

Chronic total occlusion: current methods of revascularisation

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Summary

Percutaneous coronary intervention (PCI) for chronic total occlusions (CTO) has been referred to as the “last frontier” in interventional cardiology. In recent years novel devices, refined imaging modalities and innovative techniques have increased success rate and safety of PCI for treatment of CTO remarkably. Favourable long-term outcome data and excellent performance of drug-eluting stents further support the choice of PCI for CTO recanalisation. As strategies for treating complex lesions are continuously evolving, we provide here a systematic review of current methods for CTO revascularisation. Detailed knowledge about the histopathological characteristics of CTO is crucial to understand the basic principles of advanced interventional techniques. The concept of imaging-guided PCI further enhances efficacy and safety of this complex intervention. Finally, understanding the principle of antegrade and retrograde approaches are completing the armamentarium essential for interventional cardiologists dealing with this challenging lesion subset.

Key words: chronic total occlusion (CTO); percutaneous coronary intervention (PCI); imaging-guided PCI

Introduction

A chronic total coronary occlusion (CTO) is defined as a complete obstruction of a coronary artery (TIMI 0 flow) that is more than 3 months old [1]. The exact time of occlusion, however, is often unknown but ECG changes and onset or worsening of symptoms often allow a rough

estimation. Being diagnosed in between 10% and 20% of patients with coronary artery disease (CAD) according to different studies, CTO is still left to medical treatment in most cases [2]. Although percutaneous coronary intervention (PCI) for CTO has been associated with improvement in mortality, reduction of angina frequency and the need of coronary artery bypass surgery [3], success has been hampered by procedural failure (i.e., mainly failure to cross the occlusion with a guidewire) and complications such as vessel perforation, myocardial infarction due to loss

of collaterals and contrast nephropathy [4]. Furthermore, it is well recognised that PCI for CTO causes higher interventional costs, extra laboratory time and longer radiation exposure than regular angioplasty of high-grade stenosis [5].

In recent years a strong effort has been undertaken to improve PCI equipment. Along with the introduction of new guidewires, microcatheters and low profile balloon catheters, new interventional techniques such as the retrograde approach or the parallel wire technique have emerged. Moreover, novel invasive and noninvasive imaging modalities have been adopted, which not only assist the operator during the procedure but also allow lesion characteristics, entry point and course of the occluded vessel to be assessed in advance. Consequently, success rate and safety could be significantly improved. Recently published data from multicentre registries in Japan, USA and Europe showed overall procedural success rates of 84.8%, 84.2% and 82.9%, respectively [6–8]. However, such favourable results are critically associated with operator’s experience and specialised centres [9, 10]. While randomised controlled trials comparing CTO revascularisation and medical management are still lacking, patient safety must be of utmost importance in order to achieve a beneficial risk-benefit ratio. In the present article we discuss current technical and procedural aspects of CTO intervention, based on histopathological features, dedicated cardiovascular imaging and devices, aiming to enable operators to understand, plan and safely perform CTO revascularisation.

Histopathological characteristics of CTO

A better understanding of the histopathological characteristics of CTO lesions can help to select, develop and refine interventional techniques and thus improve success rate and procedural safety. Although the histopathological course of CTO lesions is not yet understood in detail, some important features are well recognised.

