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CASE REPORT

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Intravascular lithotripsy to treat an underexpanded coronary stent: 4-Month angiographic and OCT follow-up

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Abstract

We report the case of a 79-year-old man with stable angina who underwent percutaneous coronary intervention to a severe and calcified left circumflex lesion. Despite extensive preparation of the lesion with high-pressure balloon predilatation and rotablation, the implanted stent was grossly underexpanded and failed to respond to high-pressure balloon postdilatation. The patient was readmitted 6 weeks later for intravascular lithotripsy that resulted in excellent stent expansion. Coronary angiography with optical coherence tomography 4 months later revealed sustained acute lumen gain with no evidence of stent recoil or in-stent restenosis.

KEYWORDS
coronary calcification, non-expandable lesions, rotablation

1 | CASE

A 79-year-old gentleman presented with cardiac sounding chest pain of a few months' duration. He gave a history of type 2 diabetes mellitus, chronic obstructive airways disease, and treated bladder cancer. Physical examination revealed an ejection systolic murmur in the aortic area. Transthoracic echocardiography revealed normal left ventricular (LV) size, anterolateral and inferolateral hypokinesia, and an estimated LV ejection fraction of 45%. There was moderate aortic stenosis with a peak gradient of 33 mmHg and a valve area of 1.2 cm^2. Coronary angiography (Figure 1) revealed a severe lesion in the proximal left anterior descending (LAD) artery, severe tandem lesions in a dominant left circumflex artery (LCX) separated by an ectatic segment, and a near-ostial lesion in the terminal obtuse marginal (OM) branch.

Following discussion at our local multidisciplinary team meeting, a decision was taken to offer him percutaneous coronary intervention (PCI), with close surveillance of his aortic stenosis. We proceeded to stenting of the proximal LAD with a 3 × 38 mm Promus Premier drug eluting stent (Boston Scientific, Natick, MA).

He was readmitted 2 months later for PCI to the LCX/OM. Our strategy was to stent the atrioventricular (AV) LCX disease (just distal to the ectatic segment), followed by the proximal LCX into the terminal OM branch, across the AV LCX. Using a right radial approach, the left main stem was cannulated using a 7F JL 3.5 guide catheter (Cordis, Miami, Florida) and an ASAHI SION blue guidewire was advanced into the distal AV LCX and a similar wire into the terminal OM branch. The AV LCX disease was predilated with a 2.5-mm noncompliant (NC) balloon and then stented with a 2.5 × 28 mm Promus Premier stent (Figure 1). Advancement of the stent required the support of a GuideLiner catheter extension (Vascular Solutions Inc., Minneapolis, MN). We then further predilated the proximal LCX lesion with a view to stenting this into the terminal OM branch, but despite using a 3-mm NC balloon up to 20 ATM, the proximal LCX lesion proved resistant to expansion (Figure 1). Optical coherence tomography (OCT) (ILUMIEN OPTIS; St. Jude Medical, St. Paul, MN) revealed persistence of a near-circumferential layer of calcium at this site with some intimal dissection (Figure 1). At this point, we decided to abandon the procedure but keep the patient in hospital under close observation, given the risk of abrupt vessel closure. Three days later, he was brought back for rotational atherectomy to the proximal LCX lesion. A floppy RotaWire (Cordis, Miami, Florida) was advanced into the terminal OM branch and a 1.5-mm burr used for rotablation of the proximal LCX/terminal OM disease (Figure 2). Following multiple "rota runs," and further predilatation with a 3-mm NC balloon, the proximal

