

Chronic Total Occlusion Wiring: A State-of-the-Art Guide From The Asia Pacific Chronic Total Occlusion Club



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Received 5 December 2018; received in revised form 7 January 2019; accepted 2 April 2019; online published-ahead-of-print 25 April 2019

Objective

Despite the advances in wire technology and development of algorithm-driven methodology for chronic total occlusion (CTO) intervention, there is a void in the literature about the technical aspects of CTO wiring. The Asia Pacific CTO Club, a group of 10 experienced operators in the Asia Pacific region, has tried to fill this void with this state-of-the-art review on CTO wiring.

Methods

This review explains, for proximal cap puncture: choices of wires, shaping of the wire, use of dual lumen catheter, and method of step-down of wire penetration force for successful wiring. In wiring the CTO body, the techniques of loose tissue tracking, intentional intimal plaque tracking, and intentional subintimal wiring are described in detail. For distal lumen wiring, a blunt distal cap, presence of a distal cap side branch, calcium, and sharp tapered distal stump predict cap toughness, and wire penetration force should be stepped-up in these cases. The importance of choosing between redirection, parallel wiring, and Stingray (Boston Scientific, Marlborough, MA, USA) for angiographic guidance is discussed along with which will be more successful. On the retrograde side, the problems encountered with distal cap puncture and methods to overcome these problems are explained. The method of wiring the CTO body through a retrograde approach depending on the morphology of the CTO is described. Different reverse controlled antegrade and retrograde tracking (CART) wiring methods – including end balloon wiring, side balloon entry, and conventional reverse CART – are explained in detail.

Conclusion

This is a systematic CTO wiring review, which is believed to be beneficial for CTO operators worldwide.

Keywords

Chronic total occlusion • Wiring • Percutaneous coronary intervention

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Introduction

In the past decade, the field of chronic total occlusion (CTO) intervention has rapidly developed, with several significant breakthroughs. The introduction of the retrograde technique in 2006 [1] opened up an alternative approach that has proven to improve CTO percutaneous coronary intervention (PCI) success rates. The development and wide adoption of the hybrid algorithm [2] further improved success and allowed a common language to be available for discussion and research.

The Asia Pacific CTO Club (APCTOC), a group of 10 high-volume expert CTO operators, has also authored an algorithm for global application [3]. In parallel with these remarkable technical, algorithmic, and theoretical developments, there are significant advances in CTO wire technology resulting in wires that have better torque transmission, penetration force, and wire control. Consequently, when using these wires many operators have found increasing antegrade success rates and reduction in the need of a retrograde approach. Although there have been many publications describing the retrograde approach [4,5], hybrid algorithm [2], APCTOC algorithm [3], reverse controlled antegrade and retrograde tracking (CART), and intravascular ultrasound (IVUS) usage in detail for CTO intervention [6], there has not been much written about wiring technique, despite the central importance of wiring and enormous advances made in wire technology. Previous technical wiring papers have more heavily focussed on histology rather than technique [7]. This is in part due to the difficulties in writing such a paper. Operators of CTO have a wide variation of their 'favourite' wire choice and wiring techniques. The available wires for CTO intervention are vast and most operators are only familiar with their selected favourites. Consequently, it is almost impossible to conduct a randomised trial for any wire, and only retrospective data from registries can be used to determine wire choice. The registry data is also very biased by operator choice and the results are difficult to interpret. Wiring technique remains a core part of CTO intervention and a systematic review of these techniques is lacking in the literature.

It is believed that the Asia Pacific group of operators represent not only traditional Japanese wiring techniques (ET) but also a wide opinion of wiring techniques within the Asia Pacific region. Therefore, the APCTOC hopes to provide an expert review on wiring techniques for today's CTO interventions.

The Wires

Wire Classification

There is considerable variation in wire choice among the authors of this paper. In order to simplify discussion, the wires have been broadly classified into high penetration force (HPF), intermediate penetration force (IPF), and low penetration force (LPF), and further divided into blunt tip or tapered tip (Table 1). The categories are roughly based upon tip load; however, tapered wires have a higher penetration force than blunt tip wires, despite lower tip loads. A choice of any of the wires within the same recommended class is considered reasonable.

Wire Shaping

Chronic total occlusion wire shape is described in terms of distal tip curve and secondary curve. Usually, a 40-60° distal tip curve within 1 mm from the tip is made, and a variable secondary curve is made proximal to this. The Gaia wire series (Asahi Intecc, Seti, Aichi, Japan) has a pre-shaped distal tip curve designed to provide maximal penetration and torque transmission to the tip. The distal tip curve of the Gaia serves as an example of the kind of tip curve that should make for the best penetration force and torque transmission. There is considerable variation in the secondary curve, but for CTO body wiring, a curve in the secondary bend as opposed to a sharp angle is recommended. It is believed that a curve will less likely push the wire into the subintimal space.

Wiring Philosophy

The secret to good wire control and wire penetration force is back-up support. It is always better to improve back-up support before increasing wire penetration force. An HPF wire without good back-up support becomes uncontrollable and is, therefore, dangerous. The following are recommended: a strong back-up support guiding catheter, using a side branch anchoring balloon, guide extension catheters, and microcatheter support of wires for CTO wiring.

The Proximal Cap

Choice of Wires

The choice of wire to approach the proximal cap should be guided by the proximal cap morphology, as described in the

Table 1 Classification of wires into high, intermediate, and low penetration force and blunt vs tapered tip.

