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ORIGINAL STUDIES

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Device entrapment during percutaneous coronary intervention

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Abstract

Introduction: Device entrapment is a life-threatening complication during percutaneous coronary intervention (PCI). However, the success for its management is predominantly based on operator experience with limited available guidance in the published literature.

Methods: A systematic review was performed on December 2021; we searched PubMed for articles on device entrapment during PCI. In addition, backward snowballing (i.e., review of references from identified articles and pertinent reviews) was employed.

Results: A total of 4209 articles were retrieved, of which 150 studies were included in the synthesis of the data. A methodical algorithmic approach to prevention and management of device entrapment can help to optimize outcomes. The recommended sequence of steps are as follows: (a) pulling, (b) trapping, (c) snaring, (d) plaque modification, (e) telescoping, and (f) surgery.

Conclusions: In-depth knowledge of the techniques and necessary tools can help optimize the likelihood of successful equipment retrieval and minimization of complications.

KEYWORDS
complications, coronary artery disease, PCI, percutaneous coronary intervention

1 | INTRODUCTION

During recent years the development of novel techniques and equipment improvements have increased the success rates of percutaneous coronary interventions (PCI) and enabled treatment of increasingly complex lesions. At the same time, the risk of complication remains, especially when treating heavily calcified and tortuous vessels.[1] A potentially life-threatening complication is device entrapment, which is defined as the inability to remove equipment from the body with manipulation (i.e., push–pull method), requiring additional devices or maneuvers (i.e., second wire, balloon, guide catheter extension, and snare) for retrieval. The risk of equipment entrapment in complex lesions such as chronic total occlusions (CTOs) is ~1.5%.[2] Equipment entrapment may lead to vessel perforation, vessel thrombosis, and early or late myocardial infarction. Equipment entrapment can be approached percutaneously in most cases, allowing safe completion of the procedure.[2] However, the success for its percutaneously retrieval is predominantly based on operator experience and knowledge of dedicated tools and techniques with limited available guidance in the published literature. Moreover, due to the very low incidence of this type of event, even initial expertise built up can be directly not readily available due to lack of reiteration of these techniques with a sufficient frequency. The need for a structured approach is thus welcome to avoid uncertainties and waste of time in acutely troublesome moments.

Therefore, we performed a systematic literature review aiming to summarize current knowledge of the causes, prevention and treatment strategies of the four major groups of devices potentially causing entrapment: guidewires, angioplasty balloons, microcatheters, and atherectomy devices. This overview should help the interventional community to guide clinical decision making with a stepwise solution approach.

2 | METHODS

On December 2021, we searched PubMed for articles on device entrapment. In addition, backward snowballing (i.e., review of references from identified articles and pertinent reviews) was employed. The search strategy is available in the Supplementary Appendix. A total of 4209 articles were retrieved, of which 150 studies were included in the synthesis of the data. Supplementary Appendix Table S1–S4 display potential causes, management strategies, and clinical outcomes of the included studies.

In the following paragraphs, we provide a structured algorithm for the management of device entrapment during PCI. Despite a stepwise algorithm is recommended, the order of the different techniques might vary according to patients' clinical condition, coronary anatomy, availability of material, and operator's technical skills.

3 | RESULTS AND DISCUSSION

3.1 | Guidewire entrapment

3.1.1 | Causes and prevention

Guidewire entrapment might occur after overly aggressive manipulation within a calcified and tortuous lesion, after jailing the guidewire during bifurcation stenting, and during complex CTO PCI, in particular within intraplaque tracking in calcified lesions and during the externalization process.[3] During CTO PCI, antegrade and retrograde dissection and re-entry techniques with spinning a knuckle guidewire might cause a wire knot increasing the risk of guidewire entrapment.

When shaping the guidewire tip, excessive bending should be avoided especially when applied at the junction between the flexible distal tip and the remainder of the guidewire, as it might produce a high tensile load to the wire, increasing the risk of fracture and entrapment.[4] During drilling, it is advisable to limit turns to 270°–360° alternating clockwise and counter-clockwise rotation.[5]

3.2 | Management strategies

3.2.1 | Pulling technique

In case of guidewire entrapment, gentle pulling of the guidewire is the first step. However, excessive guidewire pulling may result in detaching the outer coil from the inner core of the guidewire or even in a complete guide fracture and therefore should be avoided (Figure 1A–E).[6,7]

