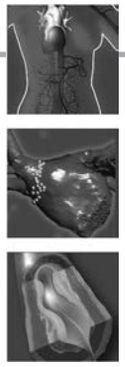

Retrograde approach for chronic total occlusion percutaneous revascularization

Coronary chronic total occlusion represents the most challenging lesion subset for interventional cardiology. Among other new techniques and developments, the retrograde approach via collateral channels in coronary angioplasty for chronic total occlusion can improve recanalization success rates. Most interventionalists will meet few cases where the retrograde approach might provide unequaled advantages, yet many are held back from choosing the retrograde approach owing to a lack of proper equipment and expertise. This article provides a detailed description of all techniques used to traverse the collateral channels and to cross the chronic total occlusion by the retrograde approach. It also illustrates the difficulties in collateral channel crossing using different examples to provide a basic guide for case selection purposes.

KEYWORDS: chronic total occlusion ■ percutaneous coronary intervention ■ retrograde approach

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The retrograde approach via collateral channels in coronary angioplasty for chronic total occlusion (CTO) can improve the recanalization success rate. Most interventionalists will meet a few cases where the retrograde approach might provide unequaled advantages, but many are held back from choosing the retrograde approach owing to a lack of proper equipment and expertise. The retrograde approach requires an intercoronary channel between the occluded artery and another patent coronary artery, which enables the distal CTO site to be reached with retrograde approach. The intercoronary channel may be a septal collateral, an epicardial collateral or a bypass graft.

Although in principle a retrograde CTO crossing is easier than an anterograde crossing because the distal cap is usually softer than the proximal cap [1], a proportion of CTOs remain very difficult to cross even with the retrograde approach. The length, duration and the presence of calcium determines the difficulty in crossing the CTO even with the retrograde approach, and among these, the distribution of calcification is one of the most important issues. The presence of calcium on fluoroscopy usually indicates a long and difficult procedure. This means that multislice computed tomography (MSCT) coronary angiography could be very helpful for understanding the course of the vessel when coronary vessel reconstruction is performed, similar to the angiographic views, especially in very long occluded segments. However, the operator should not feel discouraged in the presence of some long and difficult-looking lesions. If a good retrograde collateral channel is available and a large amount of calcium is not displayed, a very difficult CTO with an anterograde approach might often be surprisingly easy on retrograde approach. The recanalization rate increases even further when one combines a retrograde and an anterograde approach. However, it is important to be aware that the retrograde approach is not a 'curiosity' or a trick to show operative skills in live demonstrations. Although the technique is conceptually simple, its intricate and demanding requirements discourage its application without adequate proctorship [2]. Furthermore, the steep learning curve arises not only from the unaccustomed route used to approach the occlusion but also from the specific procedural material requirements and techniques.

Indication for retrograde approach

The proximal fibrous cap is usually thicker and harder than the distal cap [3]. Furthermore, the distal fibrous cap is typically tapered, therefore when the operator views it from the proximal side it looks like a convex shape. This feature, especially if calcium and fibrous tissue are present at the location, can cause the wires problems when they are pushed anterogradely, as they are redirected into the subintimal space. The proximal and distal cap characteristics are the main reason why the retrograde approach has been developed and has gained successful application in percutaneous CTO recanalization.

In our practice, an anterograde approach is generally tried first. If anterograde dissection expands to the distal true lumen or if

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wire perforation occurs, a retrograde approach should be performed as a secondary approach. Angiographic factors that contribute to success include the shape and the characteristics of the distal cap, the presence of well-developed collaterals, the presence of nontortuous epicardial collaterals and a healthy donor vessel. Of course, other factors include having knowledge of dedicated materials and techniques besides the operator's skill and experience. Conversely, unfavorable angiographic factors consist of not having clear collateral visualization, corkscrew and angulated collaterals, calcified donor vessel, distal vessel CTO bloodflow originating exclusively in collateral vessels used for the retrograde approach, the presence of multivessel disease and prior stenting in the donor vessel or presence of a bifurcation lesion at the CTO distal cap (CTO exit) (Box 1). Furthermore, we suggest that the presence of left main coronary artery disease should be assessed accurately, even if a mild disease is discovered, the retrograde approach should be contraindicated. Continuous back and forth movements with the guiding catheter in the ostium of the left main artery might adversely and irreversibly affect it, creating more complications.

A retrograde approach could be indicated as the primary approach to perform when the anatomical factors make anterograde wiring appear too difficult (a complex CTO) or, as a reattempt after previous failure, considering all favorable and unfavorable factors.

Use of collaterals for the retrograde approach

To provide an estimate of size, coronary collaterals were measured by Werner *et al.* with an electronic caliper on enlarged still images: CC1 collaterals were less than or equal to 0.3 mm in diameter and CC2 were greater than or equal to 0.4 mm [4]. When a retrograde channel is going to be used as a preferential pathway for percutaneous coronary intervention (PCI), it is generally viewed throughout its grade CC1 and CC2 course. Furthermore, CC1 and CC2 are commonly found in CTOs. Werner *et al.* reported them in approximately 85% of the cases [4]. With the improved recent angiographers resolution, this percentage is going to increase even further. However, in the remaining cases when the collateral course is not clearly detected (CC0), a retrograde approach can still be attempted. Indeed, it is not rare to use a soft hydrophilic guidewire and super-selective dye injection from a microcatheter might be able to identify a suitable collateral channel for retrograde recanalization that is difficult to see with a standard bilateral contrast injection.

The tortuosity of the collateral channel as well as the presence of calcifications into the donor vessel are some of the biggest contributors to difficulty and increased procedural risk. The placement of a microcatheter, especially a dedicated one such as Corsair™ (Asahi Intecc Co., Japan) within the collateral channel may favor its stretching, allowing a guidewire to advance easily even in very tortuous collaterals. Indeed, collateral channels might sometimes be difficult to negotiate and also might be prone to rupture when dilated. Septal collateral channels tend to be less tortuous than circumflex, right coronary artery (RCA) or epicardial collaterals. However, it is also important to take multiple orthogonal views of the collateral channels before starting a retrograde procedure, as some straight-looking collaterals can be Z-shaped in another view. Septal channel crossing is reasonably safe and dilatation does not appear to increase complications; rather, it is pushing through an over-the-wire (OTW) support catheter that might result in rupturing the channel.

Box 1. Factors contributing to the success of retrograde approach.

Favorable

- Nontortuous epicardial collaterals
- Donor vessel is healthy
- Knowledge of dedicated materials and techniques
- Operator skill and experience
- Shape and characteristics of the distal cap
- Werner's class collaterals type: CC1 and CC2

Unfavorable

- Werner's class collaterals type: CC0
- Corkscrewing and angulated collaterals
- Blood flow in distal vessel chronic total occlusion originating exclusively from collaterals used for the retrograde approach
- Multivessel disease and prior stenting in donor vessel (left main coronary artery disease)
- Presence of bifurcation lesion at distal cap (chronic total occlusion exit point)

When an intramyocardial channel ruptures or punctures, no major complications are shown [5], whereas if an epicardial collateral channel ruptures it can lead to cardiac tamponade. In addition, tortuous epicardial collaterals can lead to the 'accordion effect', with occlusion and subsequent ischemia even when using new dedicated wires such as the Fielder™ FC and XT (Asahi Intecc). Therefore, epicardial collaterals with a reasonable size and with minimal tortuosity are generally recommended for this approach [6].