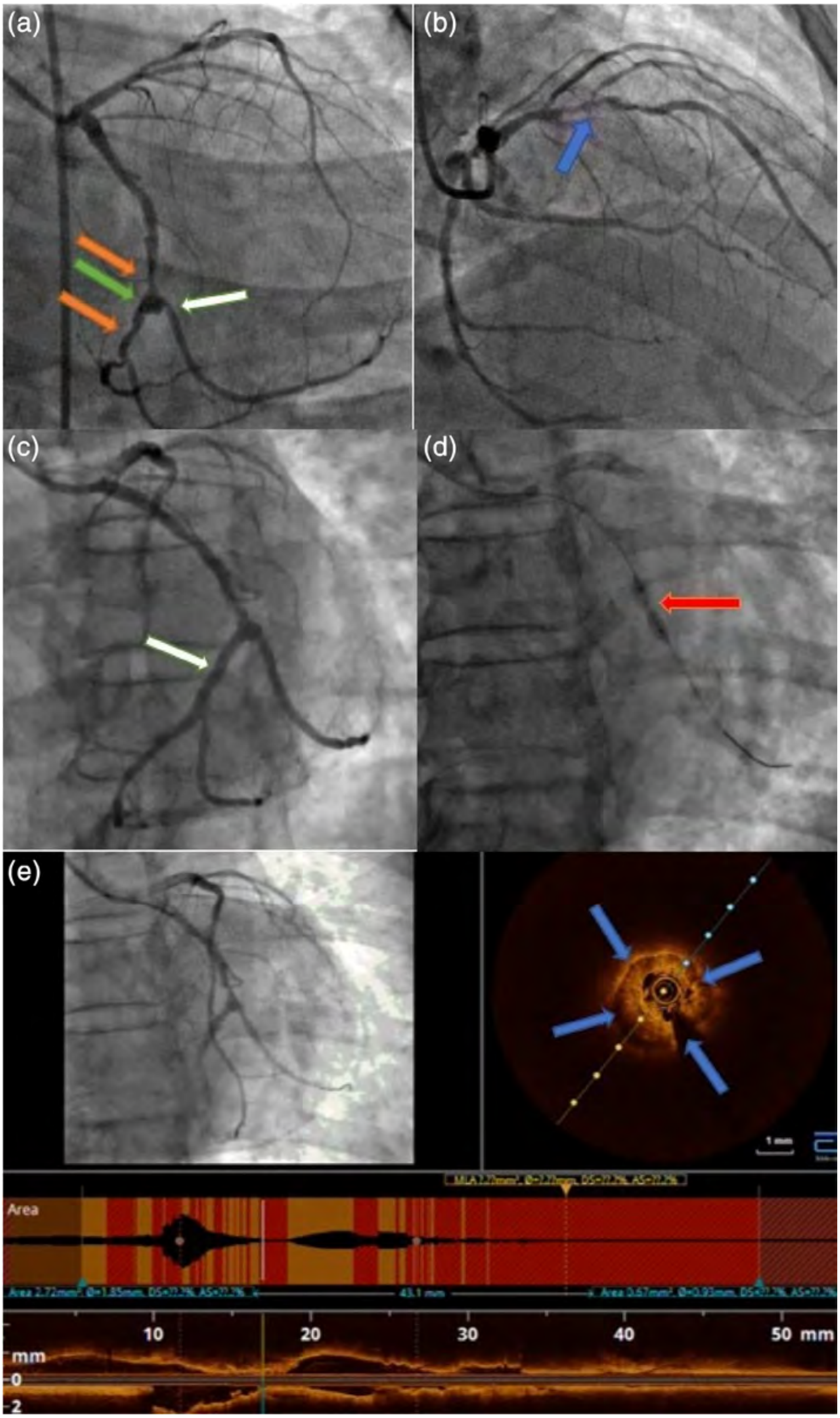

FIGURE 1 (a,b) Baseline angiographic views of LCX and LAD showing a severe proximal LAD lesion (blue arrow), tandem lesions in a dominant LCX (orange arrows) separated by an ectatic segment (green arrow), and a severe near-ostial lesion in terminal obtuse marginal branch (white arrow). (c) Caudal view of LCX after stenting atrioventricular LCX (white arrow). (d) Undilatable LCX lesion with "dog-boning" effect of balloon (red arrow). (e) Optical coherence tomography run showing a severe lesion with circumferential calcification (blue arrows). LAD, left anterior descending; LCX, left circumflex artery [Color figure can be viewed at wileyonlinelibrary.com]

