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Review Article

A step-by-step guide to mastering retrograde coronary chronic total occlusion intervention in 2018: The author's perspective

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ABSTRACT

Chronic total occlusion remains one of the most challenging subsets and represents the “last frontier" of percutaneous coronary intervention. Retrograde recanalization is one of the most significant amendments of the technique and has become an important complement to the classical antegrade approach. It yields a high success rate even in most complex patients. With emergence of important iterations, this approach has become safer, faster, and more successful. The author proposes a step-by-step guide to the retrograde approach with alternatives to various steps for operators wishing to embark on this strategy.

1. Introduction

Successful percutaneous coronary intervention (PCI) of chronic total occlusion (CTO) improves anginal status, exercise capacity, left ventricular function, and tolerance of acute coronary syndromes that may occur in future and possibly decreases mortality[1,2] and the need for subsequent coronary artery bypass (CABG) surgery[3] and the risk of arrhythmias.[4] Despite remarkable progress over the last decades, successful CTO recanalization represents the “final frontier” of PCI. CTO PCI still remains technically demanding even after developments of new devices and a wide range of guidewires.[5,6] Historically, the technical success rate has been limited to 65%–70% with the antegrade approach.[1,7] However, the retrograde approach using collateral channels (CCs) circumvents the limitations of the conventional antegrade approach. With increasing knowledge and expertise, it is expected to be a breakthrough to potentially improve the success rate of complex CTO PCI when the conventional antegrade approach is ineffective, unsafe, or inefficient.[8–10] Despite this, adoption of this technique is limited only to 15–30% of CTO PCI.[11,12]

2. Historical perspective and indications

The technique of retrograde CTO PCI was first described in 1990 by Kahn and Hartzler, who used a saphenous vein graft (SVG) to perform PCI of occluded left anterior descending artery (LAD).[13] Silvestri et al[14] demonstrated retrograde stenting of the left main artery in 1996 using SVG. The success rate of CTO PCI has been increased up to 95% with the adoption of this technique. Angiographic features of blunt occlusion with a large side branch, bridging collaterals, calcification, and long CTO are no longer considered negative predictors of success while embarking on a retrograde approach.[15] The most common indication of this approach is unsuccessful antegrade approach. It could be the initial crossing strategy (primary retrograde) in many situations such as ostial occlusions, long occlusions, severe proximal tortuosity or calcification, occlusions with ambiguous proximal cap, occlusions with a distal major bifurcation, and poorly visualized distal vessel.[16–19] Retrograde penetration of the distal CTO cap may be easier because it is tapered and softer and less ambiguous as compared with the proximal cap. Also, it is not reliant upon precise visualization of CTO origin.

3. Angiographic/assessment and selection CC analysis

In general, ad hoc PCI should be discouraged in retrograde technique to facilitate a thorough procedural planning and preparation. Studying the diagnostic images carefully and selecting a best CC is the first key to the success. Optimal angiographic planning requires dual-injection technique with complete filling of the distal collateral bed from all feeding sources. Using low magnification (13 in. instead of 8 in.) and avoiding panning considerably facilitates evaluation of CCs. The distal target vessel size, nature of the

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proximal and distal cap (clear or ambiguous), side branches, tortuosity, and calcification are other critical items of information obtained from the angiogram.

The types of retrograde CCs are bypass graft, epicardial CC, and septal CC. In severely degenerated SVG cases, it is necessary to recanalize CTO of the native coronary artery to improve long-term outcomes. Navigating an acute angulation at the distal anastomosis is one of the significant challenges of retrograde wiring through bypass grafts that could be overcome with the use of hydrophilic guidewires, the reversed guidewire technique, and the venture deflectable tip catheter. Internal mammary artery bypass grafts are least preferable as they are prone to dissect.

Septal CCs are the safest and should be preferable whenever possible. Severe septal tortuosity impedes the wire navigation, whereas THE size is less so. Compared with the epicardial CC, the septal CC is a shorter route to the recipient vessel and is less tortuous, and an injury to septal CC may not result in myocardial infarction, myocardial hematoma, or cardiac tamponade. It can also be dilated using a small balloon (1.20–1.5 mm) with a very low pressure (2–4 atm) for smooth navigation of the catheter without major adverse clinical events[15,16] At present, the Corsair and Caravel catheter (Asahi Intecc, Aichi, Japan) circumvent septal CCs dilatation with a small balloon. Straight faintly visible or even invisible septal CCs could be crossed by “surfing” technique (crossing of CC without contrast injection).[16,20] The angle of entry, angle of donor vessel, and angle at the base of the heart, if acute, could be a significant barrier to both the wire and microcatheter navigation. A combination of right anterior oblique (RAO) or anteroposterior cranial and RAO projections best evaluates these CCs. CCs with corkscrew morphology more than 90° with the recipient vessel may pose a significant challenge to advancement of the wire. It is easier to steer the wire through septal CCs from LAD to the right coronary artery (RCA) compared with from the RCA to LAD because of significant tortuosity at RCA end of CCs.

The assessment of epicardial CC includes length, tortuosity, and size. Epicardial CCs are longer and larger in size but more tortuous than septal CCs. The main criterion for these CCs is appropriate size rather than tortuosity. During the wire manipulation, there is some risk of perforation which is more serious than septal rupture. Furthermore, balloon dilation of this CC should always be avoided to prevent vessel rupture and cardiac tamponade. Although there is scarring and adherence of the pericardium to epicardium in post-CABG patients, they are exposed to epicardial hematoma that may cause catastrophic complication because of compression of cardiac chambers. This hematoma is not accessible by simple pericardiocentesis and needs complex interventions to relieve. The guidewire manipulation may lead to distant ischemia and myocardial infarction if epicardial CCs serve as the only donor artery to a viable CTO region.[16]

The ideal CC for retrograde access should be possibly relatively straight or less tortuous septal, with visible direct connection with the recipient vessel. Both the donor and recipient vessel angles should be less than $< 90^\circ$ and the entry of the CC into the recipient artery should not be close to the distal cap.

