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Review Article

Tips and Tricks for PCI of Chronic Total Occlusions – A Review

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Abstract

Chronic total occlusion recanalization still represents the final frontier in percutaneous coronary intervention. Retrograde recanalization is one of the greatest amendments of this technique. At present, it has become an integral complement to the traditional antegrade approach. Despite being most frequently used in complex patients, it has the highest success rate with the lowest incidence of complications. Since its inception, significant iterations have occurred that made this technique safer, faster, and even more successful.

Keywords: Percutaneous coronary intervention; coronary occlusion; coronary artery disease, retrograde approach.

Introduction

In overall CAD the prevalence of chronic total occlusion (CTO) of coronaries is around 20%. CTO of a coronary is characterized as the absolute cessation of coronary blood flow for around 90 days [1-3]. Due to procedural complications and greater periprocedural failure, CTO remains a very difficult subset even in this technically advanced era. The last two decades have witnessed advancement in percutaneous coronary intervention (PCI) technology for CTO and thus PCI has become more predictable with a success rate of >90% [4].

Basics of chronic total occlusions

Definition

CTO are an occlusion with the absence of antegrade flow with Thrombolysis in Myocardial Infarction (TIMI) flow 0 through the lesion with a documented duration of ≥3 months with presence of visible mature collaterals and absence of thrombus or staining at the proximal cap [5].

CTO anatomy

CTO comprises a proximal mixed fibrous and calcified cap and a distal cap. The fibrous tissue, debris, plaque microchannels determine wheatear guidewire crossing in CTO PCI is successful. The lesions which are soft loaded with lipid are seen in younger CTO's. While the older lesions are hard or calcific. Intimal plaque vessels become more in number with the increasing age of the CTO. In<1-year-old CTO lesions, the adventitia is the chief location of neovascular channels, however in >1-year-old CTO lesions, capillary numbers, and size increase in the intimal layer [6].

CTO lesions exhibit two types of histological vascular channels: 1) histologically recanalized segments which are endothelialized microchannels (160–230 μm) and are produced utilizing neovascularization. and found in the tapered stump with looser fibrous tissue, and 2) non-recanalized segments which consist of miniature vessels (<100 μm) that pass into the little side branch or the vasa vasorum and are mostly observed in non-tapered or blunt cap [6-8].

Predictive scores in CTO PCI success

Several scoring systems have been developed to determine the likelihood of CTO PCI technical success and the potential difficulty of the procedure (measured as the time required to cross the occlusion). J-CTO (Japan-chronic total occlusion score), which estimates the probability of effective guidewire crossing taking more than 30 minutes dependent upon criteria five in number (intra-lesions > 40° twist, length ≥ 20 mm, calcification, obtuse stump, and recently failed endeavor) and the case

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intricacy was delineated into simple (score 0), intermediate (score 1), troublesome (score 2), and undeniably challenging (score 3–5) [9]. Further, PROGRESS-CTO (Prospective Global Registry for the Study of Chronic Total Occlusion) score includes angiographic characteristics such as ambiguous proximal cap, left circumflex target artery, moderate/severe proximal tortuosity and lack of interventional collaterals offering an equal score to each characteristic. Like PROGRESS-CTO score, ORA (Ostial, Rentrop grade, Age score) and RECHARGE (Registry of Cross Boss and Hybrid Procedures in France, the Netherlands, Belgium, and the United Kingdom) also consider the hybrid approach; however, these three scores showed a moderate performance in predicting the success of CTO PCI with a favor for antegrade procedures [10-12]. A weighted CTO score (W-CTO) predicts antegrade wire crossing [13]. Unlike the other scores, the KCCT score which uses tomography (CT) angiographic imaging provides the probability of crossing the CTO and elucidates the difficulty in crossing and talks about procedural success. KCCT score <4 predicts the capacity to cross the lesions within 30 minutes [14].

Collateral channel evaluation

During pre-birth development, CCs develop as intraarterial connections, and they decrease in most individuals. (**Table 1)** outlined characteristics of the type of collateral channels they develop in a native occluded artery through positive remodeling. develop these CCs need somewhere in the range of 2 and 10 weeks to completely arrive at their capacity to function. These CCs regress after a successful PCI but can regenerate if the occlusion occurs again. CCs should be assessed for size, tortuosity, and angle of connection. Right Anterior Oblique (RAO) cranial is the best view for deciding the beginning of the septal CC. RAO caudal is an excellent view for the body and exit of septal CC (part of the CC closer to the posterior descending artery [PDA]). The optimal views for epicardial CC in lateral wall (diagonal-obtuse marginal vessels) are left anterior oblique (LAO) and RAO cranial and for epicardial CC between proximal circumflex and RCA are AP caudal and RAO [15, 16].

An angiographic grading system was developed by Rentrop et al [17]. to see the effect of CC in refilling the segment which was occluded. Four degrees of filling of collateral, by contrast, are distinguished but it lacks further differentiation because most are Rentrop grade 3 (complete epicardial filling by the collateral vessel of the target artery). The Werner classification adds boundaries to portray immediately apparent CCs and shows a relationship with clinical determinants of CC adequacy [18]. These CC grades are more functionally correlated to decide appropriateness for retrograde CTO PCI.

Procedural Considerations

Vascular access, guide catheter, and sheath selection

The operator's friendliness with the vascular site and knowledge of the risk/benefit ratio determines which site is to be used- transfemoral or transradial. Most operators prefer large bore (8 Fr) bifemoral access with long (45 cm) sheaths and two 8 Fr, co-axial guide catheters to maximize system stability and ease delivery. With increasing experience, a hybrid approach considering both radial (6 or 7 Fr) and femoral 8 Fr access can be preferred [19]. Retrograde guide wires should be short (90 cm) permitting the externalization of the wire. A 1F smaller introducer sheath can be connected to a regular 100cm guide catheter which is cut and made short. Removing 10 cm is usually enough [7].

