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Retrograde algorithm for chronic total occlusion from the Asia Pacific Chronic Total Occlusion club

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KEYWORDS

- calcified stenosis
- chronic coronary total occlusion
- stable angina

Abstract

Retrograde CTO PCI is an effective method to improve the success rate of CTO PCI. Despite several comprehensive and detailed descriptive papers on the retrograde techniques, retrograde CTO PCI remains difficult for many interventionists. We, the Asia Pacific CTO club, propose a new retrograde CTO PCI algorithm, which focuses on three specific problems in the retrograde approach. First, how to overcome the tough proximal cap. Then, how to cross the collateral channels safely and efficiently. Finally, how to cross the CTO and, in particular, the problems of reverse CART. We explain our new philosophy of contemporary reverse CART. We hope that this algorithm will provide the tools for operators to overcome the difficulties of retrograde CTO PCI and that it will become a platform for discussion, training, and proctoring for the retrograde approach.

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Abbreviations

APCTO Asia Pacific Chronic Total Occlusion club
BAM balloon-assisted microdissection
BASE balloon-assisted subintimal entry
CART controlled antegrade and retrograde tracking
CTO chronic total occlusion
EBW end balloon wiring
FFR fractional flow reserve
IVUS intravascular ultrasound
LAO left anterior oblique
PCI percutaneous coronary intervention
PDA posterior descending artery
RAO right anterior oblique

Introduction

The retrograde approach to chronic total occlusion (CTO) percutaneous coronary intervention (PCI) was popularised by Japanese operators in 2006[1]. The impressive success rates achieved by retrograde CTO PCI, demonstrated in many live case conferences, have led to its worldwide adoption. CTO lesions occur in 10%-20% of cases[2-4]; furthermore, retrograde CTO PCI accounts for 25%-50% of CTO PCI cases[5]. Therefore, retrograde procedures are a substantial part of interventional cardiology work. However, for many interventionists, the retrograde techniques remain inaccessible due to the technical challenges of channel crossing and reverse CART, the inherent traps that have potential to lead to horrific complications[6], and the need to learn and understand the philosophy and concepts of retrograde CTO PCI. The landmark work of Wu et al[7] provided the first detailed description of the retrograde techniques. Joyal et al[8] and Brilakis et al[9] have given the most comprehensive step-by-step description of the retrograde approach to date. However, the techniques, equipment and, more importantly, the concepts of retrograde CTO PCI have changed considerably since 2012. We, the Asia Pacific Chronic Total Occlusion (APCTO) club, propose a new algorithm for retrograde CTO PCI (**Figure 1**). This algorithm builds upon the work of Wu[7], Joyal[8], and Brilakis[9] to provide an up-to-date algorithm that focuses on the concepts of retrograde CTO PCI. Unlike the previous work, this is not a detailed step-by-step teaching method for retrograde techniques but rather an algorithm to help interventionists overcome problems encountered in retrograde CTO PCI. There is substantial focus on channel crossing and reverse CART, the two major hurdles to retrograde CTO PCI. It is hoped that this algorithm will serve as the basis for future retrograde CTO PCI proctoring and training.

The APCTO club recommends the use of the JCTO score cut-off of 2 [10] to determine whether a CTO should be undertaken under the guidance of a proctor. While every CTO patient should undergo evaluation to determine the clinical indication for CTO PCI, the threshold for engaging in retrograde CTO PCI should be even higher. A careful balance between the risks and benefits of CTO PCI, acknowledging the higher risks of the retrograde approach, should be made. Only the symptomatic patient with a large territory of proven viable ischaemic territory should undergo retrograde CTO PCI.

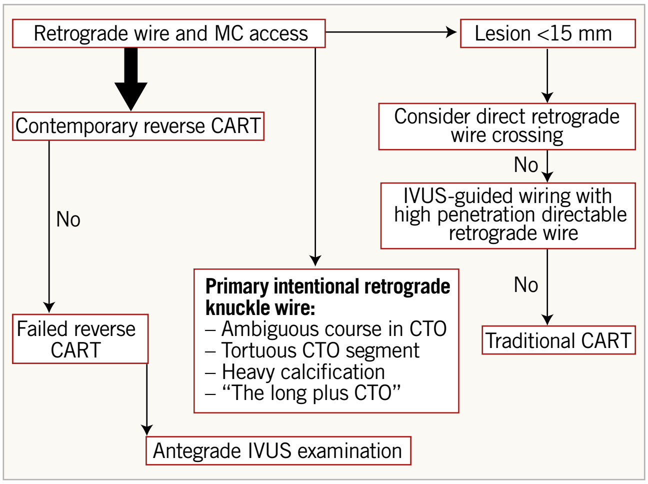

Figure 1. *Asia Pacific Chronic Total Occlusion (APCTO) club algorithm for crossing a CTO lesion via the retrograde approach.*