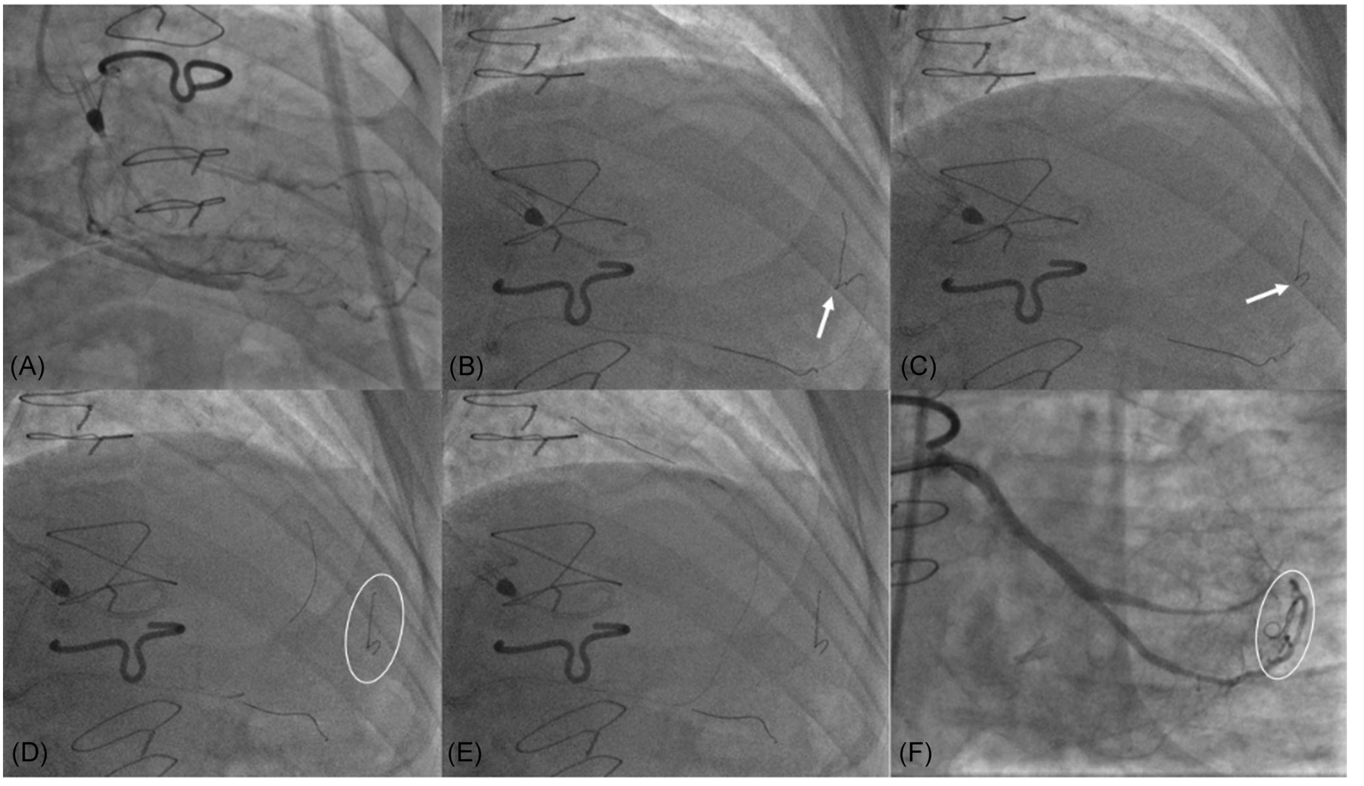

FIGURE 1 (A) Obtuse marginal chronic total occlusion (CTO) filled from epicardial collateral channels originating from the RCA; (B) retrograde guidewire entrapment into the epicardial branch (white arrow); (C) guidewire controlled rupture by simultaneous microcatheter pushing and guidewire pulling (white arrow); (D) successful retrograde wiring of a different collateral channel; (E) advancement of a retrograde microcatheter into the distal target vessel; (F) final angiographic result. RCA, right coronary artery

3.2.2 | Trapping balloon technique

To increase the radial withdrawal force to successfully retrieve the entrapped guidewire, a balloon can be advanced into the guiding catheter (a 2.0 mm balloon for 6F guiding catheters and a 2.5 mm balloon for 7F guiding catheters) with the aim to trap the entrapped wire against the wall of the catheter (Figure 2A–C). Once the wire is trapped, all the system (the entrapped wire and the trapping balloon) are pulled in block.[8,9] Excessive pulling may result in guidewire fracture, detachment of the outer coil, or in iatrogenic dissection of the proximal segments of the involved artery that could be the left main trunk.

3.2.3 | Snaring

A micro loop snare, with loop diameters of 2 or 4 mm is advanced as far as possible over the entrapped guidewire and tightened, facilitating guidewire retrieval. The snare can be loaded on the back of the wire and advance coaxially to the distal tip, here the snare can be closed and pulled together with the entrapped wire to increase the chance of withdrawal (Figure 2D–G).[10]

3.2.4 | Plaque modification technique

A balloon is advanced as far as possible over the entrapped wire and inflated, potentially freeing the wire from the surrounding tissue.[3] A second guidewire and balloon can be advanced around the entrapped one, followed by balloon inflation aiming to disengage it from the coronary artery wall. Alternatively, the twisting wire technique (i.e., trap the entrapment fragment in the helix or loops of multiple simultaneously twisted wires) might be used. The twisting wire technique is performed crossing one wire on the entrapped one with separate torquers. After a minimum of 10 turns, both wires are put in a single torquer and rotated simultaneously in the same direction with quick and close movements. Finally, both wires are firmly pulled back with the catheter as one unit.[11] However, this technique may be difficulty to perform during CTO PCI due to the difficulty crossing the lesion with additional coronary guidewires.[12]

3.2.5 | Telescoping technique

Advancing a microcatheter or balloon as far as possible over the guidewire by the trapping technique,[5] followed by gentle pulling of