Diagnostic angiography

Appropriate pre-procedural diagnostic angiography (**Table 2**) is of critical importance in CTO PCI and efforts should be made to interpret the following: (i) proximal cap morphology (blunt or tapered); (ii) the occlusion length;(iii) the quality of occluded vessel (i.e. tortuous, calcified, diffusely diseased, small); (iv) the source and direction of flow of distal vasculature, if any and (v) the course of collateral channel supply and target vasculature beyond the occlusion.

Role of multi-slice computed tomography (MSCT)

The use of MSCT will complement conventional angiography and can help in the successful completion of a successful CTO procedure. It may give information regarding various characteristics of lesions. These may include the length of lesions, quantity and quality of calcium, nature of plaque of distal vessels beyond the lesions, also tortuosity and bends in the CTO segments [20]. The characteristics of CT scan which predict failure can be length >20mm, calcification >60% or both in combination [21].

Procedural anticoagulation and monitoring

The patient should be either loaded with and maintained on dual antiplatelet therapy (aspirin plus P2Y12 inhibitor) before, during and after the procedure. Heparin is the mainstay of anti-thrombotic therapy in CTO PCI and is maintained using activated clotting time (ACT) done at 30 minutes intervals, with a goal of over 300 seconds and 250 seconds for antegrade and retrograde procedures, respectively. Bivalirudin is not recommended due to concerns of increased equipment thrombosis [22].

TECHNICAL STRATEGIES (Table 3 represent techniques for CTO PCI based on angiographic characteristics)

- **The CTO armamentarium:** The CTO toolbox comprises of both equipment and specialized techniques. Detailed knowledge this is critical to procedural success in both antegrade and retrograde techniques and requires an ongoing commitment to continual education and awareness of equipment refinements to understand its optimal use.
- **Guidewires:** A menu of highly sophisticated guidewires exists

Table 1: Characteristics of type of collateral channels.

CCs	Tortuosity (Corkscrew)	Inelastic vessel/ stenosis	Length of access vessel	Distensibility	Availability	Examples
Epicardial	Significant	Potentially	Long	Not dilatable	Moderate (>20%)	Apical LAD-PDA Diagonal-OM Diagonal-PDA LCX-PL
Septal	Slight to moderate	Rarely	Short	Dilatable	High (>50%)	LAD-PDA LAD-LAD Conus-PDA
Atrial	Moderate	Occasionally	Moderate	Not dilatable	Low (<10%)	

CCs, collateral channels; LAD, left anterior descending artery; LCX, left circumflex artery; PDA, posterior descending artery; RCA, right coronary artery.

Table 2: Areas of focus in an angiogram of chronic total occlusion (CTO) lesion.

1.	Proximal segment: tortuosity, calcification, bifurcation, anomaly of coronary origin
2.	Proximal cap: calcification, bifurcation, stump, tapered or blunt type
3.	CTO body: occlusion length, microchannel, island, contrast pooling, calcification
4.	Distal cap: calcification, tapered, diffuse plaque, bifurcation, stump
5.	Distal segment
6.	Extraluminal pathology (subintimal tract, calcification)
7.	Collateral channels: entry, body and exit from the main vessel

Table 3: Techniques for CTO PCI based on angiographic characteristics.

Variables	AWE	ADR	RWE	RDR
Clear proximal cap	+	+	-	-
Lesion length ≥ 20 mm	-	+	-	+
Good distal landing zone	+	+	-	-
Interventional CC	-	-	+	+

ADR, antegrade dissection and reentry; AWE, antegrade wire escalation; CC, collateral channel; CTO, chronic total occlusion; PCI, percutaneous coronary intervention; RDR, retrograde dissection and reentry; RWE, retrograde wire escalation

due to a recent explosion of technology. Based on the unique structural and functional properties, CTO wires may be organized into eight task-specific classes (i.e. Access, micro-channel crossing, directed navigation, collateral crossing, directed penetration, knuckling, fenestration re-entry, externalization).

- **Microcatheters:** Microcatheters are another important hardware for dedicated CTO PCI. They increase support and wire tip stiffness, allow reshaping, wire exchange and maneuverability, distal intracoronary contrast injection and avoid twisting of wires while performing parallel wire techniques. Alternatively, over-the-wire (OTW) balloons may be used. However, the microcatheters have the advantage of having a more flexible tip, more extensive internal lumen and the radio-hazy marker at its tip which gives better power to penetrate, better steerability of the wire and better lesion assessment respectively.

Antegrade approaches

Ideally, the antegrade approach requires a defined tapered stump or defined entry point of the proximal cap, however, it is technically challenging if the entry point is ambiguous or at a bifurcation.

Antegrade wire escalation (AWE) is the most used in the initial strategy especially when the CTO segment is short and proximal and distal caps are well defined. When the lesions are hard due to a more fibrous or calcific nature, a higher penetrating force will be required to advance the wire. Intimal plaque tracking requires two techniques during wire escalation, one is controlled drilling in which wire is pushed forward with spinning movements of 360-degree rotations and the second penetration in which wire is advanced with gentle rotation which punctures the CTO segments which might be fibrous or calcified.

Parallel/seesaw wiring technique adopted if a subintimal wire position is achieved during an AWE, as it avoids further expansion of the subintimal space. This technique entails leaving the subintimal wire in place (both as a marker and to obstruct the entry into the subintimal track) while introducing a second wire in parallel that is stiffer (penetration wire). This second wire is then redirected towards the true lumen of the vessel. Using a parallel wire strategy with two microcatheters at a time is called "seesaw wiring". The interventionist can move either of the two wires at a time [23].

