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STATE-OF-THE-ART REVIEW

Knuckle Guidewires to Create Dissections in Chronic Total Occlusion Percutaneous Coronary Intervention

Position Statement

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ABSTRACT

Dissection and re-entry techniques are essential to achieve safe and effective chronic total occlusion recanalization. Several studies have demonstrated similar outcomes following extraplaque stenting compared with intraplaque stenting. Dissection techniques most often involve the use of knuckled wires to progress within and beyond the chronic total occlusion segment. In this expert consensus document, the authors compare the properties of different polymer-jacketed wires for their use in dissection techniques. The authors also describe 2 principal knuckle wire behaviors, the rolling and the traveling knuckles. Finally, several adjunctive techniques for safer dissection are described.
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Dissection and re-entry techniques (DARTs) during percutaneous coronary intervention (PCI) are key to achieving safe and effective recanalization of chronic total occlusions (CTOs).[1,2] Several studies have demonstrated similar outcomes following extraplaque stenting compared with when the plaque is stented following intraplaque wiring.[1,3-7] The use of stiffer wires, especially when the course of the vessel is ambiguous, may be associated with vessel exit and perforation, especially when the exit points are subsequently enlarged with a microcatheter. The use of knuckled wires (often referred to as "knuckles") is advocated to prevent perforation, improve efficiency, and achieve safe dissection.[8,9]

Several wires are now available to perform either antegrade or retrograde dissections, and their use increases the chance of remaining within the vessel architecture. Although dissections may be performed

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ABBREVIATIONS AND ACRONYMS

BASE = balloon-assisted subintimal entry

CART = controlled antegrade and retrograde re-entry technique

CTO = chronic total occlusion

DART = dissection and re-entry technique

PCI = percutaneous coronary intervention

STAR = subintimal tracking and re-entry

within the plaque of the occlusion, it is believed that most knuckled wires travel in the medial layer of the vessel.[10] The type of knuckle, the way it is formed, its size or width, and its behavior are among concepts that need accurate description to enhance communication and effectively teach these techniques. Although antegrade and retrograde DARTs have been extensively described in textbooks[11-13] and peer-reviewed papers, the details of safe dissection techniques remain counterintuitive to many operators. We introduce new concepts of knuckle dissections and present expert consensus on best practices for performing coronary dissections during CTO PCI.

HIGHLIGHTS

- DARTs are advocated for long and calcified CTO segments to avoid perforation.
- We describe 2 fundamental knuckle behaviors, the rolling and traveling knuckles, and their use.
- Better description of knuckle behavior should enhance communication and knowledge transfer.

GETTING READY TO CREATE DISSECTION PLANES

First, operators should understand that dissection methods will have important consequences on subsequent re-entry techniques. DARTs may be appropriate only in cases in which large branches are not expected to be excluded with subsequent ballooning and stenting. Antegrade dissection can be performed after unintentional or intentional wiring of a plane within the vessel architecture, in either the intraplaque or the extraplaque space, but the wire does not track into the distal true lumen.[1,2] Intentional dissection techniques require appropriate guide support and the use of a microcatheter, usually in its shortest version available (130 or 135 cm). There are several microcatheters on the market, with different entry profiles (simple tip taper, polymeric nose cone, metallic screwlike pattern, fully metallic, etc), and it is often from trial and error that an operator may choose to switch from one microcatheter to another. We discourage the default use of lower profile microcatheters that are usually dedicated for the retrograde approach, as their thinner construction makes them more vulnerable to damage and less supportive. Also, dilating the dissection track with a larger microcatheter will be useful prior to delivering a dedicated re-entry device. Using a guide extension, especially the TrapLiner (Teleflex), can ease the initiation of the dissection and exchange of catheters. Although other guide extensions may provide similar support, the TrapLiner also offers the possibility to trap the microcatheter with its balloon inflated when forming the knuckle, augmenting the support and reducing the risk that the microcatheter will back up from its position. Moreover, the TrapLiner facilitates microcatheter exchanges and subsequent maneuvers with its balloon-trapping capacity. In antegrade dissection and re-entry, the use of a TrapLiner helps plug the dissection plane to prevent hematoma formation. Newer guide extensions, such as LiquID (Seigla Medical), have a larger internal diameter, allowing the easier use of trapping balloons inside the guide extension, and can be an alternative to the TrapLiner. Although antegrade dissection can be performed through a 6-F guide with a TrapLiner, some techniques such as power knuckle (explained later) may not be possible without removing the guide extension. As such, we recommend at least a 7-F antegrade guide.

Resistance feedback from a nonknuckled wire provides confidence that it is in the vessel architecture, especially if the wire “dances” with vessel structures such as calcium or other wires already in place. Starting the knuckle in this position will usually be the next step. The best wires to start a dissection plane are discussed in the next section. Knuckles are a more efficient way to cross long lesions and should be started early when the lesion length is >20 mm, especially when the course of the coronary is ambiguous.[8] However, if the cap of the CTO is also ambiguous, defined as an uncertain location at the presumed end of the visible coronary lumen, there are several already described strategies to create a dissection plane safely, often referred to as “move-the-cap techniques.”[10,14,15] One of these techniques is scratch and go. This involves the intentional puncture of a plaque or the wall proximal to the presumed proximal cap with a high-gram nonjacketed tapered wire, typically bent with a 45° angle at least 2 to 3 mm from the tip for better reach. If the stiffer wire provides feedback of resistance and the tip dances with the coronary architecture, the microcatheter is advanced a few millimeters into the plane, and the stiff wire is exchanged for polymer-jacketed wire. A short attempt to feel the same resistance is warranted to confirm that the

microcatheter is in the vessel structure. The balloon-assisted subintimal entry (BASE) technique (and its derivates) is another maneuver to manage an ambiguous proximal cap and may be safer than scratch and go when possible. It involves a workhorse wire in the true lumen of the proximal nonoccluded portion of the vessel (delivered at the cap or in a branch arising proximal to the cap), a semicompliant or noncompliant balloon sized to the vessel caliber delivered on the workhorse guidewire, and a microcatheter tip placed either proximal to the balloon or under the balloon body. Inflations are performed, ideally on an intimal plaque, to create dissection planes. Following this, a polymer-jacketed wire, with a longer bend (2-3 mm) or a double bend, is advanced in the dissection plane. Subintimal tracking is confirmed by the wire spiraling around the true lumen wire with the balloon in place, while "dancing" is phase with the other gear in place. Several variations of this technique have been described. When the balloon is advanced partially into a side branch and kept inflated when attempting to track the main branch wall and create the knuckle, it is referred to as side-BASE.[16] This technique is aimed at preventing the wire from entering an occluded or patent secondary side branch instead of the body of the CTO. "Power knuckle" involves using a balloon to "pin" the microcatheter while pushing the wire, already in the extraplaque, to increase support for folding the wire and creating the knuckle. Finally, BASE-power knuckle is a more aggressive but very effective technique following the BASE technique.[10] It involves inflating the balloon to pin the tip of the microcatheter under the balloon, or leaving the microcatheter tip proximal to the inflated balloon, and pushing a polymer-jacketed wire to create the knuckle while the balloon is kept inflated, hoping that the displacement of the microcatheter toward the vessel wall or the obstruction of the true lumen with the balloon, along with dissections from previous balloon inflations, will force the knuckle to track the wall, not the lumen. Operators should be ready to alternate back and forth between move-the-cap techniques to initiate the dissection safely.