4. System setup

The RCA and left main coronary arteries are engaged with 7–8F guiding catheters via dual arterial (bifemoral, biradial, femoral-radial) access. Use of transfemoral or transradial access is a matter of operator preference and experience with knowledge of risks/benefits of both. For the retrograde limb, use of short (90 cm) guiding catheters allowing the externalization of the wire is recommended with less concern about the equipment length. This is imperative if an epicardial CC is chosen. A regular 100-cm guide catheter can be manually shortened and connected to a 1F smaller introducer sheath.[16,22] Removing 10 cm is usually sufficient. Severe iliac artery tortuosity can be overcome with the routine use of long (23 or 45 cm) kink-resistant sheaths.

Strategies to reduce bleeding are crucial because unfractionated heparin is used at a higher dose than usual. The use of one or both radials offers a clear advantage in this regard. Heparin is the anticoagulation of choice as it can be reversed. An activated time (ACT) of 300–350 s should be targeted to mitigate catheter-induced thrombosis. It should be checked every 20–30 min. Bivalirudin is not recommended because of concerns of increased equipment thrombosis.

5. CC navigation and guidewire handling

The success of collateral crossing depends on an appropriate CC selection, wire tip curve, and wire handling. A clearly visible, less tortuous CC by super-selective injection, exemplified by Dr. Werner's CC[7] grade 1 or 2 should be chosen. Acute angulation, branching, cork-screw morphology, and calcification pose major hurdles for the passage of the wire.[14] A hydrophilic nontapered guidewire with an extremely small (<1 mm) curve is usually preferred for CC navigation. For this, the author prefers to use the Sion guidewire (Asahi Intecc) as the first choice that can be advanced smoothly and safely because of its coated tip and 0.7-g tip load. Its hydrophilic coating and rope coil technology facilitates good guidewire retention, advanced torque performance, and flexible atraumatic tip. The Sion Black guidewire (Asahi Intecc), a recent addition to the PCI armamentarium, becomes a useful choice for small tiny CCs because of the polymer jacket and slip coating with a rope coil structure of the tip. Even fine CCs can be effectively navigated by using the Fielder XTR guidewire (Asahi Intecc) which has a polymer jacket coating with a 0.010-inch tapered tip. The author prefers to use Suoh 3 guidewire (Asahi Intecc) in curved but nonbranching CCs. It is light weighted with a tip load of 0.3 g that gives rise to less resistance for crossing the bent point CC.

The dedicated microcatheters [such as the Corsair and Caravel microcatheter (Asahi Intecc), and Turnpike (Vascular Solutions Inc, MN, Minnesota), Finecross (Terumo, Japan)] facilitates CC crossing. The Corsair (Asahi Intecc) is an over-the-wire (OTW) hybrid catheter composed of 8 thin stainless steel wires wound with 2 thick ones. It has a soft tapered tip with tungsten braiding and a hydrophilic coating that acts as a dilator while providing remarkable CC maneuverability and crossing. It also imparts an extraordinary control of the retrograde wire. Gentle rotation of this catheter is required to advance or retract it by either clockwise or counterclockwise rotation. It is executed by performing 5–10 alternating clockwise and counterclockwise rotations while providing forward tension. Care should be taken to limit the rotations to 10 times in one direction. Caravel (Asahi Intecc) is a versatile microcatheter with braided shaft that exercises better flexibility and an excellent crossing profile (1.9 Fr). It does not require rotation and tracks remarkably through tiny tortuous septals. If the microcatheter fails to navigate the CC along the guidewire, it can be replaced with a small diameter monorail balloon with a longer shaft (>145 cm) by using the extension guidewire or the counter flush method. The author prefers to use the Finecross microcatheter from the very beginning for a very tortuous epicardial CC. Turnpikes (Vascular Solutions Inc) are a group of OTW tapered tip microcatheters with dual-layer bidirectional coil that provide exceptional tracking and navigation of the CC.[18]

The workhorse guidewire is exchanged for a CC crossing wire once it is accessed to the target CC along with the microcatheter. Depending on the type of CC used (septal, epicardial, or SVG), the crossing technique varies. Once the microcatheter reaches septal

CC, either "surfing" or "contrast-guided" technique can be used for subsequent crossing. The guidewire is advanced rapidly along the path of least resistance (surfing) until it buckles or moves forward into the distal target vessel. It is quickly retracted back and redirected to find an alternative CC in case of resistance. Forceful advancement of the guidewire may increase the risk of CC injury. RAO cranial is the most suitable view for initial wiring, and RAO caudal for entering into the posterior descending artery.

In doubtful wire position, selective injection of the contrast (as little as 2 ml) is performed; a wash out of the contrast indicates connection of the CC to the either ventricle. Wire advancement into either ventricle is benign as long as the microcatheter is not advanced. The straying of the contrast in CC indicates focal perforation.

In contrast-guided septal crossing technique, cineangiography is performed while injecting contrast with a 3-ml luer-lock syringe. Blood is aspirated before contrast injection not only to avoid air embolization but also to prevent vessel injury if the microcatheter is completely occlusive. The microcatheter is flushed before renegotiating the guidewire to minimize subsequent stickiness. The wire crossing is reattempted once continuous connection to distal vessel is established. RAO caudal projection is most suitable projection for evaluating the length and tortuosity of the distal part of septal CC. The sudden rapid and large deviations in wire-tip movement indicate entry into a cardiac chamber. Septal hematoma, manifesting as severe chest pain, may be fatal if not treated adequately, such as by coil embolization of septal CC or creation of a fistula connecting to the ventricle.[21]

Epicardial CC crossing should always be facilitated by contrast guidance. Surfing is not advisable in view of high risk of perforation. The guidewire should be rotated and not pushed in tortuous segments. Crossing may be easier during diastole. Divergence from the observed path may lead to perforation. Both arterial grafts and SVGs pose a major challenge of steering the wire through acute angulation at the distal anastomosis.

After retrograde wire position is established, it is negotiated as far as possible close to the distal CTO cap to provide sufficient backup for retrograde microcatheter navigation. In case of failure to cross, the microcatheter should be rotated rapidly clockwise or counterclockwise using both hands. Sometimes, the operator may have to dilate the septal CC or may replace Corsair or Caravel microcatheter with Finecross microcatheter. In some cases, the guiding catheter support is enhanced by deep throating, side branch anchor, or a guide catheter extension which can facilitate tracking of the microcatheter.