PROXIMAL CAP

ANTEGRADE PREPARATION FIRST PHILOSOPHY

The APCTO club promotes a strong "antegrade preparation first" philosophy[11], even in planned retrograde cases. "Antegrade preparation first" reduces the time that the retrograde system is engaged in the donor artery, CTO territory ischaemic time, and donor artery risks. It is especially important to carry out antegrade preparation when the proximal cap is tough or ambiguous, as the retrograde gear may have to be engaged for an extended period of time in the "retrograde first approach" if the operator struggles to obtain proximal cap puncture. It also encourages going directly to reverse controlled antegrade retrograde tracking (CART), which is the most efficient way to attain retrograde wire crossing. Finally, the "antegrade preparation first" philosophy removes the risks of single retrograde wire crossing in ostial lesions. However, there are some circumstances where antegrade preparation may be unnecessary, e.g., in short CTO where single retrograde wire crossing is planned or in a previously attempted case where the antegrade route is clear and there is no proximal cap problem to overcome. We also recognise that intravascular ultrasound (IVUS)-guided proximal cap puncture is a difficult technique to master, requiring experience as well as the availability of IVUS. For operators without the experience or availability, the retrograde first approach with knuckle wiring from the retrograde side to remove proximal cap ambiguity is a valid alternative.

AMBIGUOUS PROXIMAL CAP

Ambiguity of the proximal cap should be overcome with IVUS guidance. The IVUS catheter should be placed in the branch nearest to the proximal cap and withdrawn to look for the CTO site. Sometimes calcium overlaps with the proximal cap, making it impossible to locate the exact origin of the proximal cap on IVUS. However, a sudden increase in the size of the vessel will tell us roughly where the proximal cap is located. Contrast angiography should be undertaken when the IVUS is next to the CTO proximal cap. We can then use the angiogram as a guide to where the proximal cap is. Simultaneous IVUS-guided wiring of the proximal cap requires an 8 Fr system and is difficult, as the IVUS catheter often interferes with wire manipulation. Our solution is to place a low-profile dual-lumen catheter (SASUKE®; Asahi Intecc, Nagoya, Aichi, Japan) onto the wire that has a short monorail segment (OptiCross™ IVUS catheter; Boston Scientific, Marlborough, MA, USA) on it and use the over-the-wire port of the SASUKE to wire the CTO while simultaneously observing the wiring under IVUS.

TOUGH PROXIMAL CAP

The tough proximal cap presents two barriers to antegrade preparation: inability to pass a wire and inability to pass devices.

A stepwise algorithmic approach to overcome these two problems is suggested.

If the first CTO wire fails to puncture the proximal cap, a high penetration force wire **(Table 1)** should be used. Where a suitable side branch is available near the tough proximal cap, support by a twin lumen catheter is recommended. The balance between the risk of perforation and penetration power should be considered in each individual case. A higher penetration force wire can be used if the vessel course is clear and a more stepwise intermediate penetration force wire where there is ambiguity of vessel course **(Table 1)**. The next step is to use a side branch anchor balloon to anchor the twin lumen catheter in the side branch to improve penetration power. This can be performed with 7 Fr guiding catheters but is much less restrictive with 8 Fr. Alternatively, a side branch anchor balloon with a microcatheter jammed up against the proximal cap and the Conquest Pro 8-20 guidewire (Asahi Intecc) would usually be able to puncture the proximal cap. Finally, "power anchor puncture" with a large balloon inflated in the proximal vessel just proximal to the proximal cap anchoring the microcatheter underneath the balloon provides extreme puncturing force to overcome the tough proximal cap. If the high penetration wire has gone outside the vessel, we should remove the wire and check for perforation. Antegrade balloon tamponade of the vessel should be carried out to control perforation before proceeding again. Antegrade bypass by knuckle wire is also possible by "scratch and go" - using a Conquest Pro 12 guidewire (Asahi Intecc) to puncture into the proximal vessel wall and start a knuckle wire into the subintimal space to go beside the proximal cap. Alternatively, balloon-assisted subintimal entry (BASE) can be performed where a balloon is used to create dissection in the proximal vessel for a wire to enter into the subintimal space for knuckle wiring.

For operators without access to IVUS, a similar method to puncture the proximal cap with a high penetration wire followed by tipping in of the microcatheter and knuckle wiring can be used to overcome ambiguity.

If the wire can pass into the proximal cap but no device can follow, we suggest a two-tier approach.