If any wire behaves strangely and seems to advance freely outside the presumed borders of the vessel, it has likely exited the vessel structure. At this point, it is key not to advance the microcatheter, as this will expand the hole; creating a different dissection plane can exclude the exit point most of the time. If the microcatheter has already been advanced into that space, the operator should leave the microcatheter in place, use a second microcatheter, and start a different dissection plane without antegrade contrast injection with the idea that the more tissue (greater the distance) between the new dissection plane and the perforation, the more likely sealing will occur. When a microcatheter has been advanced through the adventitia, the likelihood of a clinically relevant perforation becomes much higher. Evidence of contrast extravasation when pulling the microcatheter a few millimeters back will confirm the operator's doubts. Complete removal of the microcatheter will result in more bleeding, and antegrade contrast injections will enlarge the leak and facilitate the creation of a track from the vessel to the pericardial space; maintaining the microcatheter position until proper management of the hole in the artery is key. If a retrograde approach is feasible, it should be considered promptly, as retrograde dissections and tracking are a highly effective way to seal a perforation. Therefore, operators should be facile with all hybrid CTO PCI approaches to use these intentional dissection techniques. Only when additional dissections have progressed favorably should the operator consider removing the microcatheter (while leaving a wire into the space for better subsequent access) and assess for a perforation with a gentle contrast injection. If perforation is greater than Ellis grade 1, the microcatheter should be readvanced to "plug the hole," and proper management of the perforation should be done promptly, including coiling of the track, prolonged balloon inflation, creating additional dissection planes to exclude the exit point, different retrograde tracking of the occlusion when possible, and aborting the procedure and reversing anticoagulation.

An alternative and safer technique is to avoid advancing the microcatheter over a higher gram wire that was used to puncture the extraplaque space and exchange the higher gram wire for a polymer-jacketed wire with a similar CTO bend steered to track the same channel created by the stiffer tip wire. The behavior of the polymer-jacketed wire will confirm or refute tracking of a safe extraplaque space. In case of wire exit beyond the adventitial border, the situation will be much easier to manage, as the track will only be limited to a guidewire size, as opposed to a microcatheter enlarged one. Guidewire exits from the body of the CTO are usually benign events, as the hole created is small, and plaque recoil will likely close it after the removal of the wire. However, guidewire exits proximal to the CTO body resulting from move-the-cap techniques may need to be managed as described earlier, as these exits are exposed to coronary perfusion pressure.

TABLE 1 Polymer-Jacketed Wires Knuckling Properties

	Tapered Soft Polymeric	Nontapered Stiffer Polymeric	Dedicated Wire for Knuckling
Most used	Fielder XT (Asahi Intecc)	Pilot 200 (Abbott)	Gladius Mongo/MG (Asahi Intecc)
Alternatives	Fighter (Boston Scientific), Bandit (Teleflex)	Gladius EX (Asahi Intecc), Raider (Teleflex)	None
Rolling knuckle properties	Excellent	Very good, but more difficult to fold at the beginning; great for larger knuckles	Good but will damage the wire and will likely not be usable for traveling
Traveling knuckle properties	Good, especially if in a smaller vessel; tip of wire needs to detach from the proximal area of the plaque	Not recommended, as its core is bigger, and the fold width will be larger	Excellent, primary role

Operators should exercise extreme caution when tracking a microcatheter on a high-gram tapered-tip wire believed to be in the subintimal space. Although very experienced operators can more confidently assess if a penetrative wire is not outside the vessel structure, less experienced operators should avoid tracking a hard wire with a microcatheter in the extraplaque space.

TOOLS TO CREATE AND MANAGE DISSECTION PLANES

Once the guidewire and microcatheter are confidently placed into the vessel architecture, the operator is ready to initiate the dissection. There are 3 families of polymer-jacketed guidewires currently used for knuckles (Table 1)—soft tapered polymeric wires, nontapered polymeric wires, and the dedicated knuckle wire—and 1 dedicated device, the CrossBoss (Boston Scientific). In this section we focus on their major properties, when to use them, and their limitations.

TAPERED-TIP (0.009- OR 0.008-INCH) LOW-TIP-LOAD (<1 G) FAMILY OR "SOFT TAPERED POLYMERIC". This family includes the Fielder XT (with a 0.009-inch tapered tip) and related wires with composite cores, the Fielder XT-A and XT-R (Asahi Intecc), the Bandit (with a 0.008-inch tapered tip) (Teleflex), and the Fighter (0.009-inch tip) (Boston Scientific). As composite cores can theoretically increase the risk for wire fracture, with increased metallic components at bent wire points, we recommend the classic Fielder XT, the Bandit, or the Fighter. For inventory purposes, getting used to one of these guidewires for knuckling is enough.

NONTAPERED (0.014-INCH) MEDIUM-TIP-LOAD (3 TO 4 G) FAMILY OR "STIFFER NONTAPERED POLYMERIC". This family includes the classic Pilot 200 (Abbott Vascular), the Gladius EX (Asahi Intecc), and the Raider (Teleflex). More complex composite cores, such as those found in the Gladius EX, may increase the risk for wire fracture, and some operators will prefer the Pilot 200 or the Raider in this family. The Raider also has a distal radiopaque segment extending to 10 cm, improving visualization of the dissecting edge of the knuckle compared with the Pilot 200, which has a 3-cm distal radiopaque segment.

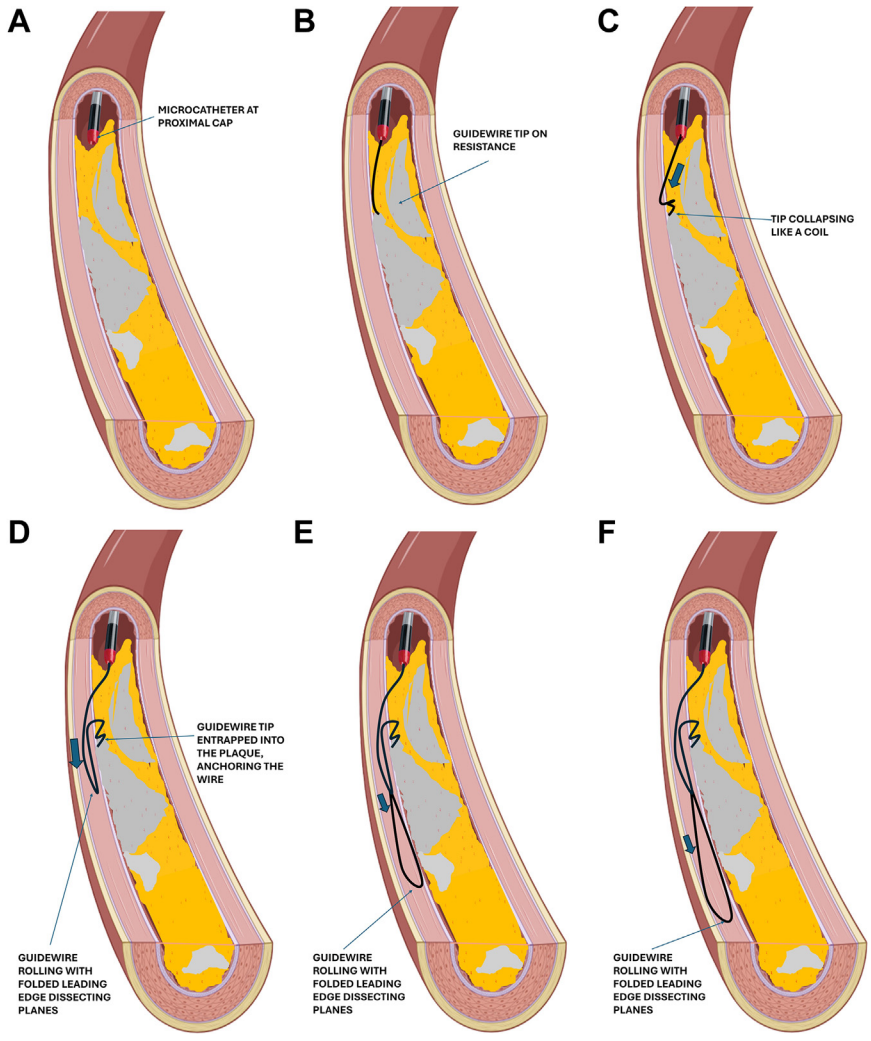
NONTAPERED (0.014-INCH) MEDIUM-TIP-LOAD (3 G) DEDICATED KNUCKLING WIRE OR THE "DEDICATED KNUCKLE WIRE". The Gladius Mongo (or MG outside the United States; Asahi Intecc) has a composite core structure that creates a weaker point 6 to 7 mm proximal to the tip aimed at directing longitudinal forces applied on the wire to turn into folding forces at this level when the tip encounters resistance. The wire tip then folds on itself, creating a tight knuckle, which can be pushed against resistance.

