-compliant balloons, as demonstrated in the ISAR-CALC trial.[19,20] While the performance of the OPN balloon was comparable to scoring balloons and showed better angiographic results, these were not statistically significant. Limitations of the OPN balloon include an increased risk of vessel perforation, especially when used prior to stent placement. The rated burst pressure of the OPN balloon is 35 atmospheres, with higher inflation pressures increasing the risk of vascular perforation. Unlike other non-compliant balloons, OPN balloons expand under high pressure. Their relatively bulky shape and extra stiffness pose challenges in re-passing the balloon after inflation due to the double-layer technology. After multiple high-pressure inflations, the OPN balloon may adhere tightly to the guidewire, potentially losing guidewire positioning upon withdrawal. Therefore, the use of an auxiliary guidewire to maintain access before removing the balloon may be necessary.

## Rotational Atherectomy

Rotational atherectomy (RA) with the Rotablator RA System (Boston Scientific) uses a high-speed rotating burr coated with diamond chips to remove calcified plaque while preserving elastic tissue. RA is usually used for calcified lesions that cannot be crossed with a balloon catheter or when balloon dilatation fails. Occasionally, RA is an off-label option for under-expanded stent sites. The new-generation RotaPro device has several features to improve usability, including single-operator performance. The primary reason for using RA is to modify calcified plaque, making balloon angioplasty and stent deployment easier. This approach shifts focus from the earlier goal of adequate plaque debulking.

The STRATAS trial evaluated the outcomes of an aggressive debulking strategy (maximum burr/artery ratio $> 0.70$, with or without adjunctive balloon inflation $\leq 1$ atm) against a routine strategy (maximum burr/artery ratio $\leq 0.70$ with routine balloon inflation $\geq 4$ atm).[21] The aggressive debulking strategy yielded only minimal difference in clinical success, final minimum lumen diameter, or residual stenosis, but was associated with higher rates of periprocedural myocardial infarction and target lesion revascularization at 6 months. Similarly, the CARAT trial found no benefit from the aggressive debulking strategy as regards procedural success or target vessel revascularization at 6 months, and noted a higher risk of angiographic complications with a larger burr/artery ratio.[22] These randomized controlled trials indicated that an approach using a smaller burr size may be preferable. The PREPARE-CALC trial was a randomized study designed to compare the efficacy and safety of rotational atherectomy (RA) versus modified balloon (MB) angioplasty (using scoring or cutting balloons) for the preparation of severely calcified coronary lesions prior to drug-eluting stent implantation.[23] In it, the RA group achieved a higher strategic success rate compared to the MB group (98% vs. 81%, $p = 0.0001$). This difference was primarily due to a higher crossover rate in the MB group (16%) compared to the RA group (0%). Both groups showed similar safety profiles, with no significant differences in procedural complications, and at five years, the RA group had a lower rate of target lesion revascularization, compared to the MB group (8% vs. 16%, $p = 0.04$).[24]

Several studies have compared the outcomes of planned vs. unplanned (bailout) use of RA in managing severely calcified coronary lesions.[25-29] These investigations give insights into procedural efficiency, complication rates, and long-term patient outcomes associated with each strategy. Planned RA is associated with reduced procedural time, fluoroscopy time, and contrast volume, compared to unplanned RA. For instance, one study reported that planned RA significantly decreased procedural time (105.56 ± 36.71 minutes vs. 139.86 ± 56.24 minutes, P < 0.001) and contrast volume (237 ± 62 ml vs. 275 ± 90 ml, P = 0.003), compared to bailout RA.[25] Also, the incidence of procedural complications, such as coronary dissections, was notably higher in unplanned RA.[26-28] One systematic review and meta-analysis on studies comparing planned vs. bail-out RA strategy showed that planned RA was associated with a shorter procedural time [mean difference (MD) -25.88 min, 95% CI: -35.55 to -16.22], less contrast volume (MD: -43.71 ml, 95% CI: -69.17 to -18.25), fewer coronary dissections (RR: 0.50, 95% CI: 0.26-0.99), fewer stents (MD: -0.20, 95% CI: -0.29 to -0.11), and a trend towards fewer periprocedural myocardial infarctions (RR: 0.77, 95% CI: 0.54-1.11). There was no difference in major adverse cardiovascular events on follow-up (RR: 1.04, 95% CI: 0.62-1.74).[28]

The 2021 ACC/AHA/SCAI guidelines recommend rotational atherectomy for heavily calcified lesions with a 2a, level B rating.[29] They state that RA can improve procedural success, despite a lack of data showing better long-term outcomes. Hence, RA is still important for lesion preparation before stenting.