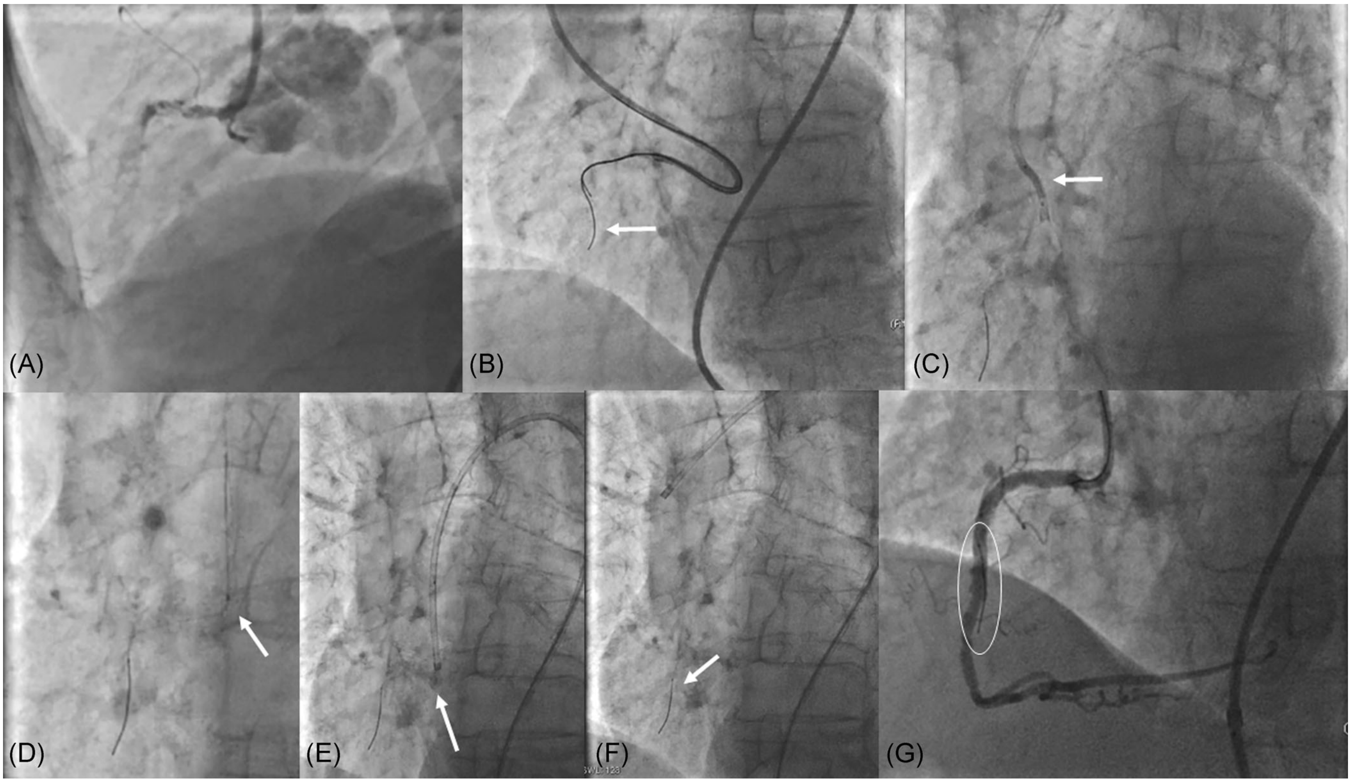

FIGURE 2 (A) Calcified RCA chronic total occlusion (CTO); (B) guidewire entrapment into the CTO body (white arrow); (C) unsuccessful trapping technique into the guiding catheter (white arrow); (D) a micro loop snare was advanced over the entrapped guidewire and tightened (white arrow); (E) the entire system (snare and guiding catheter) was pulled back (white arrow); (F) successful rupture of the distal segment of the wire that was left into the vessel architecture (white arrow); (G) final result after successful RCA CTO recanalization RCA, right coronary artery

the guidewire, allows a more focused application of the withdrawal force, facilitating its retrieval.[2,13]

3.2.6 | Bailout percutaneous strategies

If retrieval of the entrapped guidewire fails, controlled rupture of the wire may be considered (Figure 2F).[14] However, wire unraveling (i.e., unfolding of the tip coil into small filaments) might occur. Wire unraveling is much more challenging to treat than a "clean" fracture, as the distal spring coil may create a metal "bird's nest" that can lead to vessel thrombosis (Figure 3).[15] Therefore, after controlled rupture of the guidewire, intracoronary imaging should be performed to confirm that no wire coil unraveling has occurred.[5] If multiple guidewire filaments are prolapsing into the intracoronary lumen, stenting the filaments against the arterial wall may potentially prevent future migration and possibly improve rheology and decrease thrombotic risks (Figure 2).[16] This maneuver should prevent the patient from emergency surgery. Small wire fragments located in small distal branches or in collateral vessels can probably be best left untreated (Figure 1F).

3.2.7 | Surgery

Extensive manipulation within the vessel during attempted fragment removal can lead to potentially catastrophic coronary dissection,

FIGURE 3 The distal tip of a jailed circumflex guidewire became entangled with the left main stent, forming a knot. Multiple retrieval attempts failed and the distal spring coil created a metal "bird's nest" (white arrow) that needed surgical wire retrieval followed by coronary artery bypass graft. [Color figure can be viewed at wileyonlinelibrary.com]

rupture, or thrombosis. Therefore, emergency surgery may be required in the most difficult situations where all the aforementioned percutaneous retrieval techniques have failed. However, cardiac surgeons have a limited experience in removing entrapped devices from coronary arteries (due to its extremely low incidence) and efforts to avoid surgical solutions should be maximized.[15]

3.3 | Microcatheter entrapment

3.3.1 | Causes and prevention

Microcatheter over-torquing is the most common cause of entrapment, especially when inappropriate rotation is applied to microcatheters not designed for rotation.[17] Operators should also avoid microcatheter over-rotation in calcified lesions, even with coiled rotatable microcatheters, limiting the number of turns applied to a maximum of ten; followed by device releasing to dissipate accumulated torque.[5] Once a coiled microcatheter with a tapered tip cannot be advanced, any type of additional rotation must be avoided, due to the potential risk of tip detachment (Figure 4A–D).[2]

Aggressive advancement of microcatheters through complex and calcified lesions or through thin and tortuous collateral channels during CTO PCI might also predispose to device entrapment and should be performed with caution.[25] During retrograde CTO PCI advancement of two microcatheters over one externalized guidewire with both ends "interlocking" might cause entrapment.[18] Of note, when performing retrograde right coronary artery CTO PCI through septal connections emerging from a stented left anterior descending artery, the rotation of the microcatheter through the stent struts might cause its entrapment; in this setting, predilatation of the struts before crossing with the microcatheter might reduce the risk of entrapment. Finally, microcatheter manipulation without placing a guidewire inside it can lead to deformations and is highly discouraged due to the increased risk of coronary dissection and device entrapment.[5]