DEDICATED DISSECTION DEVICE (CrossBoss). Although popular at the introduction of antegrade dissection and re-entry techniques, the CrossBoss has fallen out of favor with the advent of high-performance microcatheters and the Gladius Mongo (MG) wire. The device is a stiff braided metallic catheter with a 1-mm blunt ball at the tip, tracking a 0.014-inch guidewire. Once into the occlusion, the wire is retracted and the catheter spun fast without the wire to extend a dissection plane in a less traumatic fashion. Because of its stiffness, the CrossBoss has a predilection for tracking branches arising from the outer border of the vessel, especially in the right coronary artery. It was quickly identified as a "poor starter" but remains an alternative to minimize the size of the subintimal space and hematoma in the distal segment of the dissection (often referred as "dry dissection") prior to the introduction of a dedicated re-entry device.

FUNDAMENTAL KNUCKLE BEHAVIORS

Following an understanding of how to get appropriate support to enter a dissection plane and the

FIGURE 1 Rolling Knuckle (the "Catch, Coil, and Roll" Maneuver)

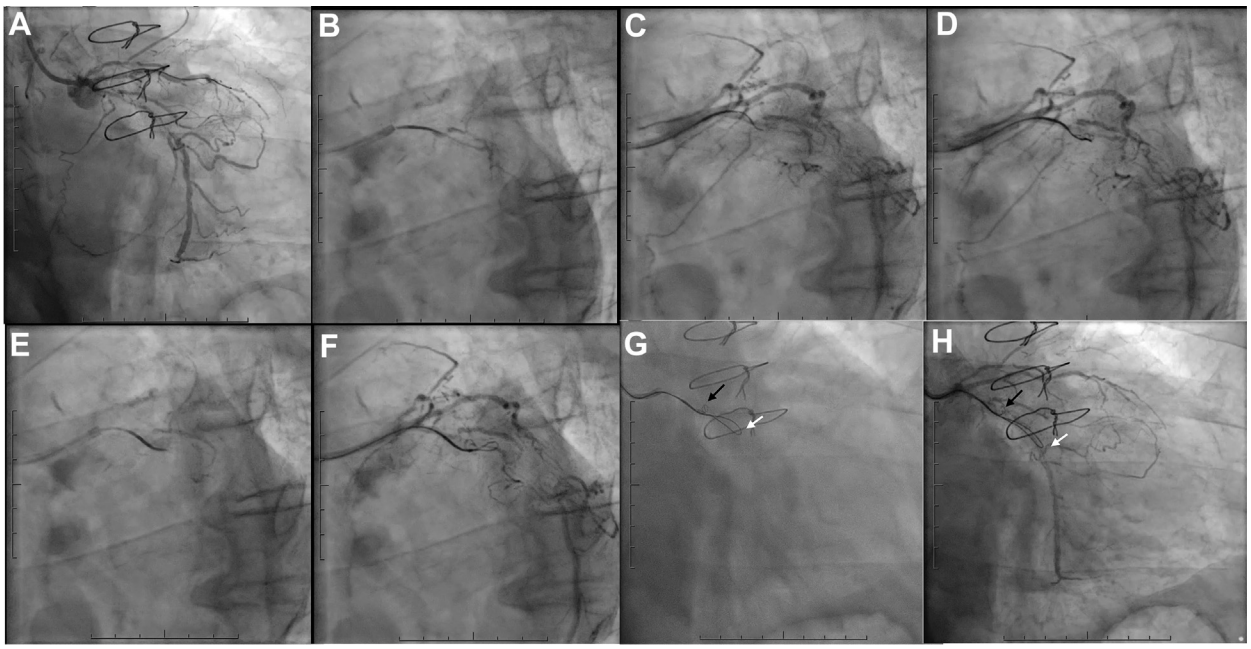


(A) Microcatheter at proximal cap. (B) Guidewire catching tissue. (C) Guidewire tip collapsing like a coil. (D) Guidewire pushed, rolling from its entrapped tip and elongating. (E) Dissection forces from the rolling edge of the knuckle. (F) Larger wire core reaching the edge of dissection.

wires that are needed for the task, the operator will need to learn how knuckled wires from the aforementioned families behave and when to use them. We divide knuckles into 2 types: the rolling knuckle (Figures 1 and 2) and the traveling knuckle (Figures 3 and 4). Understanding their behavior and when to use them will increase an operator's confidence in using the extraplaque space (Central Illustration).

THE ROLLING KNUCKLE. Although it can be done with nontapered polymeric guidewire, this action is typical of the tapered soft polymeric wires. The Fielder XT (or its equivalent) is the best wire to "feel the vessel structure," given its low gram and tapered tip design. The operator pushes the wire to collapse the few distal millimeters segment of the wire into a tight bend into the wall, as one would want to do with a small coil. The sequence of forming the rolling knuckle is as follows. First, the wire is shaped with a small distal J, or simply used straight in the case of a Fielder XT. Second, it is drilled to engage a space, hoping to see or feel the wire meet resistance and see the wire catching tissue, subsequently starting to collapse on itself in the manner of a small coil. This behavior indicates that the wire is confined to the coronary architecture, either within the plaque or