The tier-one methods are applicable to all CTO interventionists. These include the use of a side branch anchor balloon or coaxial guiding catheter extension catheter (e.g., GuideLiner® [Vascular Solutions, Minneapolis, MN, USA]; Guidezilla™ [Boston Scientific]) to push the lowest profile balloon into the lesion and inflate and deflate the balloon consecutively to break the cap. A side branch anchor balloon provides more force than a coaxial guiding catheter extension catheter in the majority of cases, especially if the side branch is near the proximal cap of the CTO. These techniques can be combined with balloon-assisted microdissection (BAM)[12], which is the deliberate rupture of the balloon, by inflation to 30 atm to cause dissection of the proximal cap. In about 50% of the cases, the next balloon after BAM would pass into the proximal cap[12]. It is important to use a small balloon for BAM and to deflate as soon as there is loss of balloon inflation pressure. Using these techniques as described, Vo et al[12] did not find any vessel perforation. The convenience and controllability of BAM has made the Carlino technique for the proximal cap[13] much less used nowadays, although the Carlino technique is still useful to elucidate vessel course and to make progress in very difficult cases[13]. The use of Tornus (Asahi Intecc) or Turnpike® Gold catheters (Vascular Solutions, Minneapolis, MN, USA) with side branch balloon anchor or coaxial guiding catheter extension catheter should be tried next. In our experience, 90% of the tough proximal caps can be overcome with the tier-one methods described above.

Tier-two methods should be undertaken by those who are familiar with their use or under proctorship. Subinitmal rotablation, using a microcatheter to exchange for a cut Rotawire™ (Boston Scientific) (with 80% of the distal radiopaque part cut off) and then using a 1.25 mm burr to ablate the proximal cap, is difficult as often the cut Rotawire cannot retrace the previous CTO wire's course. There is a risk of vessel perforation in subintimal

Table 1. Wires. Wires classified according to use for proximal cap puncture, for retrograde channel crossing and for reverse CART, listed in order of recommended preference.

	Proximal cap puncture	Reverse CART	Channel crossing
High penetration force wires	Conquest/CONFIANZA 12g, Pro 9g, Hornet 14 (Boston Scientific)	Gaia Third, Conquest/CONFIANZA 12g, Hornet 14	NA
Intermediate penetration force wires	Pilot 200, Miracle 12g, Gaia Second (if vessel course unclear)	Gaia Second, Gaia Third	NA
Low penetration force wires	NA	XT-A (for single wire retrograde crossing)	SION, SUOH 03, Sumarai RC (Boston Scientific), XT-R, SION black

NA: not applicable

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rotablation, so it is important to rotablate only the proximal cap and not to push the rotablation burr beyond. Excimer laser with contrast-assisted proximal cap ablation is another option, but there are costs and expertise limitations. Also, included in this tier are methods that bypass the proximal cap. Retrograde knuckle wiring to pass the proximal cap and performing reverse CART proximal to the CTO entry cap, so-called "extended reverse CART", is a good method to bypass the proximal cap. The antegrade equivalent of this is to use the "scratch and go" or BASE method (mentioned above) to bypass the CTO proximal cap. BASE or "scratch and go" can also be used to pass a wire in the subintimal space outside the proximal cap and, by inflating a 2.5 mm balloon on this wire, we can perform "external cap crush" to weaken the proximal cap, allowing devices to pass on the initial wire through the proximal cap[14]. If the retrograde channel can accommodate an over-the-wire balloon, a 2.5 mm over-the-wire balloon can be passed through the channel and inflated to perform traditional CART. After successful CART, the antegrade wire can be anchored in the distal true lumen with the retrograde balloon providing strong wire traction force to allow a small balloon to penetrate into the proximal cap. Reverting to traditional CART and retrograde knuckle wire bypass of the proximal cap are the two easiest methods to use of the tier-two methods.

CROSSING THE COLLATERAL CHANNELS (Table 2)

Careful analysis of the collateral channels with frame-by-frame study and the set-up required for retrograde CTO PCI, including guiding shortening[7], has been well described elsewhere[8,9] and will not be covered here. The availability of coaxial guiding extension catheters has greatly lessened the need for short guiding. Lesions in the donor artery should be stented to prevent donor artery thrombosis. Intermediate donor artery lesions that are fractional flow reserve (FFR) negative may still cause ischaemia or thrombosis when a microcatheter sits inside the artery further reducing the lumen size or causing the accordion phenomenon. Some of these intermediate lesions should be treated before commencing the retrograde approach. Critical lesions not in the path of the retrograde route but in the donor side of the coronary system should also be stented before the retrograde approach. Non-critical but significant lesions not in the path of the retrograde route can be treated after the CTO procedure is completed.