6. Connecting the antegrade and retrograde channel

The author believes in fast retrograde guidewire escalation. Retrograde penetration is attempted with a guidewire such as a Fielder XT (Asahi Intecc) with the support of microcatheter from the distal cap of a CTO lesion. If it fails, it is exchanged with Gaia family (first/second/third) and is negotiated in a retrograde manner to the most proximal part possible. Conquest Pro 12 (Asahi Intecc), Pilot 200, and Progress 200 (Abbott Vascular, USA) guidewires are reserved for a very hard and calcified distal cap. Once the tip of the retrograde guidewire successfully penetrates into the CTO lesion, one or a combination of the following different strategies is used.[10,16,21,23]

6.1. Direct retrograde true lumen puncture

The retrograde guidewire is used to completely cross the CTO, being steered upstream from the distal true lumen, through the CTO segment and into the proximal true lumen (Fig. 1). A soft guidewire such as the Fielder XT is used to attempt direct retrograde crossing of the CTO. If it fails, the author prefers to exchange it for a Gaia series of guidewire. If the CTO is severely calcified, the guidewire is appropriately replaced with a Conquest Pro, Pilot 200, or Progress 200. The microcatheter is moved forward into the antegrade guiding catheter with the retrograde guidewire. Then, this wire can be exchanged for a 330 cm RG3 (Asahi Intecc) guidewire which is retracted from the contralateral femoral sheath to allow antegrade passage of a balloon catheter (externalization). The retrograde wire into the aorta or the antegrade guide can be anchored by inflating a small balloon (2.5 mm) within the antegrade guide catheter to facilitate crossing of the occlusion with the microcatheter. If this fails, the microcatheter is exchanged for a 1.25 or 1.5 mm RX balloon to perform the retrograde balloon dilatation in the occlusion so that any subsequent procedure can be accomplished in the antegrade manner.[16] The probability of retrograde wire crossing can be enhanced by maneuvers such as inflating a retrograde balloon for more support (coaxial anchor) and using a stiffer, tapered-tip, and/or hydrophilic wires. Antegrade intravascular ultrasound (IVUS) can guide the retrograde wire into the proximal true lumen.

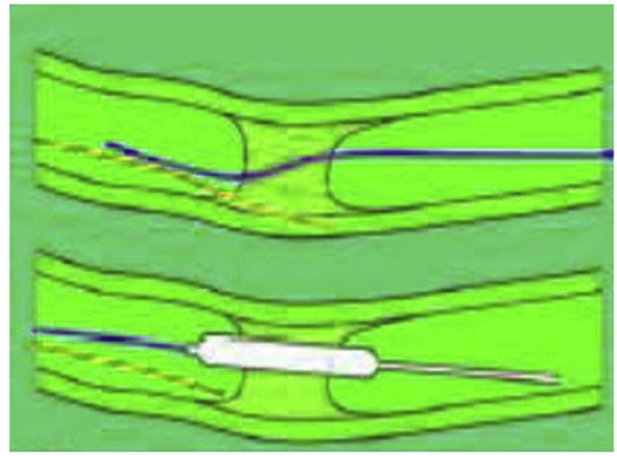

Fig. 1. Illustration of retrograde true lumen puncture.

6.2. Kissing wire technique

In case of failure of direct retrograde true lumen puncture, the retrograde guidewire can serve as a good landmark that allows much easier manipulation of the antegrade wire called as kissing wire technique (Fig. 2).[16,24] The retrograde guidewire is positioned in the intimal space so that it acts as a marker which facilitates crossing of antegrade wire almost completely through the intimal space. Two different angiographic projections should be obtained to check the position of the retrograde guidewire and to confirm that it meets the antegrade guidewire at a single point. If the two guidewires fail to overlap precisely, one of them may have entered a subintimal space. Antegrade wiring should be initiated from a site proximal to the retrograde wire so that the tips of the two guidewires can meet at a single point. However, it is difficult to align both the wires inside the occluded true channel because of the presence of many diseased layers.

6.3. Traditionally controlled antegrade and retrograde subintimal tracking

The controlled antegrade and retrograde subintimal tracking (CART) technique consists of antegrade wiring through the CTO

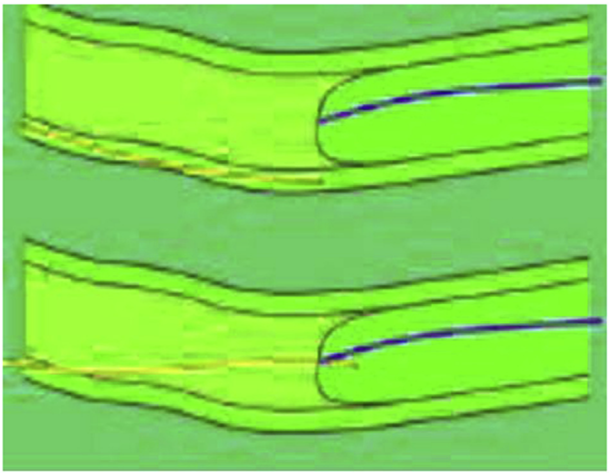

Fig. 2. Illustration of kissing wire technique.

where the retrograde balloon creates a local subintimal space for facilitating wire crossing to the distal true lumen.[16,25] With an inadvertent subintimal position of the antegrade wire, the retrograde wire is navigated across the distal true lumen into the CTO, and finally into the subintimal space at the CTO site. The subintimal space is enlarged by inflating a balloon (2.5–3.0 mm) inserted over the retrograde wire. While the balloon is being deflated, the antegrade wire is advanced further along the deflated retrograde balloon that lies from the subintimal space to the distal true lumen (Fig. 3). Then, angioplasty and stenting are performed in an antegrade manner.[26] The advantage of this technique is that it minimizes the length of subintimal tracking through the CTO lesion. The limitation is that it is not always possible to negotiate a retrograde balloon inside the occlusion, particularly in complex CTO lesions. Extension of the subintimal space to the proximal true lumen of the CTO may cause a fatal (e.g. dissection of the left main coronary artery) event when the occlusion is in the proximal segment of the left coronary system.[27] Other limitations are empiric estimation of retrograde balloon size and unpredictable procedure time. It is advisable to use the closest sized balloon inside the CTO to create sufficient wire re-entry space. The CART technique is replaced with reverse CART with the advent of the Corsair microcatheter. The CART technique is still used in some cases of ostial occlusions,