In Anchor, the wire technique is a second wire is placed inside the branch which increases the support for penetrating the CTO proximal cap with the CTO wire. Anchor balloon technique involves negotiation of a wire into a side branch (**Figure 1**) followed by a little inflatable (1.5–2.0 mm) expansion at 6–8 atm and thus facilitates advancement of a wire, balloon or microcatheters. However, there may be a risk of injury or ischemia to the side branch supplying a large myocardial territory [24].

IVUS guided wiring technique involves i) side branch IVUS guided wiring, and ii) co-axial IVUS guided penetration from subintimal space. If the proximal cap is ambiguous, the IVUS catheter can be advanced in the side branch, and it can seek a dimple at the entry that facilitates successful navigation of wire into the true lumen (**Figure 2**). It also talks about the calcification of the plaque. But to visualize the plaque the anatomic arrangement should be precise [25].

During PCI of the CTO segment, sometime wires may enlarge the subintimal space. It might happen during the parallel wire technique. The important points to decrease the subintimal space are that if IVUS images are used, there should be technical ability to translate into 3D, secondly, the type of wire chosen should be stiffer and with a tapered tip, also it should be microcatheter supported. Another point is contrasted injection is should be given very cautiously so that to avoid hydraulic dissections in the subintimal space. Multiple stents will be required to cover the whole subintimal space [25].

Antegrade dissection and re-entry (ADR) techniques are encouraged in long CTO segment (>20 mm), and good landing zone (**Figure 3**) or during AWE if the wire goes subintimal (**Figure 4**). During ADR, antegrade injections should be avoided to prevent hydraulic extension of the dissection plane, and care should be taken with wire tip control to avoid intramural hematoma. (**Table 4)** differentiate between contemporary and classic ADR technique.

Wire-assisted ADR Once the subintimal space is entered, the microcatheter is carefully advanced to the tip of the wire without allowing

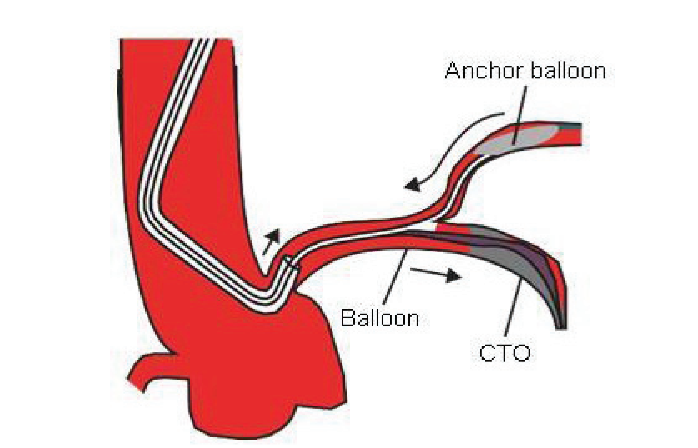

Figure 1: Schematic illustration of side branch anchor balloon technique [24].

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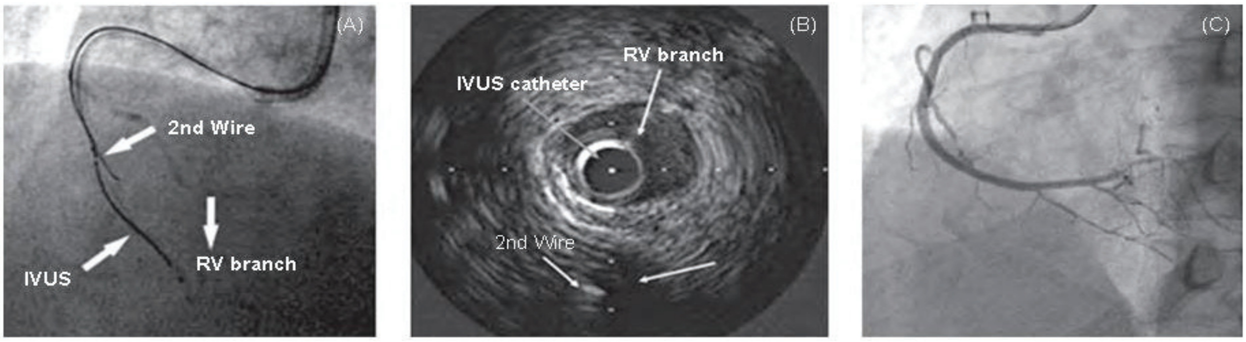

Figure 2: Coronary angiogram depicting the side branch IVUS guided wire crossing [55].

