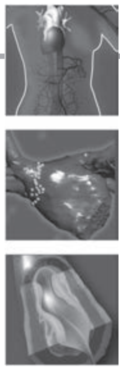

Procedure planning for chronic total occlusion percutaneous coronary intervention

To maximize procedure success, chronic total occlusion percutaneous coronary intervention should be performed within a structured framework with robust procedural planning. The logistics of ring-fencing catheterization laboratory and chronic total occlusion operators' time, and ensuring availability of specialist equipment should be established. Careful and appropriate patient selection and preparation should be in accordance with current guidelines. Thorough preprocedure angiographic analysis is vital to characterize the anatomy and complexity of the chronic total occlusion, and is key in determining the initial and subsequent strategies.

KEYWORDS: chronic total occlusion ▪ percutaneous coronary intervention ▪ procedure planning

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Chronic total occlusion (CTO) percutaneous coronary intervention (PCI) is now well established as a subspecialty within interventional cardiology. As the technique has evolved, it has become clear that robust procedure planning is key to achieving successful outcomes. This review aims to define the optimal environment for establishing a successful CTO program by defining the challenges in managing safety, patient and equipment selection, and in measuring success.

Establishing a CTO service

The framework of how CTO PCI is performed is critical in ensuring procedural success. Simply moving from *ad hoc* CTO PCI to a dedicated CTO service, within the same institution, dramatically improved procedural success rates from 62 to 81% [1].

As such, it is recommended that specific CTO days are scheduled and operators are advised that engaging in complex CTO PCI as follow-on or *ad hoc* cases under time constraints should be avoided. During cardiac catheterization laboratory planning, a minimum of 2 h should be allocated per case, with a maximum of four cases scheduled per CTO day.

Specific CTO operators should be identified within an institution, with procedures ideally performed working in pairs. Team working allows the adoption of new, complex techniques in an environment that maximizes patient safety. It is essential that this focus on safety be extended to the other healthcare workers within the laboratory team. It is recommended that key safety tasks, such as regular activated clotting time (ACT) monitoring, are delegated within this team and that engagement in procedural strategy and clinical objectives will help to continue to build this team-based approach. The number of local operators should allow each to perform a minimum of 50 CTO PCI procedures per year.

While acquiring skills and accumulating experience, or later for challenging cases or when using new technology, the support of a proctor is recommended.

Patient selection & preparation

Patient selection should be guided by the American College of Cardiology Foundation 2012 appropriate use criteria specific for CTO PCI [2]. Recanalization of a CTO is currently sanctioned by the presence of symptoms despite antianginal therapy or intermediate- or high-risk criteria on non-invasive testing [2]. Extrapolating evidence from the nuclear substudy of the COURAGE trial, an ischemic burden/viability of ≥10% in the territory of the occluded artery has been widely adopted as an appropriate cutoff for CTO PCI [3,4].

In selecting patients for CTO PCI it is important to consider patient-specific high-risk factors for the procedure, including age, chronic heart failure (particularly New York Heart Association class IV), left ventricular systolic dysfunction, peripheral arterial disease and associated arterial access issues, renal dysfunction and contrast-induced nephropathy risk.

CTO PCI-specific informed consent should be obtained. The patient should be specifically informed about the possible duration of the procedure, the need for dual arterial access and the risks of contrast and radiation exposure. As with consent for any procedure, the patient should be advised about the anticipated success rates based on local experience.

At the time of scheduling a patient for CTO PCI, the need to withhold oral anticoagulants or nephrotoxic drugs preprocedure should be considered.

Cardiac catheterization laboratory preparation

■ CTO PCI-specific equipment

It is vital, in advance of a scheduled CTO day, to ensure that all the equipment that is potentially required is available. There will be some variation depending on the preferred approach of the local CTO operators and regional availability of equipment. A CTO-specific cart or storage space is recommended to allow kit to be readily available during procedures and the monitoring of stock.

Access

Dual arterial access should be used in almost every case unless there is no obvious contralateral collateral supply to the occluded vessel territory. In such cases contralateral collaterals are often recruitable if ipsilateral collaterals are lost during the procedure, and as such it is worthwhile preparing a second access point in case this is required. Generally, 8 and 7 F long (30 and 45 cm) femoral sheaths and 7 and 6 F radial sheaths are most commonly used.