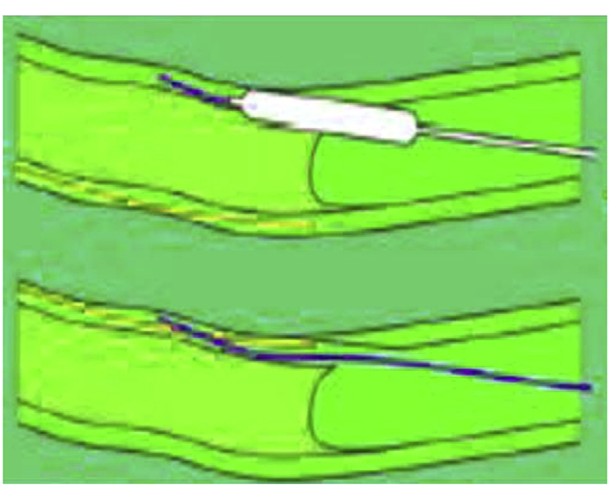

Fig. 3. Illustration of the controlled antegrade and retrograde subintimal tracking.

heavily calcified occlusions, and when the retrograde equipment is not long enough to reach antegrade guiding catheter (with long epicardial CCs and enlarged heart).[2]

6.4. Reverse CART technique

The reverse CART technique consists of dilating the subintimal space of the CTO lesion with the balloon inflated over the antegrade guidewire, creating a space in to which the retrograde guidewire is advanced (Fig. 4).[28] This is the most widely used retrograde dissection re-entry technique with subintimal position of both antegrade and retrograde wires. Care must be taken so that the tip of the retrograde microcatheter lies in the mid portion of the antegrade balloon. The antegrade balloon and retrograde catheter may appear up to 4–5 mm apart on fluoroscopy. With inflation of the balloon over the antegrade guidewire, the true lumen is moved aside to the point where the two subintimal spaces become the common subintimal space (CSS).[18] There should not be any gap between the antegrade balloon and retrograde microcatheter during the formation of CSS. The presence of a gap indicates the existence of the tissue between the two subintimal spaces and absence of CSS. The author recommends adopting higher inflation pressure or a larger diameter balloon in the absence of CSS. After deflation of the balloon, the retrograde wire followed by microcatheter could be seen "drooping" into the CSS indicating a continuous pathway from THE distal true lumen, through the subintimal space into the proximal true lumen.[18] The subintimal space may get compressed making wiring the true lumen more difficult even if CSS does exist. As compared with traditional CART, the reverse CART technique is more predictable and reproducible. An important precaution is to avoid contrast injections after creating antegrade subintimal dissection until the last stent is deployed to prevent pressurized contrast injection into the dilated segment causing a spiral dissection or hematoma and extending it downstream. When the antegrade and retrograde guidewires are located in the intimal and subintimal space, respectively, a space is created by aggressive antegrade dilatation of CTO lesion for successful navigation of retrograde wire. Another scenario arises when both the antegrade and retrograde wires are intimal. The solution is to advance either guidewire antegradely or retrogradely with the opposing wire as a marker toward the opposite channel called as "kissing wire technique." Antegrade balloon dilatation is the next strategy for smooth retrograde movement of the wire. If this fails, the author deliberately initiates the antegrade or retrograde subintimal tracking. A traditional CART technique is used if the antegrade wire is subintimal and retrograde wire, intimal (Fig. 5).

7. Iteration of reverse cart

The subintimal space may collapse after antegrade balloon inflation and deflation even in the presence of CSS.[17] This difficulty could be overcome by modifications of the reverse CART with the use of IVUS, mother and child catheter [Guideliner (Vascular Solutions Inc, Minneapolis, MN, USA), Guidezilla (Boston Scientific, USA), or Guidion (IMDS, Netherlands)], and the stent. Sometimes, it takes a longer time for successful connection (even with IVUS guidance) because of the retrograde dissection that interrupts the further directional and intentional control of the guidewire. The innovation of Gaia (Asahi Intecc) series of guidewires conceptualizes the contemporary reverse CART.[18]

IVUS-guided reverse CART

IVUS is useful to estimate the precise size of antegrade balloon that can lead to medial disruption. The risk of perforation can be reduced with IVUS guidance. Furthermore, it checks the development of medial disruption and CSS. Redilatation with a larger