## Orbital Atherectomy

The Diamondback 360 Precision™ Orbital Atherectomy System (Abbott Cardiovascular) employs a specialized device to modify and reduce calcified plaque, facilitating stent deployment and improving overall blood flow.[30,31] The procedure utilizes a device equipped with a diamond-coated, eccentrically mounted crown that orbits within the artery. As the crown rotates, it sands down calcified deposits, effectively modifying the plaque and increasing the vessel's lumen. This action not only enhances blood flow but also prepares the artery for optimal stent expansion. The system is compatible with 6 French or larger guide catheters, making it versatile for various clinical scenarios. A notable advantage of orbital atherectomy (OA) is its ability to treat varying vessel sizes using a single crown size, with the orbit diameter adjustable by modifying the rotational speed and advancement rate. During the intervention, a VIPERWIRE Advance® wire (0.014) is first navigated across the lesion. The OA device is then advanced over this wire to the target site. A key aspect of OA is that it works bidirectionally, ablating plaques while being advanced and while being retracted.[32] The device operates at two rotational speeds: low (approximately 80,000 rpm) and high (up to 120,000 rpm). The choice of speed depends on the lesion's characteristics and the desired extent of plaque modification. Low speed should be used for the initial pass, with only some lesions requiring high speed. It is advised to avoid high speed in tortuosity, severe angulation, and vessels < 3.0 mm, as there may be a risk of vessel perforation, limiting its use only to larger straight vessel segments if insufficient ablation or compliance change has been achieved after two or more runs at low speed.[31,33,34] Throughout the procedure, a continuous infusion of lubricant is maintained to reduce friction and prevent heat buildup.

The ORBIT II trial was a prospective, multicenter, single-arm study conducted across 49 sites in the United States.[34] A total of 443 patients with de novo, severely calcified coronary lesions were enrolled to further evaluate the safety and efficacy of OA prior to stent implantation. The trial reported a procedural success rate of 88.9%, defined as successful stent delivery with residual stenosis less than 50% and without in-hospital MACE. Successful stent delivery was achieved in 97.7% of cases, and less than 50% residual stenosis was observed in 98.6% of patients. Freedom from in-hospital MACE was reported in 90.2% of patients.[34] ORBIT II also reported a rate of 23% of MACE at 3-year follow-up.[35] These results indicate durable long-term outcomes with the use of OA in this high-risk patient population. The ECLIPSE trial is the largest randomized trial to date studying routine coronary atherectomy for severely calcified de novo lesions, assessing OA vessel preparation, and comparing to HPB angioplasty and/or cutting balloons.[36] The OA group achieved an average minimal stent area (7.67 $mm^2$ vs. 7.42 mm, p = 0.08) similar to the conventional angioplasty group. At one-year follow-up, target vessel failure occurred in 11.5% of patients in the OA group, compared to 10.0% in the conventional angioplasty group (p = 0.28). Rates of procedural and strategic success without the need for crossover were similar in both groups.[37] Additionally, the incidence of complications such as dissection, coronary perforation, and slow flow did not differ significantly between the two groups. It is important to note that while OA remains a valuable tool for specific scenarios, such as balloon-uncrossable or undilatable lesions, its routine application in all severely calcified lesions may not be necessary. The trial provided some evidence challenging the routine use of orbital atherectomy for the treatment of severely calcified coronary lesions, advocating instead for a tailored approach based on lesion characteristics and the judicious use of intravascular imaging.