	Blunt tip	Tapered tip
High penetration force	Miracle 12g	Gaia Third, Gaia Next Third, Conquest or Confianza Pro 9g, 12g, 8/20, Hornet 14
Intermediate penetration force	Ultimate Bros 3g, Pilot 200	Gaia Second, Gaia Next Second
Low penetration force	Pilot 50, Fielder FC	XTA, XTR, XT, Fighter

Miracle 12g, Gaia Third, Next Third, Conquest or Confianza Pro 9g, 12g, 8/20, Ultimate Bros 3g, Gaia Second, Gaia Next Second, Fielder FC, XTA, XTR, XT - Asahi Intecc. Pilot 200, Pilot 50 - Abbott Vascular, St Paul, MN, USA. Hornet 14, Fighter - Boston Scientific.

algorithm [3]. In tapered proximal cap with residual channels, an XTR wire (Asahi Intecc) should be used to negotiate the CTO. In tapered proximal cap without residual channel, an XTA (Asahi Intecc) should be used. In the blunt cap, a higher penetration force wire is usually required to penetrate the cap. If the blunt cap has a suitable nearby side branch, IVUS interrogation can often exactly locate the cap, and a dual lumen catheter should be used to direct the force of the wire towards the centre of the proximal cap and increase back-up support. For the blunt proximal cap, a balance between vessel course ambiguity and penetration force should be made. Where there is absolutely no ambiguity, an HPF wire can be used, whereas if there is ambiguity, a more step-wise increase in penetration force is recommended.

It should always be remembered that increasing the back-up force is a more controlled way of penetrating the cap compared with merely increasing the penetration force of the wire. In other words, the back-up force should be maximised before stepping-up to very high-penetration force wires. The following should be used before trying higher penetration force wires: side branch balloon anchoring, anchoring with two side branch wires to increase friction of the side branch anchor balloon, guide extension catheter, blocking balloon in side branch to prevent side branch prolapse or slippage, and power balloon inflation to trap the antegrade microcatheter

under the balloon in the proximal vessel. The usual step-up would be through blunt IPF wires, then blunt HPF wires, and finally tapered HPF wires.

Shape of Wires

The right shape of the wire is very important for proximal cap puncture. For proximal cap puncture, two bends are usually put in the wire, one about 1 mm from the distal tip and the other (secondary bend) about 4-6 mm from the distal tip, depending on the CTO cap morphology (Figure 1a). A sharper secondary bend on CTO wires used for proximal cap puncture is recommended so that it can be clearly seen when the secondary bend reaches the proximal cap (Figure 1a). By altering four variables, the wire can be adapted to any CTO cap anatomy: distal bend length, distal bend angle, secondary bend length, and secondary bend angle. The shape of the wire should be determined by the 'angle of attack' (AOA). The AOA is the angle between the antegrade wire force direction and the proximal CTO body intimal path direction. In a shallow AOA CTO proximal cap (such as the left anterior descending (LAD) CTO shown in Figure 1b) a shallow wire curve (Figure 1c) should be made, and in contrast with a steep AOA CTO proximal cap (such as the right coronary artery (RCA) CTO shown in Figure 1d) a larger secondary bend should be made (Figure 1e). The wire should puncture the cap and be pushed into the CTO body

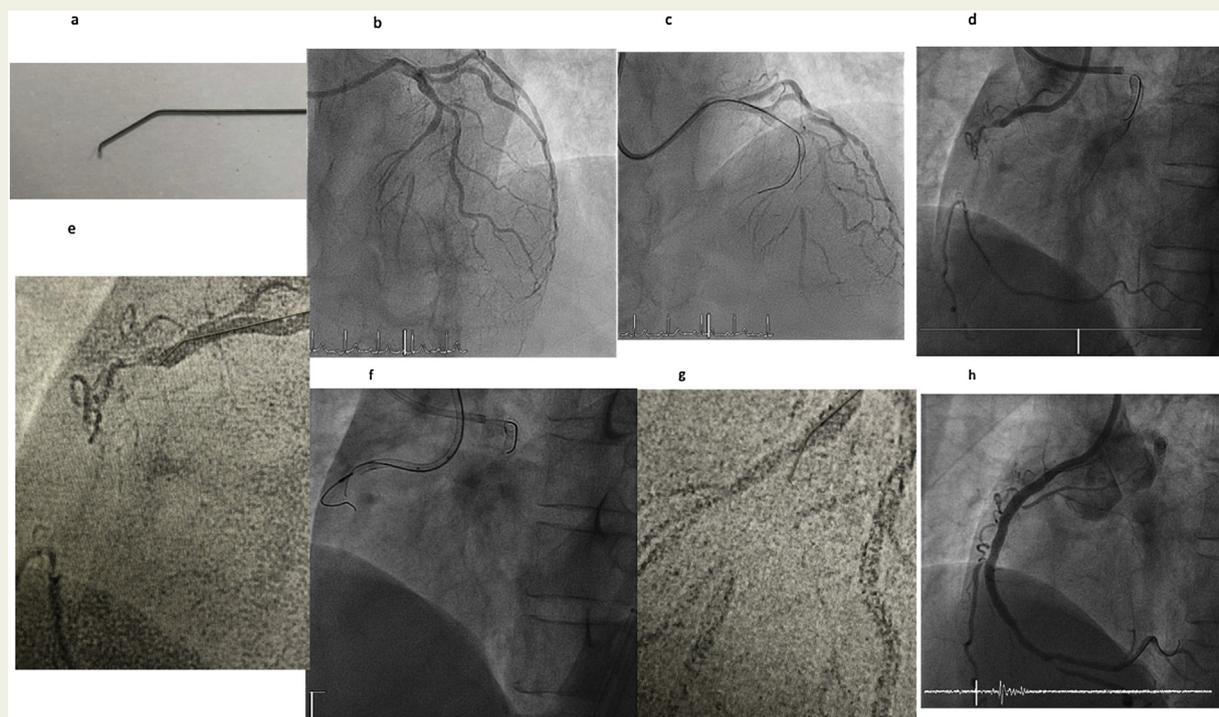


Figure 1 Tailored wire shape for proximal cap puncture. a. Sample wire shape specifically for proximal cap puncture. b. Shallow angle left anterior descending chronic total occlusion. c. Shallow secondary bend for shallow left anterior descending chronic total occlusion angle. d. Large angled proximal right coronary artery chronic total occlusion. e. Large secondary angle for large angled right coronary artery chronic total occlusion. f. Wire punctured to secondary bend at proximal cap. g. Wire punctured to point of secondary bend at proximal cap. h. Final angiographic results.

until the secondary curve reaches the proximal cap (Figure 1f and Figure 1g), at which point it should not be advanced further, as continued forward pushing of the wire would push the secondary curve into the CTO and transmit the forward force of the tip of the wire laterally into the subintimal space. If pre-procedural computed tomography (CT) coronary angiography is available, the wire shape can be made according to the angle between the proximal vessel and the CTO body measured on CT. This concept of a 'tailor-made' proximal cap puncture wire can vastly improve the chances of successful antegrade wiring by keeping the antegrade wire within the intraplaque space (Figure 1h).