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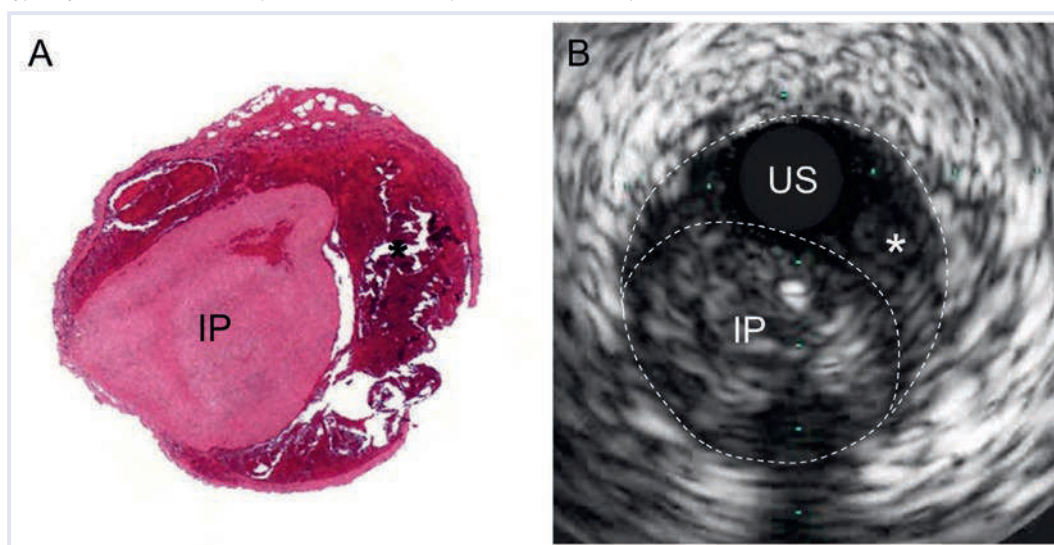
It is generally believed, that once a coronary stenosis has reached a critical grade or occludes the vessel completely, thrombus formation will occur and proceed up to the next side branch [11, 12]. Thereafter the thrombus undergoes organisation and the intimal plaque composition goes through transformation. Collagen-rich fibrous tissue is forming predominantly at the proximal and distal end of the occlusion, referred to as proximal and distal fibrous cap [12]. As the proximal cap is often hard it can pose a significant obstacle for a guidewire. Meanwhile neovascularisation of the intimal plaque is initiated from two different directions. Promoted by neovascular growth from adventitial vasa vasorum, new microvessels extend as a meshlike capillary plexus across the media into the intima. Besides, being induced by thrombus-derived angiogenic stimuli, microvessels develop as intraplaque channels [13–17]. Indeed, autopsy of CTO specimens revealed that angiographic-determined occlusions frequently show residual lumen patency by histologic criteria. Such microchannels with an average size of 200 μm and the loose connective tissue around them might be key determinants of successful wire passage through a CTO [11, 18]. Nevertheless, most microchannels were found to originate from small side branches and intimal vasa vasorum but only few connect the proximal and distal lumen longitudinally [11, 19, 20]. Furthermore, the microchannels neither run straight nor continuously. A recently published micro-CT imaging study reported a longitudinal continuity of approximately 85% of the total CTO length [21].

While the age of the CTO showed no influence on the number of microchannels in one study [11], other studies detected a decrease of both, extra- and intravascular microchannels in matured occlusions [18, 21]. The findings about the transformation of the intimal plaque are consistent and show a change from soft foam-cell-rich and cholesterol-laden intimal plaques to hard fibrocalcic lesions in old CTOs [11, 18]. This age-related increase of calcium and collagen in combination with a potential loss of microchannels and loose tissue might explain the progressive difficulty in crossing CTOs of older age.

Another fundamental aspect of CTO histopathology is the understanding of the architecture of the vessel wall. The histopathological composition of each layer determines performance and controllability of a guidewire. In the process of atherosclerosis, chronic inflammation leads to the formation of atheromatous plaques in the intima. As previously mentioned, the intima plaque composition is different in each case and subject to temporal changes. The internal elastic lamina (IEL) separates the intima from the media or, in more procedure related words, the intimal from the subintimal space. Because frequently damaged in the process of atherosclerosis the IEL is often hardly visible on histopathological examination. Consisting of smooth muscle cells and elastic tissue the media is normally around 200 μm thick but subject to thinning in the presence of atherosclerosis. Compared to the intima plaque the media consists of a histologically weaker connected tissue (low collagen content) causing less resistance, not only

Figure 1

Comparison of a histopathologic specimen of a dissected artery with intramural haematoma (A) with subintimal tracking as seen on intravascular ultrasound (IVUS) (B) shows the same pattern of disarrangement of layers. The subintimal space is easily extended within the media, which consists of histologically weaker connected tissue, causing less resistance, not only to wires but also to potential dissections and haematomas (*). Bordered by the intimal plaque on the inside (IP, inner dotted circle) and the usually still intact external elastic lamina on the outside (outer dotted circle), the subintimal space typically forms a crescent shape. (US) indicates the position of the IVUS probe.



to wires but also to potential dissections and haematomas – a key aspect in CTO PCI. Thus, what is generally referred to as subintimal tracking during PCI mostly occurs in the media. Indeed, when comparing a histopathologic specimen of a dissected artery to subintimal tracking as seen on intravascular ultrasound (IVUS), the same pattern of disarrangement of layers can be seen (fig. 1). Separated by the external elastic lamina (EEL) the adventitia forms the outer part of the vessel and mainly consists of collagen and elastic tissue with decreasing density towards the outside.

Knowledge about the architecture of a vessel and the histopathological composition of the different layers is crucial when selecting the best performing guide-wire for special interventional techniques, such as intentional intimal plaque tracking and subintimal tracking. The concept of such techniques is explained later in this article.