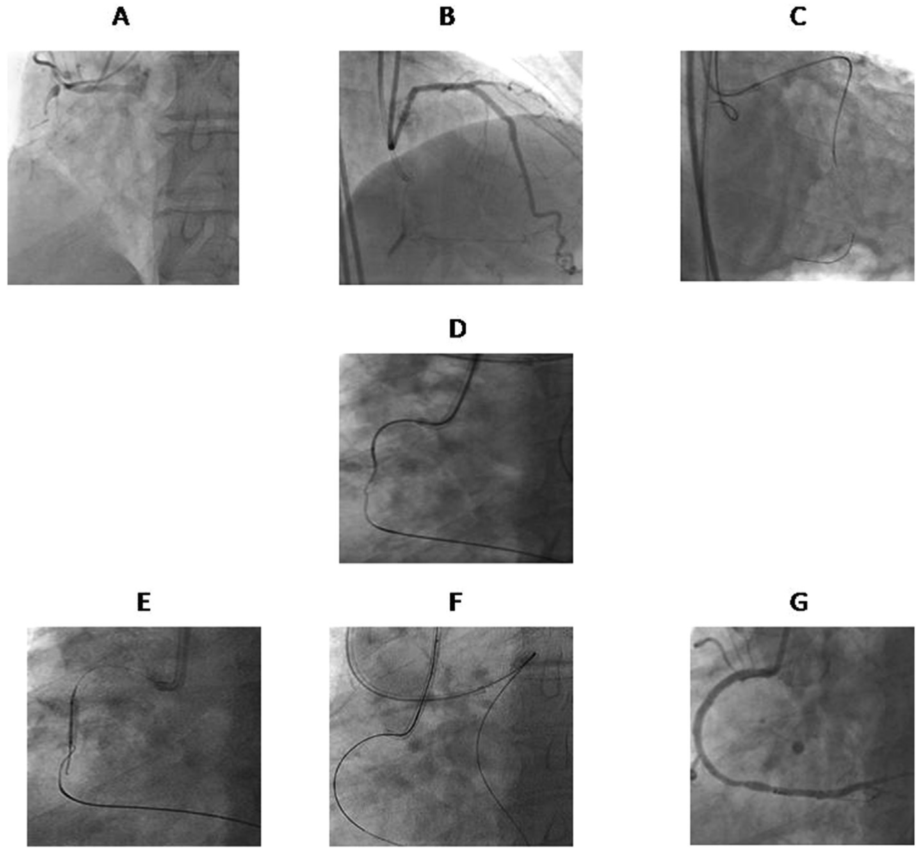

Fig. 4. (A) Coronary angiogram revealing 95% lesion of the ostium and total occlusion at the proximal right coronary artery (RCA). (B) Werner's collateral channel grade 2 from the left anterior descending artery (LAD) to the RCA. (C) Retrograde navigation of guidewire though septal collateral using a microcatheter. (D) Antegrade navigation of guidewire in RCA with microcatheter support. (E) Antegrade 3 × 18 mm balloon dilatation. (F) Advancement of retrograde guidewire with microcatheter into the antegrade guide. (G) Final result after predilatation with 3 × 20 mm balloon and deployment of 3.0 × 38 mm and 4.0 × 33 (from distal to proximal) overlapping drug-eluting stents.

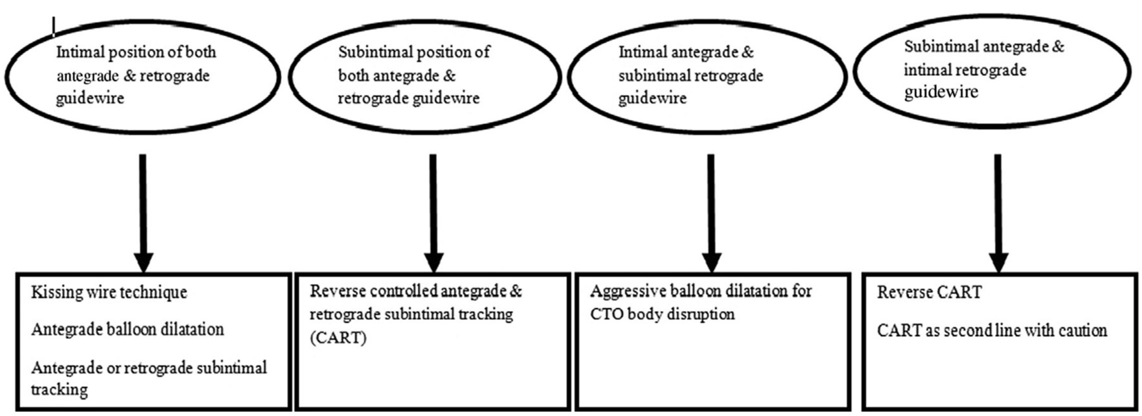

Fig. 5. Connection of antegrade and retrograde channels for successful retrograde cross (strategy based on guidewire position).

balloon may be indicated if the CSS recoils. IVUS also is useful to monitor the position of the retrograde guidewire in the subintimal space. This retrograde guidewire is better negotiated into the proximal true lumen with IVUS (Fig. 6).[16–18,27–29]

Stent reverse CART

Stent reverse CART entails creation of an open target for retrograde guidewire navigation when a stent is deployed from the antegrade true lumen into the subintimal space formed by antegrade balloon inflation. However, repeated attempts are hampered with this technique (Fig. 6).[16–18,21]

Mother–child reverse CART

This technique involves the use of a guide extension catheter such as Guideliner (Vascular Solutions Inc),[30] Guidezilla (Boston Scientific, USA), or Guidion (IMDS, Netherlands) into antegradely created space to help connect the retrograde guidewire into the antegrade guide. When positioned in the subintimal space, it provides a continuous conduit to the antegrade guide (Fig. 6). Therefore, creation of new dissection plane or wiring into side branches may not be required. Unlike a stent, the guide extension device may be removed or repositioned once there is failure of

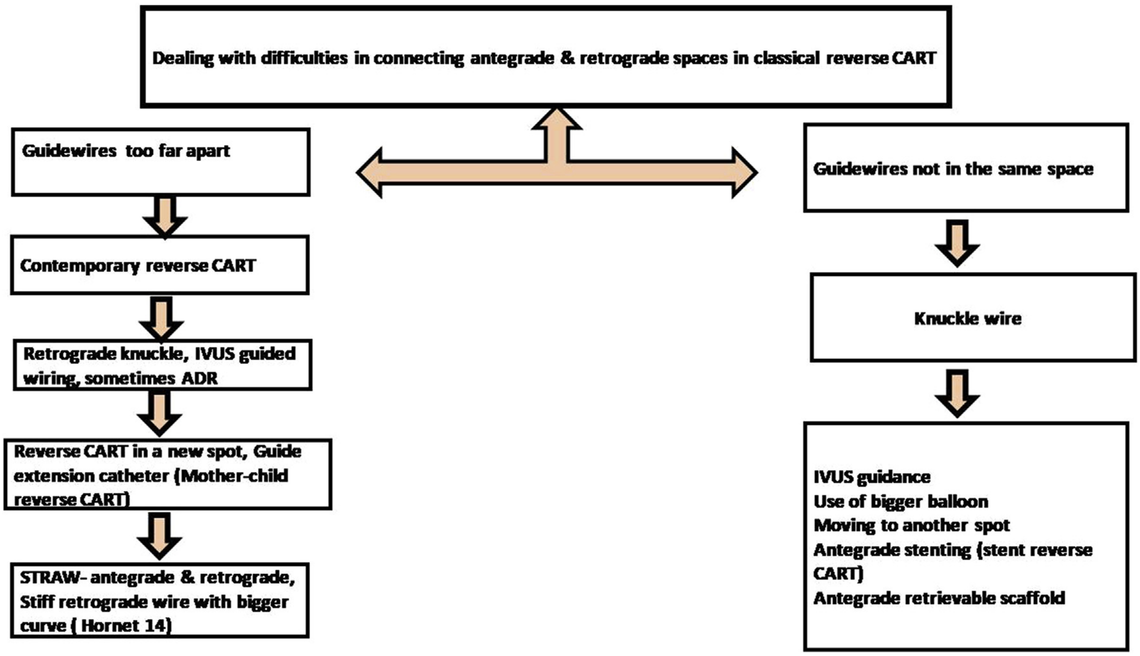

Fig. 6. Dealing with difficulties in connecting antegrade and retrograde spaces in classical reverse CART. CART, controlled antegrade and retrograde subintimal tracking; IVUS, intravascular ultrasound; STRAW, subintimal transcatheter withdrawal.