LCX lesion appeared to have expanded adequately angiographically (Figure 2). The proximal LCX and terminal OM disease was then covered with two overlapping Promus Premier stents: a 3 × 28 mm distally and a 3.5 × 16 mm proximally (Figure 2). The point of overlap was well proximal to the site of the undilatable lesion. Despite postdilating the distal stent with a 3.25-mm NC balloon up to 18 ATM, clear "waisting" could still be seen at the original site of the undilatable lesion (Figure 2). Repeat OCT revealed marked stent underexpansion,

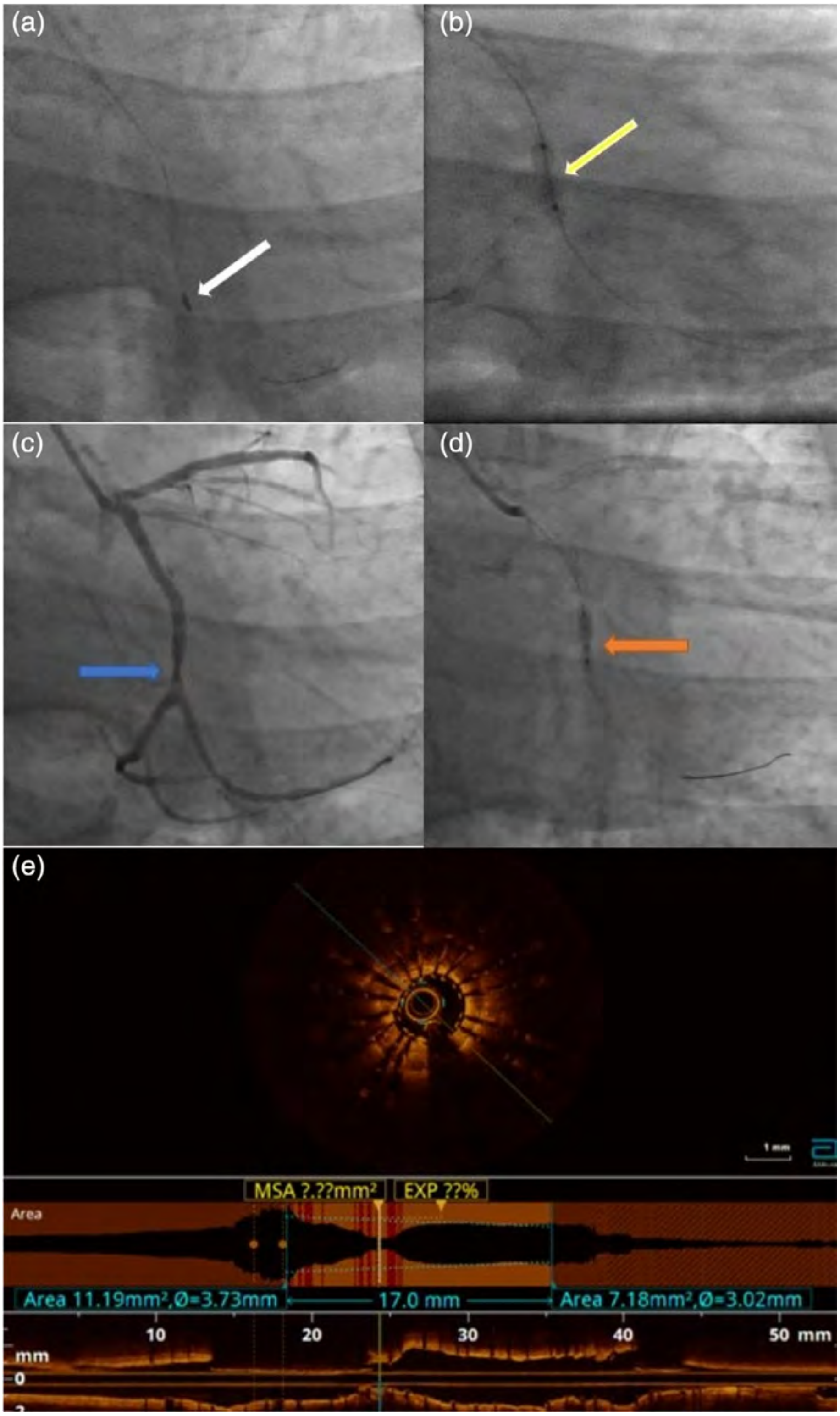

FIGURE 2 (a) A 1.5-mm rotablation burr through undilatable LCX lesion (white arrow). (b) Further predilatation post rotablation showing seemingly good balloon expansion (yellow arrow). (c) Underexpansion of LCX stent with "waisting" (blue arrow). (d) Postdilatation with a 3.25-mm noncompliant balloon showing persistent "dog-boning" effect of stent (orange arrow). (e) Optical coherence tomography run showing gross stent underexpansion due to near-circumferential layer of calcium. LCX, left circumflex artery [Color figure can be viewed at wileyonlinelibrary.com]

with a thick layer of circumferential calcification deep to the stent (Figure 2). For fear of perforation, we decided to halt the procedure at this stage and switched the patient from clopidogrel to ticagrelor to minimize the risk of stent thrombosis.

He was brought back 4 months later for intravascular lithotripsy (IVL) of the underexpanded LCX stent. The left main stem was cannulated with a 7F JL 3.5 guide catheter and a 0.014″ ASAHI SION blue wire was advanced into the terminal OM branch. Repeat OCT again revealed gross underexpansion of the more distal LCX stent. A 3 × 12 mm lithotripsy balloon (Shockwave Medical, Fremont, CA) was positioned across the underexpanded segment of the stent and inflated to 4 ATM. Ten shockwave pulses were delivered at a rate of 1 pulse