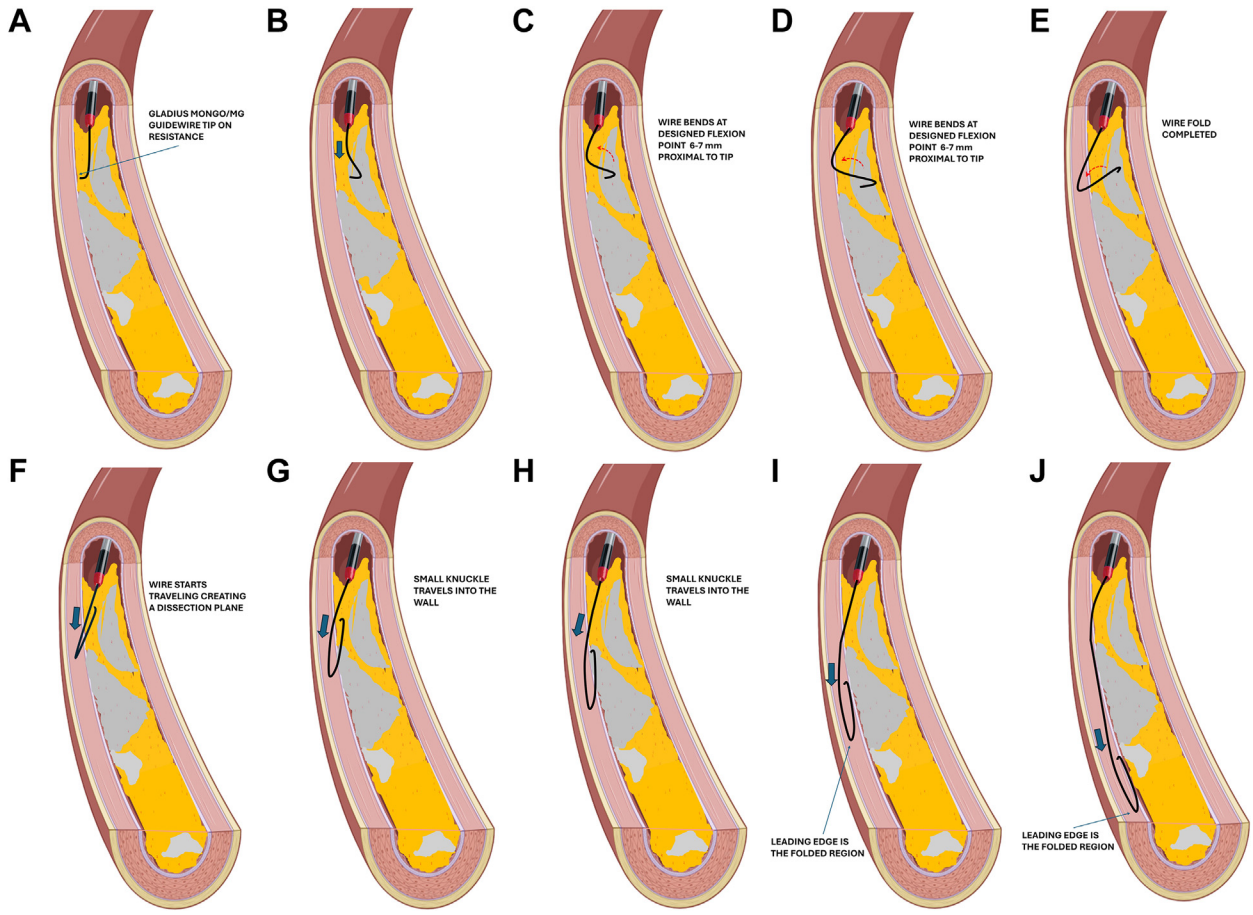
FIGURE 2 Rolling Knuckle Example



(A) Left circumflex coronary artery chronic total occlusion (CTO) with numerous bridging collateral vessels. (B) Tip injection at the proximal cap showing the bridging collateral vessels and an ambiguous cap. (C) Scratch and go with a stiff guidewire, aiming at the plaque. (D) Fielder XT pushed into the wall, collapsing like a coil. (E) Wire removed and "Carlino technique" performed to soften the tissues. (F) Fielder XT pushed again, catches the tissues and starts rolling into the CTO body. (G) The rolling edge of the knuckled wire dissects the extraplaque space (white arrow), as the tip of the wire is trapped proximal in the plaque (black arrow). (H) Angiography showing the front edge of the knuckled wire next to the true lumen distally (white arrow) while the tip of the wire is still into the proximal cap (black arrow).

within the extraplaque space. If the wire seems to extend beyond the borders, not tracking calcium or the presumed trajectory of the vessel, or forming an unusually large knuckle, it has likely exited the vessel structure. If the microcatheter has not followed into that position, the microcatheter should be pulled back a few millimeters and a different dissection plane initiated with the techniques explained earlier. Simple redirection of the dissection planes with a nontapered polymeric wire (see wire redirection later) could be done. Third, if the wire tip collapses like a coil, it is likely in a good position. Rolling the knuckle is the step typically following the "coiling" or catching part. As the tip of the wire is entrapped into the tissues, pushing the wire will create a bend, forming a knuckle. The distal wire tip will remain fixed or anchored in tissue while the more proximal knuckled body of the wire will "roll" forward into the dissection plane as it is elongated longitudinally, forming the knuckle structure. The dissection force will start with the distal softer radiopaque part of the wire, but as the wire is pushed to roll and elongate forward, the dissection force will be created by a progressive increase in the internal core size of the wire. Moving forward, the leading dissection edge will be created by a more proximal and stiffer body of the wire, opening the knuckle width or loop into a larger one. When the fold width seems to have reached the presumed size of the vessel at its front edge or even a larger size, it is likely because it was elongated or rolled enough. Subsequently, the technique will involve advancing the microcatheter, pulling the wire back into the microcatheter, and starting again the knuckle like a "coil" and, once the tip is trapped, rolling again to elongate the wire, creating dissection forces, often referred as knuckle size management (Figure 5). Retracting the wire completely sometimes results in the microcatheter tip forming a J when the dissection space is large. Although it can be disconcerting with less experience, the tip will invariably straighten when readvancing the wire. Once the wire is rolling, it should be pushed without spinning or steering the wire to avoid creating a knot or breaking the wire, especially when

FIGURE 3 Traveling Knuckle (the "Catch, Fold, and Travel" Maneuver)



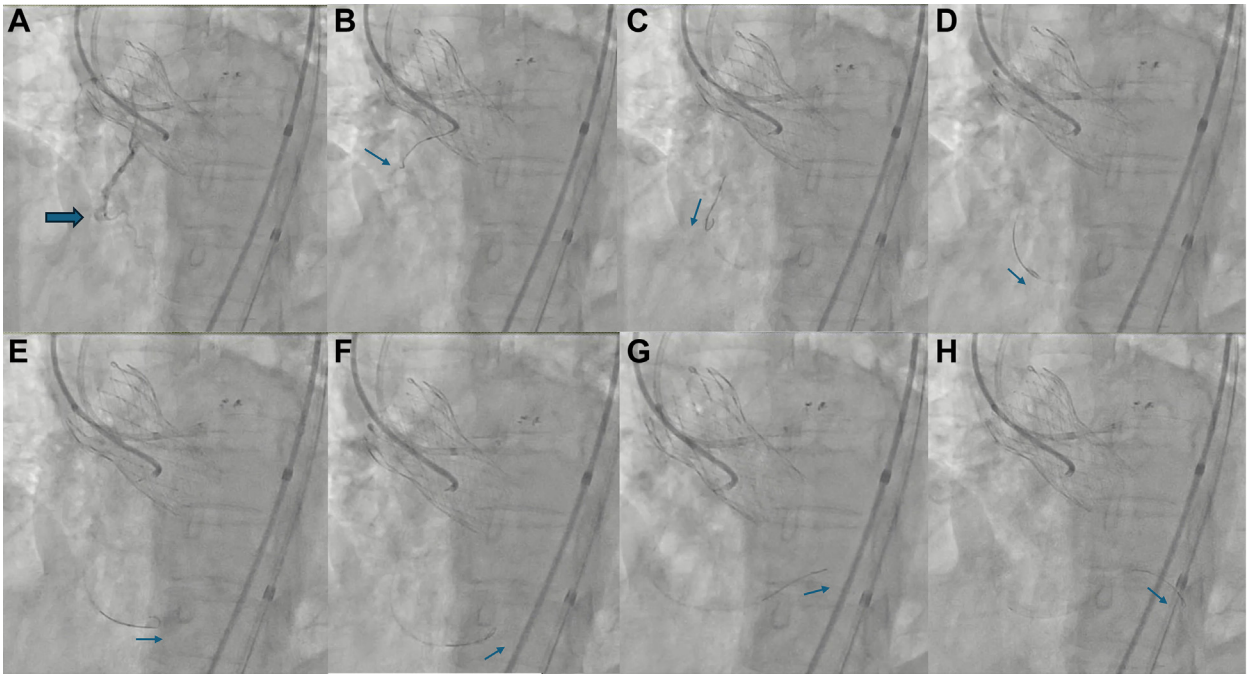
(A) Gladius Mongo tip catching tissue. (B) Longitudinal forces applied to wire. (C,D) Guidewire tip folding at the dedicated bending point. (E) Wire folded. (F) Dissection forces from the front edge of the knuckle. (G-J) Whole knuckle and wire traveling forward.

performed in the retrograde direction. In summary, the sequence required for executing a rolling knuckle can be remembered as "catch, coil, and roll."