Imaging

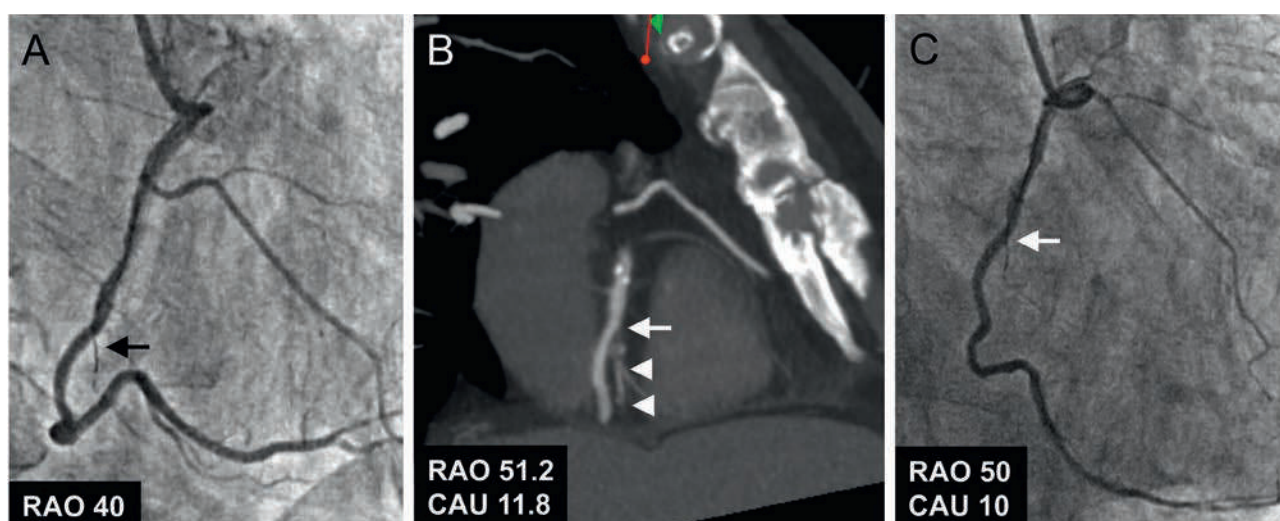
Apart from new materials and techniques, the constant development of cardiovascular imaging modalities helped to further increase success rate and safety of CTO PCI. Among noninvasive imaging techniques coronary computed tomography angiography (coronary CTA) has emerged as a reliable and widely available tool to assess CAD [22]. In addition to visualising occluded segments, CT provides information that can be used to plan complex PCI offline. Invasive imaging such as IVUS delivers high-resolution real-time imaging and therefore serves as guidance for PCI.

Coronary CTA

Different studies have found that CTA information increases the success rate of CTO interventions [23–26]. Several predictors for CTO recanalisation failure, such as lesion length, vessel course visibility, tortuosity, calcification grade, stump morphology, distal vessel opacity, presence of side branches and presence of bridging collaterals have been identified [3, 27, 28]. Coronary CTA can provide detailed information on most of these predictors, which cannot always be obtained from coronary angiograms alone. Among various postprocessing techniques developed for optimal visualisation and diagnostic evaluation of the coronary tree, volume rendering, curved multiplanar reformatting (MPR) and maximum intensity projection (MIP) are most commonly used [29]. Volume rendering does not allow differentiation between coronary artery calcifications and contrast medium. Even more important, occluded segments cannot be visualised. Curved MPR is nowadays the most popular technique to assess coronary arteries, mostly because multiplanar reconstructions can be rendered easily and accurately. MPR preserves the actual CT attenuation value (Hounsfield Units) and therefore allows delineation of calcifications from the vessel lumen. Using curved-plane reconstruction a 3-dimensionally bent vessel can be “straightened” to a 2D image. Thus, in contrast to the other postprocessing techniques, distance measurements in curved MPR images are not subject to shortening. The biggest drawback of this method, especially with respect to CTO interventions, is that the generated images are very different from angiographic views. The surrounding anatomy gets distorted and side branches cannot be depicted in the same image. The loss of landmark struc-

Figure 2

(A) Wiring (black arrow) of a chronic total occlusion (CTO) of the right coronary artery was started in the usual RAO view (RAO 40). However, entry point of the CTO and course of the vessel were unclear by angiogram. (B) Coronary CT angiogram nicely showed the bifurcation (white arrow) and the vessel course (arrow heads) in a different projection angle (RAO 50 CAU 10). (C) The angle was then adjusted accordingly in the catheterisation lab.



tures and true vessel courses make the images useless for guidance of CTO wiring. In the MIP reconstruction method, only the maximal density value at each point in a selected 3D volume is displayed. The final picture resembles a conventional angiogram as structures are projected over one another. The sliding slab maximum-intensity projection (sliding slab MIP) is a particularly helpful tool for invasive cardiologists because sliding slab MIP reconstructions can be computed rapidly from transaxial sections and allow comprehensive coronary assessment in identical projections as obtained by coronary angiography. The ability to display occluded segments in any projection angle not only permits generating perfect reference images but also allows detection of the ideal projection angle before going to the catheterisation lab (e.g., for optimal projection of a bifurcation) (fig. 2). Identifying the intimal plaque and caliber of an occluded vessel on a reference image can facilitate the wiring procedure substantially. Because structures are displayed upon their brightness, MIP further allows differentiation of calcium or metal clips from the contrast-enhanced lumen of a coronary artery. Crucial information on the calcification pattern and plaque composition can be analysed in a cross-sectional view (fig. 3). While calcium appears much brighter than the contrast-enhanced vessel lumen, fibrous tissue, thrombus and fat have lower densities and therefore appear as darker regions within the artery.