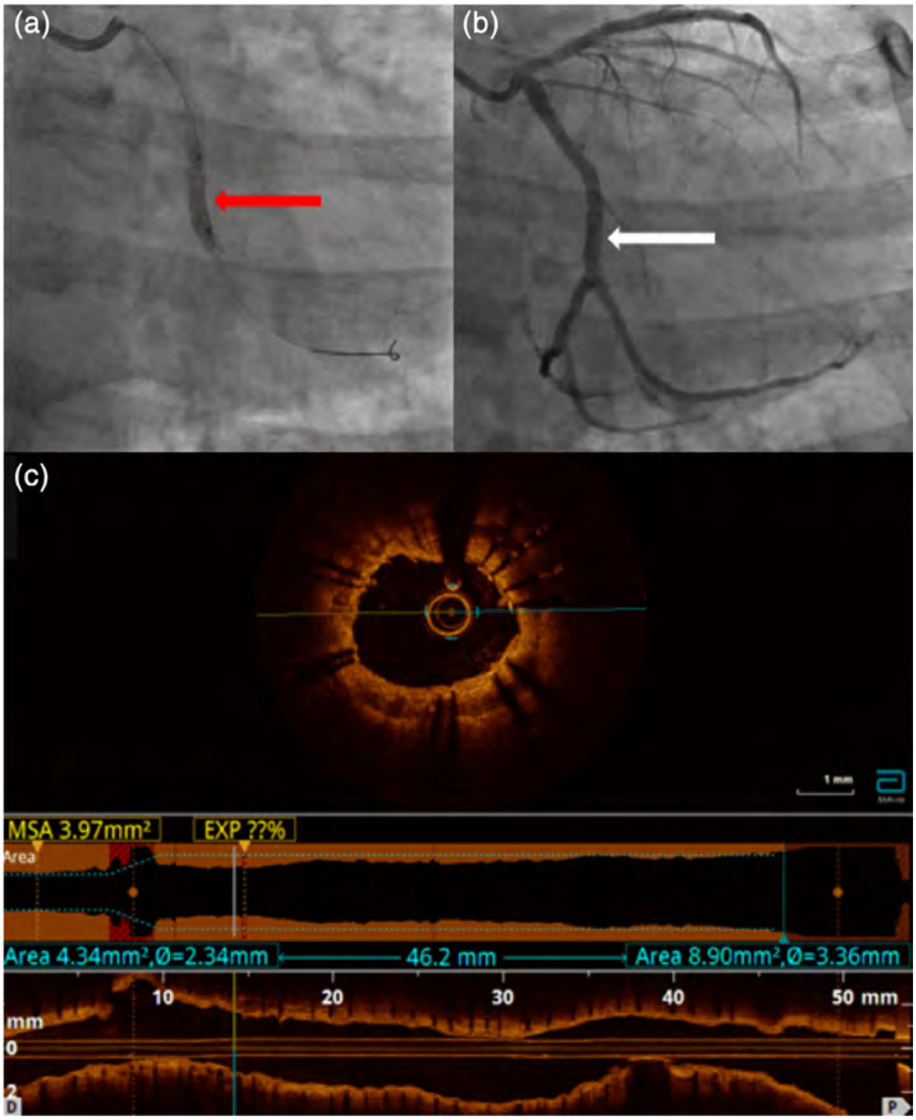

FIGURE 3 (a) IVL balloon showing absence of "dog-boning" effect (red arrow). (b) Angiographic appearance following IVL with fully expanded stent (white arrow). (c) Optical coherence tomography following IVL showing good stent expansion and apposition. IVL, intravascular lithotripsy [Color figure can be viewed at wileyonlinelibrary.com]

per second, following which the balloon was inflated further to 6 ATM for 5–10 s (Figure 3). This was repeated seven times, thus delivering a total of 70 pulses. By the end of the last inflation, the stent appeared to have expanded fully on repeat angiography, with the "dog-boning" effect no longer visible. Further postdilatation was performed with a 3.5-mm NC balloon. Complete stent expansion was confirmed on angiography (Figure 3) as well as by repeat OCT (Figure 3). Given the concerns about a potential adverse interaction between IVL and recently implanted stents, we brought him back 4 months later for repeat coronary angiography that revealed widely patent stents (Figure 4). Repeat OCT revealed a well-endothelialized stent with sustained lumen gain and no significant in-stent restenosis (Figure 4). A summary of OCT parameters before and after IVL is shown in Table 1. The definitions of the OCT parameters measured are as follows:

1. Stent expansion index: minimal stent area divided by the average of the proximal and distal reference lumen areas (i.e., within 5 mm from the edge of the stent).
2. Area stenosis: (1 – [minimum lumen area/mean reference lumen cross-sectional area]) and expressed as a percentage.
3. Asymmetry index: (1 – [minimum stent diameter/maximum stent diameter]).
4. Eccentricity index: ratio of minimal to maximal luminal diameter within the stent, per cross section (we chose three cross sections from the stented segment of interest: one proximal, one in the middle, and one distal).

2 | DISCUSSION

In this case report, we describe the successful use of IVL to treat a grossly underexpanded coronary stent implanted in a heavily calcified lesion. Although the lesion was extensively prepared with high-pressure balloon predilatation followed by rotational atherectomy, the stent remained underexpanded and failed to respond to high-pressure