Importance of Step-Down Technique

The APCTOC algorithm [3] recommends step-down of the wire penetration force once the proximal cap puncture is performed. It must be acknowledged that many operators find the use of a dual lumen catheter frustrating at this point, and all of the current authors have also had the same frustrating experience of losing the puncture wire position when they have tried to remove the dual lumen catheter for a microcatheter to perform step-down wire exchange. However, using a dual lumen catheter does provide better back-up and a more central puncture and should therefore be persisted for suitable cases. A tip for removing the dual lumen catheter is to ask the

second operator to hold the side branch wire and anchor it with his hands to the Y connector. The first operator should then carefully back out the dual lumen catheter to just over one balloon length into the guiding catheter. Then, a trapping balloon should be placed in the guiding catheter to allow safe removal of the dual lumen catheter.

It has been found that it is more difficult to maintain the wire position during dual lumen catheter removal and insertion of the microcatheter in proximal caps with large AOA.

Therefore, the following is advised: if the AOA is small, meaning the CTO entrance is straight, removing the dual lumen catheter and advancing an antegrade microcatheter into the proximal cap and then exchanging the CTO wire to a lower penetration wire works well. However, if the AOA is large (as the ostial LAD lesion shown in Figure 2a), removing the dual lumen catheter over the high penetration wire and exchanging for an antegrade microcatheter may not work well, as the microcatheter often prolapses into the side branch (Figure 2b). In this situation, the high penetration wire should be removed from the dual lumen catheter and it should be attempted to wire into the space created by the HPF wire using a lower penetration force wire such as an XTA, or in this instance a Pilot 200 (Abbot Vascular, Santa Clara, CA, USA) (Figure 2c). When the wire is advanced further into the CTO, it provides more back-up and the dual

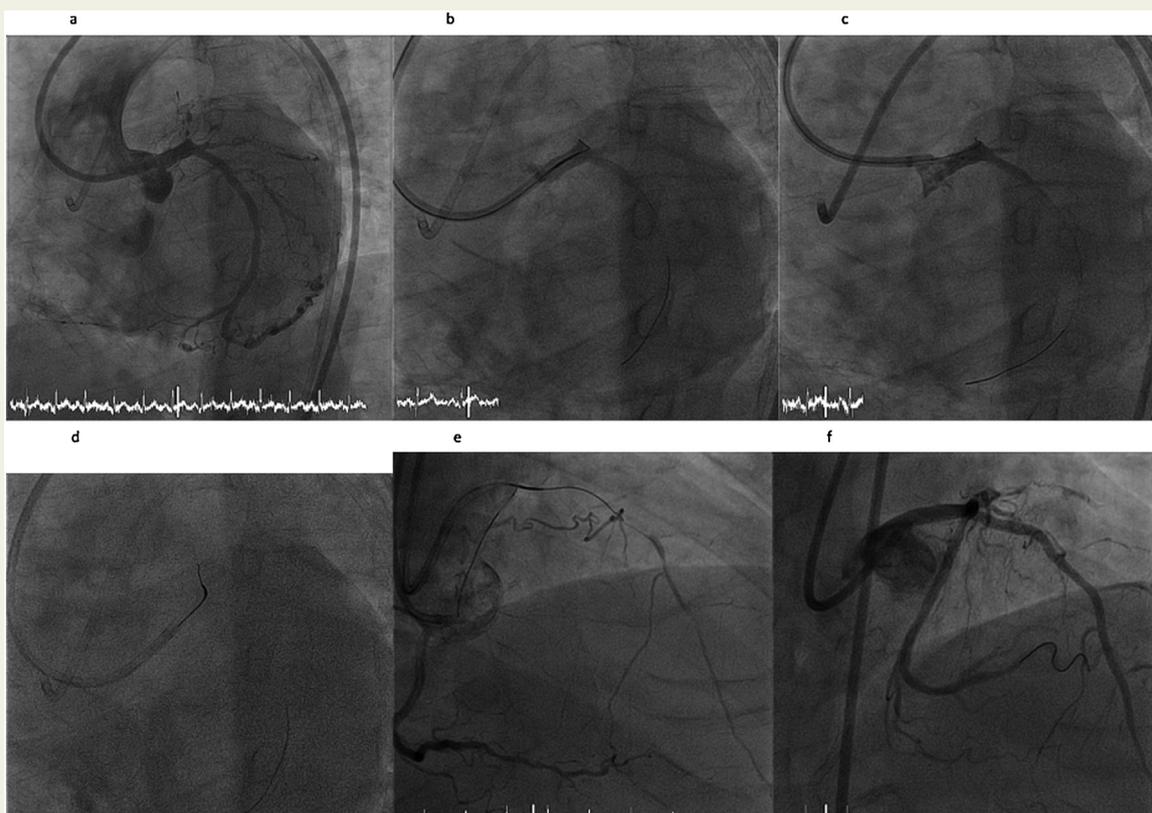


Figure 2 Stepping down from dual lumen catheter. a. Large angle ostial left anterior descending chronic total occlusion. b. Microcatheter prolapse into side branch. c. Step-down upon the dual lumen catheter. d. Exchange to microcatheter upon step-down wire. e. Wiring to distal true lumen. f. Good results.

lumen catheter may then be easily exchanged for a microcatheter (Figure 2d) allowing final antegrade wiring into the distal true lumen (Figure 2e) with good results (Figure 2f).