Guide catheters

A range of 90 and 100 cm, 8 and 7 F guide catheters should be available. In transradial centers, 6 F guide catheters will also be required. The Extra Back-Up 3.5 and 4.0 (Medtronic, CA, USA) are most commonly used for the left coronary system, and Amplatz Left 1.0 or 0.75 (Medtronic) usually preferred for the right coronary artery. Other catheters used by some CTO operators include Xtra Back Up (Cordis Corporation, NJ, USA), Judkins Left (Medtronic), Amplatz Left 0.75/2.0, Judkins Right (Medtronic), Internal Mammary (IM; Medtronic), 3D Right Coronary or Williams (Boston Scientific, MA, USA), and Sheathless Guides (Asahi Intecc, Nagoya, Japan).

Guidewires

The Fielder XT, Fielder FC, Sion, Miracle 12, Confianza Pro, RG3 (not available in US; Asahi Intecc), Pilot 200, and Progress 200T (Abbott Vascular, IL, USA) are currently the most commonly used wires in CTO PCI. In the USA, the 300 cm Viper Wire (Cardiovascular Systems, MN, USA) or the R350 (Vascular Solutions, MN, USA) is used instead of the 320 cm RG3 for wire externalization during retrograde cases.

Microcatheters and channel dilators

The most widely used devices are the Corsair (Asahi Intecc) and Finecross™ (Terumo Corporation, Tokyo, Japan) catheters, with both available in shorter (135 or 130 cm), primarily designed for antegrade use, and longer, retrograde focused (150 cm), lengths. The Tornus® (Asahi Intecc) catheter is an antegrade-only catheter designed to screw into the occlusive plaque using an

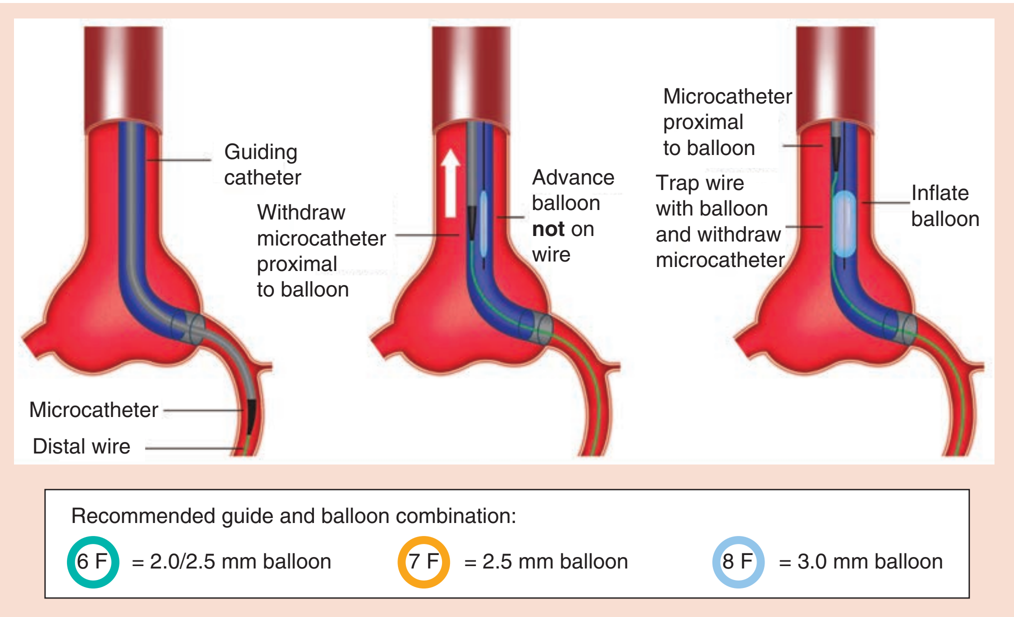

Figure 1. Trapping balloon technique.

anticlockwise rotation and is available in two sizes. The 2.6 F is most often used and widely accepted to be more effective, with the 2.1 F compatible with a 6 F guide catheter. There are a number of other competitor devices currently available, including the Valet (Volcano Therapeutics, CA, USA) and SuperCross™ (Vascular Solutions).