The best knuckle wire family for this type of dissection technique is the soft tapered polymeric, as the "coiling part" of its delivery is easier to achieve compared with a stiffer nontapered polymer-jacketed guidewire such as the Pilot 200 or Raider. As its core is smaller distal, the fold that creates the dissection force on a soft polymeric tapered guidewire will be tighter, creating a "smaller knuckle." However, smaller knuckles (with soft tapered polymer-jacketed or dedicated knuckle wire) are more likely to track occluded branches within the CTO body or more distally (Figure 6). Exchanging for a nontapered stiffer polymeric wire will create a larger fold that will not enter smaller side branches and stay in the main vessel. Folding a nontapered stiffer polymeric wire into a space created by a soft tapered polymeric one is usually easy, with the wire bent at 45°, or even with only a 1- to 2-mm bend from the tip. As the wire "catches" tissue and the tip starts collapsing, pushing the wire will create a more "powerful" knuckle compared with the softer one, as the leading edge of the dissection will be created from a larger wire core size. Knuckles may also need redirection using the techniques explained later. Rolling knuckles are the best starters but poor finishers of dissection planes, as they cause larger dissection planes that may impair subsequent attempts at re-entry, especially in the antegrade direction. Switching for a "traveling knuckle" is warranted, as described in the next section.

THE TRAVELING KNUCKLE. This behavior is typical of the Gladius Mongo (MG) and sometimes of the

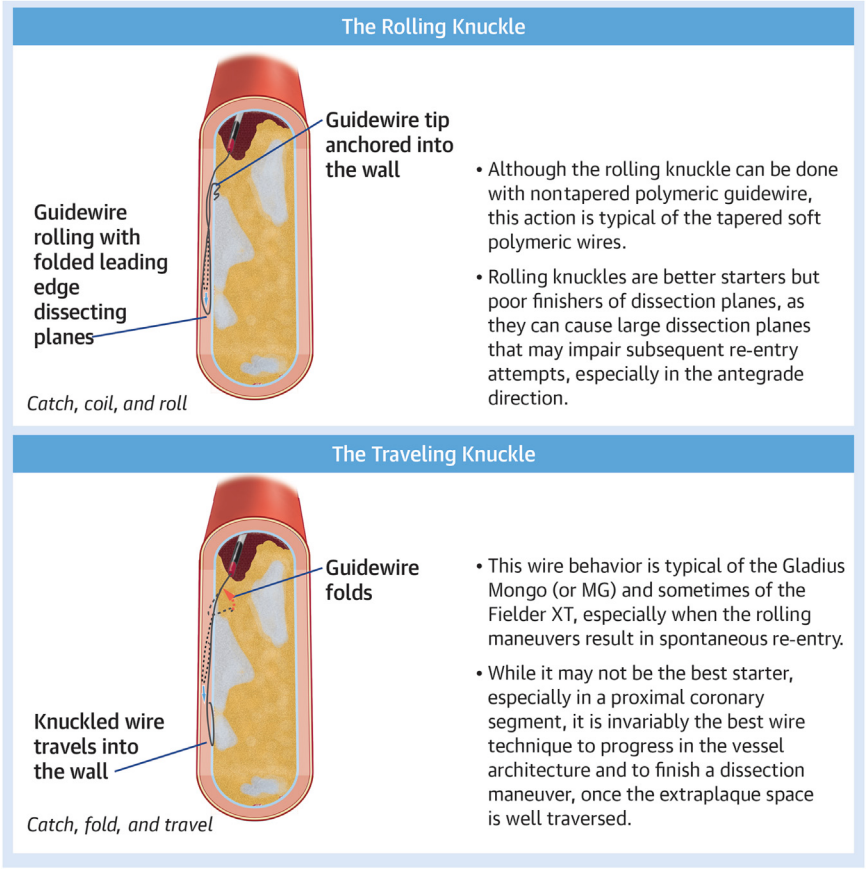
FIGURE 4 Traveling Knuckle Example



(A) Right coronary artery contrast-induced iatrogenic dissection due to malalignment of a guide catheter through a transcatheter aortic valve replacement. (B) Gladius Mongo (MG) pushed to fold on itself. (C) Microcatheter advanced and guidewire pushed to travel into the dissection plane. (D) Guidewire encounters resistance. (E) Guidewire pushed harder, which opens the fold width on the resistant area. (F) Knuckle collapses and becomes smaller in size. (G,H) Wire travels forward freely, indicating successful re-entry.

Fielder XT, especially when the rolling maneuvers result into spontaneous re-entry (at a branch or if the knuckle moved to a more superficial dissection plane), often referred as subintimal tracking and re-entry (STAR).[11] A traveling knuckle behaves very differently than a rolling knuckle. Unlike with a rolling knuckle, the tip of the wire on a traveling knuckle is not fixed in the plaque. Once the tip is folded, the whole wire moves forward, with the fold remaining at the same place on the wire. It can be remembered as the "catch, fold, and travel" knuckle maneuver. For the Gladius Mongo (MG), the fold will remain 6 to 7 mm proximal to the tip, and the whole knuckled tip is therefore moved forward. The dissection force will be at the wire bend that moves into planes, dissecting them. The fold width should remain narrow during these maneuvers (Figure 4). An unexpected enlargement of the fold width indicates a resistance to the progression of the wire but can sometimes mean vessel exit and warrants appropriate corrections, such as creating an alternative track and avoiding advancing the microcatheter. The Mongo (MG) is currently the choice wire to finish a dissection plane beyond the distal CTO cap to prepare for device-based re-entry, as it creates a relatively limited space in which the device, usually a Stingray balloon (Boston Scientific), is likely to have good contact with the vessel wall. The Mongo (MG) is also the choice wire to perform STAR, especially when pushed against the carina of big branches such as in a distal right coronary artery. The knuckle may also navigate intraplaque or superficially and re-enter into the vessel at a weaker intimal segment, which is unfortunately unpredictable. It can also behave the same way retrogradely and re-enter as a "retrograde STAR." It is important to mention few nuances in behavior when using the Mongo (MG) to create dissections in the proximal segment of a coronary: 1) initial folding of the Mongo (MG) is sometimes difficult, with a fold 6 to 7 mm proximal to the tip, especially in smaller vessels; 2) an attempt to fold the wire may result in exiting straight outside the vessel structure; 3) once the knuckle is formed, longer travel with the Mongo (MG) increases the chance to track side branches, as the knuckle is small enough to collapse and take a narrower route, increasing the risk for distal wire

CENTRAL ILLUSTRATION **Two Principal Knuckle Wire Behaviors When Using Dissection in Chronic Total Occlusion Percutaneous Coronary Intervention**



Rinfret S, et al. JACC Cardiovasc Interv. 2024;17(20):2411–2424.

perforation; and 4) if used as a rolling knuckle, its design of longitudinal forces delivered on a tight distal knuckle is defeated. As such, the Mongo (MG) carries some of the disadvantages of the CrossBoss but offers many other advantages. Although it may not be the best starter, especially in a proximal segment of a coronary, it is invariably the best wire to progress into the vessel architecture and to finish a dissection maneuver, once the extraplaque space is well controlled.

