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EDITORIAL

Intravascular lithotripsy in chronic total occlusion PCI: expanding the calcium modification armamentarium with cautious optimism

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Calcified chronic total occlusion (CTO) lesions remain the most challenging lesion subset in percutaneous coronary intervention (PCI). CTO PCI has evolved dramatically over the past decade, with the procedural success rate exceeding 85-90%, driven by advances in crossing algorithms, dedicated equipment, intravascular imaging, and operator expertise. Yet severe coronary calcification continues to represent a major determinant of procedural complexity, impaired device delivery, suboptimal stent expansion, stent failure, and adverse clinical outcomes.[1] In this setting, the emergence of intravascular lithotripsy (IVL) has generated substantial interest as a potentially safer and more versatile calcium modification technology than the current standard of care.

In this issue of AsiaIntervention, the meta-analysis by Dirjayanto et al provides important evidence on the use of IVL during CTO PCI.[2] The authors pooled data from five studies, encompassing 611 patients undergoing IVL-assisted CTO PCI, and reported an encouraging technical success rate of 97% and a procedural success rate of 94%. The rates of major adverse cardiovascular events, mortality, and perforation remained relatively low, suggesting that IVL may represent a feasible adjunctive strategy for complex, calcified CTO interventions.[2] Although preliminary, these findings contribute meaningfully to an evolving area in interventional cardiology, where randomised evidence remains scarce.

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Unlike conventional balloon-based strategies that rely primarily on barotraumatic plaque compression or atherectomy systems that ablate superficial calcium, IVL generates localised acoustic pressure waves capable of producing circumferential and transmural calcium fractures while minimising injury to surrounding soft tissue. This mechanism is particularly attractive for CTO lesions, where calcium is frequently deep, concentric, and diffusely distributed.[3,4] Traditional non-compliant, cutting, or scoring balloons may fail to adequately modify these lesions, while atherectomy devices carry increased risks of distal embolisation, slow or no-reflow, injury related to wire bias, and perforation.

The current meta-analysis highlights an important procedural reality: IVL is rarely used as a standalone strategy in CTO PCI.[2] A hybrid calcium modification approach was common, with IVL frequently combined with high-pressure balloons, scoring balloons, or rotational atherectomy. This reflects contemporary practice, in which operators increasingly adopt a "RotaTripsy" approach – using atherectomy to establish initial lesion compliance and deliverability, followed by IVL to fracture deep calcium and optimise stent expansion.[5] Rotational atherectomy primarily modifies superficial intimal calcium, whereas IVL appears particularly effective against deeper medial and circumferential calcium. Together, these technologies may provide complementary rather than competing strategies. RotaTripsy is a commonly used hybrid calcium modification approach during CTO PCI, making it difficult to determine the independent contribution of IVL alone to procedural success.

Importantly, the meta-analysis reports a pooled coronary perforation rate of approximately 5%. At first glance, this may appear concerning; however, perforation risk in CTO

PCI must be interpreted within the broader context of lesion complexity. CTO interventions inherently carry substantially higher rates of perforation compared with non-CTO PCI, particularly in heavily calcified lesions requiring aggressive plaque modification. Moreover, several perforations observed in the included studies occurred in procedures involving combination therapy or subintimal crossing techniques rather than IVL alone. The multicentre registry by Øksnes et al,[6] included in the present meta-analysis, similarly reported that all major perforations occurred in cases involving additional calcium modification devices.

Indeed, emerging comparative data suggest that IVL may offer a more favourable safety profile than rotational atherectomy in selected CTO cases. In the recent PROGRESS-CTO registry analysis by Carvalho et al,[7] IVL and rotational atherectomy demonstrated similar technical and procedural success rates; however, the perforation rate was significantly lower with IVL than with rotational atherectomy (3.2% vs 9.3%). These findings are clinically relevant because perforation remains one of the most feared complications in CTO PCI, often leading to tamponade, emergency surgery, or mortality. IVL's lower-pressure balloon inflation and reduced dependence on guidewire bias likely contribute to this safety advantage.

Nevertheless, enthusiasm for IVL in CTO PCI should remain tempered by important technical limitations.[4] The most obvious of these is its deliverability: IVL balloons possess a relatively high crossing profile and generally require prior lesion preparation before delivery. Consequently, IVL is often ineffective in true balloon-uncrossable CTO lesions. In practice, the device is best suited for balloon-crossable but undilatable calcified lesions rather than balloon-uncrossable lesions. This distinction is critical. CTO operators frequently establish a channel using low-profile balloons, microcatheters, laser atherectomy, or rotational atherectomy before IVL can be advanced to the targeted segment.