CrossBoss® & Stingray™ System

The CrossBoss® (BridgePoint Medical, MN, USA) is a blunt tipped microcatheter designed to rapidly spin through the occlusive plaque using clockwise and anticlockwise rotation. As it is advanced, it will either find a path through the luminal plaque or more commonly be diverted into the subintimal space creating a controlled and limited dissection plane. Once beyond the distal cap of the CTO it can be exchanged for the Stingray™re-entry balloon (Boston Scientific). The Stingray is a stingray-shaped balloon that is delivered to the subintimal space beyond the distal cap. There are two wire exit ports on opposing sides of the balloon, through which the Stingray wire can be advanced, puncturing through the subintima back into the luminal space. This is known as an antegrade dissection re-entry technique.

Mother-&-child catheter

The use of a mother-and-child catheter often facilitates procedural success and can used in both antegrade and retrograde scenarios, with options including the GuideLiner® (available in 6, 7 and 8 F; Vascular Solutions), Guidezilla™ (available in 6 F; Boston Scientific) and mother-and-child (Terumo).

Balloon catheters

There are a number of low-profile, semicompliant, rapid exchange (RX) and over-the-wire balloons available including the Mini-Trek™(Abbott Vascular), Ryujin™ (Terumo), Sprinter® Legend (Medtronic) and Emerge (Boston Scientific).

Snares

In performing retrograde CTO PCI, it is sometimes necessary to snare the retrograde wire in the aorta in order to allow it to be retrieved into the antegrade guide catheter. This is most commonly performed using the EN Snare device® (18 × 30 mm; Merit Medical, UT, USA).

■ Set-up & establishing procedure limits

To safeguard patient safety, a CTO PCI-specific set-up and procedure limits should be established before starting a case.

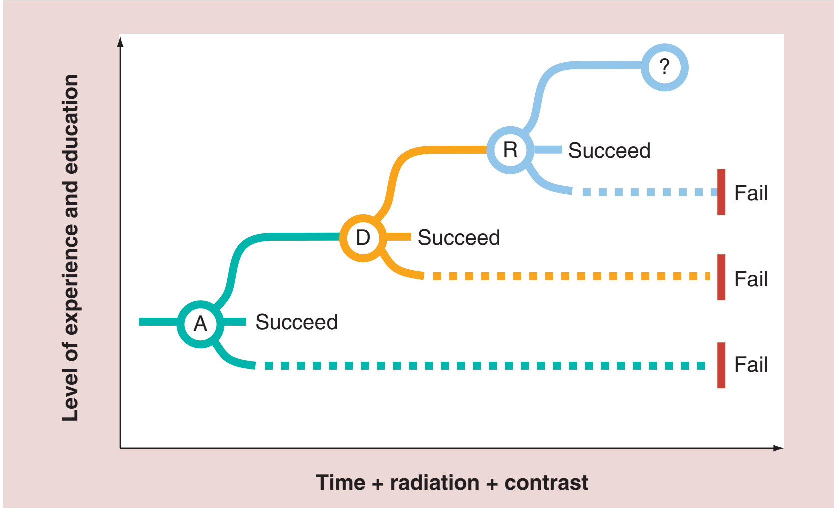

Figure 2. Approaches to chronic total occlusion percutaneous coronary intervention.
?: As yet undefined future developments in technique/approach; A: Antegrade; D: Dissection re-entry; R: Retrograde.

To minimize patient and operator radiation exposure, it is recommended that low magnification and frame count, shallow angles, multiple working views, store fluoroscopy (instead of cine acquisition and collimation) should be used. The prospective use of balloon trapping is an excellent way to facilitate equipment exchanges without the need for fluoroscopy (Figure 1). Using the RADPAD® (Worldwide Innovations & Technologies, Inc., MO, USA) lead-free surgical drape has been shown to significantly reduce radiation exposure to primary operators during prolonged, complex cases, including CTO PCI [5]. It is recommended that a case should be abandoned at a cumulative skin dose of 6 Gy if no progress has been made, 8 Gy if the CTO has not been crossed with the wire, and at 12 Gy in all cases.

The maximum recommended contrast dose should be calculated for each individual patient (5 ml × weight [kg]/Cr [mg/dl]). The contrast-induced nephropathy risk should be assessed and consideration given to pre- and post-procedure hydration on a case-by-case basis (1 ml/kg/h intravenous isotonic crystalloid 12–24 h preprocedure and 6–24 h postprocedure). If the CTO operator also performs the diagnostic procedure it can be useful to consider dual injection angiography at that stage to allow the approach and strategy to be planned, and to reduce the dose of contrast administered at the time of the PCI.