connection between the antegrade and retrograde true lumen.[16–18,21]

Contemporary reverse CART

The author prefers to use contemporary reverse CART technique where in antegrade preparation is initiated before retrograde wiring.[18] When antegrade and retrograde guidewires come together in CTO vessel, a negotiated smaller antegrade balloon (2.0 mm) close to the distal end of CTO is inflated. The shoulder of the inflated balloon is punctured by the Gaia wires. With quick deflation of the antegrade balloon, the Gaia series of guidewires penetrate the membrane between the different spaces known as contemporary reverse CART. These guidewires allow the precise intentional and directional retrograde guidewire control (Fig. 7). In case of failure, retrograde guidewire is still controllable because of smaller dissection plane created by a smaller antegrade balloon. This reduces the length of subintimal stenting that might impact the outcome of CTO PCI. Hence, long-term clinical and angiographic follow-up of patients undergoing contemporary reverse CART is needed to assess the long-term safety and efficacy of this novel technique.[18]

Confluent balloon reverse CART

This is another modification of reverse CART where in both antegrade and retrograde balloons are inflated together in a kissing fashion to create confluent subintimal space permitting retrograde guidewire navigation.[16,31]

Punctured antegrade balloon reverse CART

In this technique, the antegrade balloon is kept inflated during retrograde crossing attempts and is punctured by the retrograde guidewire, which is then advanced while the punctured antegrade balloon is retracted.[32]

7.1. The knuckle wire technique

The knuckle wire technique (KWT) is used in case of failure of retrograde wire escalation or when the CTO is quite long with vessel ambiguity. It involves creation of a small loop with retrograde polymer jacketed guidewire [Fielder FC, XT (Asahi Intecc) or Pilot 200 (Abbott Vascular, USA)], which creates subintimal space so that the antegrade wire in the subintima can be negotiated into this space. The antegrade KWT can be combined with retrograde

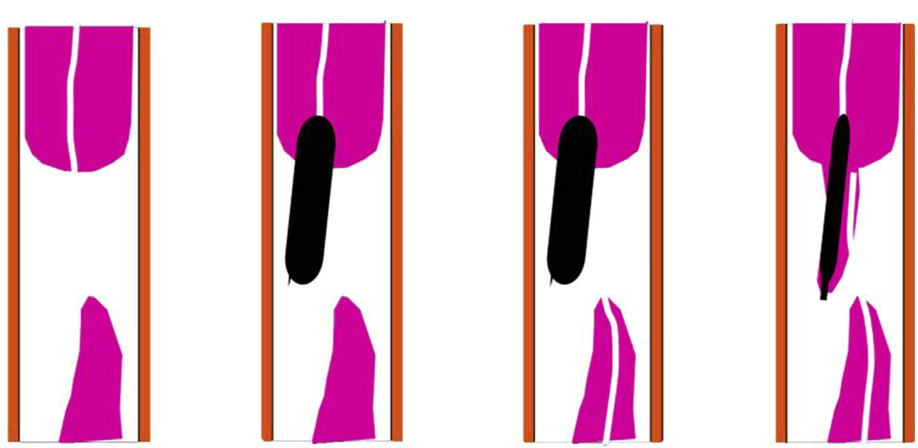

Fig. 7. Schematic illustration of contemporary reverse controlled antegrade and retrograde subintimal tracking.

KWT in complex CTO lesions. The limitations of this technique are that a longitudinal dissected plane cannot be controlled and the cross-sectional dissected area is not wide enough to lead the antegrade wire.[33] The knuckle wire should be pushed, but never rotated to avoid wire knotting.

7.2. The rendezvous (bridge) technique

This entails alignment of antegrade and retrograde microcatheters in a guide catheter at the level of the ascending aorta, after which an antegrade guidewire is pulled into a retrograde microcatheter. This antegrade wire is advanced further down beyond the CTO segment through the retrograde microcatheter.[16,34] This technique could be used in case of failure of advancement of antegrade guidewire, whereas retrograde guidewire can be negotiated using a microcatheter. This can also be applied in cases of large dissection and uncertainty in the movement of wire or in cases where CCs are small and not ideal for large retrograde balloon dilatation. This can replace wire externalization.

7.3. Retrograde delivery of stents

This technique is used rarely due to high risk of stent loss or entrapment. Retrograde delivery of stent has been reported though septal[35] as well as epicardial[36] CC. It requires adequate CC predilation. The donor artery is imaged after completion of PCI just to ascertain that there is no complication.

8. Externalization

Once the microcatheter is delivered into the antegrade guide, the crossing retrograde wire is exchanged for an externalization wire. This step is only applicable to retrograde true lumen puncture and reverse CART. The externalization of the retrograde guidewire must be carried out with utmost precaution. The deep throating of the retrograde guide catheter needs to be avoided to prevent ostial injury. While advancing the stiffer shaft of the retrograde guidewire, the CC needs to be protected by the presence of the microcatheter.

Several workhorse guidewires come in ≥300 cm (300-cm Pilot 200; Abbott Vascular, USA; 325 cm Rota floppy; Boston Scientific, USA; 335 cm Viper; CSI, St Paul, Minnesota; 330 cm RG3; Asahi Intecc) for externalization.[16] The Viper wire is extraordinarily stiff and is often difficult to pass through very tortuous CCs. The shaft of the Rota floppy wire is only 0.009" in diameter and is easily kinkable. It should be used as a last resort if no other long wires are available. RG3 is a 0.010″ tiny wire emerging as the most ideal guidewire for externalization. With loop wire condition, the tip of the delivery device reaches the inner curve of the coronary artery which provides the strongest support for the devices. Two options are available for wire externalization depending on whether the retrograde wire enters the antegrade guide catheter or not.