Septal collateral channel crossing is also easier to achieve with the left anterior descending artery (LAD) than the RCA rather than the other way round, as LAD septal origin is generally free of tortuosity and with a smaller angle take-off compared with RCA septal collateral often arising with considerable tortuosity. It is also generally easier to be certain that the retrograde wire is in the RCA than in the LAD as the wire travels along the C-shaped RCA curve after crossing the collaterals.

Finally, it is always better to choose the shorter of the two collateral channels because this improves support and the possibility to succeed in crossing the CTO. The criteria for easy collateral channel crossing are summarized in **Box 2**.

Different strategies of retrograde approach

■ System setup

In general, two 7 Fr standard guiding catheters are placed into both coronary ostia. We recommend using both guiding catheters with side holes to allow improved blood flow to the myocardium. If the guiding catheter with side holes is not available, the creation of side holes may be performed manually on standard catheters using a 21 G × 11/2 needle, on the side of the catheter at the beginning of the curve, approximately 6–8 cm from the tip of the catheter. However, other operators prefer to use guiding catheters without side holes in order to reduce mean contrast dose administrated. Shortening the guiding catheter to 85–90 cm in length may be adopted, taking advantages of the use of standard OTW balloons for retrograde approach (see below for a detailed description of the shortening technique).

■ Crossing the collateral channel

In our practice, a microcatheter is inserted into the target collateral artery with the aid of a Runthrough NS™ floppy wire (Terumo, Japan). Regarding the use of the microcatheter, we prefer to choose one that is softer, but not prone to kinking, just in case the retrograde artery is considerably tortuous. Usually, we exchanged the Runthrough with a plastic-jacket hydrophilic guidewire (Fielder, Fielder FC, Fielder XT [Asahi Intecc], or Whisper® LS or MS [Abbott Vascular, IL, USA]) as soon as the wire reaches the collateral branch. In some cases, the Runthrough wire could reach the distal target artery to the CTO lesion. In other situations, a plastic jacket hydrophilic guidewire could be used from the start. The hydrophilic guidewire has an approximately 45° bend at the tip. It is not often easy to select the best collateral channel to engage. Generally, it is almost always better to choose the shorter of the two collaterals as this improves the support. Nevertheless, the angle of take-off between the origin of the collateral channel and the main branch vessel is an important issue, which might increasingly affect the procedure result. Indeed, a 90° angle take-off does not often provide sufficient support to allow the guidewire to progress easily into the collateral channel. Generally, if no collateral engagement is obtained within several minutes of trying, a small volume of contrast dye following nitrates is injected through the guiding catheter after withdrawing the microcatheter from the main vessel, to visualize the collateral connection. This so-called 'nonselective injection' has the advantage of allowing the operator to visualize the position of the wire tip in relation to the collateral channel anatomy. This technique may be very useful in dealing with the most proximal part of the collateral channel, particularly when there is a lot of branching in the septal collaterals, but not enough to see the distal channels.

Alternatively, a 'selective injection' is performed by pushing the microcatheter down the collateral channel and pulling out the wire. A 2-ml Luer Locker syringe filled with 1 ml of contrast is connected to the end of the microcatheter and sustained negative pressure is applied until blood flushes back into the syringe. This takes some minutes as the collateral channels are small and

Box 2. Criteria for easy collateral channel crossing.

- Clearly visible
- Nontortuous
- Proximal septal collateral channel
- Preferably from the left anterior descending artery to the right coronary artery
- Blood flow not exclusively originating from collateral vessels used for the retrograde approach

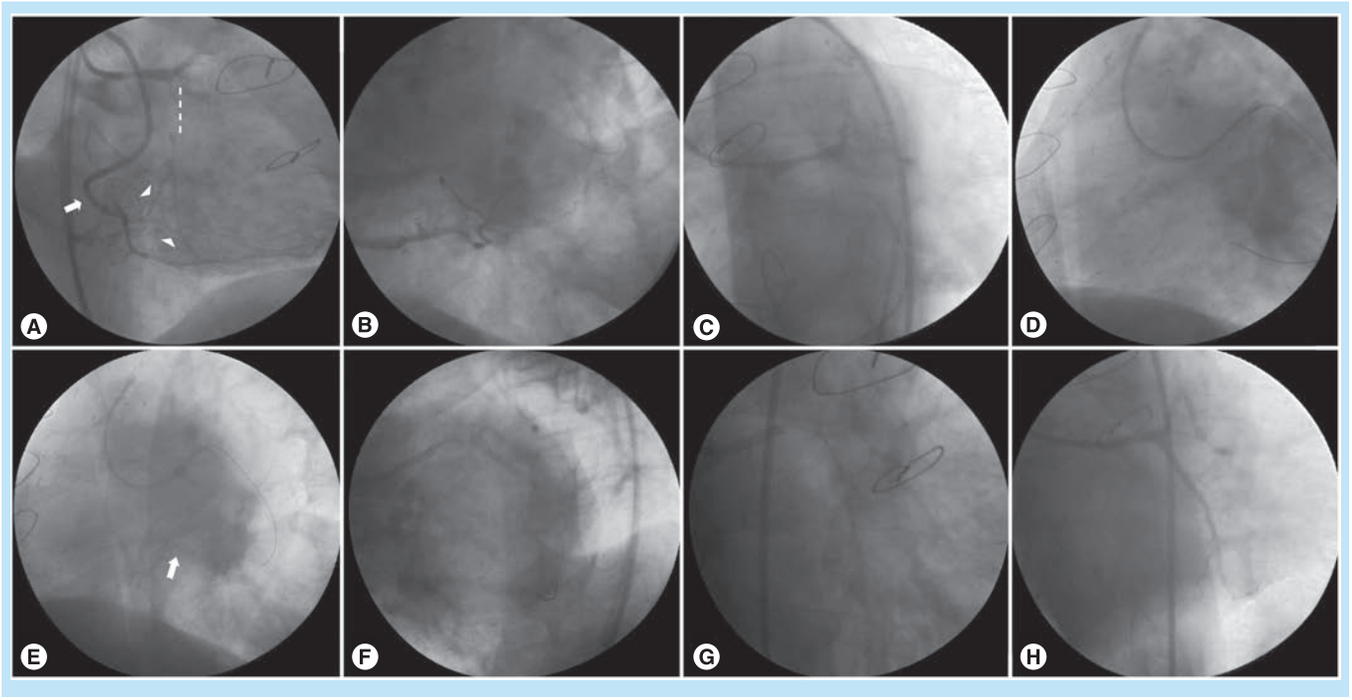

Figure 1. Pure retrograde technique. (A & B) Left circumflex artery chronic total occlusion (dotted line) with collateral circulation from native right coronary artery (arrowheads). **(C)** The lesion was approached by retrograde through a collateral branch with a floppy hydrophilic guidewire (Runthrough) inserted in an Echelon microcatheter, which was exchanged with a stiffer one that was able to advance up to the left circumflex artery ostium. **(D)** The retrograde guidewire crossed the proximal cap of the occlusion and it was advanced into the anterograde guiding catheter. **(E)** The retrograde microcatheter was exchanged with a low profile balloon (arrow), which was advanced through the vessel performing multiple dilatations by retrograde. **(F)** Afterwards, an anterograde floppy guidewire was advanced, the retrograde wire was withdrawn and multiple dilatations were started. **(G)** Drug-eluting stent implantation was started. **(H)** Final result after drug-eluting stent implantation.

blood flow is slow. Next, the contrast is injected into the support catheter and a selective channel angiogram is undertaken. The advantage of this technique is that the invisible channels often open up with selective injection, showing the operator a way to cross the collateral channels. However, with selective injections we cannot see the wire tip and its relationship with the anatomy. When the wire is placed into the microcatheter, the wiring continues under the guidance of our roadmap from the previous injection. Selective injections are generally used when the wire passes more than halfway through the collateral channel and nonselective injection can elucidate the path or if it appears likely that the septal will rupture. Nevertheless, selective injection in the collateral channel might also carry a possible, albeit small, risk of septal channel dissection, which increases if the small channel has a tortuous bend.