LEFT TO RIGHT SEPTAL CHANNELS

Left to right septal channels should be wired with a workhorse wire loaded onto a 150 cm long microcatheter. When the microcatheter is engaged into the proximal segment of the channel, selective injection should be carried out in RAO caudal and LAO views **(Table 2)**. It is advisable to aspirate blood from the microcatheter before selective injection to minimise the chance of channel damage. If we fail to aspirate blood, we should move the microcatheter back and retry aspiration. The SION™ wire (Asahi Intecc) should be used to negotiate the channel. Contrary to the experience of others[8,9], channel haematoma or rupture caused by selective injection rarely occurs when selective injection is performed in the proximal part of the left to right septal channels before any wiring has started. Selective injection after channel surfing may cause septal haematoma due to channel damage from wiring and therefore a pre-wiring selective angiogram is recommended. If wiring proves to be difficult, more distal selective angiography using rotational angiography from RAO caudal to LAO caudal (or multiple view angiography if rotational angiography is not available) is useful. There are now many specifically designed wires for channel crossing **(Table 1)** which should be used instead of the Fielder™ FC (Asahi Intecc) type polymer jacketed hydrophilic wires that were used commonly and recommended in 2012[8,9]. The main advantage of dedicated channel wires is that they can be controlled to rotate with one-to-one torque transmission allowing accurate wiring of the channel. The newer wires also have lower tip load (SION 0.7g, SUOH 03 0.3g [Asahi Intecc] compared to Fielder FC 0.8g) and less risk of channel damage. The Fielder™ XT-R wire (Asahi Intecc) should also not be used as a first-line wire for channel crossing as its tapered tip increases the risk of channel perforation and damage. Negotiating the proximal part of the left to right septal channels can be difficult due to branching. This can be overcome with a non-selective angiogram and increasing the tip curve of the SION wire.

Distal channel anatomy determines the wiring strategy. If the majority of the septal channels are relatively straight but small or

Table 2. Tips for channel crossing.

Channel	Angio	Tips	First wire	Second choice small channel	Second choice for tortuous channel	Third choice for tortuous channel
L → R septals	Selective injection*	Further distal selective injection with rotational angiogram	SION	XT-R	SUOH 03	SION black
R → L septals	Non-selective injection (or via twin lumen)	Twin lumen catheter to overcome retroflex ostium	SION	XT-R	SUOH 03	SION black
Epicardial	Selective injection*	Microcatheter follows the wire technique	SUOH 03	XT-R/SION	SION/XT-R	SION black if large epicardial channel

* Selective angiography should be performed with biplane or rotational angiography.

even invisible, channel surfing is often successful. We recommend using the SION or Fielder XT-R wires for channel surfing. The SION should be used when a more deliberate directional wiring strategy is used to cross the collateral channels, especially in channels which are moderate in size (cc2) or are tortuous. Corkscrew channels can be crossed if they are of good size: the SUOH 03 is particularly useful for larger corkscrew channels while the Fielder XT-R is useful for smaller calibre ones. We recommend switching from SION to SUOH 03, then XT-R, then SION® black (Asahi Intecc) for septal channel crossing.

RIGHT TO LEFT SEPTAL COLLATERAL CHANNELS

Right to left septal collateral channels are considerably more difficult to cross. The difficulties arise from the retroflex take-off of the channel from the posterior descending artery (PDA), and tortuosity. In retroflex take-off anatomy, the use of a twin lumen catheter such as the SASUKE or Twin-Pass® (Vascular Solutions) can be helpful **(Table 2)**. We do not recommend a routine selective angiogram from the proximal part of right to left septal collaterals as there is an increased risk of channel rupture and haematoma due to the back and forth motion of the microcatheter from PDA tortuosity. However, selective injection through a microcatheter in the PDA or through a twin lumen catheter in the PDA is often helpful to elucidate the channel course.

OTHER EPICARDIAL COLLATERAL CHANNELS

The development of the SUOH 03 wire has dramatically improved epicardial channel wiring success. The SUOH 03 has a 0.3 gram weight tip and a very flexible distal end, allowing it to find its own way through very tortuous epicardial channels. It comes in two types, pre-shaped and straight. The pre-shaped SUOH 03 is suitable for the vast majority of epicardial channels but the straight allows the operator to make a special bend in order to conform to a particularly troublesome bend in the channel. The SUOH 03, if available, should be the first-line wire to use in epicardial collaterals. With the use of the SUOH 03 it is rarely necessary to use the "microcatheter follows the wire" technique of wiring epicardial channels. The "microcatheter follows the wire" technique **(Table 2)** is used when the wire is unable to pass a bend in the epicardial channel. The microcatheter is tracked to 15 mm from the distal end of the wire and the wire is gently pulled back just to relax the forward pressure and manipulated again through the bend. After this, the microcatheter and the wire can be manipulated forward together as one unit to overcome tortuosity, always keeping the microcatheter tip 15 mm proximal to the wire tip. However, in tortuous epicardial channels where there is much to and fro movement of the microcatheter, the operator should not remove the wire and expose the tip of the microcatheter to the channel in a bend in case of channel injury or perforation. If removal of the wire for exchange is needed, it should be done when the tip of the microcatheter is in a relatively straighter segment of the channel and the operator should try to minimise the time required for such an exchange. If the SUOH 03 is not available, the SION wire with a small but large-angled tip bend should be used for epicardial channel tracking.