### Intravascular Lithotripsy

Intravascular lithotripsy (IVL) is a relatively recent advancement in the treatment of calcified coronary lesions. This technique has adopted electrical shock wave lithotripsy for urolithiasis and modified it into balloon-based shockwave delivery for heavily calcified coronary plaques. The Shockwave Medical coronary IVL catheter (Santa Clara, CA, USA) consists of a 0.014-inch guidewire-compatible, fluid-filled balloon angioplasty catheter with two spark gap–based lithotripsy emitters incorporated into a 12-mm working length balloon.[38] The system is 6 Fr compatible and consists of a semi-compliant balloon equipped with two emitters placed at both proximal and distal ends. The coronary IVL system is delivered on a rapid exchange catheter and is available in 2.5, 3.0, 3.5 and 4.0 mm diameters to allow appropriate size selection to achieve a BA ratio of 1.0~1.3. To perform IVL, the IVL balloon catheter is positioned at the target lesion and inflated to 4 atm, followed by optional balloon inflation to 6 atm.

With the balloon inflated, IVL acoustic energy can be delivered as a cycle of 10 pulses at a frequency of 1 Hz (for Shockwave C2 the maximum is 80 pulses per balloon and for the Shockwave C2+ system the maximum is 120 pulses per balloon), with intervening deflation to restore distal perfusion, which may be particularly important when treating left main lesions. An IVL pulse is produced when lithotripsy emitters create vapor bubbles within the integrated balloon, resulting in the formation of acoustic shockwaves with peak acoustic pressures up to 50 atm that propagate circumferentially and transmurally through the calcified plaques as the mechanism that induces superficial and deep fractures in the calcium deposits.[38] This distinctive method merges mechanical principles with the safety and simplicity of a balloon catheter system to effectively alter calcified plaque, thereby facilitating subsequent stent implantation and optimizing stent expansion. While IVL shows promise in addressing calcified lesions, potential complications can arise. IVL has been assessed as an adjunct to coronary stenting in severely calcified lesions through the Disrupt CAD I-IV single-arm, prospective, multicenter, nonrandomized studies.[39-42] The mean reference vessel diameter of the target lesion was 2.95 ± 0.51 mm, and the mean lesion length was 24.4 ± 11.5 mm. Severe calcification was present in 97.0% of all lesions, with a total calcified segment length of 41.5 ± 20.0 mm. Target lesion pre-dilatation occurred in 47.6% of procedures, and IVL was successfully administered in 98.7% of cases, delivering an average of 74.7 ± 42.7 pulses per lesion. Post-dilatation with a balloon immediately followed IVL in only 16.8% of cases and subsequent stent implantation in 94.1% of procedures. Stent delivery achieved a success rate of 99.5% among patients, indicating a low learning curve for the IVL procedure. The primary safety endpoint of 30-day MACE was observed at a rate of 7.3% (95% CI: 5.4% to 9.7%), primarily due to non-Q-wave MI (5.9%; 95% CI: 4.2% to 8.1%). Procedural success, defined as ≤30% residual stenosis, was achieved in 92.4% of patients (95% CI: 90.0% to 94.3%). These results were consistent across all four Disrupt CAD studies.[43] Serious angiographic complications post-IVL treatment occurred in 2.1% of patients, including flow-limiting dissection (1.8%) and slow flow (0.4%), with no incidents of perforation, abrupt closure, or no reflow.[43] The efficacy of shockwave therapy appears contingent on the location of the target lesion, aligning with mechanoelectrical coupling via activation of local stretch-activated cardiomyocyte channels. Consequently, the use of IVL can induce ventricular ectopic beats (shocktopics) and asynchronous cardiac pacing in about 41.1~77.8% of procedures.[41,44] Coronary IVL-provoked ventricular capture is often accompanied by a temporary reduction in systemic blood pressure. Although rare, IVL-induced ventricular capture might result in non-sustained or sustained ventricular tachycardia or ventricular fibrillation.