Crossing the CTO Body

The Aims of CTO Body Crossing

The aim of wiring through a CTO body is to: 1) get to the distal cap; 2) avoid wire perforation outside the vessel architecture; 3) avoid a wire going into the subintimal space; 4) avoid enlarging the subintimal space and forming a haematoma; and 5) avoid enlarging the peri-wire space, which reduces antegrade wire control. While getting to the distal cap and avoiding wire perforation is paramount to the success of the case, the other three are not essential to the same degree. Therefore, in the presence of CTO course ambiguity or severe tortuosity or calcification, the last three may be ignored and knuckle wiring be applied in order to get to the distal cap without perforating the artery.

A full explanation of the histology and therefore the wiring methods – including loose tissue tracking, intentional intimal plaque tracking, and subintimal tracking – have been published by Sumitsuji *et al.* [7]. Within the CTO body, there are two main spaces where the wire can travel through: the intraplaque ‘intimal’ space and the subintimal space. However, for the wire that travels through the intimal intraplaque space, it can travel through soft ‘loose tissue’ (so-called loose tissue tracking) or penetrating hard plaque (so-called intentional intimal plaque tracking). These three ways to travel through the CTO body will be described in turn.

Loose Tissue Tracking Method

The ideal method to achieve all the above five aims is through loose tissue tracking. In loose tissue tracking [7], an LPF hydrophilic polymer jacketed wire is used to track the loose tissue through the CTO body without penetrating into hard plaque or into the subintimal space. Polymer jacketed coating is particularly useful in loose tissue tracking, vein graft CTO, and ISR CTO. The low penetration force wire should be shaped with a 40°–60° tip bend within 1 mm from the tip. This tip bend allows the rotational force to be transmitted as a penetration force at the tip. The method to manipulate the wire in loose tissue tracking is to use torque rotation more than forward pushing, allowing the wire’s own torque transmission to transmit a small rotational penetration force to the tip, and for the wire to find its own way through the loose tissue. It is important not to over-push this kind of wire, as they tend to form a tip loop. When a tip loop is formed, the peri-wire space is markedly enlarged and antegrade wire control is lost.

There are two main reasons why the XTA wire will not make progress in loose tissue tracking: (1) the wire may migrate to a questionable position suspicious of the subintimal space, a side branch, or frankly outside the vessel. In this instance, the wire should be redirected. (2) The wire meets resistance and cannot go any further. Resistance usually

means that the wire is up against harder plaque and is always inside the vessel architecture. Therefore, the back-up force should be increased by good guiding engagement and the microcatheter be pushed towards the tip of the wire, so-called ‘weaponising’ the wire. Often, this will produce more penetration force, allowing the XTA wire to go through the plaque and continue loose tissue tracking.

However, if this fails and the wire continues to meet resistance, the strategy should be changed to intentional intimal plaque tracking. To do this, the microcatheter should be further inserted so that its tip is close to the resistant point, and then be switched out for an IPF or HPF wire to penetrate the hard plaque. After penetration, this can be stepped down again and loose tissue tracking be continued if there is still a long distance before the distal cap, but often intentional intimal plaque tracking may be continued if the distance to the distal cap is short.

Many different wires can be used for loose tissue tracking. The APCTOC algorithm recommends the use of XTA as a loose tissue tracking wire. Its soft tip stiffness means that a tip loop may be easily formed, and it is particularly important to use rotation rather than pushing to generate penetration force when XTA is used for loose tissue tracking. The Pilot wire (Abbott Vascular, St Paul, Minnesota, USA) also works well as a loose tissue tracking wire, and its higher tip stiffness results in less loop-forming tendency.

Intentional Intimal Plaque Tracking Method

Some CTOs cannot be passed with loose tissue tracking as there may be heavy calcium, course tortuosity, or continuous hard plaque obstructing the path of loose tissue tracking. In these cases, intentional intimal plaque tracking [7] should be attempted to maximise the chance of directly wiring into the distal true lumen. In loose tissue tracking, the operator does not need a lot of information about the CTO path and the wire is allowed to ‘find its own way’. However, in intentional intimal plaque tracking, it must be known exactly where the intimal path of the CTO lies. This knowledge can be obtained from pre-procedural computer tomography (CT) coronary angiogram, intra procedural IVUS guided wiring, or best guess from calcium pattern on fluoroscopy. Pre-procedural CT angiogram is not always available and the software to impose the CT upon the fluoroscopy image is still imperfect, making CT-guided intentional intimal plaque tracking impractical in many centres. It is hoped, with advances in CT or fluoroscopy interfacing, that future CT-guided intentional intimal plaque tracking will become a practical reality. Intra-procedural IVUS guidance requires the placement of an IVUS catheter into the enlarged subintimal space to guide a second wire into the intimal space. As it increases the risk of distal hematoma extension, IVUS-guided wiring is reserved for cases where prior wiring has already entered and enlarged the subintimal space. Finally, guidance from calcium pattern on fluoroscopy is extremely inaccurate and even misleading. Very experienced operators are occasionally surprised to find their ‘intentional intimal tracking

wire' was, in fact, in the unintended subintimal space. Therefore, except in rare instances of IVUS-guided antegrade wiring, intentional intimal plaque tracking is often a best-guess technique and in practice may overlap with subintimal wiring.

On the other hand, an obviously subintimal wire coursing a spiral path in the CTO segment can be left in situ as a guide for another wire to pass through the centre of the spiral 'cage' to track the intraplaque space. For intentional intimal plaque tracking, an HPF wire is required to puncture through the hard plaque. The operator should have a good grasp of the position of the intimal path before considering intentional intimal plaque tracking, to minimise the risk of perforation. Even with careful handling, however, an HPF wire still tends to easily migrate into the subintimal space at curves. Therefore, in tortuous CTOs, the operator should step down after hard plaque puncture to negotiate through the rest of the CTO body.