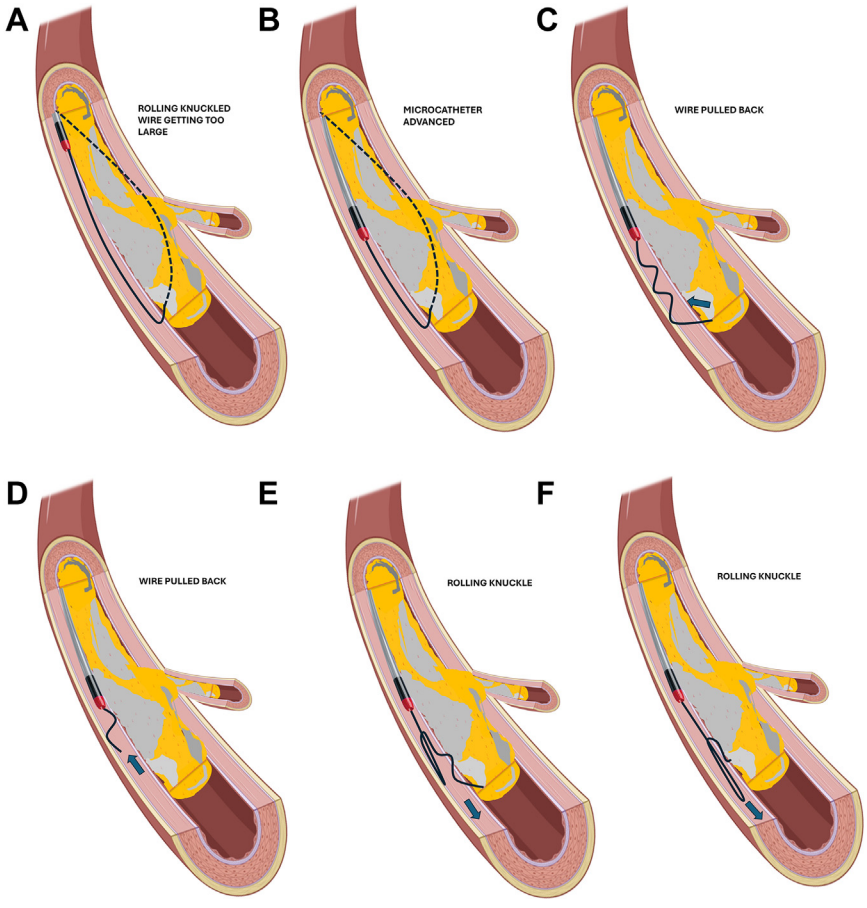
Rolling soft polymer-jacketed wires can convert into traveling knuckles if true-lumen re-entry is achieved. Separation of the distal wire tip from the vessel wall followed by a longitudinal displacement of the folded wire toward the distal true lumen, decrease in the knuckle width, and loss of resistance indicate true-lumen re-entry. On fluoroscopy, these rapid changes are manifest as a "shrink and pop" as the knuckle abruptly collapses in size and leaps forward in transitioning from the subintimal to luminal position. These characteristics make soft tapered polymeric wires the preferred wires for initiating the STAR technique.

In contrast, traveling knuckles can turn into rolling knuckles as well. Although the Gladius Mongo (MG) can travel long distances, it will sometimes meet resistance that will turn the knuckle into a rolling one. At this point, the wire will behave exactly like a stiffer nontapered polymeric wire, and its subsequent ability to travel as originally designed will be lost.

NUANCES BETWEEN ANTEGRADE AND RETROGRADE KNUCKLES

Although knuckle behavior is similar when pushed in the retrograde vs antegrade direction, a few

FIGURE 5 Knuckle Size Management

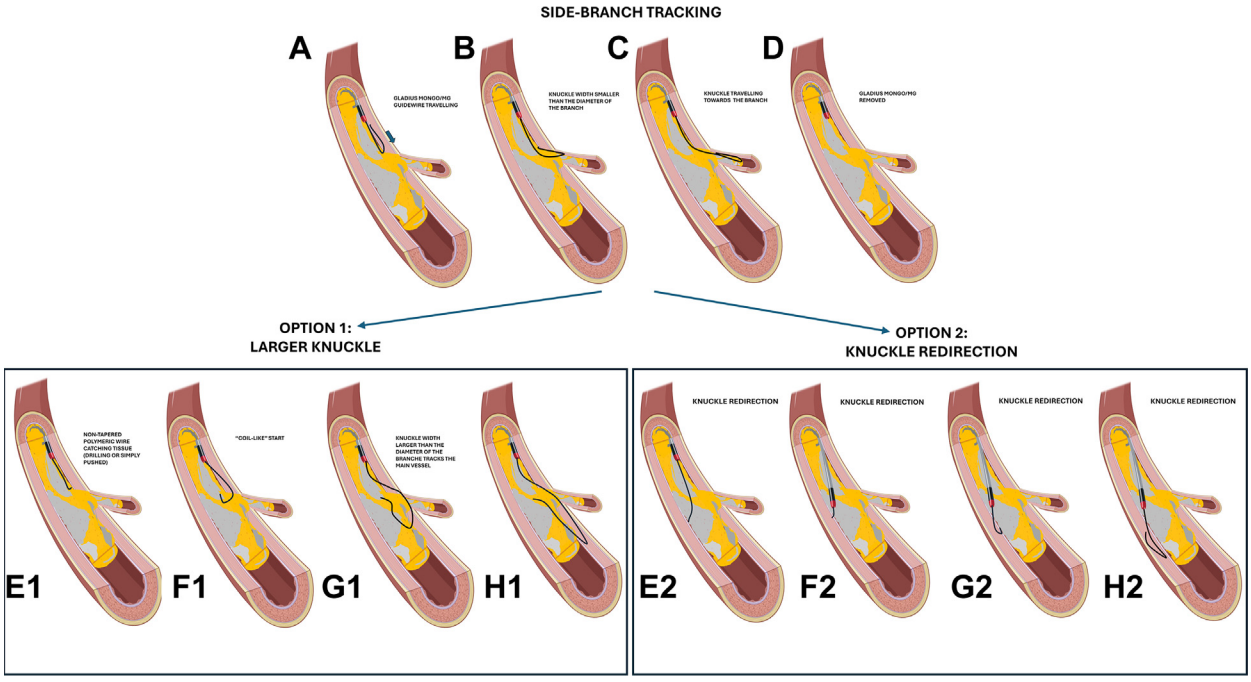


(A) Knuckle has enlarged because of the larger core of the wire reaching the folded section (elongated to its maximum). (B) Microcatheter advanced. (C,D) Guidewire pulled back. (E,F) Guidewire pushed again to roll forward.

differences must be highlighted. Retrograde knuckles, especially rolling ones, rarely track branches, as their origins are directed in the opposite direction, except for branches arising close to 90° from the main vessel or for graft remnants. As such, a traveling Mongo (MG) knuckle is less likely to track branches retrogradely and can be pushed on a longer distance, with the advantage that it can sometimes re-enter spontaneously into the proximal true lumen (retrograde STAR), something that seldom happens with retrograde rolling knuckles. The use of the Carlino technique can be helpful retrograde, especially when knuckles fail to progress.[17] The Carlino technique may also be useful antegrade in the case of stalled knuckles. In post-coronary artery bypass grafting patients, rolling or traveling knuckles can track graft anastomosis remnants; to overcome this, the use of a larger, stiffer, polymeric wire rolling knuckle can be very effective, especially antegrade, to track the main vessel instead of the graft remnant. Also, when possible, delivering a balloon distally through the occluded graft can block the entrance of the graft, in a manner like the side-BASE technique, and help track the vessel proximal to the distal anastomosis of the graft.