After the retrograde wire crosses the collateral channel and reaches the distal CTO lesion target artery, an attempt could be made to pass the microcatheter if the collaterals seem large enough. If there is no success, the microcatheter is exchanged with a 0.85-, 1.0- or 1.25-mm OTW balloon for septal channel dilatation and inflated at low pressure (maximum 2–3 atm). Subsequently, gentle pressure is put into the system so that during heart contraction the balloon might slowly advance allowing several dilatations at different channel sites, then eventually permitting the balloon to pass. Alternatively, if neither the microcatheter nor the balloon cross, the use of the septal dilator catheter (Corsair) might be employed [7]. This is a microcatheter also available in the USA that is designed for collateral channels. It has a tapered tip and screw head structure, which reinforces torque transmission and creates better backup support in penetrating the CTO.

The use of the channel dilator catheter might contribute to reducing the contrast load and radiation exposure, providing a high procedural success rate, in order to improve crossability and backup support for the retrograde guidewire. Moreover, the Corsair eliminates the need for channel dilatation in most cases. Indeed, the use of this catheter might be employed from the beginning of procedure, reducing the need for the use of standard microcatheters. After crossing the collateral channel with either a standard microcatheter, balloon or the channel dilator, the catheter is delivered into the distal coronary

artery and the soft wire can then be exchanged for a stiffer one, which may be used to cross the occlusion in a retrograde fashion.

Pure retrograde technique

This recanalization technique uses a retrograde approach with a single wire, without a simultaneous anterograde approach. Certainly, after recanalization, the anterograde wire is passed through the occlusion, performing the standard PCI procedure (Figure 1). Although this is the most elegant and neat method of retrograde recanalization, the success rate has not been as high in the past. However, the success rate is expected to increase significantly by using the channel dilator catheter. Indeed, using the Corsair, a soft hydrophilic wire might also be left in place and forced into the occlusion. The greatest advantage of this device is that it reinforces guidewire torque transmission and it creates better backup support penetrating the complex lesions retrogradely. With the soft hydrophilic guidewire, penetration may occur in a manner similar to the modified Knuckle technique (see later) because the distal fibrous cap is usually less resistant than the proximal cap; therefore, it is easier to cross with a soft hydrophilic wire, but it is also able to reach the true lumen shortly after crossing the proximal cap.

Alternatively, when using a standard microcatheter or an OTW balloon, the softer hydrophilic wire is exchanged with a stiffer wire. This is due to the long access and occasional loop route of the retrograde wire via an intercoronary channel, its poor maneuverability and the difficulty of leading it through the CTO lesion without the use of a stiffer wire. However, among stiff wires, the Miracle™ guidewires (Asahi Intecc) that use the drilling strategy are generally preferred, compared to Confianza guidewires (e.g., Conquest™, Asahi Intecc) that use the penetration strategy to advance and are therefore more cumbersome to employ when maneuverability is impaired. A step-up approach is generally suggested starting with a Miracle 3, then moving to a Miracle 4.5, 6 or 12 if the distal cap is too hard to cross. If the operator needs to redirect the retrograde wire away from the side branch of a bifurcation at the distal CTO they could exchange it for a Confianza. Finally, this technique is preferred in an ostial CTO situation, or retrograde venous bypass graft reopening, owing to the lack of anterograde engagement.

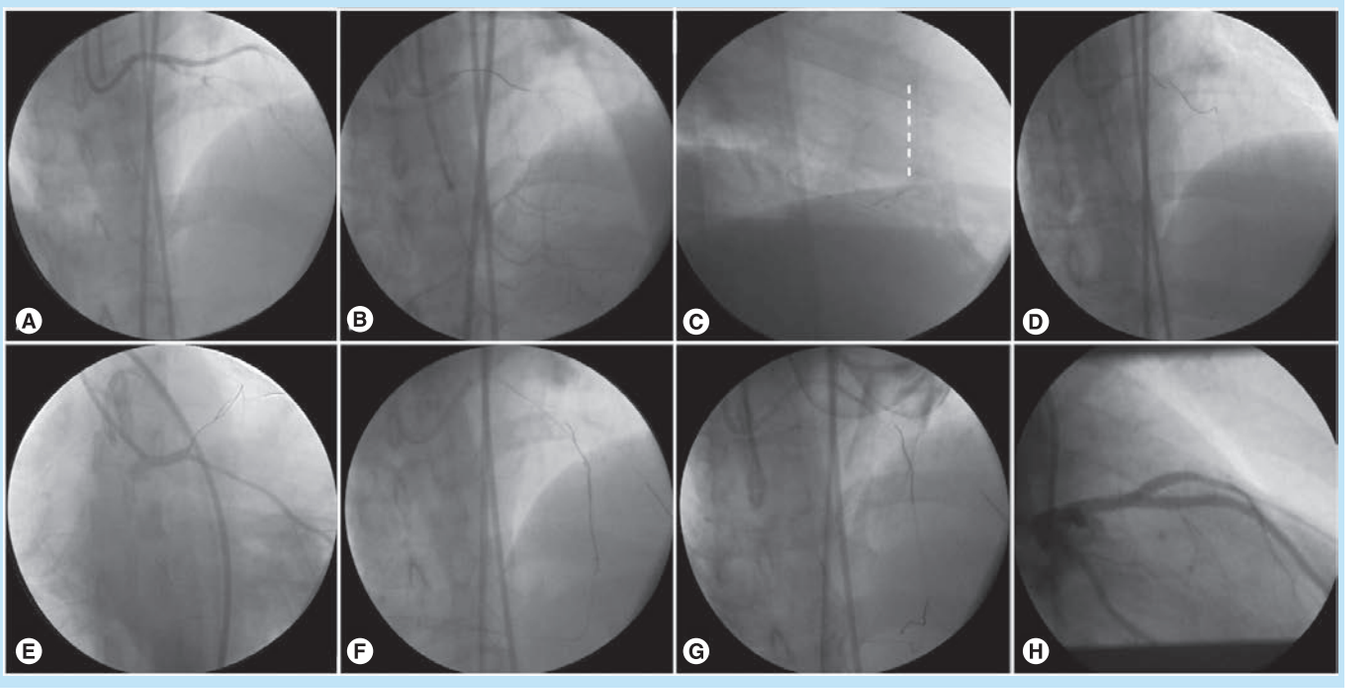

Figure 2. Kissing wire technique. (A) Left anterior descending artery proximal occlusion with ipsilateral circulation. **(B)** The lesion was approached by anterograde using a soft hydrophilic guidewire (Fielder), which was not able to get through the occlusion. **(C)** Contralateral contrast mean injection from the microcatheter was performed to visualize the retrograde collateral circulation (dotted line). **(D)** A retrograde hydrophilic guidewire (Runthrough) inserted in an Echelon microcatheter was advanced up to the distal cap of the occlusion. **(E)** The retrograde wire was used as a landmark for the advancement of the anterograde wire. Subsequently, an intermediate-stiffness guidewire (Medium) with a microcatheter was inserted in order to perform the kissing wire technique. **(F)** Medium guidewire was able to cross the occlusion by anterograde. **(G)** Medium guidewire was exchanged with a floppy guidewire (Prowater flex) and subsequently, multiple dilatations with balloons were executed. **(H)** Final result after drug-eluting stent implantation.