Step-by-Step Guidance to Step-Up and Step-Down in Wiring Through CTO Body

The reason to give up on loose tissue tracking and move towards intentional intimal plaque tracking is usually when a wire hits resistance. Resistance is an indication that the wire is still inside the vessel architecture and likely abutting plaque. In this case, it is safe to push a microcatheter towards the point of resistance and switch out for an HPF wire, a so-called step-up. After penetration, the microcatheter should be pushed forward a bit more and stepped down by exchanging the HPF wire for an IPF or LPF wire. Loose tissue tracking can then be resumed if the wire went easily until resistance, and the need for step-up to intentional intimal plaque tracking re-appears. This kind of step-up and step-down can improve the chances of successful antegrade wiring. Wire penetration force should always be balanced against CTO course ambiguity. When there is absolutely no ambiguity, a HPF wire may be confidently used. It is advised that more cautious wire step-up be applied whenever there is slight vessel course ambiguity.

IVUS-Guided Intentional Intimal Plaque Tracking

Usually, a 1.5-mm balloon is placed on the first wire, which has been advanced into the subintimal space, to allow passage of an IVUS catheter to guide the second working wire direction. Further antegrade injection of contrast after the 1.5-mm balloon dilatation should not happen, to minimise haematoma extension within the subintimal space. Current experience with IVUS-guided intentional intimal plaque tracking suggests that the Conquest and Confianza (Asahi Intecc) wires are more effective as the second working wire in successfully tracking the intimal plaque. The Gaia wires, on the other hand, tend to easily track into the subintimal space. The theory behind this is that, compared with the Conquest and Confianza wires, the Gaia wires have a softer wire core, which is better for deflection control. However, the softer tip

makes it prolapse more easily, and therefore performs less well for IVUS-guided intentional intimal plaque tracking. Where there is IVUS guidance, using HPF wires like Conquest and Confianza is not inhibited by ambiguity, as there is absolute certainty about wire position from the IVUS.

The imprecision of knowledge about the intimal plaque path limits the success of intentional intimal plaque tracking wiring. Using HPF wires also increases the chance of entering the subintimal space and expanding it, with subsequent risk of haematoma formation and extension. This means that, except in centres with excellent CT or fluoroscopy co-registration technology or extensive wiring skills, intentional intimal plaque tracking is a time-consuming technique associated with a considerable failure rate. Therefore, time, contrast, and radiation dosage should not be over-invested in this technique. Instead, strict time limits should be set upon how long is spent attempting intentional intimal plaque tracking. Indeed, some operators for whom Stingray (Boston Scientific) is a familiar technique may choose to move straight from failed loose tissue tracking to knuckle wiring and Stingray re-entry, instead of intentional intimal plaque tracking.

Antegrade Subintimal Tracking Method

The APCTOC algorithm [3] recommends the subintimal tracking method in either the antegrade or retrograde direction if the CTO is a 'long-plus' CTO. With the advance of wire technology, long CTOs can often be crossed by loose tissue tracking or intentional intimal plaque tracking techniques, and mere length alone does not necessarily mean that the crossing path must be subintimal. However, in the presence of calcification, tortuosity, or vessel course ambiguity – the so-called 'long plus' CTO – intentional subintimal tracking is preferred as it offers a quick and low-risk method for crossing the CTO body.

Antegrade subintimal tracking is the technique of crossing the CTO body by wiring in the subintimal space. A blunt tip IPF wire with hydrophilic coating or polymer jacketing should be used to avoid penetration outside the vessel architecture. The wire is manipulated by rotating it to slip forward in the subintimal space, avoiding a strong forward pushing force that may lead to vessel wall penetration. Alternatively, knuckle wiring can also allow rapid advancement within the subintimal space. However, to enable re-entry into the distal true lumen, it is important not to expand the distal true lumen subintimal space. Therefore, knuckle wiring should be reverted to single straight wiring or finished with a Cross-Boss catheter, Corsair microcatheter (Asahi Intecc) or a small balloon in order to minimise subintimal space expansion.

The Distal Cap

Method Depends on Antegrade Wire Position

The method of distal cap exit into a true lumen is dependent upon what has happened to the wire as it traverses the CTO

body. If the wire is already in the subintimal space, the method used to exit the distal cap will be very different to that when the wire is still in the intimal plaque. In loose tissue tracking, when the wire has reached the distal cap, the continued drilling manipulation of the wire will often lead to successful puncture of the distal cap into the true lumen. However, if resistance is noted at the distal cap, it is critically important not to push the wire too much, as the leading wire tip outside the microcatheter may easily form a loop and expand the peri-wire space.

Recognising a Tough Distal Cap

Certain features would suggest a 'harder distal cap', and in these cases, wire step-up to puncture the distal cap is preferable. A rounded distal cap stump (Figure 3a), the presence of a large side branch at the distal cap (Figure 3b), visible calcium at the distal cap (Figure 3c), rapid contrast filling beyond the distal cap, and sharp tapered distal cap stump (Figure 3d) are all predictive of a harder cap. Like the proximal cap, a rounded blunt stump, especially when there is a large side branch, is usually harder. Calcium, of course, is predictive of a hard cap, regardless of whether it is a proximal or distal cap. Good contrast filling means that the distal cap is facing high collateral reconstitution pressure, which hardens the cap over time. Finally, a sharp taper means that

the CTO wire will often slip off the slope of the distal cap into the subintimal space. In the current case examples, the rounded distal cap (Figure 3a) was punctured with antegrade Conquest 12 g wire and conquest 9 g in a parallel wire fashion; the large side branch case (Figure 3b) failed with an antegrade attempt; the visible calcium case (Figure 3c) failed antegrade and was successfully addressed with a retrograde approach; and the tapered tip case (Figure 3d) failed due to wire slippage off the tapered tip slope (Figure 3e and Figure 3f) and finally succeeded with distal re-entry by Conquest 12 g wire. Other clinical features such as long duration of occlusion and presence of bypass graft to the vessel also predict a tough distal cap.