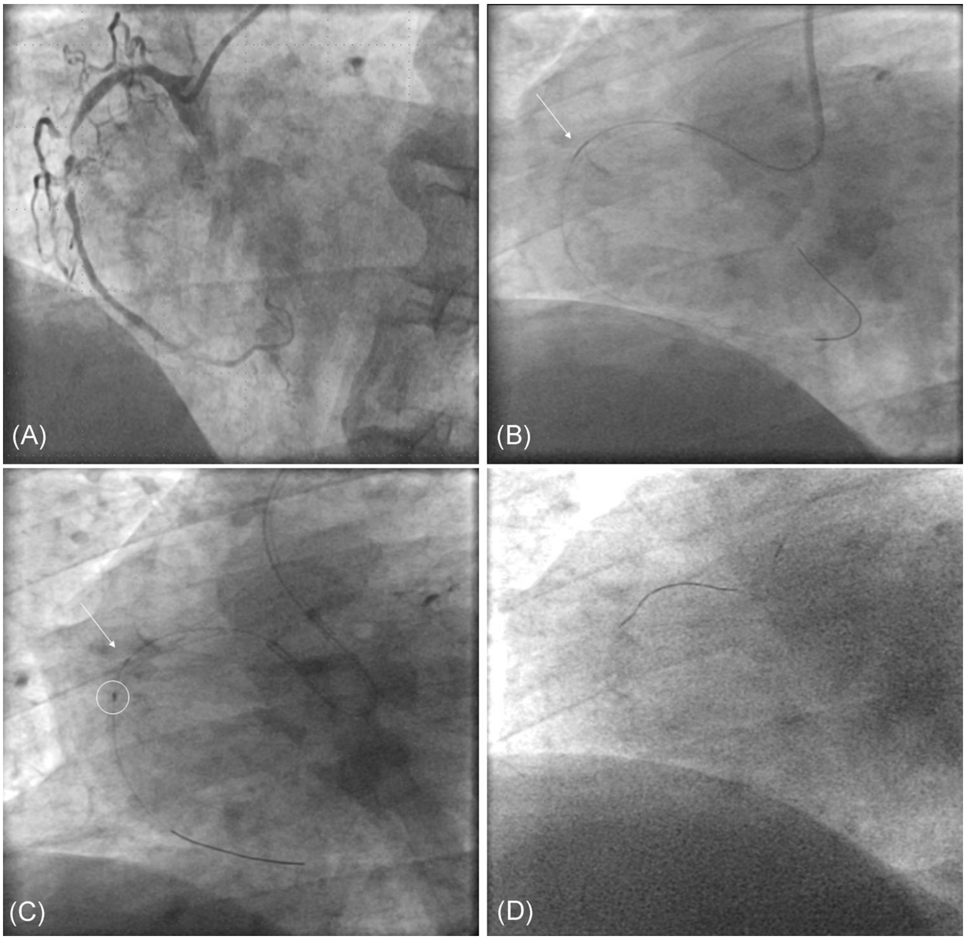

FIGURE 4 (A) Calcified RCA chronic total occlusion (CTO); (B) an antegrade Caravel microcatheter (white arrow) was forced into the calcified CTO body; (C) Caravel microcatheter tip fracture (white arrow); (D) successful retrieval of the tip fragment by pulling the entire system. RCA, right coronary artery

3.4 | Management strategies

3.4.1 | Pulling technique

Strong traction of the entrapped microcatheter should be avoided, as it may lead to vessel dissection or perforation. In addition, strong pulling may cause fracture of the microcatheter tip (Figure 5), especially with soft-tip microcatheters.[17]

3.4.2 | Trapping technique

Trapping the microcatheter shaft within the guide catheter decreases the length of the microcatheter to which traction is applied and the risk of device rupture. Ideally, ≥20 mm-long balloons (2.0 mm diameter for 6F guiding catheters and 2.5 mm diameter for 7F guiding catheters) are recommended, as longer balloon length provides more area of contact, increasing the withdrawal force and the chances to retrieve the entrapped microcatheter.[19]

3.4.3 | Snaring technique

Several small snares (<5 mm in diameter) can be advanced over the entrapped microcatheter into the coronary arteries to retrieve the microcatheter. The easiest way to get the snare into the coronary artery is to put the loop of the snare around the proximal shaft of the microcatheter and use it as a track for the snare. While pulling back, the snare facilitates the trapping of the microcatheter within the catheter. Then, the snare is removed together with the entrapped device.[2]

3.4.4 | Plaque modification technique

Modifying the plaque within which the microcatheter is entrapped may assist with retrieval. A second guidewire is advanced around the entrapped microcatheter, followed by low-profile balloon angioplasty around the entrapped device (Figures 5A–C and 6A–C).