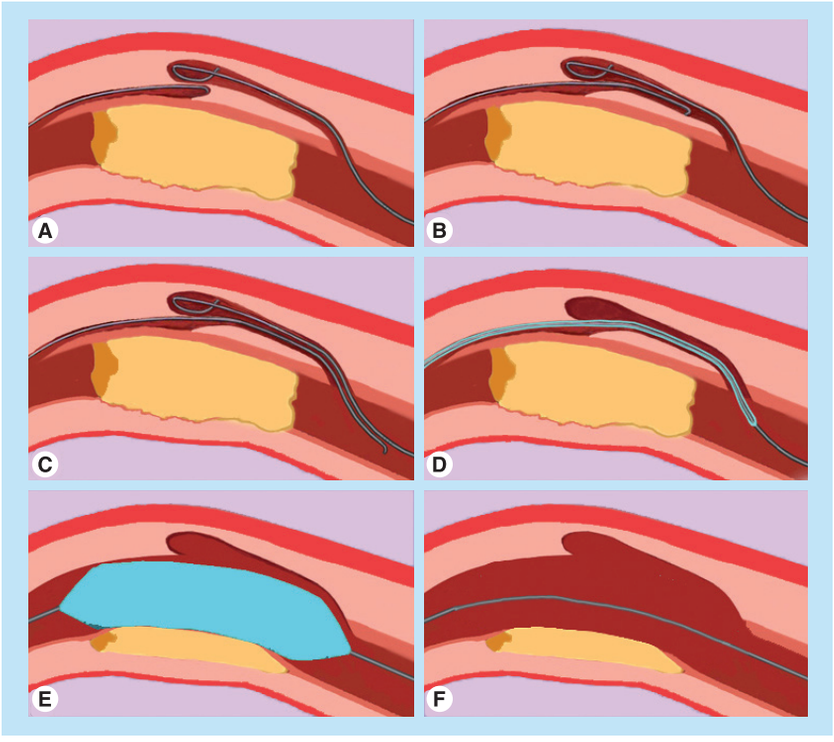

Figure 3. Cartoon scheme of knuckle technique. (A) After a failed antegrade approach, a bent tip retrograde wire is advanced in a knuckle shape, dissecting the subintimal space. **(B)** After such a dissection is created the antegrade wire is passed through the dissected lumen created by the knuckle wire. **(C)** The antegrade wire is passed into distal true lumen. **(D)** The balloon is advanced into the dissected flap. **(E)** The balloon is inflated. **(F)** Result after dilatation.

After crossing the occlusion, the distal end of the guidewire may be captured in the anterograde guiding catheter by some cumbersome maneuvers and trapped by a balloon anterogradely advanced in the guiding catheter; this is known as 'guidewire catheter trapping'. Anterograde balloon insertion may be performed without the use of a guidewire if the balloon is inflated within the guiding catheter before the side holes [8]. Although the best maximal tracking effect is achieved if the retrograde wire can be manipulated into the anterograde guiding catheter, two alternatives may be employed to the standard guidewire catheter trapping technique.

First, the guidewire may be pushed all the way up the aortic arch. The curve of the arch acts as a bend and provides friction to track the wire. This is usually possible with soft wires but if a stiff wire is used, careful attention should be paid to its tip, as it may damage the aorta endothelium.

Second, capturing the retrograde wire may be carried out using the loop snare guidewire retrieval system with the 'retrograde wire insertion in anterograde device' technique. Indeed, if the guidewire catheter trapping technique is not employed, the retrograde guidewire may lack necessary support for the balloon catheter to advance. On the contrary, a different method to generate the strongest backup support for the balloon catheter retrograde passage is the 'reverse anchoring balloon technique' [9]. Another balloon is inflated anterogradely in the lumen proximal to the CTO lesion, therefore anchoring the retrograde guidewire and generating enough support for the retrograde balloon to advance. In order to perform this technique, the occlusion site should be located at the mid to distal part of the vessel. Finally, a small OTW balloon 0.85–1.0–1.25 mm with a 150–155 cm long shaft is generally employed to dilate the occlusion retrogradely if normal guiding catheters are used. As mentioned at the beginning of this section, after obtaining retrograde recanalization, a soft-to-medium hydrophilic wire is passed anterogradely through the occlusion before a standard PCI procedure is performed.

Third, externalization of the retrograde wire through the guiding catheter placed into the donor vessel might be accomplished, especially if using Corsair as a dedicated microcatheter for the retrograde approach. In our experience with this technique, a 300-cm long guidewire (such as BMW Universal [Abbott Vascular, USA]), is generally used to cross the CTO from the donor vessel guiding catheter all the way up to the opposite femoral access and externalizing the wire. Next, a small RX balloon 0.85–1.0–1.25 mm with a 150–155-cm long shaft is slid onto the wire and advanced up to the tip of retrograde Corsair. Then, a new anterograde balloon is advanced through the CTO while the retrograde Corsair will be pulled back up to the collateral vessel. In order to remove the retrograde wire, an OTW balloon or a dual lumen microcatheter should be advanced anterogradely while the retrograde Corsair is pulled back from the retrograde system. This process should go ahead simultaneously so as to not transmit guidewire tension directly to the arterial wall, reducing the risk of cutting the artery owing to the retrograde wire pulling back, especially in cases of hydrophilic guidewire use, which may also be used. Rotawire® (Boston Scientific, MA, USA) generally provides a safer approach and could represent a reasonable alternative.

Kissing retrograde technique

This technique combines the anterograde and retrograde approaches simultaneously. If the CTO lesion is relatively soft, the retrograde wire could advance easily, stopping it halfway. If the tip of retrograde wire comes near to the CTO proximal end, maneuvering the anterograde guidewire will make both anterograde and retrograde guidewires meet in order to obtain the recanalization of CTO.

Sometimes, unexpectedly, if the anterograde and retrograde wires are in different layers, it is difficult to align them owing to the same reason explained in the anterograde approach (Figure 2).

The 'landmark retrograde technique' is a type of 'kissing' wire because the retrograde wire is used as a landmark for the anterograde guidewire, which is the only wire to advance [10,11]. Instead, the actual kissing wire technique advances both of the guidewires into the occlusion, with each one trying to meet the opposite wire. The landmark retrograde technique is generally used to reduce the use of contrast dye. After the anterograde wire crosses, the balloon catheter is advanced into the occlusion and dilatation is performed in the standard way.