Conscientious monitoring of anticoagulation is vital during CTO PCI with bilateral intracoronary equipment *in situ* for prolonged periods of time. In addition, the complexity of these cases brings with them a higher risk of coronary perforation [6]. For this reason it is recommended that anticoagulation is with unfractionated heparin, initiated with a bolus of 80 U/kg and monitoring the ACT every 30 min (with an ACT target of 250 s during an antegrade case and 350 s during a retrograde case).

It is recommended that radiation dose, contrast dose and ACT be assessed and recorded every 30 min with an active decision made to continue or abandon the procedure. It is good practice to ensure that delegated members of the team provide this information and that it is acknowledged and, if necessary, acted on.

Angiographic analysis

Prior to performing CTO PCI, time should be dedicated to thoroughly analyze the diagnostic angiogram. This will usually be single injection coronary angiography, often performed by another operator. If the CTO operator is performing the diagnostic angiogram, dual injection angiography should be considered to clarify collateral filling patterns and the length and course of the CTO.

There are a number of angiographic characteristics when determining the complexity and difficulty of the CTO, and some questions to consider when deciding on procedural strategy.

■ Complexity & difficulty of the CTO

Attempting to predefine the complexity and difficulty of a CTO prior to the procedure is an extremely valuable exercise, as it will almost always predict periprocedural complexity. This key factor determines the need to be able to employ a flexible approach using hybrid strategies.

The Multicenter CTO Registry of Japan score can be used to assess CTO complexity, with occlusions classified into easy, intermediate, difficult or very difficult (Multicenter CTO Registry of Japan score 0–5) [7]. One point is allocated for the presence of a blunt stump, length >20 mm, severe calcification, >45° tortuosity and a previous failed attempt. The Multicenter CTO Registry of Japan score has been shown to predict successful wire crossing within 30 min and overall procedure success [8,9].

■ Procedural strategy

If it were possible to completely predict and negotiate procedural complexity only a single strategy would be required. In the past, CTO PCI was often approached in this way with limited success. This led to the development of new techniques and technologies with multiple strategies now often applied during the course of the same procedure in a hybrid approach.

The primary approach to CTO PCI can be antegrade (wire-based or dissection re-entry), retrograde (wire-based) or a hybrid strategy. The wire-based techniques include microchannel crossing, wire escalation, parallel wires, controlled antegrade and retrograde subintimal tracking (CART), subintimal tracking and re-entry, limited antegrade subintimal tracking, reverse CART and reverse stent CART. In addition, antegrade dissection re-entry can be performed using the CrossBoss and Stingray System (Figure 2).

The anatomy and angiographic characteristics of the CTO will determine initial and subsequent strategies (Figure 3). There are a number of important features to consider.

Proximal cap location & morphology

Can the entry point to the CTO be clearly identified, is it tapered or blunt, and is it likely to be able to be easily engaged. A well-defined, tapered proximal cap may favor an antegrade approach, and will facilitate antegrade progress in a hybrid procedure. An ostial location, or the presence of side branches at the proximal cap, often favors the retrograde approach (Figure 4A).

Lesion length

Is the occlusion <20 or ≥20 mm in length. The antegrade wire escalation technique in CTOs ≥20 mm is associated with lower success rates and longer procedure times [8]. Thus, long occlusions are better approached using antegrade dissection and re-entry or retrograde techniques (Figure 4B).

Target vessel beyond the distal cap

Is the coronary artery immediately beyond the distal cap adequately visualized? Assess the vessel size, presence of disease and whether the

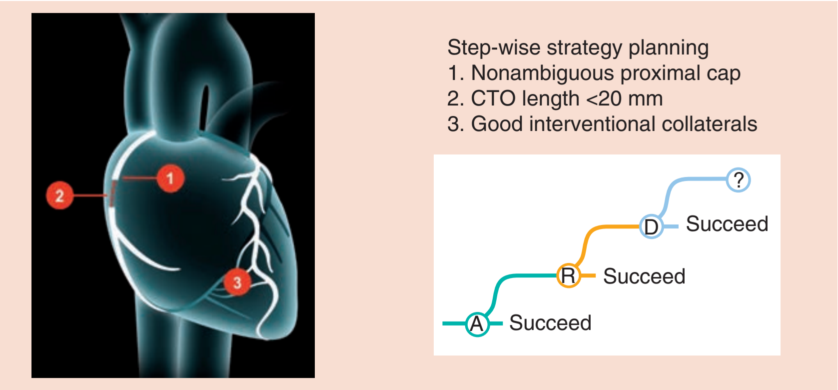

Figure 3. Step-wise strategy planning.
?: As yet undefined future developments in technique/approach; A: Antegrade; CTO: Chronic total occlusion; D: Dissection re-entry; R: Retrograde.

