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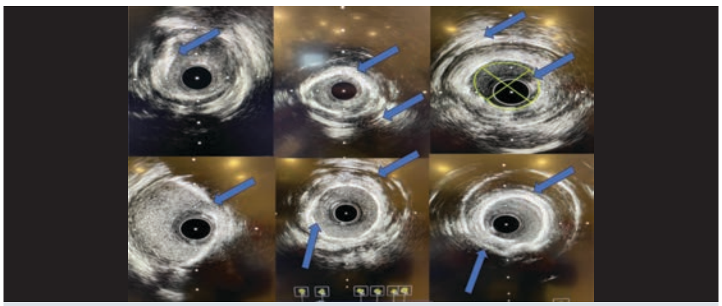

CATH LAB BASICS

Coronary Artery Calcium in PCI: Considerations for Plaque Modification

Jake Rogers, BS, Radiography and ICVT;
Professor Richard Merschen, EdS, RT(R)(CV), RCIS

It is estimated that as many as 30% of patients with coronary artery disease (CAD) requiring percutaneous coronary artery intervention (PCI) have lesions with significant coronary artery calcium (CAC).[1,2] These numbers are increasing as more people are developing risk factors associated with CAC, including classic cardiovascular risk factors like hypertension, diabetes, tobacco use, obesity, hyperlipidemia and aging.

CAC is also closely linked to chronic kidney disease (CKD), inflammatory processes, and genetic conditions. CKD affects approximately 40 million American adults, and these numbers have more than doubled since 1990.[3-5] Patients with CKD also face additional CAC risks because of associated metabolic, mineral, and bone disorders, which are associated with CAC of the media and adventitia.[3,4]

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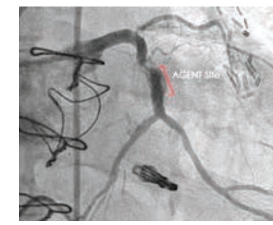
IN-STENT RESTENOSIS



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HMP Global

Coronary Artery Calcium in PCI: Considerations for Plaque Modification

Jake Rogers, Student Technologist; Richard J. Merschen, EdS, RT(R)(CV), RCIS

Continued from cover

While CAC begins to develop early in life, it typically becomes detected and clinically significant by age 70. By age 70, more than 70% of adults have some level of CAC.[3,6] Men develop CAC about a decade earlier than women, due to estrogen-related protection for women. As the estrogen effect diminishes, women's CAC rates begin to rapidly accelerate.[3,6] Additionally, the population has significantly aged over the past 20 years and the increasing numbers of elderly patients is closely linked to increases in CAC.

Clinical Presentation

CAC is a complex, diffuse disease process and commonly presents as heterogeneous disease.[6-8] It can be superficial or deep, non-obstructive, flow-limiting or completely obstructive, and replace the intima or develop subintimally.[7,8] It is not uncommon to see complicated CAC presentations such as eccentric, concentric, flow-limiting, and superficial lesions in the same vessel. Furthermore, CAC may also be complicated by micro calcifications, thrombotic or fibrotic components, extremely dense areas, and layered or concentric sheets (**Figure 1**).[7,8] The vessel lumen may also have different diameters in the same target vessel area, or involve ostia or bifurcations (**Figure 2**), which can create more challenges when performing PCI.

CAC can also be nodular. Calcium nodules (CN) are defined as an eccentric calcium mass with a convex structure within the vessel lumen that may present in as many as 30% of CAC patients (**Figure 3**).[9-12] CNs are usually