Knuckle technique

This is a variation of the controlled anterograde and retrograde subintimal tracking (CART) technique (see later), where a dissection of the subintimal space is created by forming a loop in the retrograde wire that is then advanced to the occluded segment (Figure 3). The principle is the same as the subintimal tracking and re-entry (STAR) technique from the anterograde approach with the positive lack of flow to propagate the dissection distally [12]. For this technique, soft hydrophilic wires are preferable, especially if there is good back-up support from the retrograde microcatheter, such as with a channel dilator. In a few cases, this retrograde wire may succeed in crossing the lesion, opening up the occlusion and successfully recanalizing the artery without the need of any other anterograde work. However, an anterograde stiff wire is generally required in order to get through the dissected lumen created by the knuckle wire. Work should be performed to re-enter the true lumen. After crossing the anterograde wire, a balloon catheter is advanced into the occlusion and is dilated in the standard way (Figure 4). It is worth noting that this technique is not adopted by Japanese operators as frequently as it is by European operators.

Controlled anterograde & retrograde subintimal tracking technique

As previously mentioned, CART combines the simultaneous use of the anterograde with the retrograde approach. The basic idea regarding the CART technique is to create a subintimal dissection with limited extension only at the CTO site (Figure 5) [13,14].

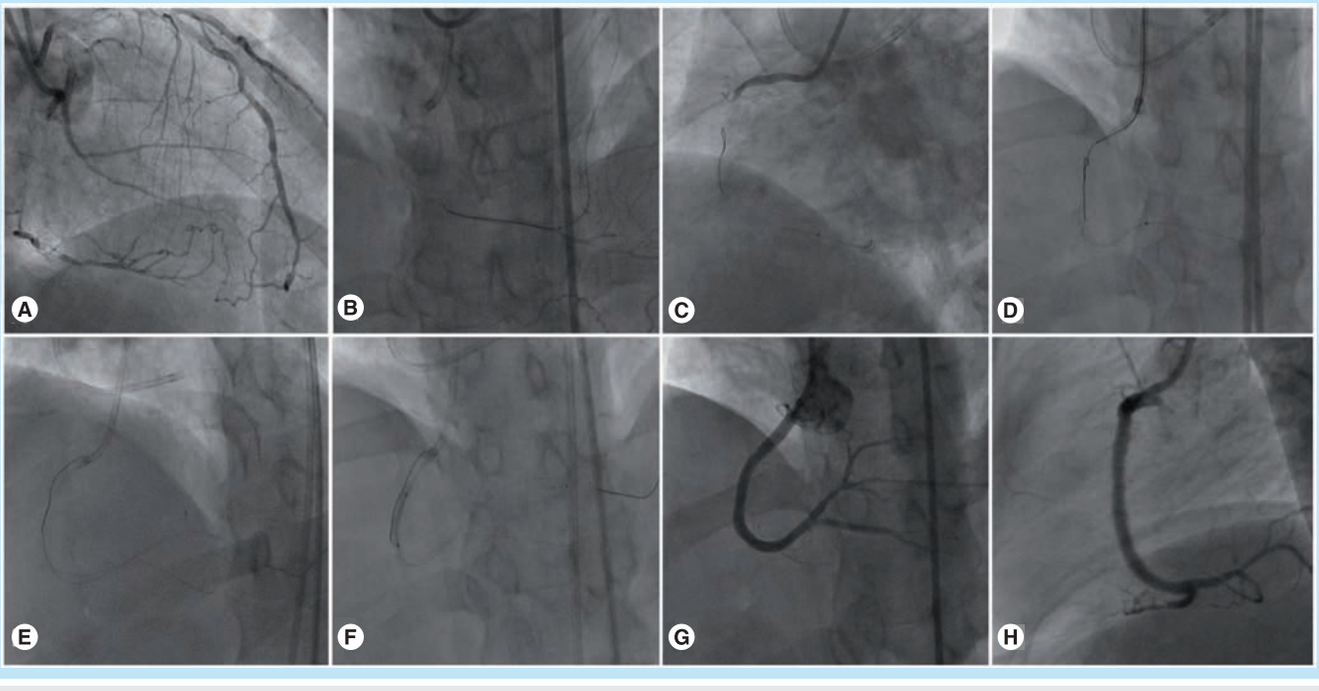

Figure 4. Knuckle technique. (A) Mid-right coronary artery occlusion with collateral circulation from septal branches. **(B)** Lesion engagement by retrograde approach through a collateral branch with a Fielder FC guidewire inserted in an Echelon microcatheter. **(C)** The retrograde wire was advanced up to the proximal part of the occlusion but it was not able to cross it; thus, the microcatheter was exchanged with a low profile balloon (Falcon 1.0 × 10 mm) and after multiple attempts at advancing the guidewire, a loop was made at its tip. **(D)** An anterograde stiff wire (Conquest Pro 9) with an Echelon microcatheter was advanced in order to perform the knuckle technique. **(E)** The anterograde stiff guidewire crossed the entire occlusion successfully and it was subsequently exchanged with a softer one. **(F)** Multiple dilatations with balloon by anterograde were then started. **(G & H)** Final result after drug-eluting stent implantation. Reproduced with permission from [26].

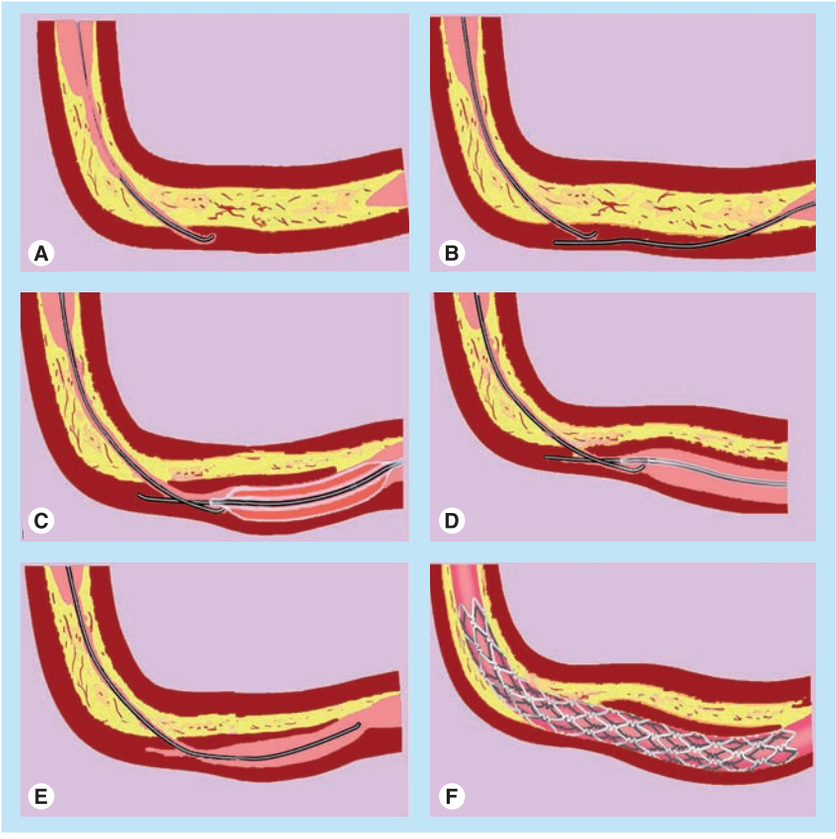

Figure 5. Controlled anterograde and retrograde subintimal tracking technique. (A) A wire is advanced anterogradely, reaching the subintimal space at the chronic total occlusion (CTO) proximal cap. **(B)** Another wire is advanced through the collateral channel and after being exchanged with a stiffer wire it is placed into the subintimal space at the CTO site. **(C)** A small-sized balloon up to 2 mm in diameter over the retrograde wire in the subintima is inflated near to the CTO distal end. **(D)** The deflated balloon is left in place to keep the subintimal space open. **(E)** Subsequently, the anterograde guidewire is advanced along to the deflated retrograde balloon. **(F)** Dilatation and stent implantation is performed with the stent positioned partly across the dissected CTO plane.
Reproduced with permission from [26].