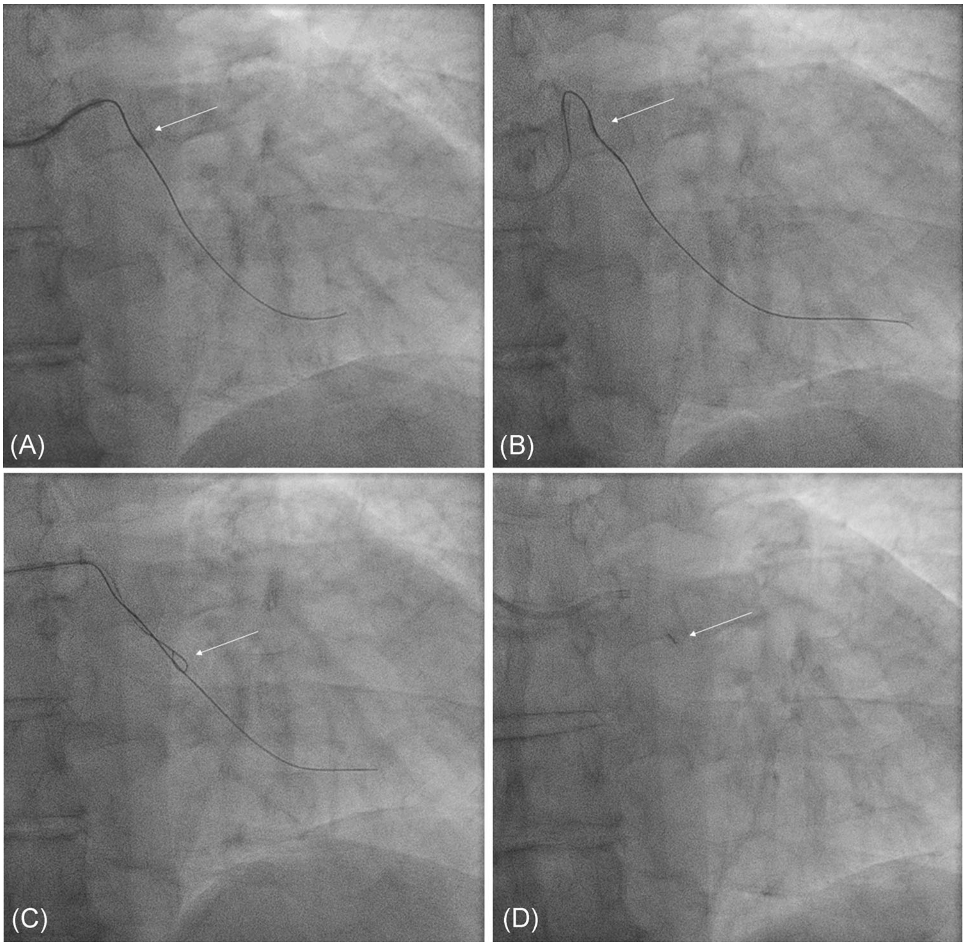

FIGURE 5 (A) Caravel microcatheter tip fracture (white arrow); (B) balloon inflation over the same guidewire to free the tip (white arrow); (C) guidewire advancement (white arrow) and balloon inflation around the fractured tip; (D) the fractured tip (white arrow) was left into the occluded vessel and the procedure was then aborted

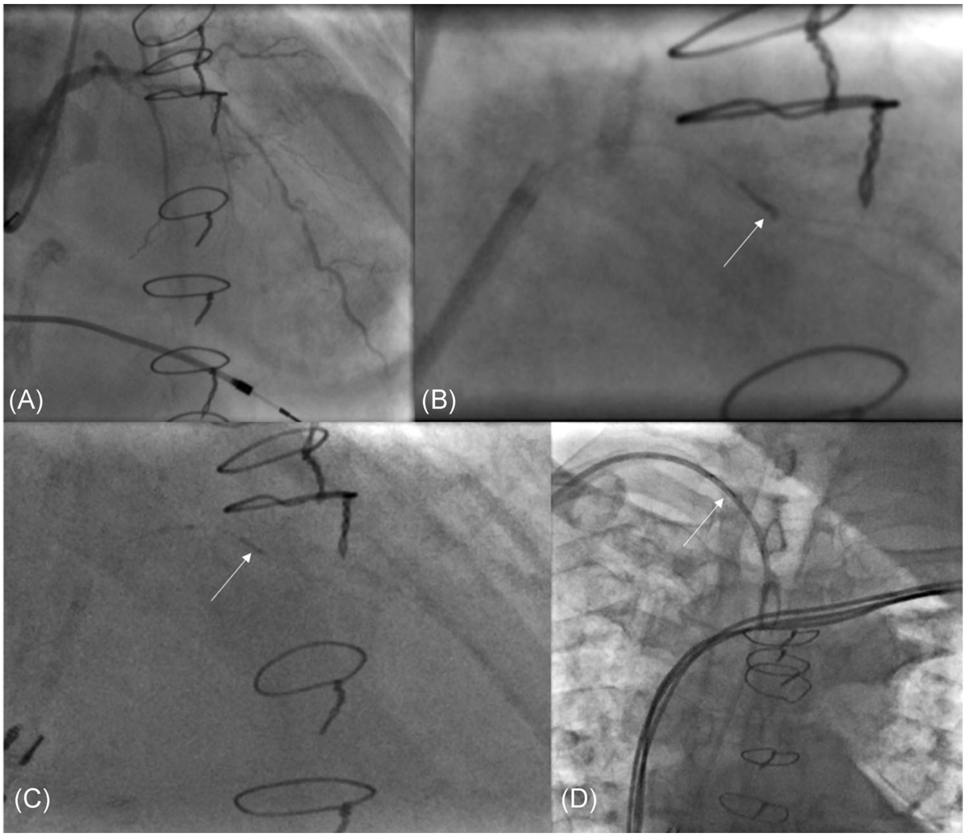

FIGURE 6 (A) Original LAD angiogram; (B) broken Corsair tip in LAD; (C) low-profile (1.2 mm) balloon angioplasty around the entrapped device (white arrow); (D) removal with the balloon. LAD, left descending anterior artery.