The shortcomings of coronary CTA are the additional 50–100 ml of contrast medium and an extra radiation dose. However, currently used nonionic contrast media bear only a minor risk for renal dysfunction [30]. Also, implementation of modern cardiac CT acquisition protocols, such as prospective ECG triggering, ECG-controlled current modulation, body mass-adapted tube voltage and prospectively triggered high-pitch spiral acquisition by the latest technology of dual source CTs allow the reduction of the radiation dose to below 1 mSV [31].

IVUS

With a miniaturised ultrasound probe attached to the distal end of a transluminal catheter, IVUS provides an axial spatial resolution of 80–150 μm and therefore precise visualisation of lumen and vessel wall. Within the arterial wall, IVUS clearly delineates the so-called media-adventitia border, i.e., the EEL. This is of particular interest in CTO PCI, as IVUS (unlike conventional angiography) can visualise the position of a guidewire within an occluded segment. Thus, intimal and subintimal guidewire tracking can be distinguished, which is crucial for antegrade as well as retrograde wiring techniques [32, 33]. Furthermore, IVUS can be helpful in identifying an ostially located entrance, especially in the unfavourable situation where

Figure 3

Information on the course, size and calcification pattern of the target vessel can be crucial for CTO interventions. The angiogram shows a very proximal CTO of the right coronary artery. Thus, vessel course and size can hardly be identified (**A**). The corresponding coronary CTA nicely displays the course of the artery. In addition, extensive calcification can be seen (**B**). Cross-sectional analysis demonstrates the location and extent of calcifications. While calcium located in the center of the vessel (as seen in the proximal part, **C**) easily deflects even stiff wires, calcium located predominantly in the vessel wall (as seen in the mid segment, **D** and **E**) is rather beneficial because it protects the wire from perforating the vessel.