Dealing with a Tough Distal Cap

In the presence of these five features, pushing the microcatheter towards the distal part of the CTO and step-up to an HPF wire is critical for success. In cases where loose tissue tracking is successful but the LPF wire cannot penetrate the distal cap, the microcatheter should also be pushed towards the distal part of the CTO and the wire be stepped-up. The wire properties that allow for successful puncture into the distal true lumen are: 1) high penetration force; 2) a tip that can catch tissue to exert penetration force; 3) good torque control and transmission, allowing it to be directed towards a

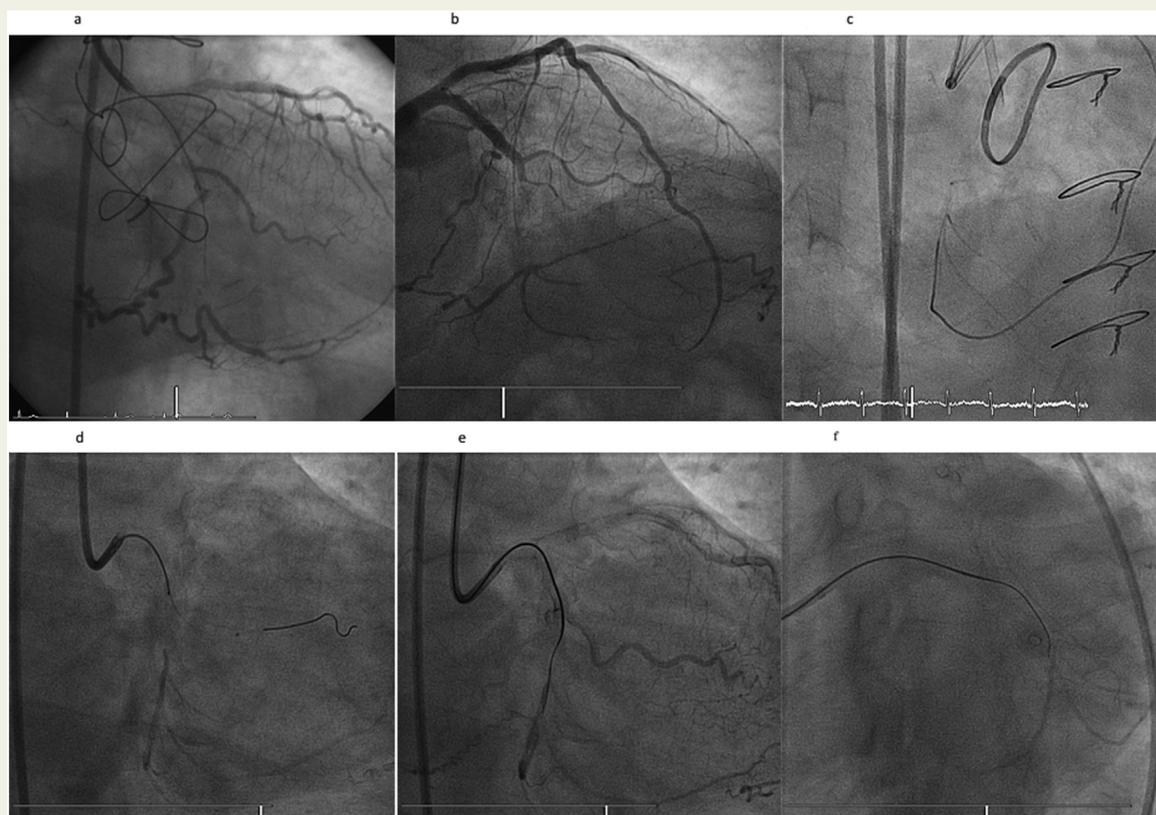


Figure 3 Predictors to tough distal cap. a. A rounded distal cap stump. b. A large side branch at the distal cap. c. Visible calcium at the distal cap. d. Tapered distal cap stump with sharp tip. e. Wire slipping off tapered distal cap. f. Wire slipping off other side of distal cap.

particular direction; 4) stiff pre-tip shaft, to allow it not to prolapse when pushed; and 5) a tip angle that allows for best penetration and torque transmission. The Conquest and Confianza pro 9 g or 12 g or Hornet 14 (Boston Scientific) wires fulfil many of these requirements. The Gaia Next Third has a high penetration force, pre-shaped tip curve suitable for penetration, and very good torque control, but its tip is slippery. Once these powerful wires penetrate into the distal true lumen, there is a danger of re-entering into the subintimal space. Therefore, whenever possible, the microcatheter should be tracked across the distal cap and a workhorse wire be used to wire into the rest of the vessel.

Antegrade Wire Fails

If the antegrade wire fails to puncture into the distal true lumen but instead goes next to the true lumen in the subintimal space, a decision needs to be made regarding the next strategy. Broadly speaking, three commonly used strategies can be considered: 1) redirection, 2) parallel wiring, and 3) Stingray. Limited antegrade subintimal tracking (LAST) and IVUS-guided wiring are usually reserved for a later stage and are beyond the scope of this work. In real life, operator experience, skill set, availability of devices, and costs often determine which method is used. However, when all three methods are equally accessible, certain angiographic characteristics favour certain strategies. Redirection is often successful if the wire is already close to the true lumen, there has not been much wiring done beforehand, the distal target is large, and there is good wire control (without much tortuosity before the distal cap). Stingray is good when there is a good re-entry site with large-calibre vessel lumen, without much calcium, and the wire is <500 microns from the true lumen [8]. Parallel wires are good for larger distances between the first wire and true lumen, and wire control can be maintained. The three choices are mutually exclusive, as once an attempt with the first method has failed, there will be substantial subintimal space expansion leading to failure of subsequent methods. Therefore, it is critically important to choose one of the three methods early on and, in effect, to abandon the other two. On the whole, parallel wiring and Stingray offer better chances of success when compared with redirection. The mistake many beginner CTO operators make is to continue with redirection while enlarging the wire space or going further subintimal without markedly increasing their chances of success. The chance of success and the diversity of the operator's experience are both better with switching to parallel wiring or Stingray.