3.4.5 | Telescoping technique

The telescoping technique through a guide catheter extension should be considered if removal of the entrapped microcatheter when all the aforementioned techniques have failed. First, the microcatheter shaft is cut and a guide catheter extension advanced over the shaft as close as possible to the entrapped device, followed by gentle pulling of the entrapped microcatheter.[2]

3.4.6 | Bailout percutaneous strategies

In case of clinical need (acute vessel closure, or risk for distal wire position loss in complex intervention) a ping-pong guiding technique to deliver an atherectomy device or a laser may assist with plaque modification and debulking.[20] In contrast to any atherectomy device, laser has the advantage of deliverability over any conventional coronary guidewire without the need for specialized guidewire exchange or risk for distal wire position loss, resulting in a feasible and effective technique to release entrapped microcatheters and fractured tips (Figure 7).[21] Successful plaque modification with the aforementioned techniques may cause distal microcatheter tip fracture migration, small vessel embolization, or distal vessel perforation.

3.4.7 | Surgery

If the microcatheter cannot be removed percutaneously, emergency surgery may be required. If microcatheter tip fracture occurs, the fragment can often be sealed behind a stent or can be left in situ (Figure 5D). However, if it is located in an aorto-ostial position or if it compromises coronary flow resulting in hemodynamic instability, emergent surgery should be considered.

3.5 | Balloon entrapment

3.5.1 | Causes and prevention

One of the major reasons for balloon entrapment is a partial shaft fracture, during its insertion into the guide catheter (if noted, a kinked shaft should always lead to immediate replacement with a new balloon). Balloons are more likely to become entrapped within a lesion if they rupture or become entangled with a previously placed stent or if balloon deflation fails.[5] As with any other device, aggressive balloon advancement through heavily calcified lesions increases the risk of balloon entrapment.[2] If so, further debulking of the plaque should be obtained before recrossing the lesion with the balloon.

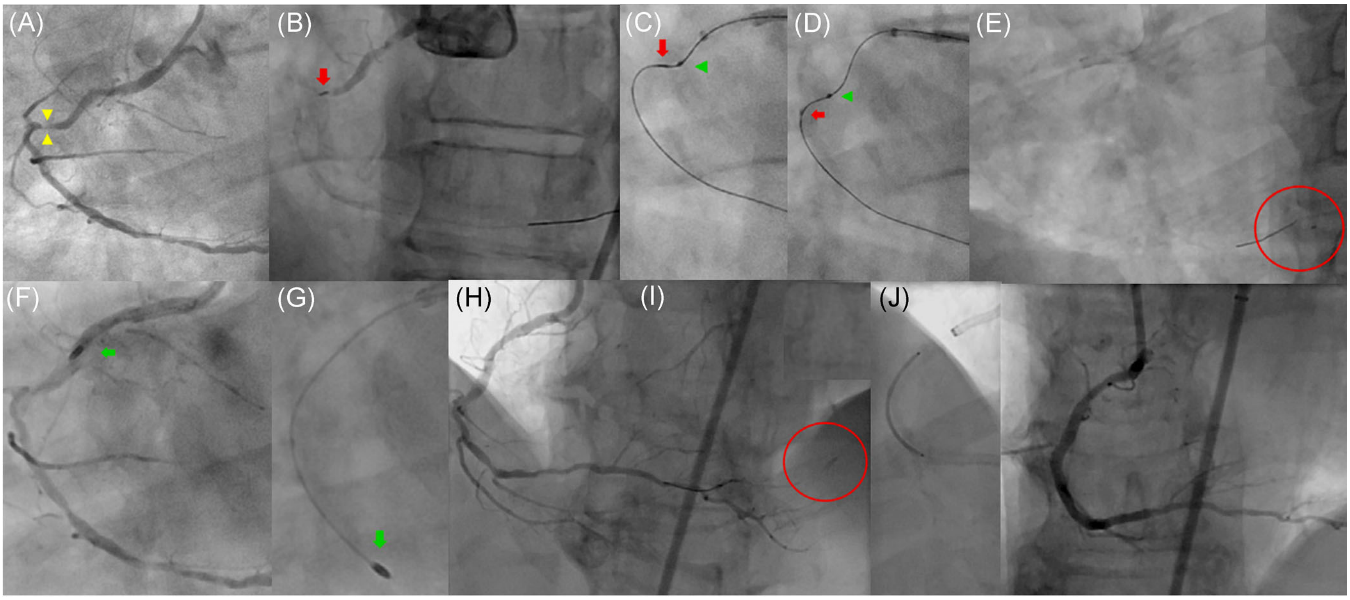

FIGURE 7 Microcatheter tip fracture during RCA percutaneous coronary intervention (PCI) managed with laser atherectomy. (A) Reattempt PCI of calcified RCA subocclusion (yellow arrowheads); (B) microcatheter tip fracture (red arrow) after successful wiring; (C) guide extension-assisted high-energy excimer laser passes (80 mJ/mm^2, 80 Hz; green arrowhead); (D) successful mobilization of the microcatheter tip (green arrowhead); (E) embolized microcatheter tip (red circle); (F, G) additional lesion preparation with rotational atherectomy due to balloon uncrossable lesion; (H) stable distal vessel perforation treated conservatively; (I, J) stenting and final angiographic result. RCA, right coronary artery. [Color figure can be viewed at wileyonlinelibrary.com]

3.6 | Management strategies for balloon entrapment

As previously described for the management of guidewire and microcatheter entrapment, a structured approach based in seven consecutive techniques is highly recommended to successfully manage this complication.