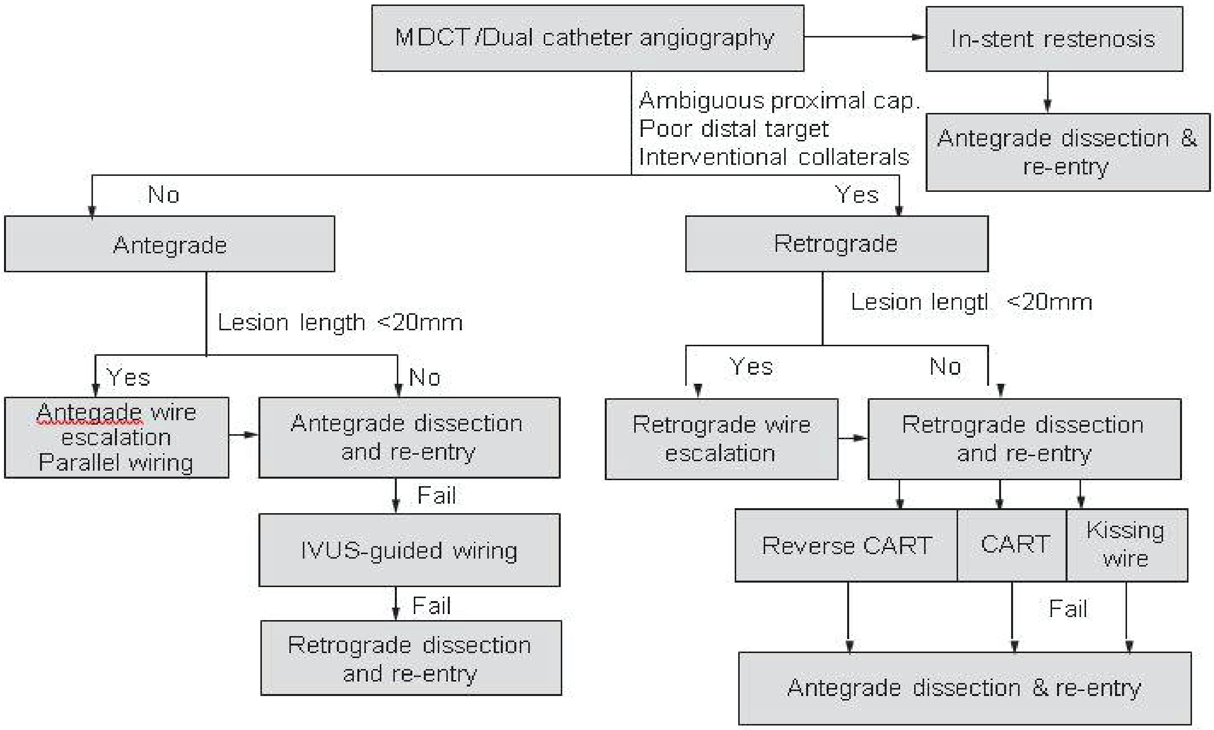

Figure 3: Algorithm of putting it altogether (expanded hybrid) algorithm in CTO PCI [56].

the wire to move forward. Next using a knuckle with a J tip (Fielder XT or Pilot 200), the wire is pushed into the subintimal space. With the creation of this knuckle, the wire is pushed through the vessel architecture to create a limited intentional dissection plane until a healthy area of the distal cap is reached. Generally, the subintimal space will provide considerably less resistance to wire movement. In the subintimal tracking and re-entry [STAR] technique knuckle wire is advanced through subintimal space and ultimately the wire reappears in true lumen distally [26], The contrast injection can be given through microcatheter or by "microchannel technique" and this is called contrast-guided STAR technique [27, 28]. In microchannel, technique contrast is delivered to enlarge, and it also can connect the microchannels which are pre-existing in the CTO segment. Another variant is Mini-STAR [29] where subintimal spaces are designed to be smaller. Another technique called limited antegrade subintimal tracking (LAST) technique uses stiffer polymer-coated or non-coated penetration wire to form the lope and redirect it into the distal true lumen [30].

The more reproducible method has been used by a dedicated device assisted ADR-technology which addresses the limitations of wire-based re-entry methods. The advantage of this device-based dissection compared to wire-based one is the lower risk of perforation (the tip of the Cross Boss catheter is deflected by the adventitia and is unlikely to exit the vessel, whereas the tip of the guidewire is much likely to perforate) and faster speed [31].

Iterations of ADR

ADR has been iterated and modified since its original description in 2011. I) **Contemporary *ADR*** developed to overcome the limitations of CrossBoss catheter such as stiffness with a bias to the outer curvature of the vessel and its preference to the side branch. ii) **Antegrade fenestration and re-entry** (AFR) is a novel technique. In these techniques, multiple fenestrations of the dissection flap separating the true and false lumen are created. This balloon is advanced over the antegrade wire into the subintimal space and is inflated at the level of the distal cap. The artery

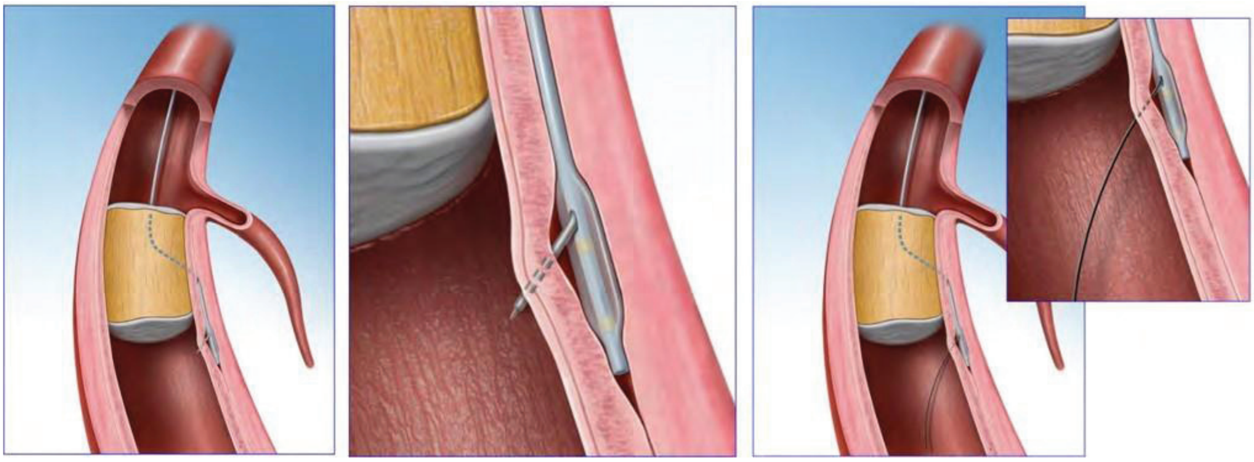

Figure 4: Schematic illustration of antegrade dissection and re-entry. Used with permission from William Lombardi.

Table 4: Contemporary versus classic ADR.