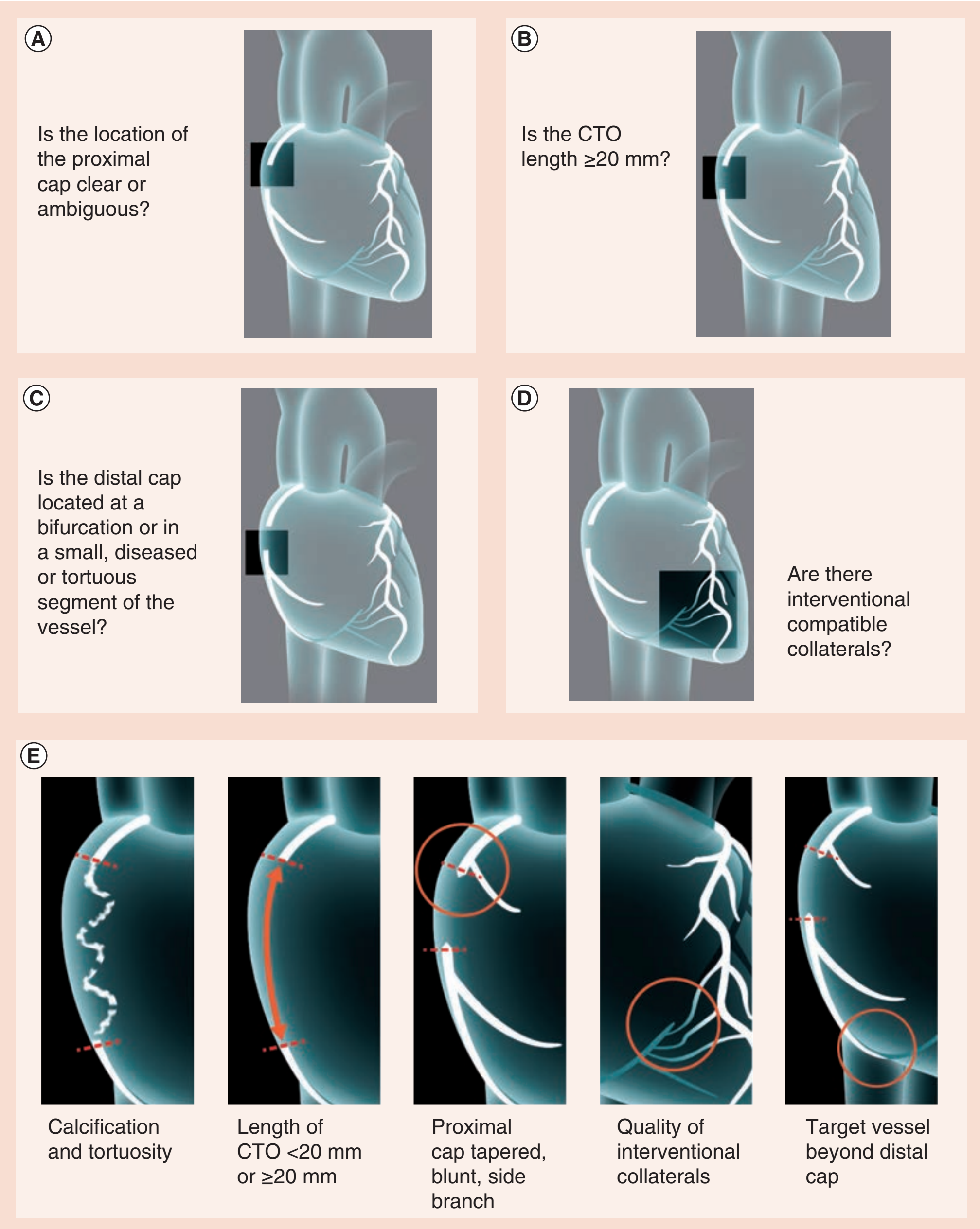

Figure 4. Chronic total occlusion characteristics. (A) proximal cap; **(B)** lesion length; **(C)** distal cap and vessel; **(D)** interventional collaterals; and **(E)** calcification and tortuosity.
CTO: Chronic total occlusion.

distal cap is located at a bifurcation. A small caliber, diseased artery, which reconstitutes at a bifurcation provides a poor target for the antegrade approach, and particularly the antegrade dissection and re-entry technique (Figure 4C).