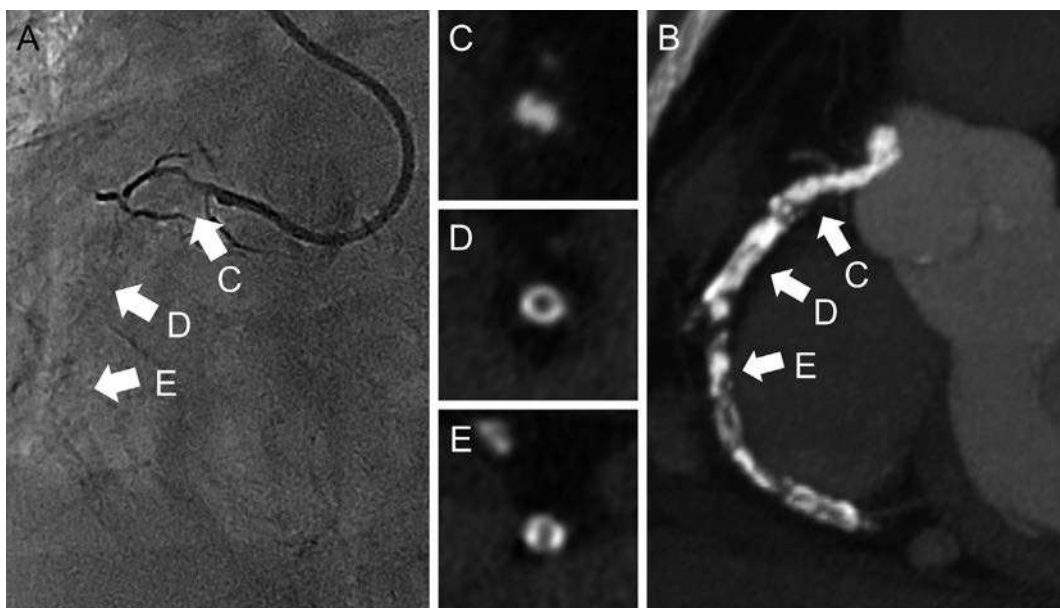
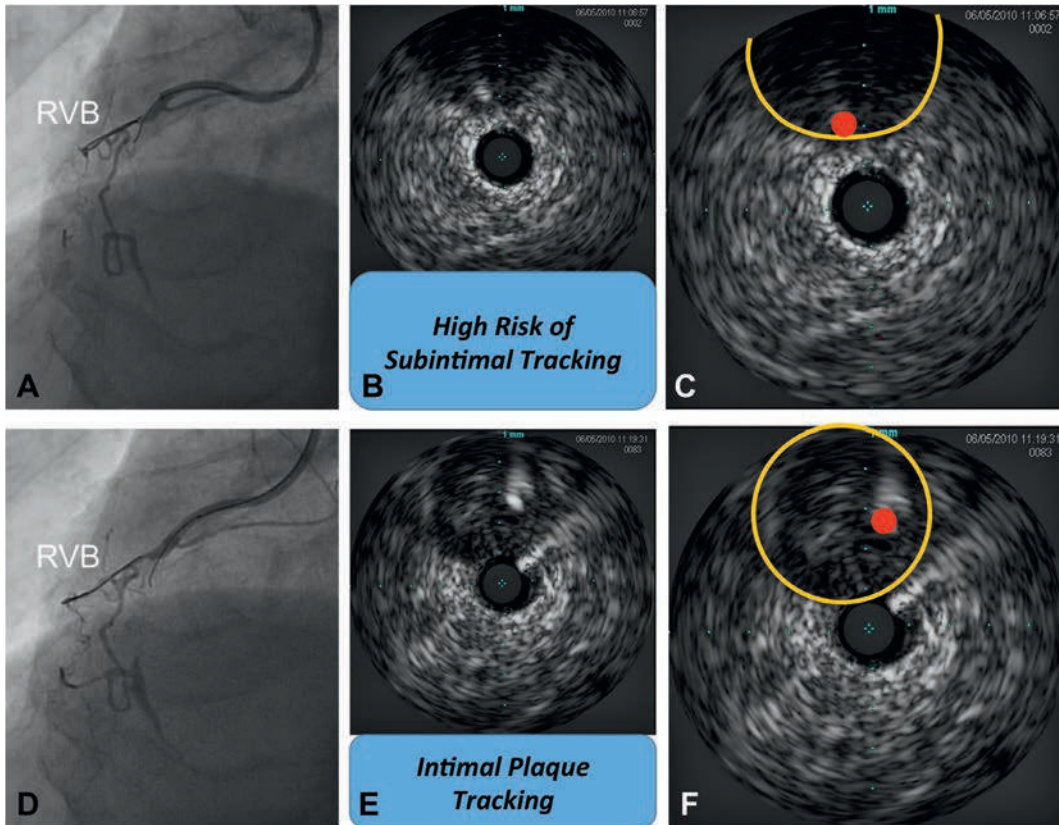


Figure 4

(A) After advancing a wire into a stumpless chronic total occlusion of the right coronary artery, its position was checked by intravascular ultrasound (IVUS) from a proximal right ventricular branch (RVB). (B, C) IVUS displayed the wire close to the external elastic lamina (EEL) at the side of the RVB, indicating high risk of subintimal tracking. (D) Consequently, a stiff wire was intentionally advanced towards the inside of the occluded vessel, i.e., more distant of the RVB. (E, F) IVUS then showed a more centrally located wire position, confirming intimal plaque tracking. Red dot marks the wire. Yellow circle marks the EEL. (Reprinted from S. Sumitsuji et al., Fundamental wire technique and current standard strategy of percutaneous intervention for chronic total occlusion with histopathological insights. *JACC Cardiovasc Interv.* 2011;4: 941–51. Copyright 2011, with permission from Elsevier.)



a stumpless CTO with a proximal side branch is present [34] (fig. 4). Finally, the usual IVUS information on the target lesion, such as CTO length, lumen area, plaque composition and distribution plays an important role in optimising stent implantation and reducing in-stent restenosis.

Current material and techniques for CTO interventions

The number of wires, microcatheters, balloon catheters and other devices designed for complex PCI and CTO recanalisation has increased considerably over the past years. The availability of such material however, differs in each country and each catheterisation lab. Here we provide a chart of the most commonly available wires according to their stiffness (tip load) (fig. 5). Throughout this article we refer to floppy (<1 g), intermediate (1–3 g) and stiff (>3 g) wires.

Before starting the wiring procedure a best possible angiogram should be obtained and optimal projec-

tion angles selected (ideally 90 degrees apart). For the latter, information from coronary CTA can be of great value, as previously discussed in this article. For best visualisation of the distal true lumen, bilateral injection should be considered. Finally, selection of an appropriate guiding catheter is crucial for successful CTO PCI.