Parallel Wiring

The parallel wiring technique allows the operator to keep the first wire, which has gone into the subintimal space next to the distal cap, as a marker wire. A second wire can then be manipulated into the true lumen and guided by the position of the first wire. The three obvious advantages of this technique are: 1) the use of contrast to locate the position of the distal true lumen can be reduced due to partially relying on

the position of the first wire; 2) the first wire can act as a rail to guide delivery of the second wire into the CTO body; and 3) the presence of the first wire reduces the risk of a higher penetration wire going outside the vessel during its manipulation through the CTO body, by acting as an indicator of the vessel course. Detailed methodology of parallel wiring, Stingray, LAST, and IVUS-guided wiring is beyond the scope of this paper.

Retrograde

The principles of retrograde wiring are different from antegrade wiring because there are three important differences: 1) due to collateral channel tortuosity, retrograde wire control is usually inferior to antegrade wire control; 2) retrograde cases are usually associated with longer CTO, with more vessel ambiguity, and therefore risk of wire perforation is higher; and 3) since reverse CART is the dominant method of completing the connection between antegrade and retrograde spaces, maintaining an intraplaque retrograde wire position is less of a priority. However, where possible, maintaining an intraplaque wire position for both antegrade and retrograde wires will make for an easy reverse CART and more time-efficient and radiation-efficient procedure. Therefore, an LPF tapered tip wire, such as XTA, is often used to begin retrograde wiring, in the hope that it will travel inside the intraplaque space towards the antegrade wire.

Distal Cap Puncture

For the majority of retrograde cases, distal cap puncture is not a problem, as the distal cap is usually softer than the proximal cap. The exception is often the distal cap with a significant-size side branch. In these cases, the retrograde wire moves towards the side branch instead of puncturing the distal cap into the CTO body. The use of an IPF wire with a stiffer pre-tip shaft, such as Pilot 200 (Abbott Vascular) UB3 (Asahi Intecc), is able to adequately address this issue. If the dominant problem is a large angle between the approaching retrograde path and the CTO distal cap (the AOA), a low-profile dual lumen catheter, such as Sasuke (Asahi Intecc), may be attempted to be passed through the collateral channel over the original retrograde wire into the side branch, and a second wire be inserted to penetrate the CTO distal cap, in a similar manner to the use of dual lumen catheter for proximal cap puncture. In a rarer instance where the distal cap is genuinely hard, the use of an HPF wire such as Conquest or Confianza 12 g is warranted. This kind of gradual 'step-up' of penetration force is necessary in the retrograde side due to increased difficulty in wire control and manipulation.

Retrograde CTO Body Wiring

The method of retrograde wiring should be determined by the CTO morphology. In short CTOs, the APCTOC algorithm suggests retrograde wire crossing [9]. Therefore, loose tissue tracking techniques should be used by manipulating an LPF tapered tip wire such as XTA. It is often surprising how easy

it is to perform retrograde loose tissue tracking, because the distal cap is usually soft, and the side branches have a very retroflex angle in relationship to the retrograde wire direction, making them less likely to be entered. If this fails, a directable IPF wire, such as Gaia Second or Third, should be used to wire towards the antegrade true lumen, with IVUS guidance from an antegrade wire if available.

The 'long-plus' CTO (a CTO that is >20 mm in length, and is calcified, or tortuous, or has significant course ambiguity) should be wired with subintimal wiring such as knuckle wiring or intentional subintimal wiring, as per the APCTOC algorithm [3]. The threshold for subintimal wiring should be lower in the retrograde approach compared with antegrade, as the risk of perforation is lower and success rate of reverse CART is high.

For other CTOs that are not 'long-plus', an intraplaque connection of antegrade and retrograde space should be aimed for. This should begin with loose tissue tracking with XTA or similar wires from the retrograde direction. The two commonest reasons for failure of loose tissue tracking are: 1) the wire hits resistance and is unable to move forward, or 2) the wire is moving easily but into an uncertain location. If the wire is in an uncertain position due to ambiguity, it is best to shift to knuckle wiring. If the wire is stuck, wire step-up is required. There is always the option of advancing the

antegrade wire to meet the retrograde wire in the retrograde approach, so, before loose tissue tracking from the retrograde direction is abandoned, it is worth considering further antegrade wiring to see if the antegrade system can be advanced in the intraplaque space towards the retrograde wire to reduce vessel course ambiguity. The priority should be maintaining the intraplaque position of the antegrade wire, as reverse CART is easier when the antegrade wire is intraplaque rather than subintimal. If knuckling were to be done, retrograde wire knuckling would be favoured over antegrade wire knuckling.

Reverse CART Wiring

For successful reverse CART, an HPF wire with excellent direction control is needed, such as Gaia Second or Third. The retrograde microcatheter should be advanced as much as possible to enhance control of the wire tip, and the wire should be directed towards the antegrade balloon (so-called directed reverse CART [10]). If it is believed that both antegrade and retrograde wires are intraplaque, reverse CART should be directed by wiring the retrograde wire towards the end of the inflated antegrade balloon, the so-called end balloon wiring technique (Figure 4a). Wires generate highest penetration force if pushed directly ahead; therefore, wiring towards the end of the inflated balloon provides the easiest