	Contemporary ADR	Classic ADR
Set up	8Fr Femoral with 8Fr Trapline or 6Fr Radial without guide extension	8Fr Femoral with supportive guides AL0.75/EBU 3.5
Initial microcatheter	Corsair/Turnpike family135 cm but still end with the CrossBoss to limit dissection zone	CrossBoss
Re-entry catheter	Stingray LP	Stingray
Re-entry wire	More flexible approach-Stingray wire/ConfianzaPro 12/Hornet 14/ Gaia3/Astato30	Stingray wire
Re-entry technique	More often Stick and swap with polymer jacketed wire eg. Pilot	Stick and go
Hematoma management	Active management with Trapliner upfront and preemptive STRAW	STRAW if loss of visualization of distal vessel

to balloon ratio should be 1:1. A soft polymer-coated guidewire is then advanced across the fenestrations created by balloon inflation from the subintimal space into the true lumen. It is relatively inexpensive and easy to perform the technique.

Retrograde Approach

The retrograde technique involves the crossing of collateral channels from the donor's vessel to the distal CTO segment using a wire or special microcatheter. In cases where there is calcification ambiguous proximal cap, this strategy can be used as the primary approach. Also, lesions that have bifurcation at distal occlusion and poorly visualized distal bed, this approach has advantages. It is also employed when the Antegrade strategy fails (**Table 5**) [32].

Navigation through collateral channel

The CCs which are visible in direct connection with the recipient vessel (at least Werner 1 grade); or straight or have shallow bends and angles that are <90 degrees are ideal for retrograde access. The target CC is navigated initially with a workhorse wire which is further navigated with a dedicated microcatheter. Further surfing or contrast guided techniques can be used to cross it subsequently. The guidewire is pushed rapidly along a path that offers the least resistance and then it may buckle and move forward into the distal vessels (surfing) [4, 33, 34]. If there is any resistance wire can be withdrawn and redirected to cross another CC. If little or no progress is made after several minutes, selective injection of the CC is done to delineate the precise connection with the target zone. Epicardial collateral channel crossing should always be facilitated by contrast guidance.

Crossing of the occlusion

- Once the collateral channel has been navigated successfully and retrograde microcatheter advanced to the distal cap, there are various ways to cross the lesioDirect retrograde true lumen puncture involves retrograde wire navigation through the distal cap, body of CTO and proximal cap into the true lumen of the Antegrade vessel **(Figure 5)**. It is generally employed in short lesions without significant tortuosity where the proximal vessel is unambiguous [35]. A directed penetration or directed navigation wire is used to breach the distal cap and advance through the occlusion. Once the true lumen position of the wire is confirmed in the proximal vessel, both the wire and retrograde microcatheter is pushed ahead into the antegrade guiding catheter. A long externalization wire is used to exchange the retrograde wire this long wire reaches the hemostatic valve of the antegrade guide. To cross the occlusion with the microcatheter the retrograde wire can be anchored into antegrade wire by using a 2.5mm balloon inflated to anchor it. The retrograde wire crossing can be facilitated by inflating a retrograde wire for the more coaxial anchor. Also, stiffer wires or wires tapered tips or hydrophilic wires can be used if required. The retrograde wire can be redirected into the true proximal lumen by antegrade IVUS [4]. At this stage, this retrograde wire is traded for a long externalization wire which is withdrawn from the hemostatic valve of the antegrade guide. The retrograde wire into the aorta or the antegrade guide can be secured by blowing up a little inflatable (2.5 mm) inside the antegrade guide catheter to work with the intersection of the impediment with the microcatheter. The likelihood of retrograde wire intersection can be improved by moves, for example, swelling a retrograde inflatable for more help (coaxial anchor) and utilizing a stiffer, tightened tip, and additionally hydrophilic wires. Antegrade IVUS is helpful to direct retrograde wire into the proximal genuine lumen [4].

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- The retrograde wire can be used as a road map for the facilitation of antegrade wire manipulations to enter true lumen distally with retrograde wire as the marker (**Figure 5**). It can be confirmed in two different angiographic projections that retrograde wire meets the antegrade wire at a single point. The subintimal space is entered in all probability if the two guide wires do not overlap. When the antegrade wiring is initiated, it should be done at a site that is proximal to the retrograde wire, in this way the tips of the two wires can reach a single point [4].
- Classical controlled antegrade and retrograde subintimal following (CART) or reverse CART has been employed in instances of failed procedures. In the classical CART technique if an antegrade wire goes subintimal a connection is created between the distal true lumen and antegrade subintimal space in this technique subintimal space is enlarged by inflating a balloon over the retrograde wire. The antegrade wire is then advanced over the deflated retrograde balloon. Then the antegrade wire is advanced so that it enters the true distal lumen (Figure 5 and Figure 6). As dedicated microcatheter are available, this CART technique is now superseded by the newer technique that is reverse CART [4, 24].

Hybrid algorithm

Putting it inside and out (expanded hybrid algorithm) [4] (Figure 3) addresses a combined strategy involving antegrade and retrograde approaches. This helps to standardize the procedure and improve outcomes and helps to leverage the approach which is most safe and effective for a given patient. This involves quickly changing the strategy whenever required and an abandoned strategy can be given a comeback [4].