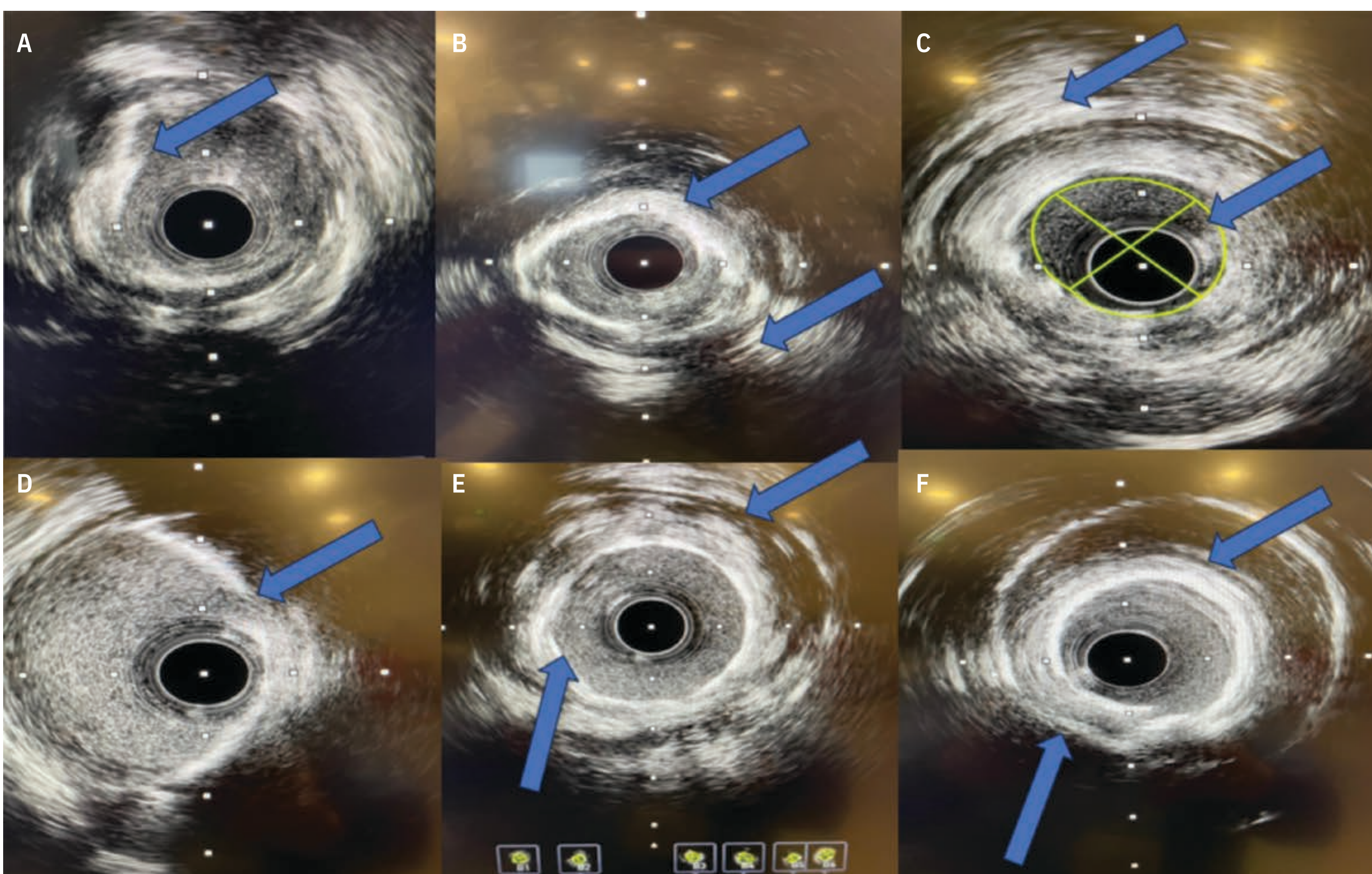

Figure 1. Types of calcium. Shows the complexity of coronary artery calcium (CAC). (A) Calcified nodule with layers of deep and superficial calcium. (B) Superficial calcium with >270-degree arc and deep calcific sheets. (C) Fibrocalcific CAC with superficial and deep calcium. (D) Superficial, eccentric calcium. (E) Concentric ring of superficial calcium, as well as deep calcium. (F) Severe, superficial, concentric calcium; >1 mm deep layer of calcium with acoustic shadowing at 7 o'clock.

accompanied by a heavily calcified plaque underneath and acoustic shadowing on IVUS imaging.[9-11] In some scenarios, including acute coronary syndromes (ACS), CNs can present as eruptive, unstable lesions with a disrupted fibrous cap and thrombus. CNs may also present as non-eruptive, heavily calcified, stable lesions that are extremely resistant to PCI.[9-11] CNs are associated with significantly higher rates of adverse events during PCI, including vessel dissection, perforation, tissue extrusion, or mechanical deployment issues with stents.[12-14]

Challenges

Because of its complexity, CAC can be associated with significant PCI challenges. This includes reduced technical and clinical success rates due to stent damage, stent under deployment and malapposition, and higher stent restenosis rates (**Figure 4**). Therefore, properly modifying, treating and imaging of CAC is essential to optimizing PCI outcomes. Intravascular imaging is highly recommended to determine the severity of CAC and choose the best strategies, such as atherectomy, balloon-based technologies, and stents, to treat CAC.

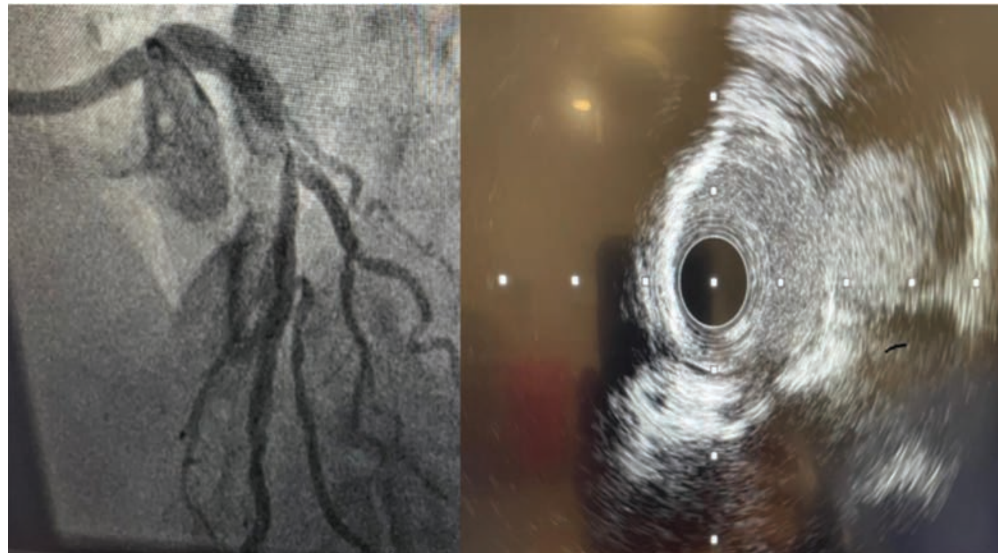

Figure 2. Bifurcation lesion. Left anterior descending (LAD)/diagonal stenosis. Intravascular ultrasound (IVUS) revealed calcific disease in the LAD and a normal diagonal artery. IVUS shows eccentric superficial disease (blue arrow) and a deeper component (white arrow) that was successfully treated with intravascular lithotripsy (IVL), noncompliant (NC) balloon, and provisional LAD drug-eluting stent (DES).