Size & suitability of collaterals for intervention

The ideal collateral to facilitate the retrograde approach is septal rather than epicardial, can be easily accessed via a healthy donor vessel, has minimal tortuosity and enters the occluded vessel a reasonable distance beyond the distal cap. If the collateral vessel is the only support to the occluded segment, there is a significant risk of intraprocedural ischemia. The presence of optimal collateral characteristics favors the retrograde approach. If there are some unfavorable features these should be weighed up against the antegrade characteristics when deciding on an initial retrograde approach or adopting this as an early crossover strategy (Figure 4D).

Calcification & tortuosity

The presence of severe calcification and/or tortuosity in the occlusive segment is unfavorable

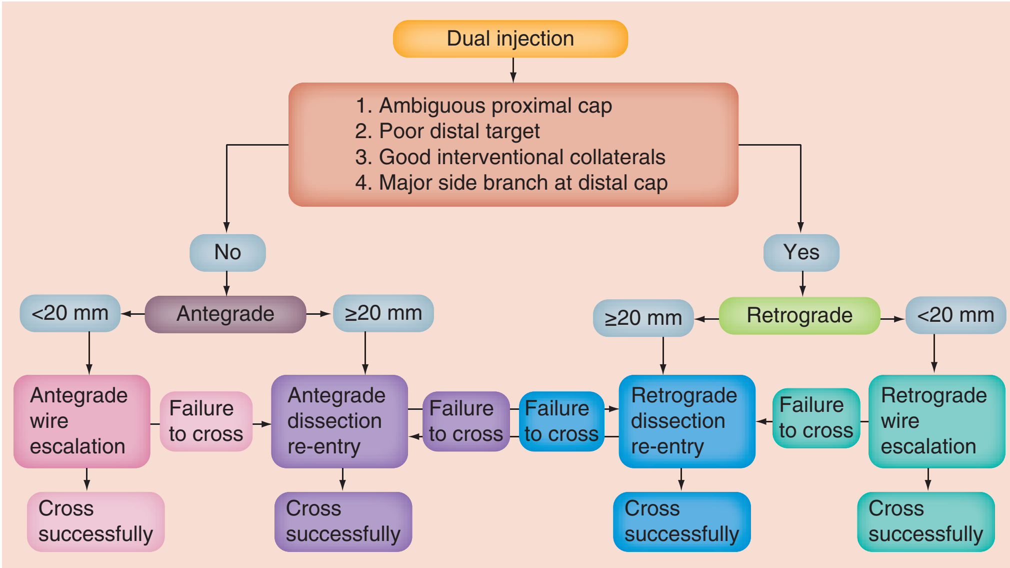

Figure 5. Procedural strategy algorithm.

for the antegrade approach, and in particular the antegrade dissection and re-entry technique. Such lesions are often best tackled using the reverse CART technique if there are suitable interventional collaterals. Rotablation may be required to facilitate antegrade progress and subsequently to debulk the calcific, occlusive plaque to allow optimal stent deployment (Figure 4E).

Brilakis *et al.* have devised an algorithm to guide procedural strategy based on these characteristics of the CTO anatomy (Figure 5) [10]. The algorithm requires the consideration of four key questions (Figure 6):

- Is the location of the proximal cap clear or ambiguous?
- Is the distal cap located at a bifurcation or in a small, diseased or tortuous segment of the vessel?
- Are there interventional compatible collaterals?
- Is the length of the CTO >20 mm?

Based on this information, following the algorithm, a hierarchy of favored strategies can be decided upon. Having devised strategy A, it is recommend that the sequential steps of the procedure are planned and, in addition, bail-out strategies B and C are also mapped out. The focus should be on working efficiently, moving on quickly to the next strategy if there is no significant progress.