MICROCATHETER CROSSING

In septal channels, a long torque transmitting microcatheter such as the Turnpike, Turnpike LP (Vascular Solutions), or Corsair (Asahi Intecc) should be the initial channel dilator. If the Corsair fails to cross, we recommend switching to the Turnpike LP, which can be rotated for channel dilatation and has a lower profile **(Table 3)**. If the Turnpike LP is not available, a new Corsair or Caravel (Asahi Intecc) should be tried as the tip coating of the Corsair catheter is easily roughened by manipulation and a new Corsair often will pass. The use of a short Corsair with better torque transmission to dilate the channel is also an option. A very low-profile microcatheter, such as the Finecross® GT (Terumo, Tokyo, Japan) or the Mizuki (Kaneka Medix, Osaka, Japan), can often pass the channel even if the Corsair, Caravel, or Turnpike LP has failed; however, these provide less support for CTO crossing and they pass better after Corsair or Turnpike dilatation of the channel and therefore should be reserved as second-line. If these methods fail, a 1.25 mm balloon dilated at 4-6 atm to the channel using the push forward and dilate method described by Wu et al[7] can be used to dilate the septal channel and the Corsair can often pass after this dilatation. Never dilate an epicardial channel as dilatation does not enlarge an epicardial channel and can cause channel rupture and tamponade.

In epicardial channels, the choice of microcatheter is determined by channel anatomy and CTO anatomy. If the channel is large enough to accommodate a Corsair/Turnpike and the body of the CTO is such that the operator anticipates the need for rotational drilling of the Corsair to cross the CTO, then a Turnpike or

Table 3. Tips for crossing microcatheter through channel.

Channel	Corsair/Turnpike will not cross	Switched microcatheter will not cross	Failure to cross after balloon dilatation
L → R septal	Switch to Caravel/Turnpike LP*	1.25 mm balloon to dilate channel	Side branch anchor balloon
R → L septal			Beware too tortuous PDA to septal channel angle
Epicardial		Switch to Finecross	Beware too small channel

* If septal ostium stented → dilate septal ostium with small balloon.

Corsair should be used. Conversely, in smaller epicardial channels and softer CTO, a Finecross could be used. If a Corsair or Finecross cannot cross the channel, a Turnpike LP is again a good option for these cases. Alternatively, other lower-profile microcatheters such as the Mizuki or Caravel could be used. If none of these microcatheters can cross, a reassessment of the channel and guiding catheter is needed. If the operator considers the channel to be robust enough to pass a retrograde microcatheter and the operator feels that a lack of guiding support is in part the reason for failing to cross the channel, then an anchor balloon placed into the main branch just distal to the take-off of the channel can be used to support the microcatheter crossing. We advise caution in using this technique due to the risks of epicardial channel rupture.

HOW TO CONNECT ANTEGRADE AND RETROGRADE SPACE

THE PHILOSOPHY OF CONTEMPORARY REVERSE CART

The majority of retrograde CTOs should be crossed with contemporary reverse CART **(Figure 1)**.

One of the main motivations for the APCTO club to write a new retrograde algorithm is the change in philosophy of reverse CART. Although CTO operators have differing ideas about what contemporary reverse CART is, we all agree that the contemporary reverse CART era started with the availability of more directable retrograde wires, such as the Gaia wires (Asahi Intecc), which allowed successful reverse CART to be performed with much smaller 2.0 or 2.5 mm antegrade balloons. At the beginning of the reverse CART era, which began with the introduction of the Corsair as the dominant retrograde crossing microcatheter in 2009 **(Table 3)**[15], the wires available for retrograde wiring were limited and were very difficult to control. Consequently, the only method to complete reverse CART was to make the antegrade target space bigger. Therefore, in that era, we started using IVUS to size the vessel so that we could use the largest possible balloon to perform reverse CART. If that failed, we used a coaxial guiding catheter extension catheter to perform reverse CART, and ultimately adopted stent reverse CART which produced the largest possible antegrade space. These techniques all rely on making the antegrade target space larger.

In the contemporary reverse CART era, there was a sudden decrease in antegrade target space size as it was no longer necessary to make a large space since the retrograde wire was much more controllable. Unfortunately, despite being five years into the contemporary reverse CART era, we have still not learnt to maximise the advantage of directable retrograde wires. If the solution to retrograde wire crossing in the reverse CART era was to make the antegrade target space larger, then the solution to retrograde wire crossing in the contemporary reverse CART era is to make the retrograde wire more controllable. Therefore, the philosophy of contemporary reverse CART is to maximise the retrograde wire control in four main ways. 1) Antegrade preparation first to allow an antegrade target to be set up before retrograde wiring. This results in minimal retrograde wire manipulation. 2) Back-up force to support the retrograde wire and choosing a site for reverse CART that maximises retrograde wire control. 3) Virgin territory wiring of the retrograde wire. Finally, 4) the end balloon wiring (EBW) technique. These four together form the EBW method for reverse CART.

IMPROVING RETROGRADE WIRE CONTROL – BACK-UP FORCE AND REVERSE CART SITE

Wire control is improved with good back-up force and, conversely, lack of back-up force leads to poor wire control. Therefore, it is important to drill the retrograde microcatheter into the distal cap of the CTO and keep the retrograde microcatheter near the tip of the retrograde wire to afford the best back-up and enhance the retrograde wire control. It is also easier to control a wire in a straight segment of the vessel as opposed to a tortuous part. Therefore, a relatively straight part of the vessel should be chosen as the reverse CART site before we start wiring in either the antegrade or the retrograde side of the CTO. This premeditated site of reverse CART should be at least 15 mm proximal to the distal cap to allow the retrograde microcatheter to anchor into the CTO to give support to the retrograde wire.