Although antegrade knuckles should usually be kept small close to an antegrade re-entry site, it is different when performing the controlled antegrade and retrograde re-entry technique (CART) and reverse CART. Retrograde knuckles with a larger width, rolled and elongated up to the proximal cap, will facilitate puncture toward the extraplaque space from the

FIGURE 6 Side-Branch Management



(A) Gladius Mongo (MG) traveling. (B) Width of the knuckle is smaller than a branch. (C) Wire tracks the branch and gets off track with the main vessel. (D) Wire behavior recognized and wire pulled back. Option 1: (E1) Wire with larger core pushed on resistance. (F1) Wire folds. (G1,H1) Knuckle is larger than the branch and therefore tracks the main vessel. Option 2: (E2) Wire steered to track away from branch and aiming at resistance. (F2) Microcatheter advanced. (G2) Gladius Mongo (MG) knuckled. (H2) Knuckled wire travels in a different plane.

antegrade side. Similarly, a retrograde puncture attempt toward a larger antegrade knuckle will be easier.

ADJUNCTIVE MANEUVERS FOR MORE EFFECTIVE AND SAFER DISSECTION PROCEDURES

THE "JACKHAMMER" MANEUVER. Starting a knuckle is a counterintuitive maneuver for most operators. Although finesse and delicate push and rotation of wires are warranted when traversing a plaque in a patent true lumen or a collateral channel, more abrupt forces need to be applied on a wire to create a dissection, especially after it has started to behave as a coil, to form the knuckle edge. It is often through jerky movements, in the fashion of a jackhammer, with repetitive longitudinal tapping forces applied on the wire that the knuckle will form and progress.

USE OF ORTHOGONAL VIEWS. When performing dissection in a CTO vessel, it is key to ensure that the wire components' (tip, body, and fold) position remains in the vessel structure. Indications of a potential exit of the knuckle include an enlarged knuckle disproportional to the size of the vessel or a wire not "dancing" with the distal true lumen or the calcium, contrast extravasation, and visualization of an increasing distance from the wire and coronary structures such as calcifications, contrast stains, old stents, or surgical clips. Frequent changes of the C-arm position in orthogonal views or the use of biplane views, when possible, will help ensure that the wire is tracking appropriately. If the knuckle does not increase in size but fails to track the distal vessel, the knuckle has deviated toward a side branch, and caution should be exerted to stop the dissection at this point and redirect the knuckle as explained later.

AVOIDING CONTRAST AND SALINE INJECTION. Operators should never inject contrast or saline via the antegrade guide, as a controlled dissection can turn into an uncontrolled one by hydraulic pressurization. Removing the antegrade syringe from the manifold is a simple tip to avoid inadvertent antegrade injection and uncontrolled hydraulic

dissection. If operators are using automatic injectors, they should be used only on the retrograde catheter. Also, blood for activated clotting time should be aspirated from the retrograde guide, as a flush of the catheter after blood withdrawal can extend a dissection.

AVOIDING "EXPLODING" KNUCKLE. An exploding knuckle is one that starts in a compacted form but quickly becomes larger, often larger than the presumed size of the vessel being dissected. Recognizing the behavior early is key, as it indicates an exit from the vessel architecture. With a traveling Gladius Mongo (MG) knuckle, an exit will be evidenced by an awkward and unpredicted unfolding of the distal part of the knuckle, indicating that the wire is not contained anymore into a confined space. Although it may rarely indicate re-entry when dissecting a very large vessel, a retrograde injection will allow the operator to confirm re-entry or a more likely wire exit. If a wire exit is suspected or confirmed, the microcatheter should be pulled back a bit and knuckling reattempted with a soft tapered polymeric wire, starting like a coil, and followed with a rolling technique. Once resistance is felt, the wire is then pushed and elongated. If the wire keeps repeating the same behavior, a nontapered and stiffer polymeric wire can be used if the vessel is presumed to be larger than 3 mm. Otherwise, a wire redirection technique should be considered (**Figure 6**).

KNUCKLE REDIRECTION. If the knuckle is believed to enter branches or go off track, or following the occurrence of an exploding knuckle, a knuckle redirection must be performed. The ambiguity of the course of the vessel at this point will guide wire selection. When ambiguous, we prefer the use of a stiffer nontapered jacketed wire, with a small CTO bend, drilled and directed toward a different segment of the vessel, like toward a clear calcified segment. If feeling resistance, the microcatheter is advanced, and the wire knuckled with a coil and rolling technique. Alternatively, a traveling knuckle technique with a Mongo (MG) can be subsequently performed (**Figure 6**).

Some operators will occasionally use a midgram or stiffer wire to redirect a dissection track. The Gaia Next 2 or 3 (Asahi Intecc), or the Judo 3 or 6 (Boston Scientific) with their high steerability and intermediate tip load can be effective, as they also provide good distal tip feedback, confirming that the wire remains in the vessel structure prior to advancing the microcatheter. Again, these wires should be used judiciously and allowed to advance only 2 to 3 mm beyond the resistant point then be "de-escalated' to polymer-jacketed wires to confirm their presence in the vessel architecture with a proper "dance."

Rotating a knuckled wire should never be performed retrogradely, as it can turn the wire tip into a knot, preventing retrieval of the guidewire into the microcatheter and forcing the operator to pull the wire and retrograde microcatheter altogether and to start over. Although pulling all the retrograde gear from a graft or a septal connection is usually benign, it could have disastrous consequences through an epicardial collateral. In contrast, steering a knuckle antegrade is something that can be tried, especially to redirect a dissection plane; knotting the wire will be less consequential, as the antegrade gear can usually be pulled safely. Operators should be able to track the same antegrade planes already created with new wires.

CARLINO TECHNIQUE. A small tip injection of contrast from a microcatheter can help change tissue compliance and delineate the vessel structure. It is especially useful after successful "coiling" with a soft polymeric tapered guidewire that cannot progress toward elongation or rolling (**Figure 2**). After the collapsing of a wire confirms the proper position in the vessel structure, the wire is removed, and injection of 0.5 to 1 mL of contrast in the area will help confirm the position and initiate the dissection.[18] Taking the wire back or using a stiffer nontapered one may subsequently succeed.

ASPIRATION FROM THE TIP OF THE MICROCATHETER. Although this technique is often essential to mitigate the expansion of a hematoma in the dissection planes prior to re-entry, it may also be helpful during dissection techniques, especially when the knuckle wire seems to "float" into a coronary segment, without progression. Reduction of the hematoma space could provide less opportunity for the microcatheter to deflect backward, increasing the chance that the knuckle can continue moving forward. It will also improve the visualization of the distal vessel target with contralateral contrast injection, to ease subsequent re-entry maneuvers.

BALLOON ANCHORING. Balloon anchoring can be done in several ways. If support is lacking, an anchoring balloon can be inserted into a side branch to increase support for the knuckle push or the microcatheter advancement. If a TrapLiner is used, inflating the balloon will trap the microcatheter in place to facilitate the rolling of a knuckle. Otherwise, a balloon can also be inserted into the proximal

patent part of the vessel (or in the distal tip of the guide) to pin the microcatheter for the same purposes (power knuckle).

ALTERNATING BETWEEN MICROCATHETERS. Although the same microcatheter can sometimes be used from the proximal part of the vessel up to the reentry site, poor progression despite good movement of the wire can indicate microcatheter "fatigue," tip damage, or inadequate properties for the task and should warrant a change of microcatheter. We discourage the use of thinner microcatheters, usually dedicated for the retrograde approach, as they are less resistant to damage or overtorquing and do not dilate the track as well as 3-F microcatheters.