The planned strategy may influence the procedural set up. The majority of CTO operators routinely use bilateral 8 F guide catheters to facilitate a complete hybrid strategy, while also maximizing back-up and support. Some operators use a 6 or 7 F retrograde donor vessel guide catheter, as this is adequate to facilitate the use of the standard retrograde kit. Similarly, if antegrade dissection re-entry with the CrossBoss Stingray system (Boston Scientific) or intravascular ultrasound guidance are not potential strategies, some operators will also use a 7 F antegrade guide catheter. This may be further influenced by the presence of proximal branches suitable to allow anchoring of the guide, or a significant proximal vessel platform for the delivery of the GuideLiner mother-and-child support catheter.

Interventional collaterals

The term ‘interventional collateral’ refers to a collateral supplying the occluded vessel, which can be traversed by both wire and equipment. This threshold may vary according to the experience of the operator and the clinical scenario. Both septal and epicardial collaterals are used in the retrograde approach to CTO PCI. These should be studied in detail during preprocedure angiographic analysis and again following dual injection angiography, using multiple views and avoiding foreshortening. Occasionally, it may be appropriate to explore possible communicating collaterals using microcatheter injections during a preceding diagnostic angiogram or PCI.

There are two established collateral grading systems. The Rentrop classification assesses the extent of collateral filling of the recipient artery [11]. Rentrop grade is categorized as: 0, no vessel filling by collaterals; 1, filling of distal side branches of the epicardial vessel by collaterals;

2, partial filling of the epicardial artery by collaterals; and 3, complete filling of the epicardial artery by collaterals.

The size of the collateral channels is described by the collateral connection (CC) grade: CC0, no continuous connection; CC1, continuous thread-like connection; and CC2, continuous, small side branch-like connection [12].

Looking specifically at the quality of the collaterals in retrograde CTO PCI, a Japanese single-center series reported that the presence of grade CC1 collaterals, collateral tortuosity <90°, and a connection angle with the recipient vessel <90°, were significant predictors of success, while epicardial collateral use, grade CC0 collaterals, a corkscrew channel, a connection angle with the recipient vessel >90° and nonvisibility of a connection with the recipient vessel were significant predictors of failure [13].

Sianos *et al.*, reporting data from seven European retrograde CTO PCI centers, found that septal collaterals were accessed in 79.4%, and epicardial collaterals in 20.6% of patients. In 80.6% of cases, a wire was successfully delivered through the collaterals to the recipient vessel beyond the occlusion, with an overall procedure success rate of 91.5% [14].

In the Japanese series, septal and epicardial collaterals were used in 67.5 and 24.8% of cases, respectively. In the other 7.6% of cases, saphenous vein graft 'collaterals' were used. The collaterals were crossed with a wire successfully in 73.2%, and the procedure was completed retrogradely in 65.6% of cases [13].

In the recently published Japanese multicenter registry evaluating the retrograde approach, in 801 patients across 28 centers, procedural success rate was 84.8%, of which 71.2% were completed retrogradely [15]. Comparing practice in 2009–2010 there was a dramatic increase in the use of channel dilators (95.3 vs 36%), with an associated increase in collateral channel crossing with a wire and catheter (81.1 vs 70.6%), and accessibility of epicardial collaterals (36.9 vs 27.6%). There was increased use of the reverse CART technique (66.5 vs 41.9%) and decreased procedure time (203.3 vs 187.9 min), but no significant improvement in the overall procedural success rate. Multivariate analysis identified age ≥65 years and lesion calcification as unfavorable factors and the use of a channel dilator as a favorable factor for retrograde procedural success.

Having analyzed the collaterals carefully, a hierarchy of those most likely to facilitate safe and successful passage of the wire and catheter should be established. Whether a collateral is suitable for intervention will depend on the experience