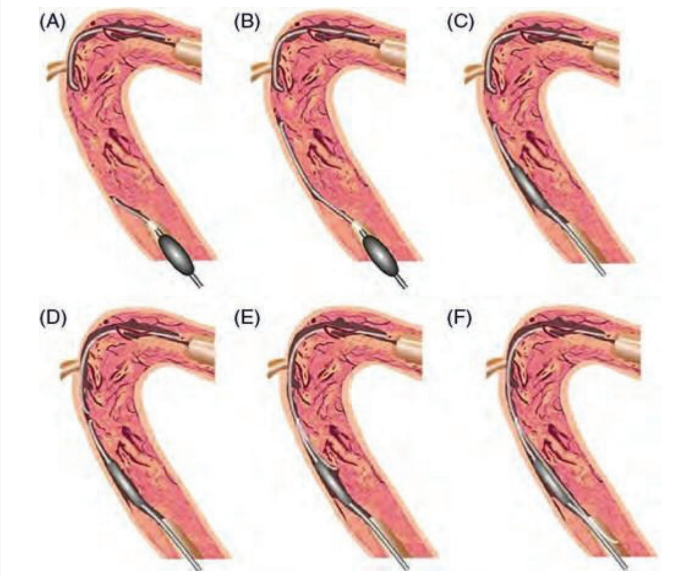

Figure 6: Schematic representation of the key steps in CART. (A) Antegrade wire is advanced into the coronary chronic total occlusion, then into the subintimal space. The retrograde wire is placed at the distal end of the coronary chronic total occlusion, then introduced into the coronary chronic total occlusion, and finally into the subintimal space. (B) A small balloon (1.5–2 mm) is advanced over the retrograde wire into the subintima (C) The balloon is inflated inside the coronary chronic total occlusion. (D) The deflated balloon should be left in place to keep this subintimal space open. (E) The two subintimal dissections provide a "re-entry space" for the antegrade wiring. (F) The antegrade wire is advanced further along the deflated retrograde balloon into the distal true lumen [57].

Table 5: Indications of the retrograde approach.
• Ostial occlusion
• Ambiguous proximal cap: blunt stump, side branch
• Long occlusions
• Severe proximal tortuosity or calcification
• Poor distal target
• Bifurcation at distal cap
• Good interventional collateral channel
• Failed antegrade attempt

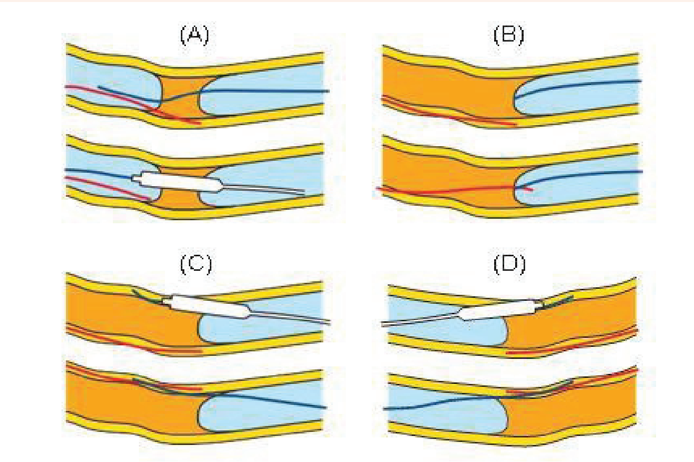

Figure 5: (A) Schematic illustration of the retrograde crossing tech-niques. (A) Direct retrograde crossing (direct retrograde navigation of guide-wire into the true lumen of the antegrade vessel). (B) Kissing wires. (C) Classical controlled antegrade retrograde subintimal tracking (CART) (D) Reverse CART [4].

Solutions to balloon uncrossable CTO

The most common cause of failure of CTO procedure is the inability to cross the lesions and even after successful wire crossing the failure to cross with the balloon is the second commonest cause. [37] Several methods can be utilized to help cross such lesions with the balloon (including use of small balloons, low-profile microcatheters, increased guide support, laser or atherectomy, or subintimal modification). One of the simplest and widely available techniques is the balloon-assisted microdissection or "grenadoplasty" technique, during which a small (usually1.25 or 1.5 mm) [38], compliant balloon is advanced quite far into the proximal cap and is inflated at burst pressures to cause rupture of the balloon, causing microdissections around and into the cap and facilitating crossing with a new low-profile balloon. Laser is another very useful tool that does not require wire exchange as compared to rotational atherectomy [39]. Subintimal techniques for balloon uncrossable lesions include (a) "subintimal space plaque modification," during which the subintimal space is crossed with a second wire (parallel to the intimal lesion crossing wire), followed by either balloon angioplasty of the sub- intimal space or formation of a knuckle wire in the subintimal space, favourably modifying the lesion and the proximal cap and allowing balloon advancement into the true lumen, and (b) "subintimal distal anchoring" [40], during which a balloon is crossed into the subintimal space and inflated to anchor the true lumen wire facilitating its entry **(Table 6)**.

Unraveling the complications encountered during CTO PCI

CTO PCI is related to a higher rate of associated complications. The associated complications like Coronary perforations occur more frequently with CTO PCI. The team should be ready to treat these complications. For large vessel perforation covered stents are required and for distal wire and CCs perforations coils are required. A balloon is passed through one guide catheter and is inflated at a site proximal to perforations. Another guiding is engaged, and covered stent is delivered through it and inflated to seal the perforations. This is called the Ping-Pong technique. Coils required large delivery microcatheter such as procreate from Terumo, Japan, or Renegade from Boston Scientific. During delivery, the migration of the coil in the main vessels should be avoided otherwise it can cause the occlusion of the vessels. Another method is to inject clotted blood or subcutaneous fat from a microcatheter which might seal the small perforation. Epicardial CCs required perforation to be sealed from both sides with coiling [41]. In retrograde strategy, if there is thrombus or dissection of donor's vessel, it may cause occlusion of the donor artery. It can lead to threatening hemodynamic instability. The ACT should be kept around 300 sec to avoid this complication and attention should be given to watching the pressure waveform. During wire externalization the movement of the guide should be watched as the deep engagement of the tip of the guide catheter may result in dissection. Immediate stenting of the dissected vessel should be done if such complication arises to restore antegrade flow. Other complications which occur quietly during CTO PCI can be contrast nephropathy, MI, aortocoronary dissection, Transient ischemic attack (TIA), stroke, stent loss, device entrapment and other vascular access complications **(Table 7)** [41, 42].