CAC Identification on Imaging

CAC is visible on coronary artery tomographic angiography (CCTA) and conventional radiography, as well as fluoroscopy and cine angiography. Coronary computed tomography calcium scoring (CAC scoring), and CCTA are commonly used diagnostic tools for initially evaluating the presence and severity of CAC. CAC scoring, using the Agaston scale, is an important, cost-effective screening tool for assessing the risk of cardiovascular events and determining calcium burden in coronary arteries. However, it cannot differentiate between intimal and medial plaque, nor determine the

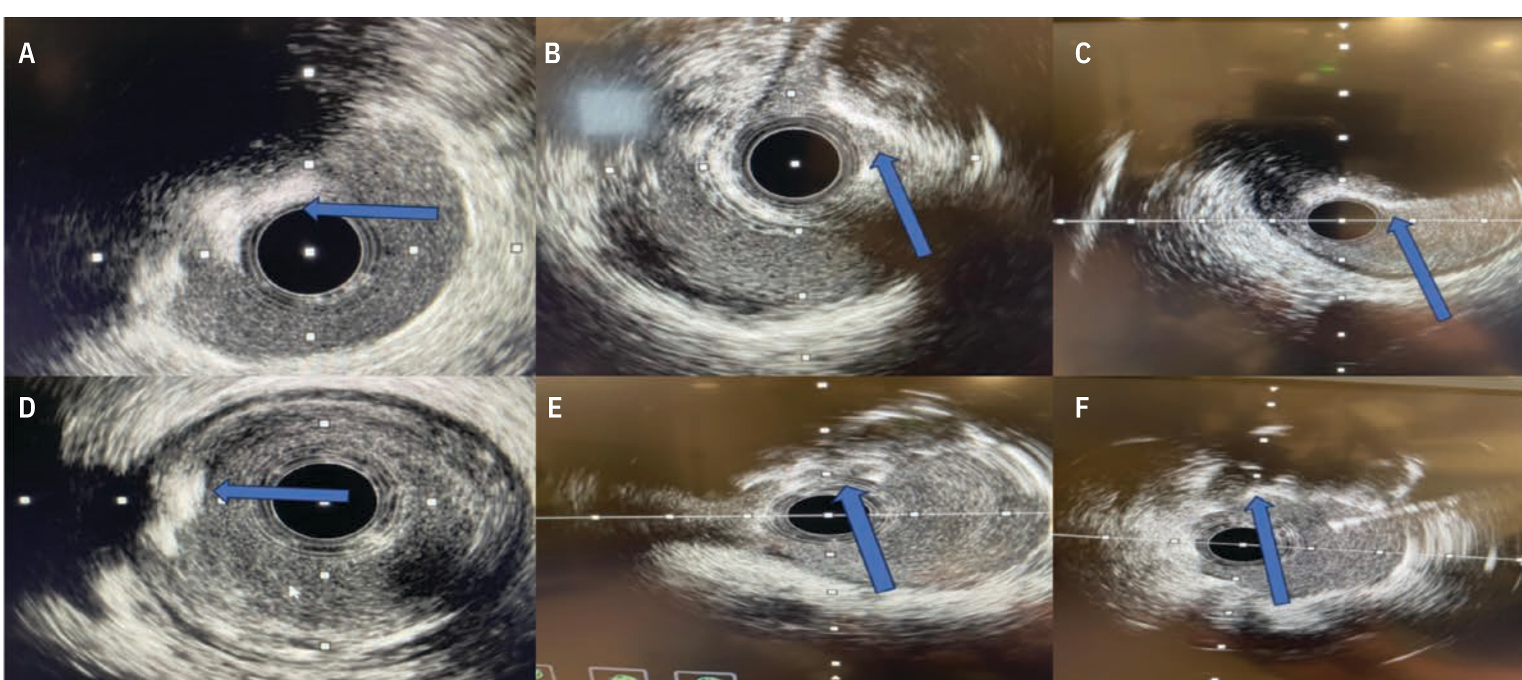

Figure 3. Calcified nodules (blue arrows). Note the convex-shaped, eccentric, protruding lesions with acoustic shadowing.