IMPROVING RETROGRADE WIRE CONTROL – VIRGIN TERRITORY AND WIRE SPACE EXPANSION

Wire control is much better when the wire is travelling through virgin territory. When a wire first enters a CTO, it makes a 0.014-inch hole and all around this wire is solid plaque. If you turn the wire and push forward, the solid plaque surrounding the wire would support the wire, enhancing both its torque control and its penetration power. However, after a period of wire manipulation inside the CTO, the wire enlarges the space surrounding it. The wire is no longer surrounded by solid plaque but rather by blood-filled spaces. When you torque a wire inside a blood-filled space, the wire tip catches on some plaque but the wire body continues to turn. This leads to the whip phenomenon and loss of wire control. Therefore, to maximise wire control we should hit our target on the first virgin run of the wire into the CTO and avoid over-torqueing of the wire and enlarging the wire space. Performing antegrade preparation first and minimising retrograde wiring can improve retrograde wire control.

IMPROVING RETROGRADE WIRE CONTROL – END BALLOON WIRING (EBW)

Wires are forward-moving devices: the majority of the force the wire exerts is immediately in front of the wire. Most retrograde operators today still overlap the antegrade and retrograde wires in the CTO and then inflate the antegrade balloon for reverse CART. This sets up the retrograde wire parallel to the balloon and the retrograde wire will be directed to enter the side of the balloon **(Figure 2A)**. They assume that the retrograde wire will easily move sideways into the antegrade balloon space **(Figure 2B)**, but wires are much more controllable and have higher penetration force when wiring into something in front of the wire. The penetration force in front of the wire tip is much

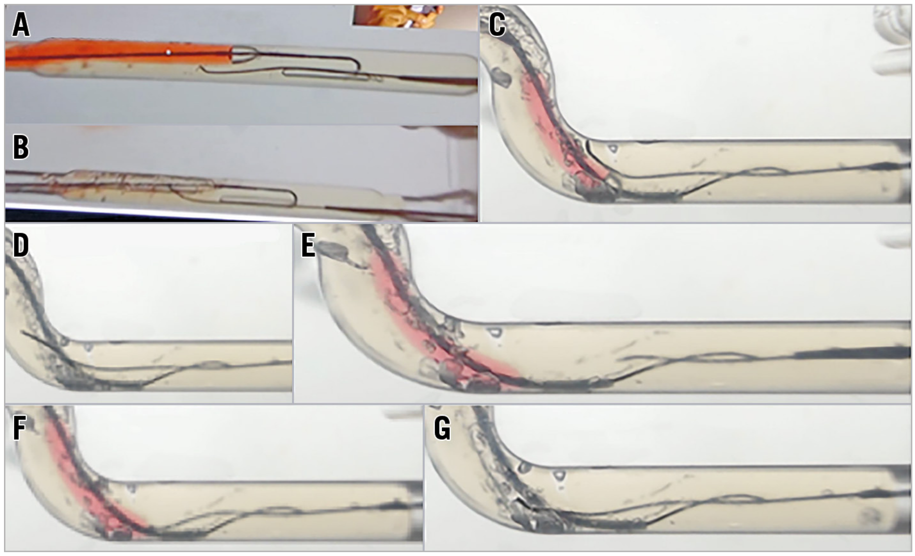

Figure 2. *Different ways the retrograde wire moves in reverse CART to illustrate end balloon wiring. A) Parallel starting position of contemporary reverse CART balloon and retrograde wire. B) Presumed side wiring into antegrade balloon space. C) Wire easily goes through the space to the opposite wall. Wire going up parallel to the balloon if starting at the side. D) Wire going through antegrade space into the opposite wall. E) End balloon wiring (EBW) start position. F) End balloon wiring. G) Successful end balloon wiring into the antegrade balloon space.*

higher than the penetration force going to the side. Therefore, wires often go up parallel to the balloon **(Figure 2C)** or through the antegrade balloon space into the opposite wall and enter the subintimal space again **(Figure 2D)**. To maximise wire control, we should inflate the antegrade balloon before the wires overlap **(Figure 2E)**. Then the retrograde wire can be manipulated through virgin CTO body territory aiming for the end tip of the balloon **(Figure 2F)** (EBW) and can be controlled into the balloon space quickly and easily **(Figure 2G)**.

In the contemporary reverse CART era, the main method of wire crossing in retrograde CTO PCI should be contemporary reverse CART. The EBW method of contemporary reverse CART should be possible unless the retrograde wire has already gone subintimal or there has been extensive retrograde wire manipulation. However, our algorithm recognises two exceptions to contemporary reverse CART: the short CTO, and the long and tortuous or ambiguous or calcified CTO, which we label as "long-plus CTO" **(Figure 1)**.