## Special Lesions – Calcified Nodules

Calcified nodules (CNs) are a specific form of coronary artery calcification characterized by irregular, protruding calcium deposits within the arterial lumen. These nodules can disrupt blood flow and pose significant challenges during percutaneous coronary interventions. They are categorized into two types (eruptive and non-eruptive CNs) based on their surface characteristics.[45] Eruptive CNs exhibit a disrupted fibrous cap with adherent thrombi, indicating biological activity. These nodules are associated with higher rates of stent failure and unfavorable clinical outcomes. Non-eruptive CNs have an intact fibrous cap without thrombi, representing either healed eruptive CNs or protrusions of calcium due to plaque progression. These nodules are biologically inactive and less likely to cause acute events, compared to their eruptive counterparts. OCT is a pivotal tool in identifying and assessing CNs due to its high-resolution imaging capabilities. A retrospective study found a 3-fold risk of adverse events with CNs in patients undergoing RA.[46] A small propensity-matched study showed no difference in acute lumen gain, mal-apposition, or target vessel revascularization between patients treated with or without RA.[47] The pooled analysis of the Disrupt CAD serial studies evaluated the efficacy of coronary IVL in treating severely calcified coronary lesions, with a specific focus on CNs.[48] This analysis aimed to determine the impact of IVL on both acute procedural outcomes and long-term clinical events in lesions with and without CNs. Among these, CNs were identified in 18.7% (29 out of 155) of the lesions using OCT imaging. IVL facilitated successful stent implantation in all cases, regardless of the presence of CNs. Despite a higher calcium burden, the final minimal stent area (CN: 5.7 $mm^2$ vs. non-CN: 5.7 $mm^2$; $p = 0.80$) and stent expansion (CN: 79.3% vs. 80.2%; $p = 0.30$) were comparable between the two groups. In the CN group, the final stent area and expansion at CN sites were 7.6 mm2 and 89.7%, respectively. The cumulative incidence of target lesion failure at 2 years was 13.9% in the CN group and 8.0% in the non-CN group ($p = 0.32$).[48] Early restenosis has been linked to the re-protrusion of the CN into the stent.[49,50] Eruptive CNs have shown worse long-term outcomes compared to non-eruptive CNs, despite achieving better acute stent expansion. This may be due to a higher risk of eruptive CN re-protrusion.[3,51] The cause of CN reappearance in-stent is not known and could be through acute or subacute intrusion or continued growth of the CN. Prospective studies are warranted to evaluate the effectiveness of different treatment strategies for eruptive CNs, including the necessity for lesion modification, the optimal calcium modification techniques, and the outcomes of various stent implantation approaches.[52]

## Treatment algorithm for calcified CAD

The group consensus on the treatment algorithm for calcified coronary lesions is shown in Figure 1, which guides the selection and sequencing of various calcium modification techniques, including balloon-based therapies, atherectomy and IVL. This structured approach aims to optimize procedural outcomes and improve patient prognosis. It incorporates angiographic assessment of calcium deposits, supplemented by intracoronary imaging (IVUS/OCT) to characterize calcium burden. Calcium burden is stratified based on scoring systems of calcified lesions by intravascular imaging (Table 1). Based on the calcium burden, a tailored treatment strategy is selected, employing a range of calcium modification techniques.

### Step 1: Lesion Assessment

Use initial angiography to identify moderate/severe calcified lesions. Evaluate angiographic evidence of calcification using intravascular imaging to assess the necessity and determine the appropriate method for calcium modification. Calcium scoring systems can further aid in risk stratification.

### Step 2: Intravascular Imaging Devices/Balloon Crossability

Predilation with a low-profile balloon may be required to facilitate the advancement and