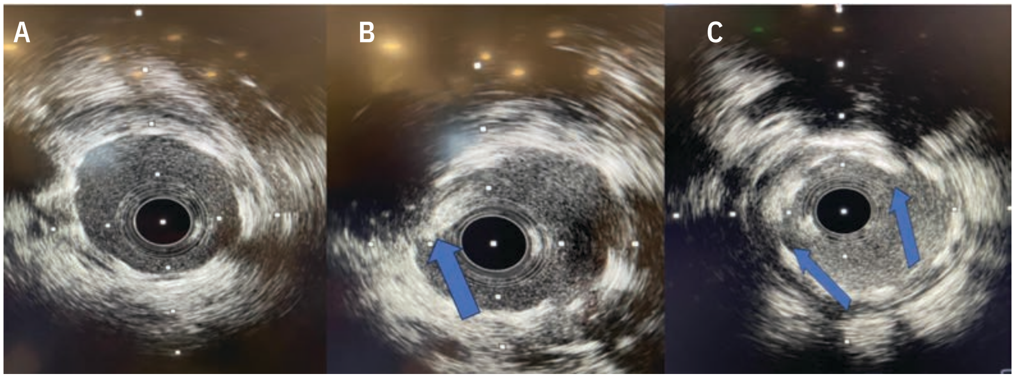

Figure 4. Demonstrating the challenges of stent deployment in CAC. (A) Proper stent apposition. (B) Calcified nodule extruding through the stent (blue arrow). (C) Stent under-expansion and malapposition (blue arrows).

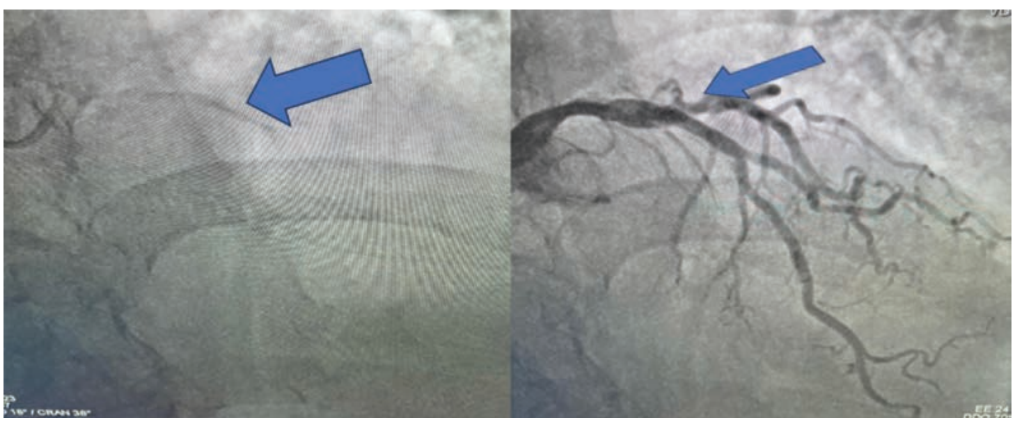

Figure 5. Patient had a positive calcium scoring test and radiographic evidence of CAC. Angiogram revealed coronary arteries with mild, non-obstructive disease.

presence of obstructive disease (**Figure 5**).[15] Calcium scoring only provides a cumulative calcium burden score without identifying plaque composition or vulnerability.[15]

CCTA is an excellent imaging modality to visualize CAD. However, CCTA is also limited in diagnosing the true severity and complexity of CAC. It can overestimate the severity of disease due to variables such as blooming artifacts, vessel overlap, and smaller plaques in a vessel.[16,17] CCTA also requires intravenous contrast, gating techniques to eliminate motion artifacts, and heart rate and rhythm control to produce high-quality images. CCTA is valuable for assessing CAC, but still needs improvements in specificity to quantify CAC severity.[16,17]

CAC can also be visualized on conventional radiographs like a chest x-ray. In the cath lab, CAC is visualized as a pre contrast injection with fluoroscopy or cine angiography. Angiography alone cannot determine the morphology, complexity, or severity of CAC, because it is a luminogram that does not assess blood flow directly.[18,19] When injecting contrast through the vessel lumen, angiography has the potential to overestimate CAC severity because dense calcium can obscure lesion morphology and vessel boundaries. Because of limitations in interpreting CAC with angiography, intravascular imaging is essential to determine the complexity and severity of CAC.

IVUS and OCT

Intravascular ultrasound (IVUS) or optical coherence tomography (OCT) are recommended for PCIs involving CAC. These imaging systems visualize the vessel lumen and wall layers, determine the morphology and severity of CAC and the target vessel revascularization (TVR) area, and help to determine appropriate plaque modification strategies to optimize procedural outcomes. IVUS is a well-established technology using either a mechanically rotating single-element system or phased-array system through a 5 or 6 French catheter. It provides high-quality data that helps determine morphology, diameter, and length of a TVR area. IVUS is also recommended for assessing stent deployment, challenging in CAC. Rotational IVUS, using a pullback sled, can accurately determine lesion length, which also helps optimize stent positioning. Multiple IVUS runs can be performed during a procedure without using iodinated contrast, which is required with OCT, allowing the operator to easily assess the vessel at key procedural intervals, and ensure proper stent expansion and deployment. IVUS is usually more readily available than OCT, another important consideration.

Additionally, IVUS can be performed over a .014-inch guidewire using a monorail catheter and with guide extension catheters. It has a helpful scoring system to assess the severity of CAC and determine if plaque modification is advised. The IVUS calcium score uses four features to assess CAC severity: a superficial calcium arc >270° extending >5 mm, 360° calcium, the presence of a calcified nodule, and vessel diameter <3.5 mm.[20] A score of 2 or more suggests a higher risk of stent underexpansion and supports plaque modification.[20] Commonly used IVUS and OCT criteria for CAC modification are shown in **Table 1**. These criteria are relative, and the presence of diffuse flow-limiting disease, severely obstructive calcium, or calcified nodules may also require plaque modification techniques.