Another unresolved challenge is the optimal sizing of IVL balloons in CTO vessels with negative remodelling. Chronic occlusion frequently results in vessel shrinkage, diffuse fibrosis, and underestimation of true vessel calibre both angiographically and by intravascular imaging.[8] Oversizing an IVL balloon in this context may increase the risk of vessel injury, particularly in extraplaque or subintimal spaces. Conversely, undersizing may lead to inadequate calcium fracture and persistent stent underexpansion. Most experienced operators therefore rely heavily on intravascular ultrasound (IVUS), proximal and distal reference vessel dimensions, and a stepwise escalation strategy when selecting the IVL balloon size. Conservative initial sizing, followed by optimisation after restoration of distal flow, has become a common practice.

The findings of this meta-analysis also underscore the increasing role of intravascular imaging in CTO PCI. Among the included studies, Oliveri et al provided the most comprehensive intravascular imaging assessment with detailed pre- and post-PCI IVUS analyses, including minimum stent area, stent expansion, eccentricity index, and calcium fracture assessment.[5] Øksnes et al[6] and Kostantinis et al[9] also reported extensive IVUS-guided procedural optimisation in nearly 90% of cases, primarily for lesion characterisation, confirmation of wire position, and post-stent optimisation. This imaging-guided approach is more important when IVL is used for extraplaque crossing, where inadvertent treatment within the subintimal space could theoretically increase the risk of perforation.

One intriguing observation in the meta-analysis is the high procedural success observed in lesions with higher Japanese CTO scores. Although hypothesis-generating, this may suggest that IVL provides value in highly complex, calcified CTO subsets where conventional plaque modification methods are inadequate. Severe calcification has long been recognised as a major contributor to CTO PCI failure, and technologies capable of effectively modifying deep calcium without substantially increasing procedural risk are urgently needed. Whether IVL can meaningfully improve long-term outcomes – such as reducing restenosis, target lesion failure, and concerns regarding stent durability – remains unknown.

Several limitations of the current evidence deserve emphasis. First, all included studies were observational, with no randomised controlled trials available. Selection bias is therefore unavoidable. Operators likely reserved IVL for lesions deemed particularly difficult or resistant to standard therapy. Second, the sample sizes remain relatively small, and heterogeneity in procedural strategy, lesion complexity, and adjunctive calcium modification devices limits interpretability. Third, follow-up durations were relatively short, preventing robust assessment of long-term durability and clinical outcomes. Finally, important procedural variables – including IVL timing, balloon-sizing strategy, number of pulses delivered, and intravascular imaging protocols – were not standardised across the studies.

Despite these limitations, the meta-analysis by Dirjayanto et al[2] provides valuable early evidence supporting IVL as an important addition to the CTO calcium modification armamentarium. Rather than replacing established techniques such as atherectomy, IVL will likely assume a complementary role within hybrid procedural strategies tailored to lesion morphology, crossing mechanism, and operator expertise. The future of CTO PCI is unlikely to rely on a single calcium modification technology; instead, procedural success will increasingly depend on intelligent integration of multiple devices guided by intravascular imaging and contemporary CTO algorithms.

Looking forward, several key questions remain unanswered. Which CTO morphologies will benefit most from IVL? Should IVL be preferred in intraplaque versus extraplaque crossing? What is the optimal sequencing relative to atherectomy? Can IVL reduce long-term stent failure in heavily calcified CTOs? And perhaps, most importantly, can IVL improve safety without compromising procedural efficiency in increasingly complex interventions? Addressing these questions will require prospective comparative studies and, ideally, randomised trials that incorporate standardised imaging and long-term follow-up.

For now, IVL appears to be a promising, increasingly adopted adjunctive technology in CTO PCI. The present meta-analysis provides reassurance regarding procedural efficacy and acceptable short-term safety while simultaneously reminding us that the evidence remains early and incomplete. As PCI continues to evolve, IVL may ultimately prove to be a valuable instrument in an expanding, increasingly sophisticated toolbox for the treatment of complex coronary calcification.

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Conflict of interest statement

The authors have no conflicts of interest to declare.

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