8.1. Externalization when retrograde wire enters the antegrade guide catheter

Wiring the antegrade guide is easier and preferable and may be aided by guide catheter extension (i.e Guideliner, Guidezilla, or Guidion) into the antegrade vessel. Once retrograde guidewire enters the antegrade guide, a trapping balloon is inflated within the antegrade guide next to the wire to facilitate negotiation of the retrograde microcatheter into the antegrade guide. The retrograde wire is removed while the retrograde microcatheter remains within the antegrade guide. The wire to be externalized is inserted through the microcatheter. Once the externalized wire approaches the antegrade guiding hub, the operator needs to detach the copilot and place a finger over the hub of antegrade guide until the retrograde wire is felt tapping on the finger. Retrograde wire is pushed 5–7 cm out of the guide, once the tap is felt. Then, a wire introducer is placed into the antegrade copilot, and the externalized soft tip of the wire is threaded. The introducer and copilot over the wire are slided and reconnected without flushing. Flushing after reverse CART can result in hydraulic dissection. The retrograde guidewire is pushed until 20–30 cm of the wire has come out from the Y-connector. If the externalized wire is damaged, it may be cut off to facilitate loading of balloons or stents.[16,37,38]

8.2. Snaring the retrograde wire

Even if the antegrade guide is coaxial, retrograde wire may fail to enter the guide in conditions such as aorto-ostial lesions or extremely tortuous vessels or whenever there is a poor retrograde wire control. Difficulty in wiring the antegrade guide can be overcome by snaring. The 3-snare system, referred to as tulip snare (EN Snare; Merit Medical Systems, South Jordan, USA), is considered the most useful snaring system for externalization. The larger the snare the better the externalization. An 18 × 30 mm EN Snare, which is 6F compatible, is preferred.[16,37] The snare is pulled back into a snare introducer, once it is removed from the package. The guide catheter is used instead of the snare delivery catheter for snare delivery. The snare is introduced into the antegrade guide by inserting the introducer through the Y-connector. The snare is moved forward out of the antegrade guide and opened. Then, it snares the externalized wire brought into the aorta by the microcatheter. The snaring should be done immediately proximal to the radiopaque portion of the wire.[38] PCI can be performed using rapid exchange equipment after successful externalization of the retrograde guidewire. Care must be taken to ensure that the tip of the antegrade equipments does not meet with the tip of the retrograde equipment to avoid interlocking and entrapment.

9. Externalized wire removal

After the completion of PCI, the retrograde microcatheter is readvanced into the antegrade guide, unless resistance is encountered. It must protect the CC until the soft wire tip is back in the CC. Both antegrade and retrograde guiding catheters are disengaged from the coronary ostium and pulled back 3–4 cm into the aorta to avoid ostial dissection because of externalized wire retraction (the antegrade guide is disengaged by pushing the externalized wire and the retrograde guide by fixing the microcatheter using it as a rail for guide retraction) After establishing guiding catheter control, the externalized wire is withdrawn gradually, synchronizing with the heart beat, taking care not to kink it. Then, the retrograde microcatheter is withdrawn into the donor vessel leaving the retrograde wire in the CC. The dye is injected into the retrograde guide to ensure that there is no injury to the CC. In case of CC perforation, the microcatheter is readvanced over the retrograde guidewire to cover the perforation and possibly deploy coils. If there is no CC injury, the guidewire is removed after readvancing the microcatheter to further decrease the risk of injury, especially in epicardial CCs with marked tortuosity.[16,37,38]

10. Putting it altogether: further navigating toward recanalization

Putting it altogether aims at optimally integrating the skill sets using simple anatomic assessment by multiple detector computed tomography or dual-catheter angiography and then crafting provisional strategic mapping. The purpose is to standardize the procedure and improve the outcomes of CTO PCI by venturing conditional probabilities of leveraging approaches when they are most likely to be safe and effective.[38,39] The interventionists must review the four parameters on the initial angiogram: (1) proximal cap (clear or ambiguous) (2) length of the lesion (<20 mm or ≥ 20 mm); (3) quality of the distal target (size, visibility, involvement of meaningful outflow branches); and (4) interventional CC. The initial and provisional strategies are outlined (Fig. 8) based on these parameters. This radical conceptual change in CTO PCI revolutionizes procedural efficiency and reduces radiation exposure and contrast utilization.

11. Complications encountered during retrograde procedure

There remains an augmented risk of donor artery injury owing to the spasm, dissection, or thrombus formation. Equipment withdrawal or externalization of snared wire may cause deep engagement of the guide catheter leading to ostial dissection. CTO PCIs are more susceptible to donor artery thrombosis, given the typical longer duration of the procedure and accommodating microcatheters in the vessel. The interventionist must ensure back bleeding and good flushing after removal of any equipment. ACT should be monitored at least every 30 min to maintain it between 300 and 350 s. The donor artery should be stented in case of dissection. Aspiration thrombectomy and additional heparin may be required for donor artery thrombosis.

The guidewire and balloon kinking or entrapment into CC, dissection, perforation, and hematoma formation in the CC are the complications exclusive to the retrograde technique (Table 1).[44] Many CC ruptures appear to be benign and do not require further management. The use of dedicated microcatheters [such as the Corsair and Caravel (Asahi Intecc), Turnpike (Vascular Solutions, MN, Minnesota), Finecross (Terumo, Japan), Micro 14 (Roxwood Medical, Redwood City, California)] is safer than a balloon and rarely causes CC dissection or perforation even with excessive tortuosity. The septal wire needs to be retracted if it shows excessive kinking while advancing microcatheter to prevent perforation. Septal perforations usually do not lead to adverse consequences although septal hematomas[40] and even tamponade[41] have been reported. In one case report, septal hematoma manifesting as an echo-free space caused asymptomatic bigeminy and severe chest pain and was resolved spontaneously.[42] Perforation into cardiac chamber usually does not result in complications until and unless there is balloon dilatation or advancement of additional device.[43,44] Perforation causing hemorrhage within the myocardium rather than the ventricle leads to gradual enlargement of hematoma which needs to be treated by hemostasis.