Limitations of IVUS include that it can overestimate the lumen area by 10% and that results may be less reproducible compared with OCT.[21-23] IVUS is also considered less effective than OCT for assessing deep calcium and stent deployment. Dense calcium can obscure the vessel lumen with acoustic shadowing.[22,23] Overall, however, IVUS is easy to set up and use. It provides high-quality information about the TVR area. IVUS can also assess diffuse disease areas within a lesion, provide valuable information about stent deployment, does not use contrast, and reduces radiation exposure by using ultrasound to provide critical lesion data.

OCT uses coherent near-infrared light to visualize the coronary artery lumen and assess CAC. The high resolution of OCT enables better assessment of CAC versus IVUS because

OCT visualizes the arterial walls through dense calcium and eliminates acoustic shadowing.[23] OCT is also considered to be superior to IVUS in determining the thickness, depth, and eccentricity of calcified lesions. OCT-based imaging is associated with improved post-PCI outcomes because of its superiority in assessing stent apposition[23,24] and identifying post-PCI stent complications, including edge dissections, malapposition, and underexpansion. OCT has a "rule of 5" scoring system that is similar to IVUS for interpreting CAC, with a few notable exceptions.[21-24] OCT's main limitation is the need to use iodinated contrast for blood clearance, which is a major consideration with patients who have CKD. OCT generally requires a pre-scripted pullback sequence, whereas IVUS can be manually controlled, making it more versatile in some situations.

Table 1. Commonly Used IVUS and OCT Criteria for CAC Modification.[20-23]

Imaging Technique	IVUS	OCT
Length of calcium*	>5 mm	>5 mm
Arc of calcium*	>270°	>180°
Calcium is 360°	Yes or no	n/a
Vessel diameter	<3.5 mm	n/a
Nodular calcium	Present or not present	n/a
Thickness of calcium	n/a	>0.5 mm

*For the IVUS calcium score, calcium arc >270° and calcium length >5 mm are considered a single combined criterion.

Table 2. Procedural Considerations for Use of Orbital vs Rotational Atherectomy.[25,28,29]

Categories	Orbital Atherectomy	Rotational Atherectomy
Vessel size	Small to large	Small to medium
Wire	.014-inch wire	.009-inch stainless steel wire
Type of lesion	Large-caliber vessels, fibro-calcific disease, diffuse disease	Ostial, tortuous, diffuse disease, possible calcium nodules
Movement	Bidirectional	Unidirectional
Catheter size	6 French	6 French for burrs up to 1.75 mm

Atherectomy

After assessment with intravascular imaging, numerous adjunctive devices are available to treat CAC and prepare the vessel for stenting. This includes atherectomy and balloon-based devices. Atherectomy is an important treatment step for CAC, with three major devices available for use: rotational atherectomy (RA), orbital atherectomy (OA) (**Table 2**), and laser atherectomy (ELCA). Atherectomy debulks calcium from the lesion and prepares it for further modification and stenting. If a CAC lesion is not crossable with IVUS or balloons, atherectomy devices should be considered as the initial interventional step (**Table 3**).

Rotational Atherectomy. RA is a well-established technology that can be used to modify CAC. RA ablates inelastic CAC tissue while maintaining the integrity of elastic tissue, due to the principle of differential cutting.[25] RA is effective for ostial lesions, uncrossable lesions, vessels with small-to-medium lumen vessels, tortuous, diffuse disease, and heavily calcified lesions that cannot be dilated or crossed with balloons. It may be beneficial for treating non-eruptive CNs. Additionally, clinical trials are now demonstrating the effectiveness of using RA with either intravascular lithotripsy (IVL) or cutting balloons to further modify CAC before stent placement.[26,27]

Some important considerations for RA include the need for larger guide catheters for burrs >1.75 mm, which are uncommonly needed. The procedure also requires an .009-inch stainless steel wire, and this wire may not navigate easily through CAC lesions. Additionally, the wire is not optimal for balloon angioplasty and stent delivery, so the procedure may require multiple wire exchanges using an over-the-wire (OTW) catheter. RA can also cause bradycardia in right coronary artery (RCA) lesions. No-reflow phenomenon can occur, especially in cases where there is extreme burr deceleration.

Orbital Atherectomy. Orbital atherectomy ablates CAC and fibro-calcific debris in vessels sized from 2-4 mm using bidirectional sanding, and centrifugal and pulsatile forces. It is a single 1.25 mm device that advances over a tapered .014-inch guidewire. OA is able to treat larger luminal areas than RA by using bidirectional movements and changing the speed of the device.[28] It is preferred for larger caliber vessels, but can also be used in ostial disease and smaller lumen vessels. Overall, however, RA is generally considered superior to OA for tight ostial lesions, and smaller caliber and more tortuous lesions.