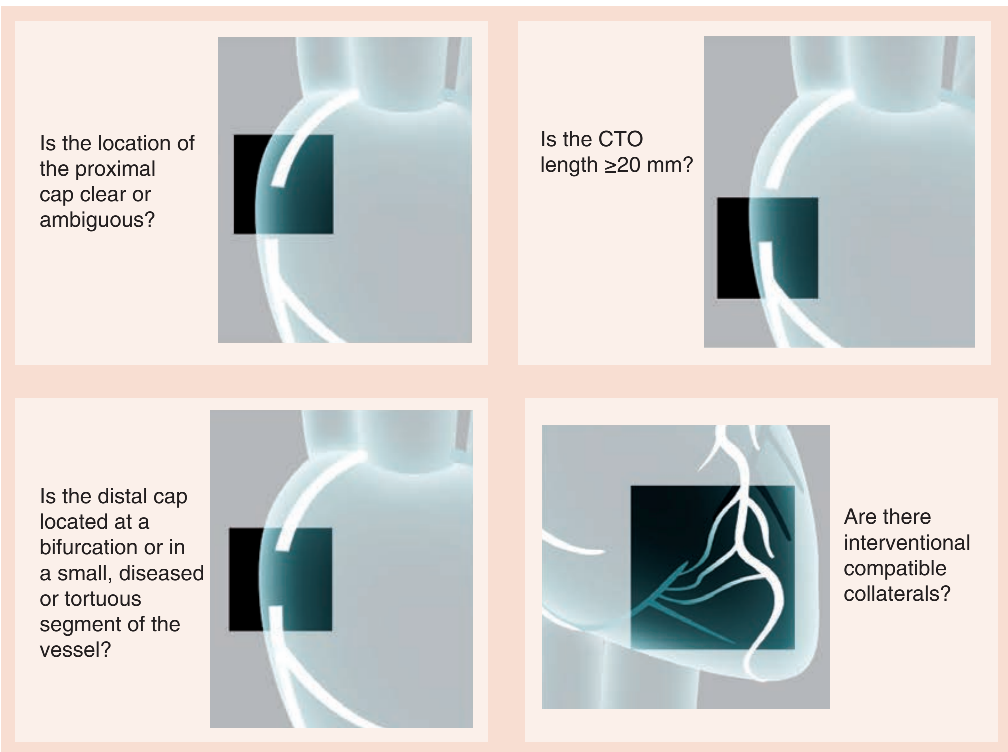

Figure 6. Key algorithm questions.
CTO: Chronic total occlusion.

of the operator. The operator should consider whether they have developed the skills to use the collaterals available, with this threshold rising as experience is accumulated.

Computed tomography coronary angiography

Computed tomography coronary angiography (CTCA) can be useful in procedure planning for CTO PCI by identifying factors known to influence PCI success rates, such as calcification, severe tortuosity and length of the occluded segment [8,9].

A Japanese series looking at the effect of routine preprocedure CTCA in 100 consecutive CTO PCIs found no significant difference in procedure success rates, irradiation time or contrast dose between those who had or did not have CTCA [16].

CTCA can be useful in mapping the ambiguous course of a vessel beyond an occlusion, when this is not clear on antegrade, retrograde or dual injection coronary angiography. It is particularly helpful in understanding anatomy distorted post-CABG, where the insertion point of saphenous vein grafts are not well understood angiographically, but can lead to significant tenting of vessels. Furthermore, it can be occasionally useful in identifying the location of an ostial occlusion of the right coronary artery or left main stem, or anomalous coronary arteries.

At the present time, most CTO PCI centers use nonroutine CTCA in particularly complex cases. Transmission of CTCA images to the cardiac catheterization laboratory as reference or fusion data can further facilitate planning the procedural strategy in these difficult cases [17].

Conclusion

A successful CTO service is dependent upon robust procedure planning, encompassing the logistics of catheterization laboratory and CTO operator's time, ensuring availability of specialist equipment, careful patient selection and preparation, detailed angiographic (and CTCA in some cases) analysis, and establishing a predefined and clear procedural strategy.

Future perspective

With the growing recognition that high-volume operators with specific skill sets working within a dedicated CTO service improve procedure efficiency and success rates, we anticipate that there will be a steady growth in CTO PCI over the next 5 years, and that this will be accompanied by a continuing evolution of techniques and technology.

Financial & competing interests disclosure

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Executive summary

- Moving from *ad hoc* chronic total occlusion (CTO) percutaneous coronary intervention to a dedicated CTO service improves procedure success rates.
- CTO percutaneous coronary interventions should be performed by CTO operators, performing ≥50 cases per year, on dedicated CTO days.
- Clinical appropriateness is paramount in patient selection.
- By planning ahead, operators should ensure that CTO specific equipment is available on CTO days.
- Procedure safety limits should be established prior to starting each case.
- Time should be dedicated preprocedure to performing detailed angiographic analysis and to assess anticipated difficulty, complexity and potential hazards.
- A hierarchy of procedural strategies should be defined.

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