PLAQUE MODIFICATION DURING DISSECTION MANEUVERS. If microcatheters fail to progress into a dissection plane (as opposed to the plaque), the use of a small (≤1.5 mm) balloon, especially one with an ultra-low profile, can help overcome resistant areas after dilatation. However, we do not recommend balloon-assisted microdissection,[19] as intentionally bursting a small balloon can result in the perforation of the adventitial border. With a retrograde approach, the operator can also trap a retrograde wire with an antegrade balloon to facilitate the progression of a retrograde microcatheter. In the same fashion but only when feasible (large septal collateral or saphenous vein graft as a retrograde conduit), an antegrade wire can be trapped with a balloon delivered retrograde. Creating an alternative dissection track is sometimes the only solution that will result in progress of the microcatheter. Finally, the use of a small rotational atherectomy burr (1.25 or 1.5 mm) to modify the resistant area, especially if calcium is present, can be performed by experienced operators. Of note, it is sometimes necessary to cut a few cm of the tip of the Rotawire (Boston Scientific) to allow the burr to reach the area of resistance. Following this, the operator will advance a microcatheter on the Rotawire, remove the Rotawire, and resume the dissection techniques, expecting some progression at the site where they were stalled. Because of differential cutting or ablating properties, the Rotablator (Boston Scientific) burr is expected to shave the calcium while avoiding trauma to the adventitial border. However, such principles have their limit, and aggressive use or bigger burrs can result in dramatic perforation and should be avoided.

INTRAVASCULAR ULTRASOUND. Despite the several characteristics of the shape and behavior of the knuckle (tactile and/or visual feedback), there is no reliable real-time fluoroscopic finding to prove or confirm intra- or extraplaque location of the wire. Although a large rolling knuckle will usually progress extraplaque, smaller ones and traveling knuckles can progress intraplaque. The final dissection route can only be confirmed by intravascular ultrasound examination.[20] As such, bidirectional knuckles and dissection planes during a retrograde procedure do not ensure that both wires are in the same intraplaque or extraplaque space. Intravascular ultrasound can help identify their true location and solve difficult reverse CART.[21]

CONCLUSIONS

More liberal use of the extraplaque and subintimal spaces has resulted in a higher success rate, improved efficiency, and likely reduced complications in complex CTO PCI cases over the past 15 years. Stenting of a subintimal space is associated with a similar risk for long-term major adverse cardiac events compared with intraplaque stenting, supporting the use of dissection as an efficient and safe strategy in CTO PCI.[1,3-9] Although knuckled wires have been incorporated into most operators' technical portfolios, the various nuances had never been described. By better understanding knuckled wire behavior and methods to achieve safe and effective dissection planes, operators will gain a deeper understanding of retrograde or antegrade dissection technique nuances, which are paramount to achieving higher success while keeping the risk for complications as low as possible.

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REFERENCES

1. Azzalini L, Carlino M, Brilakis ES, et al. Subadventitial techniques for chronic total occlusion percutaneous coronary intervention: the concept of "vessel architecture". *Catheter Cardiovasc Interv*. 2018;91:725–734.

2. Azzalini L, Karmpaliotis D, Santiago R, et al. Contemporary issues in chronic total occlusion percutaneous coronary intervention. *JACC Cardiovasc Interv*. 2022;15:1–21.

3. Rinfret S, Ribeiro HB, Nguyen CM, Nombela-Franco L, Ureña M, Rodés-Cabau J. Dissection and re-entry techniques and longer-term outcomes following successful percutaneous coronary intervention of chronic total occlusion. *Am J Cardiol*. 2014;114:1354–1360.

4. Karatasakis A, Danek BA, Karacsonyi J, et al. Mid-term outcomes of chronic total occlusion percutaneous coronary intervention with subadventitial vs. intraplaque crossing: a systematic review and meta-analysis. *Int J Cardiol*. 2018;253:29–34.

5. Megaly M, Buda K, Karacsonyi J, et al. Extraplaque versus intraplaque tracking in chronic total occlusion percutaneous coronary intervention. *Catheter Cardiovasc Interv*. 2022;100:1021–1029.

6. Rempakos A, Alexandrou M, Simsek B, et al. Trends and outcomes of antegrade dissection and re-entry in chronic total occlusion percutaneous coronary intervention. *JACC Cardiovasc Interv*. 2023;16:2736–2747.

7. Walsh SJ, Hanratty CG, McEntegart M, et al. Intravascular healing is not affected by approaches in contemporary CTO PCI: the CONSISTENT CTO study. *JACC Cardiovasc Interv*. 2020;13:1448–1457.

8. Brilakis ES, Mashayekhi K, Tsuchikane E, et al. Guiding principles for chronic total occlusion percutaneous coronary intervention. *Circulation*. 2019;140:420–433.

9. Wu EB, Brilakis ES, Mashayekhi K, et al. Global chronic total occlusion crossing algorithm: JACC state-of-the-art review. *J Am Coll Cardiol*. 2021;78:840–853.

10. Brown C, Wyman RM. How to deal with difficult antegrade issues. In: Rinfret S, ed. *Percutaneous Coronary Intervention for Chronic Total Occlusion: The Hybrid Approach*. Cham, Switzerland: Springer International; 2022:119–131.

11. Galassi AR, Sucato V, Giunta R, et al. When, why, and how to perform wire-based antegrade dissection and reentry technique. In: Rinfret S, ed. *Percutaneous Coronary Intervention for Chronic Total Occlusion: The Hybrid Approach*. Cham, Switzerland: Springer International; 2022:101–106.

12. Walsh SJ. When and how to perform contemporary device-based antegrade dissection and reentry technique. In: Rinfret S, ed. *Percutaneous Coronary Intervention for Chronic Total Occlusion: The Hybrid Approach*. Cham, Switzerland: Springer International; 2022:107–118.

13. Creaney C, Hanratty CG. How to cross the occlusion using a retrograde approach, how to externalize, and how to snare long wires. In: Rinfret S, ed. *Percutaneous Coronary Intervention for Chronic Total Occlusion: The Hybrid Approach*. Cham, Switzerland: Springer International; 2022:199–209.

14. Vo MN, Karmpaliotis D, Brilakis ES. "Move the cap" technique for ambiguous or impenetrable proximal cap of coronary total occlusion. *Catheter Cardiovasc Interv*. 2016;87:742–748.

15. Alexandrou M, Rempakos A, Al Ogaili A, et al. Balloon-assisted subintimal entry (BASE) in chronic total occlusion percutaneous coronary interventions. *Catheter Cardiovasc Interv*. 2023;102:834–843.

16. Roy J, Hill J, Spratt JC. The "side-BASE technique": combined side branch anchor balloon and balloon assisted sub-intimal entry to resolve ambiguous proximal cap chronic total occlusions. *Catheter Cardiovasc Interv*. 2018;92:E15–E19.

17. Alexandrou M, Rempakos A, Al Ogaili A, et al. Use of the Carlino technique in chronic total occlusion percutaneous coronary intervention. *Am J Cardiol*. 2023;207:305–313.

18. Carlino M, Azzalini L. Letter: what is the Carlino technique? *EuroIntervention*. 2023;18:e1388–e1389.

19. Vo MN, Christopoulos G, Karmpaliotis D, Lombardi WL, Grantham JA, Brilakis ES. Balloon-assisted microdissection "BAM" technique for balloon-uncrossable chronic total occlusions. *J Invasive Cardiol*. 2016;28:E37–E41.

20. Song L, Maehara A, Finn MT, et al. Intravascular ultrasound analysis of intraplaque versus subintimal tracking in percutaneous intervention for coronary chronic total occlusions and association with procedural outcomes. *JACC Cardiovasc Interv*. 2017;10:1011–1021.

21. Fan Y, Maehara A, Yamamoto MH, et al. Outcomes of retrograde approach for chronic total occlusions by guidewire location. *EuroIntervention*. 2021;17:e647–e655.

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