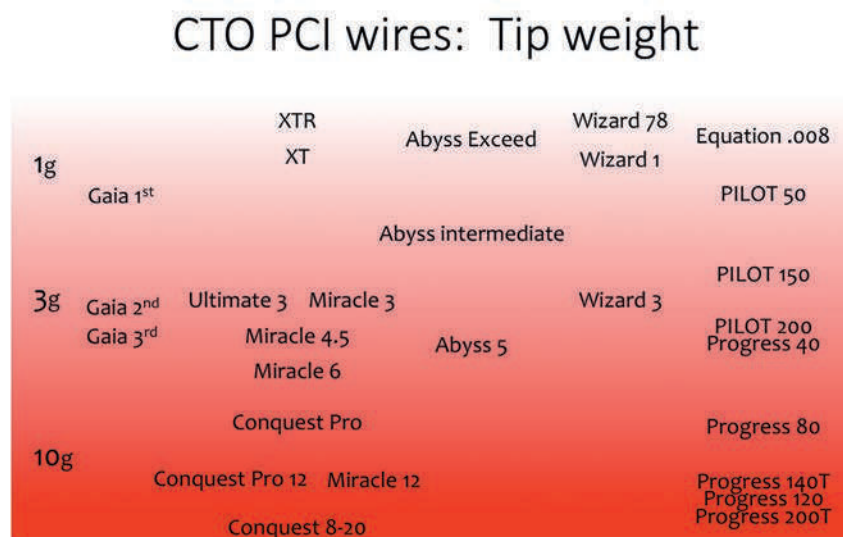
Maximal back-up force, good stability and coaxial orientation are important factors, especially if radial approach with smaller guiding catheter size (6 Fr) is used.

Wiring

Since the failure of opening a CTO is mainly caused by the inability of advancing a guidewire beyond the lesion, advances in wire technology have largely been responsible for improved procedural success in PCI of CTO. Being aware of the histopathological fundamentals and imaging information, wire selection and guidance becomes a more logical process. Fundamental con-

Figure 5

Common available guidewires according to their stiffness measured by tip load.



cepts of CTO wiring include the antegrade approach and the retrograde approach, which will be discussed separately. The use of a microcatheter for wire support, facilitated transmission of torque to the wire tip as well as easy and safe wire exchange is generally recommended. Over-the-wire (OTW) balloons can be used alternatively; however, their tip is less flexible and its exact position invisible (no radiopaque marker). In the absence of a true lumen in CTO, wire tracking should be referred to as either intimal or subintimal.

Antegrade approach

Generally, the antegrade approach using the single wire and/or parallel wire technique is attempted before changing to a more complex retrograde approach. For an antegrade procedure intimal plaque tracking is crucial as success rates decrease substantially once the wire enters the subintimal space. Intimal plaque tracking can either be achieved by loose tissue tracking or by intentional intimal plaque tracking. The concept of *loose tissue tracking* is based on the histopathological finding that angiographic determined occlusions frequently show residual lumen patency with microchannels and loose connective tissue around them [11, 18]. We therefore recommend starting the wiring procedure with an intermediate-stiffness guidewire. A tapered wire is more likely to enter loose connective tissue. Once entered, an intermediate wire will automatically track tissue with low resistance rather than penetrating into a hard atherosclerotic plaque. This concept is supported by the PIKACHU trial (Prospective Multi-center Registry of IKAzuchi-X for Chronic Total Occlusion) where approximately 70% of CTO's could be

crossed with an intermediate-stiffness 0.010 inch hydrocoated wire [35]. Wire handling for loose tissue tracking is similar to wire control in acute myocardial infarction cases, where the wire can be advanced smoothly by continuous rotation of the wire tip. Once the wire gets stuck and/or loose tissue tracking is impossible the strategy should be changed to the concept of *antegrade intentional intimal plaque tracking*, where the tip of the wire is intentionally directed into the intimal plaque. For this purpose, a stiff tapered wire with higher penetration force should be selected. The recently developed Gaia Second guidewire (Asahi Intecc, Japan) has gained wide acceptance among interventional cardiologists due to its excellent one-to-one torque transmission, enabling the operator to steer the wire through tortuous arteries. This ability, usually inherent to stiff wires, is combined with the advantages of an intermediate tip load (3.5 g), enabling the wire to select tissue with less density and therefore stay within the intimal plaque. Nonetheless, the difficulty of intentional intimal plaque tracking is to understand the position of the wire tip and to rotate and advance it in the right direction. In presence of a proximal side branch, IVUS can be used to visualise the wire position at the CTO entry point (fig. 4). The use of integrated imaging information from IVUS, coronary CTA and bi-plane angiography is generally helpful and highly recommended for adequate understanding of vessel anatomy and plaque composition. In segments where the resistance increases, as in the presence of dense fibrous tissue or calcifications, the wire is easily deflected towards the subintima. Such segments of high density can possibly be "punctured" by stiff wires; however, stiff wires tend to go straight and easily perforate the ves-

sel wall. After crossing a segment with high resistance, a “step down” to an intermediate guidewire should be considered, especially when a tortuous vessel is treated.