The perforation can rapidly lead to fatal tamponade and may be difficult to control in case of epicardial CC. It should never be dilated to reduce the risk of perforation. Some case reports have demonstrated that there is potential for the development of loculated effusions that may compress the cardiac chambers or the development of intramural hematoma with avulsion of the epicardial arteries as a consequence of vessel perforation in post-CABG patients.[44] Epicardial CC perforations are prevented by meticulous wire manipulation ensuring position of the wire before advancement of the microcatheter, cautious injection of contrast through its tip ensuring that back bleeding is possible before injection of contrast, withdrawing epicardial CC wire after ascertaining no perforation at the end of procedure, and avoiding surfing of the epicardial CC.[44] Negative pressure from the wedging microcatheters might sometimes be sufficient to seal the ruptures. Advancing microcatheter and coiling from both the sides might be required to address perforations.[43,44,46] It is advisable to perform dual-contrast injection from both the sides to ensure that there is no bleeding from the antegrade or retrograde side.

Karmpaliotis et al[47] demonstrated lower success and higher complication rates with retrograde technique as compared with antegrade-only technique. Therefore, an initial antegrade approach should be embarked on whenever feasible. This is further sustained

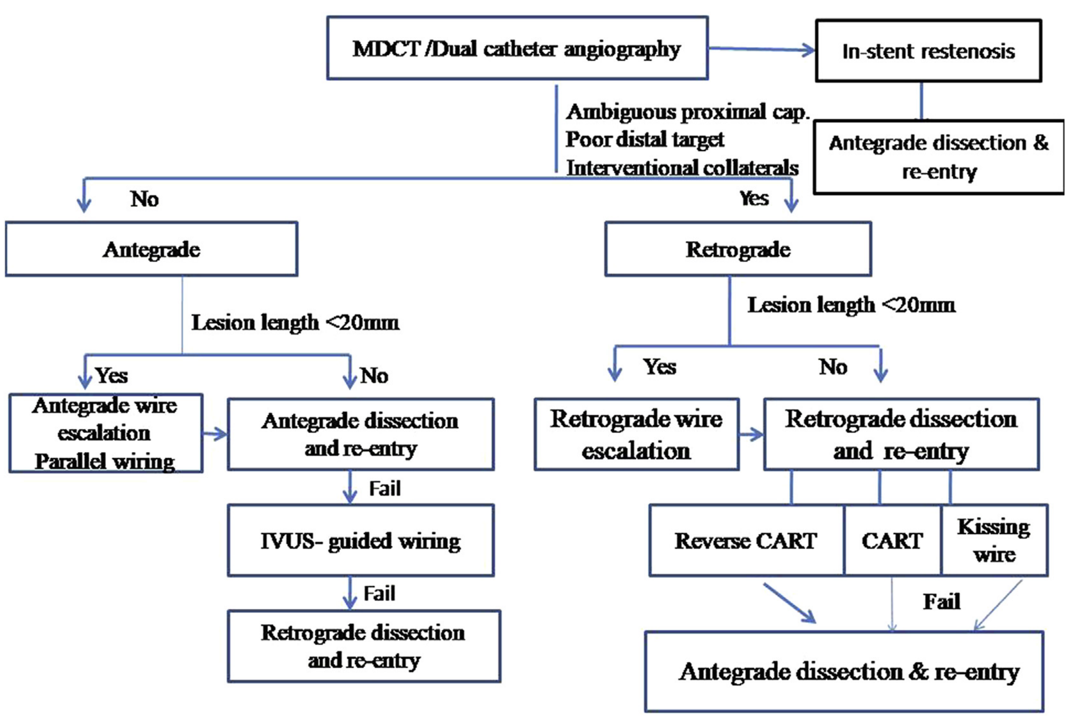

Fig. 8. Algorithm of putting it altogether in CTO PCI.[39] CART, controlled antegrade and retrograde subintimal tracking; IVUS, intravascular ultrasound; MDCT, multidetector computed tomography.

Table 1
Complications of Retrograde CTO PCI: Prevention and Bail out.[44,45]

Complications	Prevention	Bail out
• Coronary perforation	• Verification of guidewire position before microcatheter advancement	• Coil and fat embolization for distal vessel & CC perforation • Covered stent/prolonged balloon inflation for large perforation • ± Pericardiocentesis • Prolonged balloon inflation
• Collateral perforation/rupture	• Careful selection of collateral • Preference to septals	• Heparin neutralization • Embolization if necessary • Immediate hemostasis in epicardial CC perforation • Careful observation in case of septal (fenestration or embolization if chest pain)
• Donor vessel trouble (thrombus, dissection)	• Retrograde guide position & waveform monitoring • Adequate flushing • Activated clotting time (300–350 s)	• Stenting of dissection • ± Hemodynamic support • Thrombus aspiration
• Equipment loss or entrapment	• Proper lesion preparation before device delivery	• Retrieval with snares • To leave in situ & cover

CC, collateral channel.

by the longer procedure time, higher contrast and radiation requirement, larger number of stents, and more frequent use of hemodynamic support with the retrograde approach. However, retrograde attempt was an important contributor to the overall increased success rates observed in this contemporary registry.[47] The comparison of final technical success between antegrade-only and retrograde cases may be biased in favor of antegrade procedures, as many failed antegrade procedures subsequently underwent a retrograde attempt and were, thus, classified as retrograde. No procedure is 100% safe, and the interventionist must know when to stop. The fear of complications should not deter an interventionist to perform this procedure if it is significantly beneficial to the patient. The author strongly feels that retrograde or the backdoor should not be locked as of today despite some catastrophic complications most of which are preventable.[44]

12. Conclusion

A growing body of evidence demonstrates that successful PCI of CTO translates into clinical benefit. However, because of the perceived procedural complexity, there is underutilization of PCI for CTO. Technical and procedural success rates have risen tremendously over few years, as a result of the operator experience, improved equipments, the refinements of retrograde approach, and the introduction of “putting it altogether”, along with the development of the dedicated groups of experts focusing on technical developments and collaborative efforts to share experience worldwide. Further technical improvement is deemed necessary to simplify the techniques, making them safer, more standardized, and predictable. Favorable evidence from future randomized trials may encourage the interventionists to further engage in this challenging endeavor.

Conflicts of interest

The author has none to declare.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.ihj.2018.08.011.

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