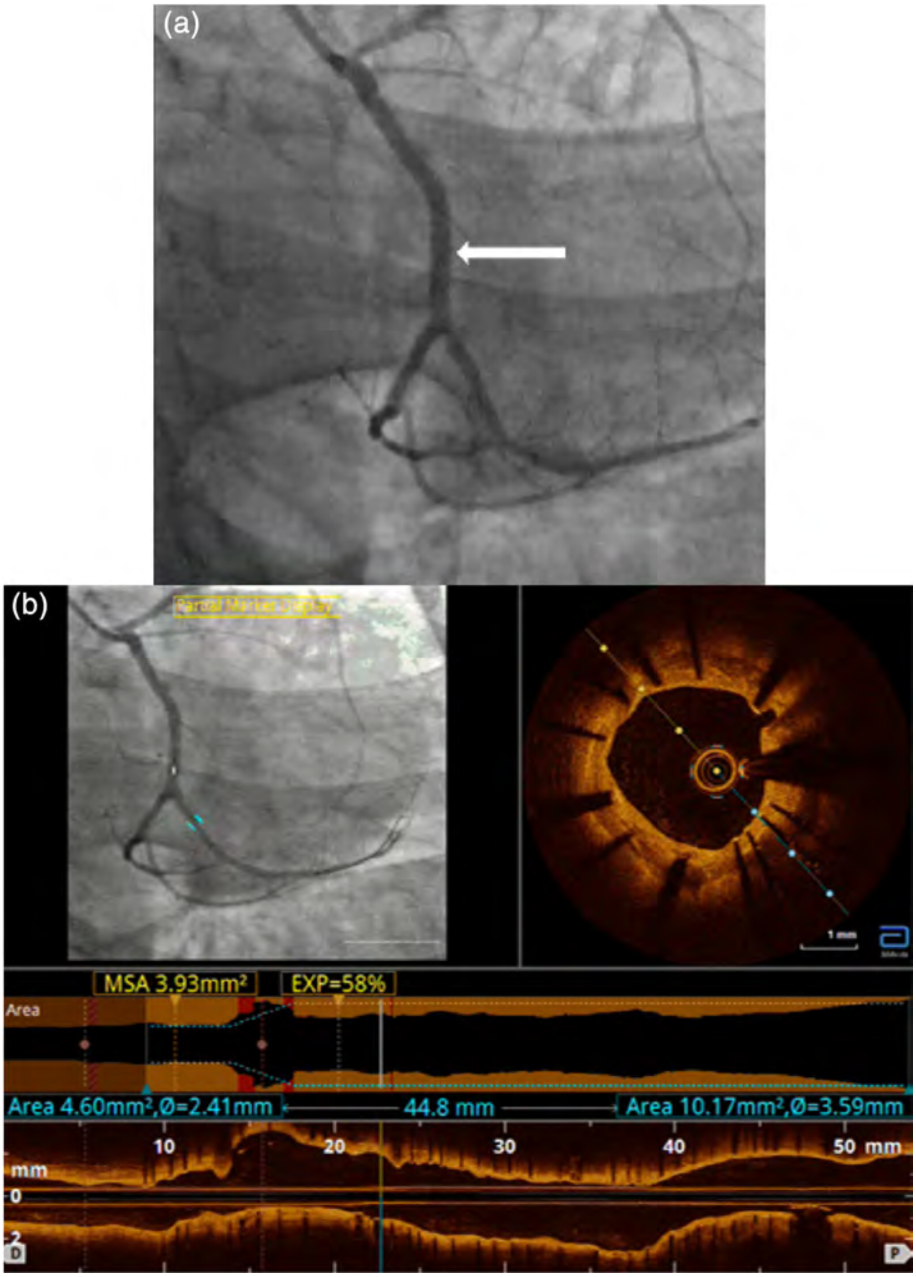

FIGURE 4 (a) Coronary angiography 4 months post intravascular lithotripsy showing good left circumflex artery stent expansion (white arrow). (b) Optical coherence tomography run showing well endothelialized stent and sustained lumen gain [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 1 OCT parameters

OCT parameters	Prestenting	Poststenting	Post-IVL	4 Months post-IVL
Minimal lumen/stent area (mm^2)	0.77	1.88	4.97	5.89
Stent expansion index		0.41	0.78	0.84
Area stenosis (%)	81	59	22	16
Asymmetry index		0.5	0.17	0.2
Eccentricity index				
Proximal stent edge		0.86	0.91	0.92
Mid-stent		0.81	0.90	0.90
Distal stent edge		0.57	0.78	0.80

Abbreviations: IVL, intravascular lithotripsy; OCT, optical coherence tomography.

balloon postdilatation. As shown on OCT, the underlying mechanism for this was persistence of a near-circumferential ring of calcium deep to the stent. By contrast, application of lithotripsy sonic waves resulted in uniform stent expansion at a balloon inflation pressure not exceeding 6 ATM.