Once the guidewire enters the subintimal space, the chance for successful antegrade CTO recanalisation decreases considerably. An angiographic sign of subintimal tracking is a sigmoid shaped course of the guidewire, reflecting a spiraling course around the vessel. If subintimal tracking is suspected, caution should be exercised when visualising the situation by contrast injection or IVUS catheter. Both bear the risk of extending the subintimal space (i.e., the easily dissected media) and compressing the distal true lumen. Once the latter collapses, successful wiring becomes virtually impossible and further ischaemic myocardial injury might occur. Nevertheless, even if the wire enters the subintimal space, special techniques such as the parallel wire technique and/or IVUS guided antegrade wiring still allow the return to intimal plaque tracking. When using the parallel wire technique the first guidewire is left in the subintimal space or where it got stuck within the plaque. A second wire is then advanced into the intimal plaque. The position of its wire tip should be frequently checked from different angiographic angles to ensure intimal plaque tracking as far as possible. Finally, there are several reentry techniques with the common idea of puncturing the tissue between the subintima and distal true lumen using a stiff wire or a special reentry device. The “CrossBoss and Stingray Re-Entry System” (Boston Scientific, Natick, MA, USA) has recently been developed to allow re-entry at a selected location [36]. In contrast, the subintimal tracking and re-entry (STAR) technique relies on reentry of a stiff wire tip primarily at a distal side branch bifurcation [37]. However, it must be pointed out that long subintimal tracking has a risk of incomplete revascularisation due to side branch occlusion and should therefore be reserved as a final option for antegrade CTO recanalisation.

Retrograde approach

Once antegrade wiring has failed the retrograde approach offers another way to successful CTO revascularisation. However, a retrograde procedure is time consuming as it involves several procedural steps. Careful time management is important to maintain high procedural safety. Based on imaging information (presence of factors for antegrade failure) and bilateral angiogram (availability of collateral channels) the operator should have a rough time plan before starting the intervention. In order to keep the procedure time under control, changing to a retrograde procedure should be considered no later than 60 minutes after unsuccessful antegrade wiring.

Channel selection

The first key step for retrograde wiring is to identify a suitable collateral channel. Unfortunately such channels are usually of small caliber size and often present a tortuous course making them fairly vulnerable. As injury to an epicardial channel can easily cause cardiac tamponade, selection of a septal channel is preferred [38]. In general, a very soft guidewire with microcatheter support should be selected. The microcatheter not only supports the soft guidewire and enables easy wire exchange but also serves for tip injection of contrast media to confirm the course of the channel. For safety, we generally recommend to confirm backflow of blood by applying negative pressure with a syringe before performing contrast injection. In recent years specific devices for smooth and soft channel negotiation have been developed. Our first choice for tortuous channels is the Suoh guidewire (Asahi Intecc, Japan). Upon availability and/or need for better torque control, a Sion or Fielder XTR guidewire (Asahi Intecc, Japan) can alternatively be selected. The Finecross MG (Terumo, Japan) is our first choice as microcatheter; if more pushability is required, the Corsair microcatheter (Asahi Intecc, Japan) is more effective. The Tornus microcatheter (Asahi Intecc, Japan) serves rather as a dilatation device than as a conventional microcatheter. With spiral wedges at the tip it can be screwed into hard CTO lesions but should not be used to enter collateral channels. When dedicated microcatheters are not available, small OTW balloons can be used instead, however, higher friction and unclear tip position due to a missing tip marker must be taken into account.


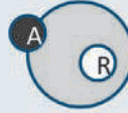
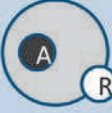
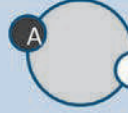
Wire manipulation for channel negotiation should be performed differently from the way a wire is directed through a CTO. While virtually no pushing force is applied, the wire should be advanced by gentle rotations to reduce friction and the risk of perforation. When resistance is experienced, channel anatomy and integrity should be confirmed by tip injection using different angiographic views. Septal channels are usually best visualised in RAO caudal, RAO cranial and lateral projections.