Data suggests both RA and OA are safe and effective as pre-treatment strategies before stent deployment and have similar overall outcomes. However, OA is associated with lower rates of all-cause mortality, TVR, coronary artery bypass graft (CABG) surgery, and fluoroscopy time.[29] OA also provides advantages for setup because it doesn't require

Table 3. Differences Between Balloon-Mounted vs Atherectomy Devices.[26,27]

Categories	Balloon-Mounted Devices	Atherectomy Devices
Types	Non-compliant, high pressure, lithotripsy, cutting, scoring	Rotational, orbital, laser
Wires	Monorail or OTW .014-inch	OTW, .009-inch RA, .014-inch OA
Side branches	Can be protected with wire	Unable to ensure protection of side branches
Lesion treatment	Lesion modification	Ablation, debulking
Vessel size	2.5-5 mm for balloons, except IVL (2.5-4 mm)	Sizes vary for RA; OA is 1.25 mm

OTW = over the wire; RA = rotational atherectomy; OA = orbital atherectomy; IVL = intravascular lithotripsy

Table 4. Procedural Considerations for Intravascular Lithotripsy.[35,36,37,39]

Sizing	1-to-1 sizing with a range of 2.5 to 4 mm diameter, and 12-mm length balloon
Target lesions	Treats superficial and deep calcium, concentric and eccentric disease, may be effective for calcific nodules
Eruptive or non-eruptive	Recommended for non-eruptive calcific nodular lesions
Technology base	Ballon-mounted
Rate and inflation	10 pulses per inflation, low-pressure inflations at 2-6 atmospheres

a nitrogen tank or foot pedal to operate. The .014-inch wire also reduces the amount of wire exchanges, as a full intervention can theoretically be completed over the guidewire.

ELCA. Laser atherectomy is not a front-line treatment for de novo CAC lesions. Its best CAC clinical indications are for in-stent restenosis, chronic total occlusions (CTOs) and non-CTO lesions that are truly uncrossable, even with the use of RA or OA.[30,31] In these cases, ELCA modifies the plaque and creates a channel that allows for the use of other atherectomy devices and balloons.[30,31] However, RA, OA and balloon-based technologies are far more likely to be used for CAC modification in de novo and non-CTO lesions.

Balloons

There are also numerous balloon-based technologies for CAC plaque modification. Balloons modify plaque through a variety of processes such as high-pressure inflations, lithotripsy, and the use of atherotomes and metal scaffolding for cutting into plaque. When specialty balloons can be delivered, there are numerous advantages to balloon-based treatments. All balloon-based options can be performed over an .014-inch wire using either a monorail or OTW system, which allows the entire procedure to be completed with a single wire. Balloon-based technologies also allow for side branch wiring and protection for bifurcation lesions. They can also be used with guide extensions and buddy wires. When a balloon expands in CAC, it helps ensure that the vessel will conform to the 1:1 stent ratio needed for optimal stent deployment. Several studies support a comprehensive approach for CAC treatment that integrates balloons and atherectomy to modify plaque, maximize the vessel lumen, and improve stent deployment success.

Of note, even with advances in the construction of specialty balloons, deliverability of these balloons may be difficult in many patients with CAC. Additionally, balloon-based devices are vulnerable to unsuccessful treatment of an area, and issues such as "dog-boning" or "watermelon seeding" during inflations. Repeated unsuccessful inflations can limit the ability to perform atherectomy during the procedure, and cause dissections, perforations, and other complications. Additionally, many specialty balloons treat small, defined areas, which may limit their effectiveness in treating diffuse CAC. RA and OA should be considered for diffuse disease, along with balloon-based treatment.

Noncompliant (NC) Balloons and High-Pressure Balloons. Since compliant or semi-compliant balloons may not properly expand CAC lesions, NC balloons can be considered as a method to adequately prepare calcified lesions prior to stenting. NC balloons are effective for lesions with superficial, concentric CAC because they have a more predictable diameter and deliver better stent expansion results than compliant or semi-compliant balloons. NC balloons are also less likely to dog bone or watermelon seed. Although NC balloons can be inflated to relatively high pressures (20-24 atmospheres [atm]), they may still be vulnerable to dog-boning or rupture in a heavily calcified vessel.[32] There is also increased risk for vascular injuries with high inflations, so high-pressure inflations should be performed carefully. NC balloons are also the preferred balloon for post dilation of stents, especially in CAC patients with suboptimal stent deployment. Therefore, NC balloons are an essential, frontline CAC treatment device.

High-pressure NC balloons (HPB) are double-layered balloons capable of expansion to 35 atm and can be considered when a regular NC balloon fails to properly dilate a CAC lesion. HPBs were recently compared to IVL and scoring balloons, and found to be effective for treating CAC in limited clinical trials.[33,34] When using HPBs, it is recommended to initially use a 0.6 to 0.7 ratio, similar to RA, to modify CAC. The vessel can then be expanded to a 1:1 ratio if necessary. Inflations for HPB should be done slowly, using a dedicated inflation device. Any inflation above 20 atm

Dedication

This article is dedicated to **Professor Gerard "Jerry" W. Keimer**, who passed away suddenly on January 5, 2026, at the age of 59. He was an educator, radiologic and computed tomography technologist, innovator, friend, devoted family man, and colleague who was loved by his students, staff, friends, and family. His professional work exemplified everything that should be found in an educator: genuine passion, dedication, professionalism, and a genuine caring for his students and their success. He created a dynamic, exceptional Computed Tomography Program at Thomas Jefferson University, and also published on computed tomography in *Cath Lab Digest*. He will always be missed, and we are grateful that we had the opportunity to walk alongside him for a while.