3.6.1 | Pulling technique

Sometimes balloon rotation before gentle pulling may rewrap the balloon and facilitate its retrieval. Similarly, gentle backwards and forwards movements may help free the entrapped balloon.[22]

3.6.2 | Trapping technique

A balloon is advanced within the guide catheter as close to the tip as possible, followed by balloon inflation at high pressure to trap the balloon shaft. The entire system (guide catheter and entrapped balloon) is then retracted as a unit.[2,23]

3.6.3 | Snaring technique

A micro snare is advanced over the entrapped balloon shaft as distal as possible, tightened, and withdrawn. Successful snaring of the device is easier when the entrapped balloon is located proximally in the coronary artery.[24]

3.6.4 | Plaque modification technique

A second guidewire and balloon are advanced within the same guide catheter (or through a second guide catheter) and inflated around and distal to the entrapped balloon to modify the plaque and free the device.[25]

3.6.5 | Telescoping technique

To perform the telescoping technique, the balloon shaft is cut and a guide catheter extension advanced over the shaft as close as possible to the entrapped balloon before reattempting withdrawal.[2]

3.6.6 | Bailout percutaneous strategies

More aggressive debulking techniques such as rotational, orbital, or laser atherectomy, might be considered in case of hemodynamic instability with the aim of fragmenting the entrapped devices and jailing them underneath the stent struts.[26] Attention must be paid as these techniques may lead to distal embolization, vessel dissection, and coronary artery perforation.

3.6.7 | Surgery

When all the aforementioned percutaneous techniques have failed, surgery should be considered.

3.7 | Management strategies for balloon failure to deflate

If the reason for entrapment is failure to deflate, a Y-connector with two manometers applying negative pressure, can help to completely deflate the balloon before trying to pull it out. If the size of the balloon is smaller than the reference vessel diameter, the operator can attempt to withdraw the balloon (without deflating it) into the guide catheter. Alternatively, a controlled rupture of the balloon can be performed. This technique requires the advancement of an over-the-wire balloon or microcatheter over a second wire next to the entrapped balloon, inflating it at low pressures (2–4 atm). The wire of the over-the-wire balloon is then removed and replaced by a stiffer guidewire (such as a Confianza Pro 12), which is used to puncture the entrapped balloon and deflate it.[27] As a bailout strategy, laser atherectomy can be used to perforate the balloon. Attention must be paid as heat delivery to the balloon by the Laser can potentially melt the plastic of the balloon leading to coronary artery perforation.[28]

3.8 | Management strategies for balloon shaft rupture

With balloon shaft fracture, the first step is to identify where the fracture occurred and whether a portion of the retained balloon fragment is inside the guide catheter or not. If inside, it can be trapped with another balloon and successfully removed as previously described (Figure 8A–C). To improve the chance of a successful retrieval of the trapped balloon fragment, a guide catheter extension should be advanced over the fragmented balloon shaft and then the trapping technique can be performed. Alternatively, if the retained balloon fragment is outside the guide catheter, snaring of the retained balloon catheter fragment can be attempted. A last bail-out solution is the "capture" technique, which consists in advancing a guide catheter extension over the same guidewire of the balloon attempting to "capture" the entrapped fragment; then a trapping balloon technique inside the guide catheter extension is performed to trap and remove the fractured segment.[29] If all aforementioned techniques fail, surgery should be considered.

3.9 | Rotational atherectomy burr entrapment

3.9.1 | Causes and prevention

Three main mechanisms have been proposed as potential causes of burr entrapment as follows: (1) aggressive advancement of small burrs (especially the 1.25 mm burr) through a calcified lesion without debulking a significant amount of calcified tissue. In this situation, the ledge of calcium proximal to the burr may prevent burr withdrawal afterwards ("kokesi" phenomenon); (2) advancement of a large burr against a severe calcified and long lesion without sufficient pecking motion; in such a situation, the rotational speed may significantly decrease and the burr might get entrapped (Figure 8A).[30] Gentle pecking motion of the burr accompanied by runs shorter than 15 s should be performed to avoid burr entrapment. Larger burr/artery ratios (>0.6) are preferred to avoid the burr advancement through the lesion without significant plaque debulking. (3) Advancement of the burr in severe angulated lesions may lead to a significant velocity decrease with the subsequent risk of burr detachment and entrapment.[31] Additional strategies to prevent burr entrapment include avoiding the burr stop distal to the lesion and starting or stopping rotablation within the target lesion.[31]

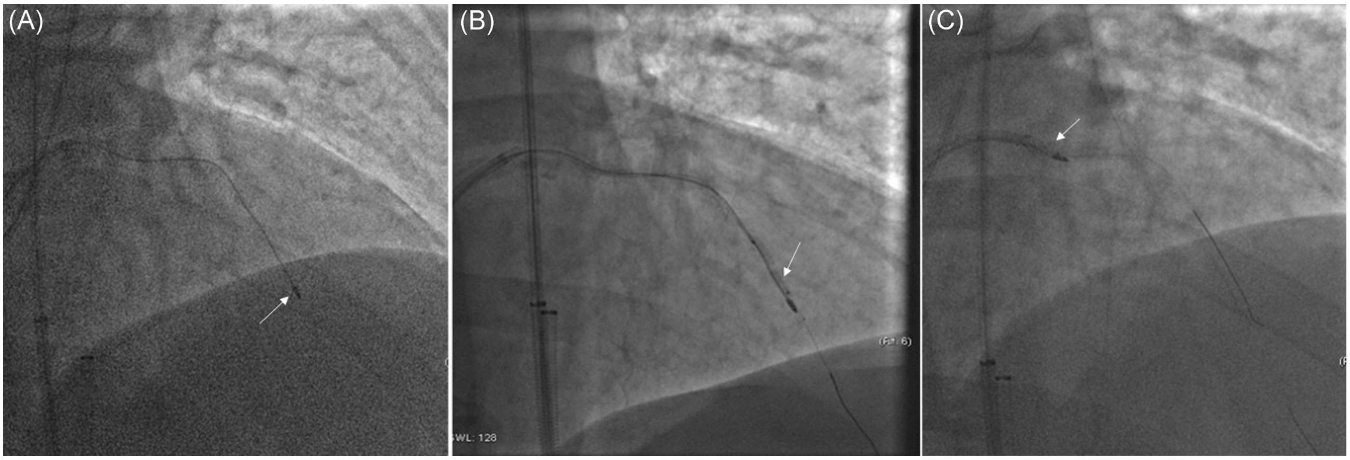

FIGURE 8 (A) A 1.25 mm burr entrapment (white arrow) into LAD; (B) balloon inflation (white arrow) around the entrapped burr; (C) successful withdrawal of the entire system (white arrow). LAD, left descending anterior artery.