First, a wire is advanced anterogradely; usually it reaches the subintimal space at the CTO proximal cap or within a few millimeters of the occlusion. Second, another wire is advanced through the collateral channel and after being exchanged with a stiffer wire it is placed into the subintimal space at the CTO site. After advancing a small balloon (1.0–1.25–1.5 mm) over the retrograde wire in the subintima, the balloon should be inflated in the subintima and also on the course from this subintimal space to the CTO distal end. One recommendation to keep this subintimal space open, is to leave the deflated balloon in place. This makes it easier to advance the anterograde wire further along the deflated retrograde balloon, which lies from the subintimal space to the distal true lumen CTO (Figure 6). This technique allows limited subintimal tracking situated only in the portion of the CTO lesion, and avoids problems when re-entering into the distal true lumen. After successful recanalization, dilatation and stent implantation are performed with the stent positioned partly across the dissected CTO plane.

Reverse controlled anterograde & retrograde subintimal tracking technique

A reverse approach of the standard CART consists of dilating the balloon that is in the subintimal space, within the CTO lesion anterogradely, instead of retrogradely, in order to make the target space for the retrograde guidewire penetration (Figure 7) [8]. Nevertheless, guidewire manipulation is more difficult through the retrograde than the anterograde approach owing to the long course, and there are many angulations over the entire course of the retrograde path. This is why this technique was hardly ever performed in the past. The channel dilator catheter Corsair has recently been approved in Europe and the USA. As the channel dilator catheter Corsair is dedicated to selective collateral channel engagement, it has made this approach the most favored among Japanese interventionalists. Indeed, Corsair reinforces torque guidewire transmission, creating better backup support to penetrate the CTO, therefore favoring retrograde true lumen penetration. However, if retrograde subintimal dissection occurs, the retrograde wire may still find its way out of the true lumen vessel if a balloon is inflated in the subintima anterogradely. The main advantage of the reverse CART is that the channel dilator easily tracks the retrograde way without the disadvantages and difficulties involved in advancing a balloon catheter retrogradely. Conversely, the balloon catheter can easily find the dissection way from the anterograde approach. A hydrophilic wire is generally used to cross the channel collaterally. It should be emphasized that anterograde dye injection should never be carried out before stenting owing to its character of iatrogenic dissection; otherwise, the anterograde dissection might be expanded. For the purpose of stent position, contralateral injection should be performed.

Intravascular ultrasound use in retrograde chronic total occlusion recanalization

A novel modification of retrograde recanalization by intravascular ultrasound (IVUS)-guided reverse CART has been recently proposed by Japanese operators [15]. IVUS guidance can be used for crossing the retrograde wire to the anterograde true lumen via the subintimal connection

and it also allows estimation of the optimal balloon size of the anterograde balloon after predilatation with a small balloon matching the vessel size for making medial disruption, thereby reducing the risk of perforation. Moreover, the use of IVUS, compared with conventional retrograde procedures also reduces the use of contrast medium to nearly a half [15, 16].

Tips & tricks for the retrograde approach

To facilitate anterograde or retrograde wire passage into the subintimal space, a bigger size balloon is preferred to make the dissection easier (2 mm diameter). This is why the reverse CART technique can be adopted more easily. Indeed, a 2.0 balloon may be difficult to advance retrogradely instead of anterogradely. Furthermore, in calcific donor main coronary artery, retrograde channel dilators might cause problems along the advancement. A buddy wire technique in the donor vessel may be adopted in order to reduce friction and to successfully strengthen the vessel course.

■ Drawbacks of the retrograde approach

The biggest drawback is requiring a second guiding catheter (usually ≥7 Fr) in the donor artery or healthy coronary artery. One of the biggest complications is when the proximal coronary artery dissects from the tip of the guiding catheter. The consequences may be disastrous if prompt recanalization is not obtained with the stenting procedure. Thus, attention should always be paid to the coronary ostium, making sure multiple views of the left main artery are provided, especially in the case of multivessel disease. Indeed, patients treated for CTO are generally those with multivessel disease and multiple risk factors, in whom an unrecognized left main disease may often be found.

Second, if the patient has multivessel disease and there is indication for PCI CTO, which has been treated first according to our standard procedure and is unsuccessful, we can still take the patient to surgery and achieve complete revascularization. However, in order to perform the retrograde approach safely, tight or even moderate