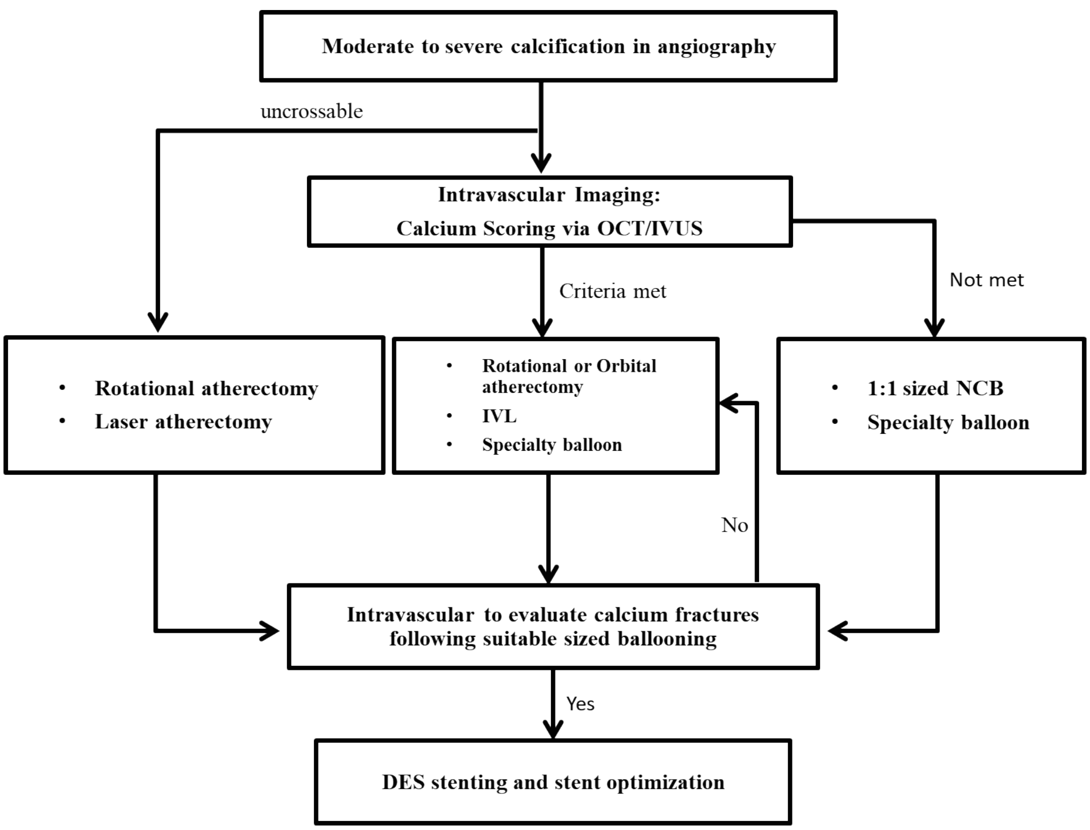


**Figure 1.** Treatment algorithm for severe/moderate calcified coronary lesions.
Specialty balloon denotes cutting balloon, scoring balloon or ultra-high pressure OPN balloon; NCB: non-compliance balloon.
Criteria met means the IVUS-derived calcium score is ≥ 2, Fujino's OCT-derived calcium score is 4 or Sato OCT-derived calcium score is ≥ 2.

delivery of the intravascular imaging catheter. If the balloon successfully crosses, proceed with predilatation. If it does not cross, attempt crossing with a microcatheter. Should the microcatheter fail to cross, consider laser, atherectomy or alternative access strategies.

### Step 3: Calcium Modification Strategy (Tiered Approach)

An IVUS-derived calcium score less than two, or OCT-derived calcium score less than 4 suggests mild to moderately calcified lesions, for which balloon-based therapies are typically sufficient. Utilize non-compliant balloons (NCB) or specialty balloons (cutting/scoring balloons), and if optimal balloon expansion is achieved, perform stenting. In cases of suboptimal expansion, consider IVL. Drug-eluting balloons may be considered, particularly for in-stent re-stenosis within calcified lesions. For severely calcified lesions (IVUS-derived calcium score of at least two, or Fujino's OCT-derived calcium score is 4 or Sato OCT-derived calcium score is ≥2), employ an escalating balloon strategy, involving high-pressure NCB, specialty balloon, and IVL. Optimal expansion leads to subsequent stenting, whereas suboptimal expansion necessitates the consideration of rotational or orbital atherectomy. For severely calcified lesions, a combination approach is often required, typically involving atherectomy and/or IVL. Final balloon optimization can be achieved using NCB or specialty balloon. Reassessment with intravascular imaging is crucial if suboptimal expansion persists.

### Step 4: Stenting and Optimization

Post-stent intravascular imaging is essential to assess stent apposition and expansion. Stent under-expansion is addressed with high-pressure NCB.

### Step 5: Final Assessment and Completion

Confirm adequate stent expansion with intravascular imaging. Perform final balloon post-dilatation as needed.

## Conclusion

In conclusion, PCI for calcified coronary lesions is a complex procedure associated with both short-term and long-term risks, including vessel perforation and stent thrombosis/restenosis. Despite these challenges, there are several strategies and technologies available to optimize PCI results, including the obligatory use of intravascular imaging tools and unique device therapies for calcified plaque modification, such as cutting balloons, atherectomy and lithotripsy. These techniques can enhance lesion preparation, stent delivery, and stent implantation and optimization, and potentially improve patient outcomes. Therefore, PCI can be an option for severely calcified coronary lesions when interventionists understand the complexities and risks associated with this procedure. Further large-scale studies are needed to provide data on long-term outcomes of PCI for such severely calcified coronary lesions.

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