THE EXCEPTIONS TO CONTEMPORARY REVERSE CART

THE SHORT CTO – SINGLE WIRE CROSSING

Once the retrograde wire and microcatheter have crossed the channel, contrast injection through the microcatheter should be performed to elucidate distal cap morphology. The true length of the CTO and the distal cap characteristics can then be known. The majority of CTOs requiring a retrograde approach are longer than 15 mm but, if the true length of the CTO is less than 15 mm, our algorithm **(Figure 1)** recommends attempting single retrograde wire crossing of the CTO, except when the CTO is in the ostial LAD or ostial LCx. This exception is to prevent subintimal tracking of the retrograde wire into the left main which may cause haematoma formation, leading to compromise of the other artery (LAD or LCx). Therefore, in ostial LAD and LCx short CTO, we should carry out antegrade preparation first and wire crossing should be performed with reverse CART. In all other short CTOs, retrograde single wire crossing should be used.

If there is a suitable side branch at the proximal cap of the short CTO, single wire crossing should be carried out under IVUS guidance to prevent the loss of the side branch.

If single retrograde wire crossing fails in the short CTO, reverse CART is usually not a good bail-out technique because the retrograde wire is often in the subintimal space while the antegrade wire would be in the true lumen. The distance between the antegrade and retrograde wires is wide, and the retrograde wire has to travel sideways quite a long way within a short longitudinal distance to reach the antegrade space, which is often impossible. Persisting in attempting to perform reverse CART would often lead to the retrograde wire going into the subintimal space in the vessel proximal to the CTO site, leading to loss of the proximal side branch or proximal vessel haematoma. Therefore, we recommend antegrade IVUS-guided retrograde wiring as the first bail-out method.

If antegrade IVUS-guided retrograde wiring fails, we should bail out with traditional CART by removing the retrograde microcatheter with an extension wire, 1.25 mm balloon dilatation of the septal channel, and passing a 2.5 mm over-the-wire balloon to the distal lumen. In this situation, the antegrade wire and the retrograde balloon are both in the true lumen and the distance between them is short. Therefore, traditional CART is almost always successful.

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THE LONG PLUS CTO – INTENTIONAL SUBINTIMAL TRACKING

The second exception to contemporary reverse CART is the "long plus CTO". We do not believe that length alone is predictive of failure to cross the CTO body with traditional wiring techniques. However, when a long CTO is accompanied by tortuosity or calcium or ambiguity, so-called "long plus CTO", traditional wiring is highly likely to fail and therefore intentional subintimal wiring should be used as recommended by the algorithm **(Figure 1)**. The main method of intentional subintimal wiring from the retrograde side is knuckle wiring. For most retrograde operators, retrograde knuckle wiring is the fastest and safest way to cross these long plus CTOs. If a retrograde knuckle wire is used, we should use a large balloon for conventional reverse CART.

IVUS-GUIDED REVERSE CART (Figure 3)

When contemporary or conventional reverse CART fails, the next step should be IVUS examination on the antegrade wire using an end imaging IVUS catheter, such as the Eagle Eye® (Volcano Corp., San Diego, CA, USA). This is the recommendation not only of the APCTO club but also from established consensus papers[16].

Although conventionally the result of IVUS examination is classified into four possible wire positions, our algorithm considers the IVUS examination results in three categories: 1) there is a connection between the antegrade wire and the retrograde wire; 2) there is no connection and the antegrade wire (and thus IVUS) is intraplaque; and 3) there is no connection and the antegrade wire is in subintimal space **(Figure 3)**. The reason for this classification is because, when the antegrade wire is intraplaque, whether the retrograde wire is intraplaque or subintimal makes no difference to the subsequent methods needed to complete wire crossing. For beginner retrograde operators, this classification is much easier to read as there is no need to locate the retrograde wire position, which can be difficult on IVUS. Also, for operators without IVUS, this classification allows them to follow the steps of the algorithm based on whether they think the antegrade wire is intraplaque or subintimal, and whether the wires are connected – information that one can make an educated guess on from the fluoroscopic findings.

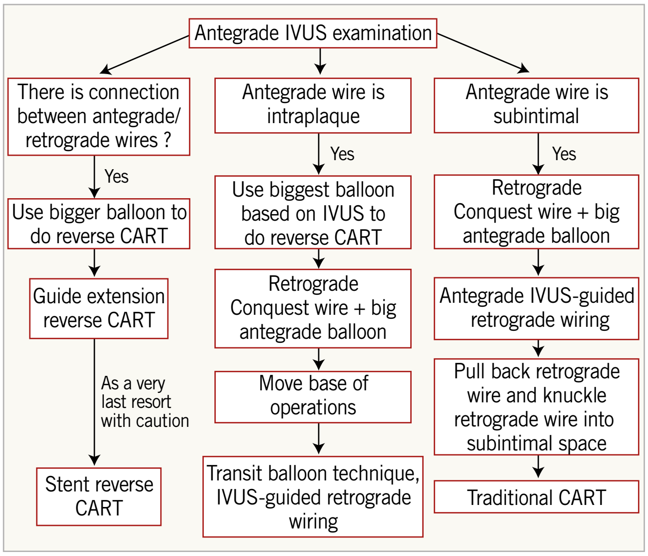

Figure 3. *APCTO club algorithm for intravascular ultrasound (IVUS)-guided reverse CART.*