Although the use of IVL to treat underexpanded coronary stents has recently been described,[1,2] this case is unique for two reasons. First, it demonstrates the efficacy of this technology for modifying calcified lesions where rotablation, widely regarded as the gold standard, has failed. In the two previously described cases,[1,2] the lesions were "prepared" with high-pressure balloon predilatation only and it can be argued that had rotablation been utilized prior to stent implantation, IVL may not have been necessary. Second, to our knowledge, this is the first case report to document short-/medium-term angiographic and OCT outcomes of an underexpanded coronary stent treated successfully with IVL. We herein report favorable outcomes at 4 months post-IVL, with sustained luminal gain and absence of significant recoil or in-stent restenosis.

Coronary calcification poses a real challenge to the interventional cardiologist and is associated with a higher risk of stent underexpansion, stent thrombosis, and ischemic target lesion revascularization.[3] A heavily calcified lesion may be difficult to cross with a guidewire, balloon, or stent, and may prove resistant to adequate modification prior to stent implantation. Commonly used methods for achieving this include predilatation with compliant/NC balloons, use of specialized balloons, (e.g., very high-pressure balloons [OPN NC]; SIS Medical AG, Frauenfeld, Switzerland), cutting balloons, scoring balloons, and rotational/orbital atherectomy. Often, a combination of these methods is required for a satisfactory result.[4]

Both IVL and atherectomy modify calcific plaque but do so in different ways. Rotational atherectomy causes eccentric ablation of calcium along the course of the guidewire (so-called guidewire bias), forming smooth longitudinal grooves in the vessel wall.[5] To reach more deep-seated calcium, larger burrs are likely to be needed, which may increase the risk of vessel injury.[6] Contemporary guidelines on rotational atherectomy have moved away from an aggressive debulking to a plaque modification strategy, recommending use of a single 1.5-mm burr to achieve this.[7] Orbital atherectomy results in more significant tissue modification compared to rotational atherectomy but carries a higher risk of deep vessel injury.[5] By contrast, the lithotripsy balloon emits circumferential acoustic pressure pulses capable of inducing multiple fractures in both intimal as well as medial (deep) calcium, at effective pressures of around 50 atm. These circumferential fractures facilitate uniform stent expansion and reduce the risk of malapposition and stent asymmetry.[8] Importantly, the salutary effects of IVL seem to be more pronounced the greater the extent of calcification within the vessel wall.[9]

If a stent remains underexpanded following high-pressure balloon postdilatation, the available options are limited. Use of a scoring or cutting balloon poses a risk to the integrity of the stent, especially its coating, whilst postdilating at higher pressures (>18 ATM) with an NC/OPN balloon predisposes to strut fracture, stent deformation, or balloon/vessel rupture. Excimer laser, with or without contrast, has been used successfully to treat underexpanded stents,[10] but is only available in selected centers and carries some risks.[11] Rotational atherectomy of the stent, also known as "stentablation," is feasible and carries good short-term outcomes, but is associated with a high target lesion revascularization rate and unique procedural complications, including strut embolization and burr entrapment.[12]

Whilst the use of IVL in de novo calcified coronary lesions has been shown to be safe and effective,[13] its use in newly implanted, unendothelialized stents is currently off-license. Bench testing studies have shown that IVL can cause flaking of the stent polymer coating, as well as pitting of the metal itself which can predispose to corrosion. Whether these risks can be mitigated by delaying IVL for several weeks post stent implantation remains speculative, but the favorable OCT findings at 4 months post-IVL in the present case are clearly reassuring. Continued follow-up beyond 4 months is, however, essential to ensure that the observed benefits are sustained long term.

The present case highlights the value of intravascular imaging in guiding intervention on calcified lesions. OCT is superior to fluoroscopy in defining not only the presence of calcium, but also its distribution.[8,14] For instance, the presence of a calcium arc >180° and >0.5 mm thick by OCT is predictive of poor stent expansion and should lead to extensive attempts at lesion modification prior to stent implantation. Repeat OCT following initial lesion preparation will inform the operator as to the need for further plaque modification, using the same or a different device, prior to stent implantation.[14] Had this been performed in the present case, it may have led to additional rotablation with a larger burr(s) and possibly superior lesion modification.