OTHER NOVEL TECHNOLOGIES/DEVICES

Mechanical vibration and therapeutic ultrasound

The selective penetration which occurs because of elasticity difference between different tissue types is called the Mechanical vibration crossing method. The elastic vessel wall is not damaged by vibrational energy; however, atherosclerotic plaque is shattered. Similarly, the ultrasound destroys atherosclerotic plaque by leaving the adjacent vascular wall unaffected. A generator that changes AC power into a high-frequency current transmits vibrating energy to the catheter [43].

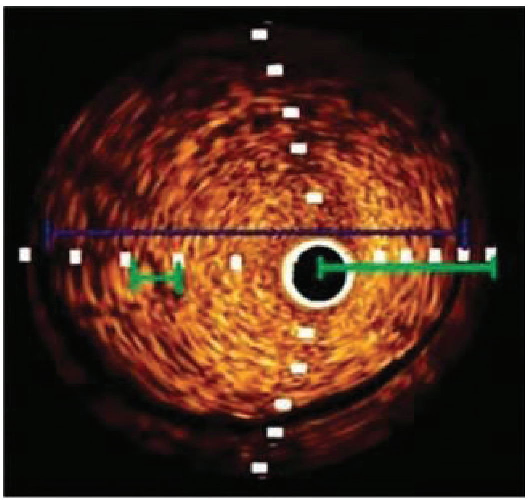

Figure 7: Forward looking IVUS (view of 5mm away; tick marks are 1 mm in cross-sectional plane for easy diameter sizing. This vessel is 9 mm across). Courtesy Volcano corporation, San Diego, CA, USA [49].

Table 6: Management of balloon uncrossable CTO.

Augmented guide catheter support	Lesion modification
• Larger guide catheter with more supportive shape	• Appropriate small balloon (1.20–1.5 mm) manipulation
• Long arterial sheaths	• Wedgies & grenadoplasty (Intentional balloon rupture)
• Deep engagement	• Microcatheters:Tornus, Corsiar, Carvel, Finecross,Turnpike
• Guide catheter extension	• Excimer laser: ablative and acoustic energy
• Guide catheter extension	• Rotational atherectomy
• Buddy wire	• Seesaw balloon-wire cutting technique
• Anchor balloon: side branch, distal target vessel or subintimal at or below lesion site	• Multi-wire plaque crushing technique
	• Crowbar effect
	• Retrograde approach

Blunt micro-dissection

The whole length of CTO segment plaque can be gently fractured and separated by Frontrunner. It does sow without any increase in any incidence of perforation or MI. The device opens against the plaque and the vessel lumen interiorly. In refractory in-stent CTO, it has a huge role. As the device passes through the occlusion stent helps in controlling the device [44].

Optical coherence reflectometry (OCR) and radiofrequency (RF)

A microcatheter in which a tissue-selective imagining system is incorporated is used as OCR. This technology transmits near-infrared rays from optical fiber which is incorporated 0.014'' guidewire. The back-scattered light can identify the differentiation of normal walls and diseased plaque. The operator is wound by a visible and audible signal and one can redirect the wire inside the vessel structure and dissection or perforation can be avoided.

Using laser and electrical impedance, two other intravascular imaging techniques are also proposed of which: I) the laser approach includes tissue differentiation by contrasting the optical fluorescent attributes of the energized tissues with healthy and plagued tissue, and ii) the electrical impedance approach uses the distinction in impedance of electricity between the abnormal plaque and the vessel [45].

Lasers

The clinical lasers cuts and dissolves tissue type by using a high-energy beam of light. In this way, it helps in crossing and debulking. There are photochemical and photomechanical reactions due to the absorption of the laser beam into the biological tissues. It results in the development of shock waves which can vaporize and fragment [46].

EMERGING CONCEPTS AND INNOVATIONS

Newer material and tools

Fighter (Boston Scientific, Natik, MA, USA) is a new generation

Table 7: Prevention and bail out of complications of CTO PCI.

Complications	Prevention	Bail out
Aortocoronary dissection	• Avoid aggressive guide catheter intubation • Use of guide catheter with side holes	• Stenting of ostium • Emergency surgery in case of AR, cardiac tamponade
Coronary perforation	• Verification of guidewire position before microcatheter advancement	• Coil and fat embolization for distal vessel & CC perforation • Covered stent/prolonged balloon inflation for large perforation • ±Pericardiocentesis
CC perforation/rupture	• Careful selection of CC • Preference for septals	• Prolonged balloon inflation • Heparin neutralization • Embolization if necessary • Immediate hemostasis in epicardial CC perforation, careful observation in case of septal (fenestration or embolization if chest pain)
Donor vessel trouble during retrograde technique (thrombus, dissection)	• Retrograde guide position & waveform monitoring • Adequate flushing • ACT (300–350 seconds)	• Stenting of dissection • ±Hemodynamic support • Thrombus aspiration
MI	• Avoidance large SB dissection • ACT (300–350 seconds esp during retrograde technique)	• Low threshold for PCI • ±Hemodynamic support
CIN	• Adequate pre & post PCI hydration • Minimum contrast use	• Support care
Equipment loss or Entrapment	• Proper lesion preparation • Prior to device delivery	• Snares to retrieve • To leave in situ and cover with stent
Radiation skin injury	• Use of X-ray in need only • Radiation reducing x-ray systems	• Support care • Follow-up several weeks after PCI • ±Endovascular treatment

polymer jacketed hydrophilic wire for loose tissue tracking and knuckling. Other newer generation wires i.e. Judo 1 (for antegrade microchannel), Judo 3 (for fibro-calcific lesions), Judo 6 (extra penetration with excellent steerability in tight lesions), Hornet 10 (penetration wire with excellent control), Hornet 14 (highest penetration force in the market) which have smallest tip profile and compound-taper stainless-steel core.