IVUS SHOWS THAT THE ANTEGRADE WIRE AND THE RETROGRADE WIRE ARE IN THE SAME SPACE

If there is a connection, using a larger balloon to perform reverse CART will usually succeed. If this fails, it is most commonly due to the retrograde wire being caught up in disease, dissection, or tortuosity between the connection point and the antegrade guiding ostium. This is particularly common in mid right coronary reverse CART. In these situations, one should go straight to coaxial guiding catheter extension catheter reverse CART **(Figure 3)**. If this fails, we can use IVUS to locate the connection site and put a coaxial guiding catheter extension catheter at that site and try to wire it, or use the transit balloon technique[17]. Stent reverse CART – placing a stent by landing the distal end of the stent just at the connection point – can be carried out as a last resort.

IVUS SHOWS NO CONNECTION BUT THE ANTEGRADE WIRE IS INTRAPLAQUE

If there is no connection and the antegrade IVUS is in the plaque, our aim is to crack the plaque to make a connection. Therefore, the largest balloon sized by IVUS should be used to perform reverse CART. If this fails, we should use a retrograde high penetration force wire (Conquest 12) to puncture the antegrade space.

When this fails, one should move the reverse CART site ("move the base of operations" in hybrid terminology) to a more favourable site and reattempt reverse CART. The coaxial guiding catheter extension catheter assisted transit balloon technique is an extremely powerful technique to bail out these cases[17] **(Figure 3)**. IVUS-guided retrograde wiring is also possible but this requires great experience with IVUS-guided wiring. We do not recommend stent reverse CART if the IVUS does not show connection between the antegrade and retrograde wires.

IVUS SHOWS NO CONNECTION BUT ANTEGRADE IVUS IS SUBINTIMAL

Finally, the antegrade wire (and IVUS) is subintimal and there is no connection. This is the most difficult situation in which to perform successful reverse CART. Using a large balloon will not work, as the balloon will expand the subintimal space, stretching out the media and adventitia of the vessel, but once the balloon is deflated the space will just collapse, making it impossible to wire into. Therefore, we should start with large antegrade balloon inflation and retrograde Conquest wire puncture while the balloon is inflated. If this fails, we should pull back the retrograde wire and attempt to knuckle a PILOT® 200 (Abbott Vascular, Santa Clara, CA, USA) wire from the retrograde side, as the retrograde PILOT 200 will very likely go into subintimal space and spontaneously make a connection to the antegrade wire space **(Figure 3)**. After retrograde wire pullback and knuckle, IVUS can be repeated to confirm the connection and we can follow the algorithm for wires with connection. If knuckling fails to connect the wires, the next step is to revert to traditional CART. If even traditional CART fails, we can employ the confluent balloon technique[18], which is an extremely powerful reverse CART tool.

As with any detailed retrograde CTO PCI technical paper, this work may encourage its readers to perform retrograde CTO PCI. Therefore, we feel it is our responsibility also to point out the inherent traps that can cause catastrophic complications in retrograde CTO PCI. However, this is beyond the scope of this paper; we refer our readers to our other work[6].

Conclusions

In the retrograde CTO PCI field, there have been few technical overview papers, the most recent being more than five years ago. Many new devices and concepts have been developed since the last comprehensive review. We, the APCTO club, deemed it the right time to propose a new algorithm for retrograde CTO PCI. This algorithm builds upon the excellent work of the hybrid operators and avoids overlap by referring to their work. We hope this algorithm will form the next step to encourage safer and more efficacious retrograde CTO PCI procedures.

Impact on daily practice

This retrograde algorithm provides very practical advice to overcome the major hurdles of successful retrograde CTO PCI channel crossing and reverse CART. Different wires and techniques to overcome problems associated with particular retrograde channels are needed for success. The different methods to achieve retrograde/antegrade connection in different CTO morphologies are described and a detailed explanation of how to carry out IVUS-guided reverse CART is given. By following this algorithm, operators can markedly improve their retrograde CTO PCI success.

Conflict of interest statement

S. Harding has received honoraria for speaking from Boston Scientific, Medtronic and Asahi, and acted as a proctor for Boston Scientific and Bio-Excel. E. Tsuchikane is consultant for Boston Scientific, Nipro, and Asahi. E. Wu is a proctor for Boston Scientific and St. Jude Medical, and owns Medtronic shares. The other authors have no conflicts of interest to declare.

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