In conclusion, we have shown that IVL is effective at treating stent underexpansion secondary to severe underlying calcification. We have also shown that the acute lumen gain achieved with IVL is sustained at 4 months, with no significant in-stent restenosis or stent recoil. IVL is intuitively simple to use and has a short learning curve. This, coupled with its efficacy at dealing with severe and diffuse coronary calcification, is certain to lead to its widespread adoption by interventional cardiologists in day-to-day practice.

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REFERENCES

1. Watkins S, Good R, Hill J, Brinton TJ, Oldroyd KG. Intravascular lithotripsy to treat a severely under-expanded coronary stent. EuroIntervention. 2019;15:124-125.
2. Ali ZA, McEntegart M, Hill JM, Spratt JC. Intravascular lithotripsy for treatment of stent underexpansion secondary to severe coronary calcification. Eur Heart J. 2018. https://doi.org/10.1093/eurheartj/ehy747. [Epub ahead of print]
3. Madhavan MV, Tarigopula M, Mintz GS, Maehara A, Stone GW, Genereux P. Coronary artery calcification: pathogenesis and prognostic implications. J Am Coll Cardiol. 2014;63:1703-1714.
4. Kassimis G, Raina T, Kontogiannis N, et al. How should we treat heavily calcified coronary artery disease in contemporary practice? From atherectomy to intravascular lithotripsy. Cardiovasc Revasc Med. 2019;20:1172-1183.

5. Kini AS, Vengrenyuk Y, Pena J, et al. Optical coherence tomography assessment of the mechanistic effects of rotational and orbital atherectomy in severely calcified coronary lesions. Catheter Cardiovasc Interv. 2015;86:1024-1032.
6. Cohen BM, Weber VJ, Relsman M, Casale A, Dorros G. Coronary perforation complicating rotational atherectomy: the U.S. multicenter experience. Cathet Cardiovasc Diagn. 1996;suppl 3:55-59.
7. Barbato E, Shlofmitz E, Milkas A, Shlofmitz R, Azzalini L, Colombo A. State of the art: evolving concepts in the treatment of heavily calcified and undilatable coronary stenoses – from debulking to plaque modification, a 40-year-long journey. EuroIntervention. 2017;13:696-705.
8. Serruys PW, Katagiri Y, Onuma Y. Shaking and breaking calcified plaque: lithoplasty, a breakthrough in interventional armamentarium? JACC Cardiovasc Imaging. 2017;10:907-911.
9. Ali ZA, Brinton TJ, Hill JM, et al. Optical coherence tomography characterization of coronary lithoplasty for treatment of calcified lesions: first description. JACC Cardiovasc Imaging. 2017;10:897-906.
10. Veerasamy M, Gamal AS, Jabbar A, Ahmed JM, Egred M. Excimer laser with and without contrast for the management of under-expanded stents. J Invasive Cardiol. 2017;29:364-369.
11. Topaz O, Ebersole D, Das T, et al. Excimer laser angioplasty in acute myocardial infarction (the CARMEL multicenter trial). Am J Cardiol. 2004;93:694-701.
12. Ferri LA, Jabbour RJ, Giannini F, et al. Safety and efficacy of rotational atherectomy for the treatment of undilatable underexpanded stents implanted in calcific lesions. Catheter Cardiovasc Interv. 2017;90:E19-E24.
13. Wong B, el-Jack S, Newcombe R, Glenie T, Armstrong G, Khan A. Shockwave intravascular lithotripsy for calcified coronary lesions: first real-world experience. J Invasive Cardiol. 2019;31:46-48.
14. Karimi Galougahi K, Shlofmitz RA, Ben-Yehuda O, et al. Guiding light: insights into atherectomy by optical coherence tomography. J Am Coll Cardiol Intv. 2016;9:2362-2363.

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