3.10 | Management strategies

3.10.1 | Pulling technique

When entrapment occurs, the first line strategy is to manually pull the rotational system back with on-Dynaglide or off-Dynaglide rotation.[32] A deep guide-catheter intubation, with subsequent forceful pull of the entire system may increase the chances of device retrieval. However, aggressive retrieval maneuvers may lead to vessel perforation, burr shaft fracture or iatrogenic artery dissection. A simple technique, not frequently employed, is to perform a gentle pull on the rotablator wire. This wire will not fully enter the burr because the distal tip is larger; this action may slightly change the axis of the trapped burr and facilitate retrieval.

3.10.2 | Trapping technique

Trapping the Rotablator shaft within the guide catheter decreases the length to which traction is applied increasing the withdrawal force.[2] However, strong traction must be avoided as it may lead to vessel dissection or perforation.

3.10.3 | Snaring technique

After disassembling the Rotablator apparatus, the advancement of a 4 mm snare over the shaft just proximal to the burr provides direct traction on the burr increasing the chances to withdrawal the device.[33] The combination of the snaring and telescoping technique, using simultaneously a guide catheter extension and a 4 mm snare can also be applied; advancing the snare through the guide-catheter extension and opening it at the entrapment site to facilitate the trapped burr release.[34]

3.10.4 | Plaque modification technique

If the aforementioned techniques fail, the Rotablator disassembly allows the advancement of a second guidewire and a balloon catheter with a ping-pong guiding catheter technique. The second guidewire is advanced distal to the entrapped burr and balloon inflations around the entrapped burr are performed to free it (Figure 8B–C).[2] However, the inflation of a balloon alongside the entrapped burr could significantly increase the risk of coronary perforation or rupture.

3.10.5 | Telescoping technique

If previous approaches fail, the most effective technique is to cut the Rotablator drive shaft sheath and the catheter shaft to allow the advancement of a guide catheter extension as close as possible to the entrapped burr. A simultaneous maneuver of pulling the Rotablator system and pushing the guide catheter extension increases the chances to release the entrapped burr.[35,36]

3.10.6 | Bailout percutaneous strategies

As a last bailout strategy, operators can cross the site of entrapment with a second guidewire in a subintimal fashion and then re-enter into the distal true lumen with the subintimal tracking and reentry technique. This is followed by advancement and inflation of a small balloon to dislodge the entrapped burr.[37]

3.10.7 | Surgery

When all percutaneous attempts have failed, emergency cardiac surgery is indicated.

4 | CONCLUSIONS

A methodical, algorithmic approach to prevention and management of device entrapment can help to optimize outcomes. The recommended sequence of steps is as follows: (a) pulling, (b) trapping, (c) snaring, (d) plaque modification, (e) telescoping, and (f) surgery; however, the order of the different techniques might vary according to patients' clinical condition, availability of material and operator's technical skills. In-depth knowledge of the techniques and necessary tools can help optimize the likelihood of successful equipment retrieval and minimization of complications.

CONFLICTS OF INTEREST

Kambis Mashayekhi reports consulting/speaker/proctoring honoraria from Abbott Vascular, Abiomed, Ashai Intecc, AstraZeneca, Biotronik, Boston Scientific, Cardinal Health, Daiichi Sankyo, Medtronic, Shockwave Medical, Teleflex, and Terumo. Emmanouil S. Brilakis reports consulting/speaker honoraria from Abbott Vascular, American Heart Association (associate editor Circulation), Amgen, Asahi Intecc, Biotronik, Boston Scientific, Cardiovascular Innovations Foundation (Board of Directors), ControlRad, CSI, Elsevier, GE Healthcare, IMDS, InfraRedx, Medicure, Medtronic, Opsens, Siemens, and Teleflex; owner, and Hippocrates LLC; shareholder: MHI Ventures and Cleerly Health. Pierfrancesco Agostoni reports consulting/speaker/proctoring honoraria from Abbott Vascular, Boston Scientific, Medtronic, and Neovasc. Gabriele L. Gasparini reports consulting/speaker/proctoring honoraria from Terumo, Asahi Intecc, IMDS, Boston Scientific, Medtronic, Abbott Vascular, and Cardinal Health. Mohaned Egred reports consulting/speaker/proctoring honoraria from Abbott Vascular, Boston Scientific, Philips, Spectranetics, Volcano, Teleflex, Vascular Perspective, Merrill, Sveltte, EPS Medical, and AstraZeneca. Alexandre Avran reports consulting/speaker/proctoring honoraria from Boston, Biotronik, Terumo, Asahi, Orbus, Abbott, IMDS, and Alvimedica. Roberto Garbo reports consulting/speaker/proctoring honoraria from Teleflex, Abbott Vascular, IMDS, Terumo, Asahi Intecc, and Boston Scientific. Arun Kalyanasundaram and Jorge Sanz-Sánchez report no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the Supporting Material of this article.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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