Retrograde intimal plaque tracking vs retrograde subintimal tracking

Once guidewire and microcatheter have passed the channel and reached the distal entry point of the CTO we usually switch to an intermediate guidewire to advance into the occluded segment. Since the distal fibrous cap is generally softer than the proximal one [19], intimal plaque tracking is observed in up to 60% of IVUS examinations [39]. When intimal plaque tracking can be suspected, the retrograde wire should be carefully advanced as it might enter the proximal lumen directly (*retrograde wire cross*). However, as the

Figure 6

Once the antegrade and retrograde wire overlap sufficiently, IVUS can be performed to visualise their exact positions. Depending on which of the 4 possible patterns is seen, the next logical procedure step can be selected. **(PP)** If both wires are located within the intimal plaque, either antegrade ballooning can be performed (to help to connect the 2 wires in the same lumen) or the retrograde wire can be further advanced to directly cross to the proximal lumen (retrograde wire cross). **(PS)** When the antegrade wire is found in the intimal plaque but the retrograde wire runs subintimally, either antegrade ballooning can be performed (to dissect the media and connect the 2 wires in the same lumen) or the antegrade wire is further advanced. **(SS)** If both wires are found in the subintima, antegrade ballooning is likely to connect the wires in the subintimal space. **(SP)** When the antegrade wire runs subintimally and the retrograde wire is still in the intima plaque, antegrade ballooning will not be successful because connection to the intima is rather unlikely. In this particular case the retrograde wire should be further advanced and the situation reevaluated more proximally (or to succeed by retrograde wire cross).

		Antegrade wire	
		Intimal Plaque	Subintima
Retrograde wire	Intimal Plaque	PP  antegrade ballooning and retrograde wiring	SP  retrograde wiring and more proximal connection
	Subintima	PS  antegrade ballooning or more distal connection	SS  antegrade ballooning

retrograde wire usually travels a long way through a small and tortuous collateral channel, controllability is limited and care must be taken, especially when using stiff wires. If the retrograde wire gets stuck or its position is unsure, it still can be used as a landmark to further advance the antegrade wire into the distal true lumen (*kissing wire cross*) [40].

Even if the retrograde wire migrates to the subintimal space, success is likely to be achieved [41]. As previously mentioned, the wire can be easily advanced within the subintimal space, since tissue resistance is low. Once the antegrade and retrograde wire tip overlap, ballooning is performed. The created lumen should connect the two wires and therefore finally allow wire crossing. Ballooning can be performed either on the retrograde wire using the *antegrade and retrograde tracking (CART) technique* or on the antegrade wire using the *reverse CART technique*. When applying the CART technique, the antegrade wire is advanced into the space dilated with the retrograde balloon. When reverse CART is performed, the retrograde wire is advanced into the space created by the antegrade balloon. Reverse CART has the advantage that the balloon is advanced on the antegrade wire and does not have to pass a collateral channel following the retrograde wire [41]. In addition, it allows the primary use of IVUS to

visualise wire positions and to select the ideal site for dilation with a properly sized balloon. Within the segment where the ante- and retrograde wire overlap, four different image patterns exist (fig. 6). The only case where antegrade ballooning is not likely to connect the two wires is when the antegrade wire lies in the subintimal space and the retrograde wire is located in the intimal plaque. In this particular case the retrograde wire should be further advanced, either to directly cross to the proximal lumen or to migrate to the subintimal space. IVUS and ballooning can then be performed more proximally.

Retrograde wire externalisation

In case the CTO could be crossed with the retrograde wire (as by retrograde wire cross or reverse CART), the lesion is not accessible for stenting yet (since the stent would have to pass through the collateral channel). Therefore retrograde wire externalisation has to be performed. In this specific technique the retrograde wire is advanced into the antegrade guiding catheter followed by the microcatheter. When the microcatheter is securely placed in the antegrade guiding catheter, the retrograde wire can be exchanged for a long wire. Generally we choose the RG3 externalisation wire

(Asahi Intecc, Japan); if not available a floppy rota wire (Boston Scientific, Natick, MA, USA) can be used alternatively but high friction is likely to be experienced. Once the long wire is retrogradely externalised through the haemostatic valve of the antegrade guiding catheter, selected PCI devices (e.g., balloons, stents) can finally be advanced antegradely with good wire support. Care must be taken when stenting the distal part of the target vessel, as the externalised wire not always passes through the main distal branch. Should this situation arise a second wire can be advanced antegradely into the target branch after sufficient ballooning, preferably using a microcatheter or, if needed, a Crusade double-lumen microcatheter (Kaneka Corp., Japan).

Conclusion

PCI for CTO can be performed with high success and low complication rates. Vast evidence that using drug-eluting stents yields very low restenosis and reocclusion rates [42–48] and emerging evidence that CTO recanalisation improves survival, enhances left ventricular function, reduces angina and improves exercise tolerance [49, 50] further supports the choice of PCI for CTO recanalisation. However, profound knowledge about histopathological CTO characteristics and the supportive use of dedicated cardiovascular imaging as well as mastering advanced procedural techniques using special devices is crucial for successful and safe interventions. We hope that the present article helps interventionalists to better understand the logic and stepwise approach to carefully plan and successfully carry out safe CTO revascularisation.

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