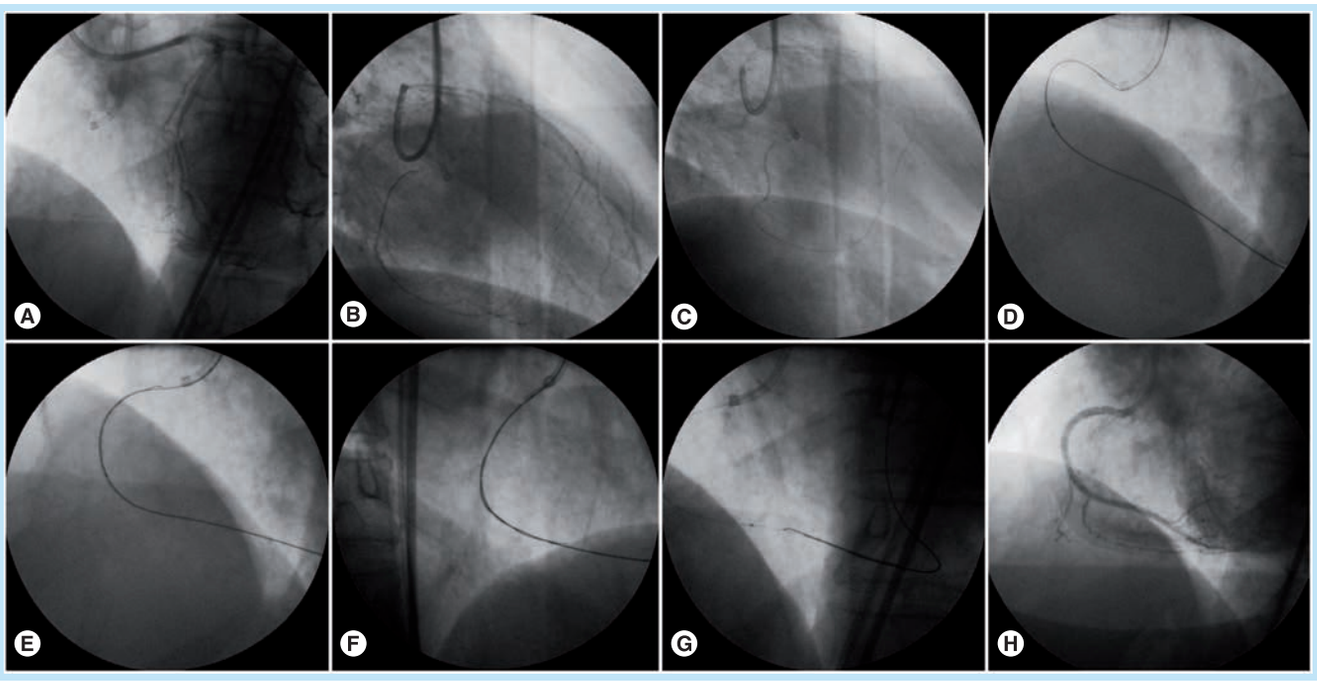

Figure 6. Controlled anterograde and retrograde subintimal tracking technique. (A) Right coronary artery ostium chronic total occlusion with collateral circulation from septal branches. **(B)** Approach of the lesion by retrograde through a septal branch with a floppy hydrophilic guidewire (Runthrough) inserted in an Echelon microcatheter. **(C)** Microcatheter did not advance through the collateral branch, thus it was exchanged with an over-the-wire low-profile balloon (Falcon 1.0 × 14 mm), which was advanced up to the distal cap of the occlusion. **(D)** Runthrough was exchanged with a stiff nonhydrophilic guidewire (Miracle 4.5), which was able to cross the occlusion. However, the guidewire could not be advanced into the right coronary artery-guiding catheter because it was in a different plane. Therefore, a stiff guidewire (Conquest Pro 9) was inserted by anterograde with a microcatheter to perform the kissing wire technique. **(E)** The anterograde stiff guidewire was not able to penetrate the true lumen; thus, the retrograde balloon was inflated in order to perform the controlled anterograde and retrograde subintimal tracking technique. **(F)** The anterograde guidewire was able to pass through the occlusion. **(G)** The stiff anterograde wire was subsequently exchanged with a floppy guidewire and multiple dilatations with different balloons were started. **(H)** Final result after drug-eluting stent implantation.

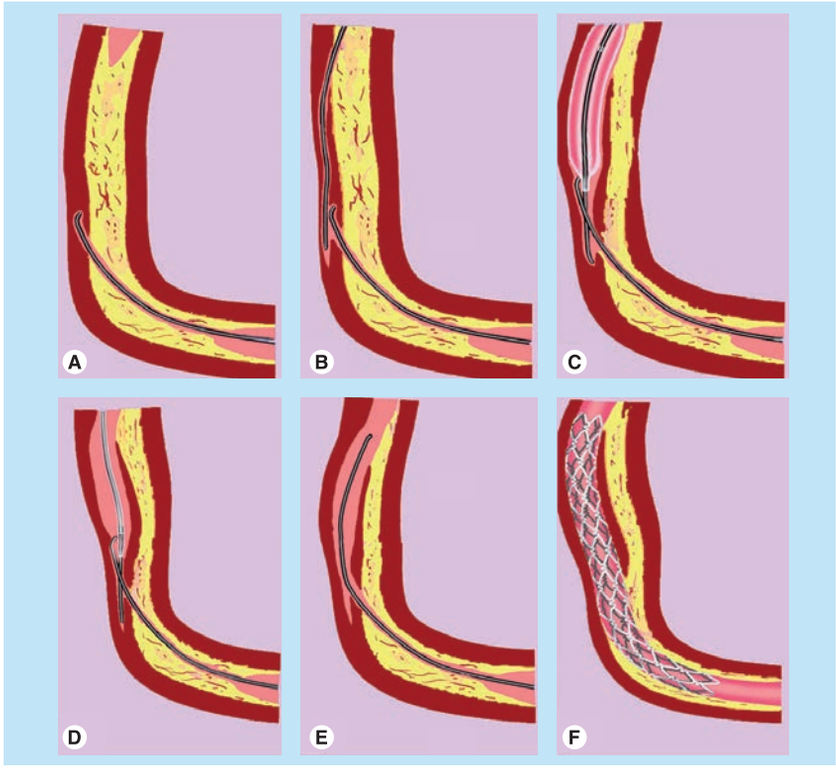

Figure 7. Reverse controlled anterograde and retrograde subintimal tracking technique. (A) A wire is advanced retrogradely through the collateral channel, reaching the subintimal space at the chronic total occlusion (CTO) distal cap. **(B)** Another wire is advanced anterogradely and it is placed into the subintimal space at the CTO site. **(C)** A small-sized balloon up to 2.0 mm in diameter over the retrograde wire in the subintima is inflated near to the proximal CTO site. **(D)** A good suggestion to keep this subintimal space open is to leave the deflated balloon in place. **(E)** Subsequently, the retrograde guidewire is advanced along to the deflated anterograde balloon. **(F)** Dilatation and stent implantation are performed with the stent positioned partly across the dissected CTO plane. Reproduced with permission from [26].

stenosis in the donor artery should first be treated to prevent severe ischemia during the retrograde approach. In addition, if the CTO retrograde approach is unsuccessful, the patient will not be completely revascularized. This issue could often be raised and discussed appropriately before starting the procedure.

Third, owing to long stasis or handling the guiding catheter, the guidewire and the balloon catheter, thrombosis may occur in the coronary artery from which the collateral channel arises and determines profound and severe ischemia. This is a life-threatening condition that should never occur. Therefore, the activated clotting time should be measured every 30 min and last longer than 300 s, achieved by intravenous bolus injection of heparin.

■ Guiding catheter shortening

Shortening the guiding catheter might be needed if a retrograde approach is used and is required to reach the occlusion with a standard length balloon. This is generally performed by cutting 10 cm or more from the guiding catheter and connecting the two cut ends (a 6 Fr sheath for a 7 Fr catheter and a 7 Fr sheath for a 8 Fr catheter) [17]. After flushing and preparing the sheath with the dilator inside the sheath, a 2.5–4.0 cm section of the sheath is cut. The dilator/introducer ensures that the sheath does not crease whilst cutting. Then, the dilator/introducer is pushed out from inside the sheath segment with arterial forceps. Both ends of the sheath are dilated by forcefully inserting the forceps into the segment of the sheath in a rotating manner. The aim is to flare out the ends of the sheath segment so that it could accommodate the larger sized guide. Flaring can be assisted by a small longitudinal cut along the ends of the sheath. Having dilated and flared out both ends, the guiding catheter cutting is completed.

In most cases, a 10-cm guiding catheter is removed approximately 2 cm away from the proximal end of the guiding catheter. However, if the CTO is very close, it is recommended to cut more of the catheter off. With this type of maneuver the guiding catheter is often wrinkled when cutting with scissors, but the shape of the cut edge could easily be restored by gently squeezing in a 90° vector of the cutting scissors. The gentle insertion of the arterial forces to open up the lumen is also helpful, but care must be taken not to flare out the ends. The cut sheath segment is now applied to the two ends of the cut guiding catheter and by pushing firmly will connect the two segments together. A sharp aspiration back with the contrast syringe is used to ensure that there is no air leak and no bubbles. A piece of gauze is placed under the connected segments before a firm forward flush to check for contrast leakage. In case of tortuous aortic anatomy or kinking in the femoral artery, very strong manipulation of the guiding catheter rarely causes the pieces to detach. Therefore, these types of maneuvers should be avoided when guiding catheter shortening is performed, manipulating and torquing the guide, if necessary only from the distal end after the connection [11].

Role of multislice cardiac computed tomography in chronic total occlusion retrograde recanalization

Modern MSCT provides a comprehensive assessment of coronary anatomy [18–19]. Non-contrast-enhanced scans (CT calcium scoring) allow assessment of calcified plaque burden, which is a reliable sign of chronic atherosclerotic changes. Coronary calcium scores have been shown to

correlate with the total atherosclerotic plaque burden; by contrast, it significantly underestimates the total atherosclerotic plaque burden. Contrast-enhanced CT scans allow the separation of lumen and vessel, and subsequently the identification of both calcified and noncalcified plaque [20].