should be increased by five atmospheres every 10-20 seconds.[33,34] Deliverability may be more difficult than other devices, due to bulkiness. HPBs may also have little impact on nodular or eccentrically calcified plaques.[33-35]

Intravascular lithotripsy (IVL). IVL is an important advance in treating CAC. IVL modifies CAC plaques using a balloon catheter that emits acoustic pressure waves, causing calcium micro fractures across a range of calcification arcs.[35] IVL is associated with less medial injury than cutting and ultra-high-pressure balloons while effectively inducing calcium fractures, including in lesions with smaller calcification arcs (**Table 4**).[36]

IVL uses low inflation pressure of 2-6 atm because it only needs to make contact with the vessel wall to deliver therapy, minimizing the chances for dissection and perforation. Shockwave (Johnson & Johnson MedTech), for example, has balloons that are 2.5-4 mm in diameter and 12 mm in length, and can deliver 12 rounds of therapy for a max of 120 pulses. The increase in pulses from 80 to 120 in the newer generation of the device improves its ability to treat diffuse disease. IVL has also been studied in calcified nodules and can induce fractures in superficial, deep, and eccentric calcium, broadening its applicability across different calcium morphologies. IVL can also be used in conjunction with atherectomy, especially for diffuse and/or heterogeneous lesions, to optimize outcomes.[36,37] Limitations include the available size range (2.5-4 mm for coronary lesions), its relatively short length (12 mm), which can limit its ability to treat diffuse disease, and challenges in deliverability, a challenge for all balloon-based, adjunctive CAC treatments.

Cutting and Scoring Balloons. Cutting balloons are NC balloons with atherotomes, or microsurgical blades, on the surface, that create longitudinal, micro-incisions in CAC with low pressure inflations (6-12 atm).[38] Cutting balloons have been found to be superior to compliant and NC balloons for treating CAC, and effective as part of a hybrid strategy using RA. There is limited clinical evidence of non-inferiority to IVL for superficial calcium treatment.[39] Overall, cutting balloons, when deliverable, can be effective for ostial lesions, bifurcation lesions, superficial calcium, and fibrocalcific disease.[40]

Scoring balloons are semi-compliant or sometimes NC balloons, that have external silicone or nitinol wires to create micro incisions in CAC.[38,39] Scoring balloons are generally sized up to 75% of the reference vessel diameter and inflated slowly. This allows the balloon to generate focused energy on the area while scoring into the plaque to create micro incisions. Scoring balloons are useful for concentric and eccentric calcification, where focal scoring lines facilitate subsequent stent expansion.[39-41] Primary limitations include reduced effectiveness in deep calcification or nodules, where deeper plaque disruption may be required.[40,41]

No significant differences have been reported between cutting and scoring balloons for complications such as perforation, dissection, slow/no flow, in-hospital death, myocardial infarction, or repeat revascularization.[39-41] Therefore, it is operator preference and experience that may guide the decision on whether to use a cutting or scoring balloon.

Conclusion

CAC can pose significant challenges for modification and successfully preparing the vessel for stenting during PCI. Plaque modification can be complicated by heterogenous disease within the target vessel, bifurcations, eruptive and non-eruptive coronary nodules, and deep calcium. CAC is a major challenge for successfully deploying stents and requires a well-planned approach for technical and long-term clinical success. There are numerous adjunctive therapies to treat CAC and optimize outcomes, including atherectomy and balloon-based therapies. Clinical trials have also indicated that hybrid strategies, such as using atherectomy and specialty balloons, may optimize outcomes and better manage complex CAC. ■

Find the article by Rogers and Merschen with References and Appendix Tables 1-2 online:

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Appendix Table 1. Important Clinical Trials Studying Treatments for Coronary Artery Calcium.

PREPARE-CALC. In 200 patients with complex calcified coronary lesions, target vessel failure (TVF) and major adverse cardiac event (MACE) rates were low and similar with modified balloons (cutting or scoring balloons) or rotational atherectomy (RA) after 2 years, when used with a sirolimus drug-eluting stent. The study also suggested that RA may be more favorable in longer lesions, whereas modified balloons may be more favorable in shorter lesions, which are generally more amenable to balloon-based treatments. Additionally, optical coherence tomography (OCT) imaging was recommended before lesion preparation and at the end of the procedure to assess lesion morphology and stent results, while 9-month late lumen loss was assessed angiographically.[1]

ORBIT II. In a prospective, single-arm study of 443 patients, ORBIT II demonstrated that orbital atherectomy before stenting in severely calcified lesions was safe, effective, and associated with low rates of adverse ischemic events. There were non-intravascular ultrasound (IVUS) and IVUS imaging groups studied, and although long-term MACE rates were similar, the IVUS cohort required fewer stents and had a greater post-atherectomy minimum lumen diameter.[2]

ROTA-CUT. In a trial of 60 patients, ROTA-CUT found that combining rotational atherectomy with cutting balloon angioplasty did not improve minimum stent area compared to RA followed by noncompliant balloon angioplasty. RA + cutting balloon produced significantly more calcium fractures than RA + noncompliant balloon (50.0% vs 22.6%), but this did not translate into a larger minimum stent area. Both strategies, however, were safe, with low procedural and clinical complication rates. IVUS was performed at baseline if possible, after lesion preparation, and at the end of the procedure; the primary endpoint was minimum stent area assessed by IVUS.[3]