The Plasma Wire™ System is a new bi-polar wire system utilizing plasma-mediated ablation for channel creation to facilitate CTO PCI. It appears to be useful for ablation of the proximal cap, antegrade re-entry, retrograde re-entry with or without calcium ablation. Channels through the CTOs were successfully created within a few seconds by applying radiofrequency energy [47].

NovaCross (NitiLoop, Herzliya, Israel) is a novel microcatheter with an extendable segment that provides forward support and improved penetration of the proximal fibrous cap using any CTO guidewire. The CrossLockTM (Radius Medical, Hudson, MA, USA) device, which is a variant of the OTW anchoring balloon with an OTW system with a distal elastomeric balloon that can be inflated from 1 mm to 8 mm in diameter, however, use of these types of support catheters is no longer advantageous [48].The SwiftNINJATM (Merit Medical, West Jordan, UT, USA) steerable coronary microcatheter is another device that has a controlled adaptable tip and is controlled utilizing a dial in the handgrip. This gadget empowers the client to change the point of the microcatheter tip physically and can help in navigating tortuous anatomy. FineDuo (Terumo, Japan) is a dual lumen micro-catheter. It has a low profile and has a multi-functional ability. In tortuous and angulated anatomy, it provides support and improves accessibility. It improves the guidewire manipulation as it has a double lumen which also helps in avoiding tangling in guidewires. There is an OTW lumen exit port which helps in creating a greater rotation range.

The TrapLiner® (Teleflex, Wayne, PA 19087, USA) is a rapid exchange guide extension catheter that combines the ability to provide backup support with the ability to trap a guidewire with a balloon against the inner wall of a guide catheter. It makes ADR possible and easier even through a 6F guide catheter and can also be used in retrograde to improve support and ease the exchange of microcatheters.

Forward looking-intravascular ultrasound (FL-IVUS)

The fundamental development with FL-IVUS **(Figure 7)** [49] is that it can image anterogradely distal catheter tip hence the need for side branch IVUS navigation is obviating. This IVUS gives us information about the proximal CTO cap. Moreover, it can be combined with the 3D reconstruction technique. It can also help in characterizing the lesions distal to the occlusion. The guidewire position can be maintained in the true lumen by keeping the catheter centered [33, 50].

Magnetic navigation system (MNS)

Another clever imaging framework that might be useful in the treatment in case CTOs is the MNS, Niobe (Stereotaxis, St. Louis, Missouri). The framework uses two extremely durable magnets mounted on articulating or turning arms that are encased inside a fixed lodging, with one magnet on one or the other side of the patient table. These magnets produce attractive route handles that are under 10% of the strength of fields normally created by MRI hardware, and in this way, require altogether less safeguarding, and cause essentially less obstruction, than MRI gear. The NIOBE magnets exactly steer the functioning tip of the devoted guidewires, utilizing the 3D recreation of the coronary artery.

Coregistration of the 3D guide with MSCT information might help the administrator in exploring the wire through tortuosity inside the impeded section, keeping it coaxially along the vessel all through its course. If it tends to be successfully combined with an RF source at the wire tip, such a framework might advance into a remote-controlled, semi-robotized technique.

Drug-eluting balloons for CTO PCI

Medication eluting balloons have been the objective of examination taking a gander at bringing down the chances of in-stent restenosis. They likewise require a more limited duration of antiplatelet treatment.

Collagen and collagenase

In CTO lesions a collagen-rich matrix forms a barrier at the proximal cap. There is an enzyme that dissolves this collagen called Collagenase. It may enhance the ability to cross the lesions. In animal studies, the local delivery of this enzyme has resulted in a different effect on the matrix of plaque compared to normal vessel walls [51, 52].

Soundbite

Recently a device has been developed which is called the Soundbite [53] which uses shock waves so that crossing of the proximal cap can be facilitated. A micro hammer is used to disseminate the shockwaves to its tip. There was recently an ex vivo trail in an amputated leg with this system.

Orbital atherectomy

In calcified CTO Orbital atherectomy can help. It can facilitate plaque removal and can cause softening of the plaque and can help in dilatation, it can be especially useful in tough CTOs where device crossing is not possible [54].

Modifications of reverse CART

During the reverse CART procedure, there may be compression or collapse of the subintimal space after antegrade balloon inflation and deflation. This makes the entry of retrograde wire into true lumen difficult even when common space exists. The Iteration of reverse CART can be done by using IVUS. The mother and catheter Guidezilla have been used in the capture technique or a stent reverse CART technique can be applied. The concept of contemporary reverse CART has been introduced to facilitate the procedure with the innovation of Gaia (Asahi Intec, Japan) series of guidewires using smaller diameter balloons [35, 55].

Conclusion

In conclusion, huge progress in techniques and technologies make CTO-PCI an essential option for any modern coronary catheter laboratory. CTOs have commonly encountered lesions with a low success rate of PCI due to technically challenging procedures. A deep understanding and extended use of CTO techniques and materials is a quantum leap in interventional cardiology and can be considered as the most modern current method. With the understanding of updated interventional techniques and the development of dedicated tools, the success rate of CTO PCI has significantly improved over the last few years. Despite the high success rate of various crossing devices in CTO lesions, there is yet a requirement for an invention and optimal crossing gadgets due to various limitations such as crossing heavily calcified occlusion, crossing of smaller and tortuous arteries due to limited directional flow, limited trackability and increases the risk of side branch entry and dissection. Thus, further technical up gradation is required to work on the strategies and making them more secure and successful.

Author Contributions

The lead author of the review article is Dr Rohit Mody. Dr Debabrata Dash, Dr Bhavya Mody had equal and substantial contributions in the formation of this review article. They were involved in conceptualization, data curation, formal analysis, resources, software, validation, visualization, writing – original draft, Writing – review & editing.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Ethical approval was not required since it is an accepted procedure.

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