The use of cardiac MSCT in percutaneous CTO revascularization acts as a useful tool. It reveals the coronary ostium position, the CTO length, the collateral circulation path, proximal tortuosity to the occlusion, tortuosity of the occluded segment and the vessel size. Especially in complex CTOs, with long segments, no stumps, severe calcifications and severe tortuosity, MSCT might be beneficial in attempting CTO revascularization [21]. Garcia-Garcia *et al.* studied 142 patients with CTO lesions by MSCT in order to show angiographic predictive factors of successful revascularization. By multivariable analysis, the only independent factor associated with successful revascularization was the absence of severe calcifications as defined with MSCT [22]. Therefore, a better understanding of the anatomical features of the occluded segment might modify the revascularization strategy. In particular, vessel shrinkage, presumably reflecting the age of the CTO, often induces the guidewire to track outside the vessel (coronary perforation). Moreover, the location of calcifications as assessed by MSCT might not only influence the selection of guidewires but also the balloons or the devices. In case of hard calcified lesions, in our experience, a small diameter balloon with a hydrophilic coating and good shaft maliability are usually required to cross the occluded segment.

Considering the significant amount of contrast and radiation, it would not be sensible to propose a cardiac CT scan before each PCI CTO attempt. However, we suggest performing a cardiac CT scan in patients with unfavorable angiographic characteristics and/or with a previously failed PCI attempt. The decision whether or not to perform a contrast-enhanced CT scan after the calcium scoring scan might depend on which information the interventional cardiologist intends to obtain. A calcium scoring scan allows the operator to obtain information concerning the presence of calcium in the occluded segment. Conversely, the contrast-enhanced scan gives information regarding a 3D vessel course, calcium distribution and collateral circulation.

In conclusion, a CT scan might orientate the choice of PCI approach. When a CT scan shows a CTO with an ostial location, long occluded segments, severe tortuosity and calcifications, a retrograde approach as an initial strategy might represent a reasonable indication for higher procedural recanalization success.

Table 1. Complications and in-hospital outcomes in Japanese and European series.

	Japanese series; n = 22 (%)	European series; n =21 (%)
Complications		
Cardiac tamponade	2 (0.4)	0 (0)
Emergent PCI	2 (0.4)	NA
Emergent CABG	0 (0)	0 (0)
Blood transfusion	8 (1.6)	NA
Wire entrapment	NA	1 (0.6)
Coronary perforation	36 (7.2)	NA
Collateral perforation/hematoma	NA	12 (6.9)
Donor vessel dissection	NA	2 (1.1)
Access site surgery	2 (0.4)	NA
Gastrointestinal bleeding	1 (0.2)	NA
Contrast-induced nephropathy	6 (1.2)	NA
Radiation dermatitis	0 (0)	0 (0)
In-hospital adverse outcomes		
All-cause death	2 (0.4)	0 (0)
Q-wave myocardial infarction	1 (0.2)	0 (0)
Non-Q-wave myocardial infarction	10 (2.1)	7 (4.0)
Cerebral transient ischemic attack	0 (0)	1 (0.6)
Stent thrombosis	0 (0)	NA

CABG: Coronary artery bypass graft; NA: Not available; PCI: Percutaneous coronary intervention.

Retrograde recanalization: Japanese versus European approach

Differences in approaching CTO lesions by retrograde may be found between European and Japanese expert operators. Japanese operators tend to adopt the retrograde approach as the initial intended strategy [23] while the European operators are more prone to use such a technique immediately after a failed conventional attempt by anterograde [24]. For those concerning technical issues, European interventionalists generally prefer to use smaller guiding catheter sizes (6 or 7 Fr) compared to the 8 Fr sizes, which are customary in Japan. Moreover, Japanese experts tend to increasingly apply the reversed CART technique [24] while European operators have not adopted this variation as yet. Furthermore, IVUS guidance for retrograde wire re-entry is used frequently by Japanese interventionalists as the IVUS technique is reimbursed during PCI procedures. Another important point is that in Japan, preprocedural MSCT is gaining increasing attention and it is mandatory in cases of complex lesions in order to decide if the procedure should be started in a retrograde fashion. In Europe, MSCT is not routinely used, mainly owing to costs and availability of equipment.

■ Procedural & in-hospital outcomes

In a global series of 175 patients, the overall success rate demonstrated by the EuroCTO club was 83.4% [23] while in a more recent Japanese registry, which enrolled 498 patients with 528 CTO lesions, a success rate of 86.6% was reported [24]. There was no periprocedural death in the European series while in the Japanese registry it occurred in only one case. The European series reported a rate of coronary perforation plus septal hematoma of 6.9%, an incidence of periprocedural myocardial infarction of 4% (only non-Q-wave) and wire entrapment in 0.6% of cases. In the Japanese registry, periprocedural non-Q-wave myocardial infarction occurred in 2.1% of cases while symptomatic Q-wave myocardial infarction was reported in 0.2% of procedures. Moreover, Japanese operators experienced angiographic coronary perforation in 7.2%; however, this resulted in cardiac tamponade (0.4% of procedures). Table 1 summarizes procedural complications and in-hospital outcomes in both the Japanese and European series. It is worth noting that in both series, operators reported high fluoroscopy time and mean contrast administration: in the EuroCTO club experience the mean of fluoroscopy time was 59.3 min and the mean contrast used was 420.9 ml while the Japanese registry reported a median fluoroscopic time of 45 min for successful procedure and contrast volume administered with a median value of 293 ml for all procedures performed. Both experts groups recommend an adequate hydration 24 h pre- and 24 h post-procedure and periodical clinical follow-up, especially in cases of a high amount of radiation exposure in order to promptly recognize the occurrence of radiation-related skin burns.

Conclusion

In cases of suitable collateral circulation, the retrograde approach might improve procedural

Executive summary

Background

- The retrograde approach via collateral channels in coronary angioplasty for chronic total occlusion can improve the success rate, especially in cases of difficult anterograde approach or in cases of previous anterograde failure. During retrograde approach, the tortuosity of the collateral channel is one of the biggest contributors to difficulty and procedure risk, as well as presence of left main disease into the donor vessel.

Technique key point issues

- The use of a specific device, such as the CROSSER® microcatheter, may contribute to collateral crossing.
- The pure retrograde technique uses a retrograde approach with a single wire, without a simultaneous anterograde approach.
- The kissing retrograde technique combines the anterograde and retrograde approaches simultaneously.
- The basic idea concerning the controlled anterograde and retrograde subintimal tracking technique is to create a subintimal dissection with limited extension only at the chronic total occlusion site.
- The use of multislice computed tomography can help the procedure but concerns regarding radiation exposure, contrast load administration and costs should be evaluated.

When to stop retrograde attempt

- In case of the formation of a large dissection on collateral channel or collateral rupture, it is advisable to stop the procedure, stabilize the patients and to schedule the patient for another attempt or reconsider surgery. Moreover, before starting the procedure, the total amount of contrast agent to be injected should be calculated. The procedure should be stopped if this amount is exceeded.

Conclusion

- Although the retrograde approach is conceptually simple, it requires very skilled operators and a long learning curve. It is advisable to start with the help of an expert retrograde operator as a proctor.

success rates, especially in cases of difficult anterograde approach. Although the retrograde approach is conceptually simple, it requires very skilled operators and a long learning curve, which intricate and demanding supplies discourage without adequate proctorship [25].

Financial & competing interests disclosure

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