ROLLER COASTR-EPIC22. In a randomized trial of 171 patients comparing RA, intravascular lithotripsy (IVL), and excimer laser coronary angioplasty (ELCA) for the treatment of patients with calcified coronary lesions, IVL was noninferior to RA in terms of stent expansion. ELCA did not meet noninferiority criteria when compared to RA in the intention-to-treat analysis. No significant differences were observed among the three arms in minimum stent area, procedural success rate, and complications, although complications were numerically lower with IVL. The primary endpoint of the trial was percentage of stent expansion assessed by OCT.[4]

Short-CUT. In a trial of 413 patients, results showed cutting balloon angioplasty was noninferior to intravascular lithotripsy for the treatment of moderate-to-severely calcified coronary lesions. The study also showed that were no significant differences in stent expansion, calcium fractures, strategy success, intra-procedural adverse events, or MACE out to 30 days between the two treatment groups. IVUS was used to guide the procedures and assess the primary endpoint, which was post-procedural minimum stent area at the site of maximal calcification measured by IVUS.[5,6]

VICTORY. In a trial of 282 patients, findings showed the super-high-pressure noncompliant balloon was noninferior to IVL for final stent expansion. Similar rates of acute procedural and strategy success were observed across both groups, as well as several patient subgroups, and there were no significant differences in safety outcomes, including coronary artery dissections, perforations, or side branch occlusions. The primary endpoint was final stent expansion assessed by OCT.[6,7]

Disrupt CAD III. In a prospective, single-arm study of 384 patients, IVL (Shockwave, J&J MedTech) treatment before stenting of severely calcified lesions was associated with low 1-year rates of MACE, ischemia-driven target lesion revascularization, and stent thrombosis. The IVL catheter was successfully advanced and therapy delivered in nearly all lesions. An OCT sub study demonstrated calcium modification and favorable stent expansion after IVL. IVL is delivered at low balloon pressure, and rates of serious angiographic complications, including flow-limiting dissection and perforation, were low.[8]

ECLIPSE. The ECLIPSE trial compared orbital atherectomy (OA) with balloon angioplasty before stent deployment in patients with heavily calcified coronary lesions. The study included 2005 patients and found that OA did not reduce 1-year TVF or significantly increase post-procedural minimum stent area compared with a balloon-based strategy. PCI was guided by intravascular imaging (IVUS or OCT) in 627 (62.2%) of 1008 patients in the in the OA group and 619 (62.1%) of 997 in the balloon angioplasty group. The trial suggested that when a calcified lesion can be crossed and prepared with a balloon, it should be considered the first option. OA, however, should be considered for lesions that are uncrossable with balloons or that don't respond well to balloon angioplasty.[9]

Author Notes:
Several of these studies enrolled 200 or fewer patients, while others had much larger sample sizes and larger numbers of centers participating in the clinical trials. Two of the atherectomy trials, PREPARE-CALC and ORBIT II, discussed the importance of drug-eluting stents (DES). This is particularly important for rotational atherectomy, which was initially studied as a primary treatment option for CAC when DES technology did not exist. The use of hybrid strategies was discussed in several of the trials, and this will likely become a more common approach to treat complex, heterogeneous disease. Also, the use of intravascular imaging has significantly increased our understanding of the complexity of CAC, and is essential for choosing the optimal treatment strategies for the treatment of CAC when performing PCI.

Appendix Table 1. Important Clinical Trials Studying Treatments for Coronary Artery Calcium.

Continued from previous page **References**

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Appendix Table 2. 10 Tips for Practice for Performing PCI on Coronary Artery Calcium.

1. For coronary artery calcium, consider the use of extra support guide catheters to deliver percutaneous coronary intervention (PCI) devices, and larger French catheters for severe disease and bifurcation lesions.
2. When performing PCI, intravascular imaging is highly recommended to determine morphology, lesion length, diameter, and proper stent placement.
3. For difficulty in delivering PCI devices, consider guide extension catheters, and buddy wires.
4. For diffuse disease and lesions where balloons and intravascular imaging cannot be advanced, consider atherectomy.
5. For cases of in-stent restenosis, chronic total occlusions (CTOs), or uncrossable non-CTO lesions, consider using excimer laser coronary angioplasty.
6. For diffuse and complex disease, consider hybrid strategies that use atherectomy and balloon-based treatments.
7. For ostial lesions that don't respond to normal balloon angioplasty, consider cutting balloon or atherectomy.
8. For bifurcation lesions, balloon-based treatments allow side branches to be protected, and larger-sized catheters (7 and 8 French) may be necessary for complex PCI, using techniques such as crush and culotte stenting.
9. For diffuse lesions that have different luminal diameters, evaluate the stent inflation chart to determine the maximum expansion size and create an optimal vessel lumen with expansion of appropriate-diameter stents. For instance, a 2.5 mm stent may be able to expand to 3.5 mm, and a 3.0 mm stent can expand to 4.25 mm.
10. Consider use of a noncompliant balloon prior to as well as after stenting for optimal stent expansion.