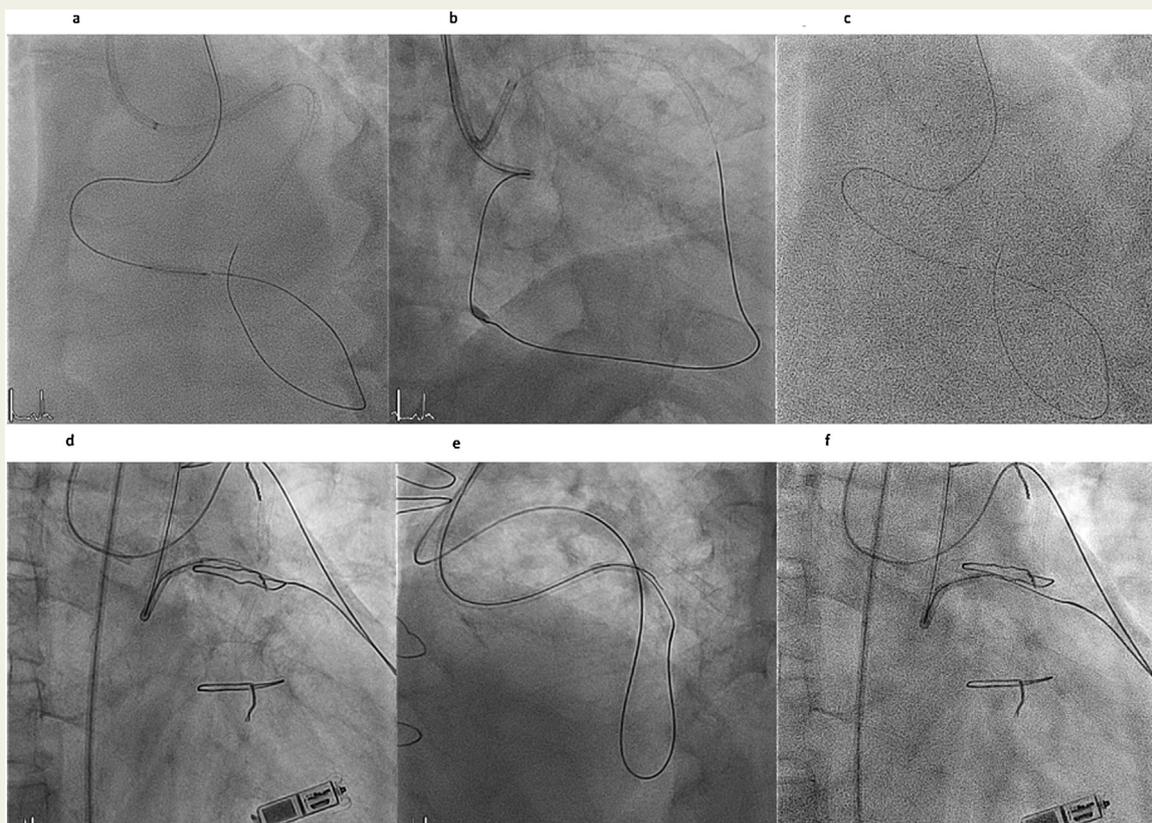


Figure 4 Directed reverse CART methods. a. End balloon wiring Left anterior oblique view. b. End balloon wiring Right anterior oblique view. c. Successful end balloon wiring. d. Side balloon entry technique. e. Side balloon entry in orthogonal view. f. Successful side balloon entry.

way of achieving successful reverse CART. However, this should not be persisted with if end balloon wiring fails after a brief couple of tries, as wire control will be reduced by the expanded peri-wire space that is created. Instead, proceed to side balloon entry technique (Figure 4b), in which the antegrade balloon is inflated to collapse the peri-wire space and control of the retrograde wire is restored. With the antegrade balloon inflated, the wire tip should be directed towards the balloon from the side and confirmed in multiple orthogonal views (Figure 4c and Figure 4d). Then the balloon should be deflated while the retrograde wire is simply pushed forward without any rotation, entering the void created by the antegrade balloon (Figure 4d).

If it is believed that antegrade and retrograde wires are both subintimal, the penetration force of the retrograde wire is no longer relevant, as the two wires will be connected in the same space once an antegrade balloon is inflated. A directable soft hydrophilic polymer jacket coated wire should be used, such as Sion Black (Asahi Intecc) to complete reverse CART. In such a case, simple manipulation of the retrograde wire into the antegrade balloon void with gentle pushing can achieve successful reverse CART. This is no longer directed but conventional reverse CART [10].

If the antegrade and retrograde wires are in different spaces and confirmed by IVUS (i.e., antegrade wire is subintimal while retrograde is intraplaque, or vice versa) then dilatation with a larger balloon for reverse CART should be tried. If this fails, a retrograde HPF wire such as Conquest or Confianza 12 g is required to penetrate through the thick tissue into the balloon void, under real-time IVUS guide if possible. If the antegrade wire is subintimal, simply using a larger antegrade balloon is often ineffective, as the expanded subintimal space often re-collapses due to the elastic nature of the subintimal space and therefore an HPF retrograde wire is often needed.

Wire Property and CTO Crossing

Once all of the previous information is understood, it is obvious that three kinds of wires with differing properties are needed to cross a CTO: one for proximal cap puncture, one for CTO body crossing, and one for exiting into the distal true lumen. Of course, every now and then one wire – such as XTA, Pilot 200, Gaia Second, or Conquest Pro – can perform all three roles in a CTO, but this is a rare clinical scenario. Persisting with a wire that does not work for the particular task is a frequent cause of being stuck without progress, failing the case, and even causing complications. Therefore, the take home message is to have a low threshold to switch to the appropriate wire with the appropriate shape for each of proximal cap puncture, CTO body crossing, and distal true lumen exit. By careful analysis of the diagnostic images, which CTO require three different wires can be predicted without attempting to use a single wire to perform all three tasks. This understanding should also govern the future development of wire technology. Instead of focussing on developing one series of very controllable, directable,

fixed-shape wires with differing penetration forces, at least three different types of wires with properties that specifically overcome the problems of proximal cap, CTO body, and distal true lumen exit should be developed, each with its own different penetration force.

Conclusions

This review provides a systematic technical guide to CTO wiring. It divides the wiring tasks into proximal cap puncture, CTO body traversing, distal cap exit, retrograde distal cap puncture, retrograde CTO body wiring, and reverse CART wiring. In each area, the type of wires, the shaping of the wires, and the manipulation techniques are reviewed. Case examples for newer ideas are discussed. Such a work is of course limited by the biases inherent by operator favourites and techniques. Yet, this kind of review is critical for the beginner CTO operator to understand and grasp, in order to provide good guidance for their procedures.

Disclosure and Conflict of Interest

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. Dr Tsuchikane is a consultant for Boston Scientific, Abbott Vascular, NIPRO, and Asahi. Dr Harding has received honoraria for speaker engagements from Boston Scientific, Medtronic, Asahi, and is a proctor for Boston Scientific and Bioexcel. Dr Wu is a proctor for Boston Scientific and Abbott Vascular. Other authors have no conflicts of interests in the products or distributor of the products.

There were no grants, financial support, or industry relationships relating to this work.

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