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Review Article

Conquering Retrograde Coronary Chronic Total Occlusion Intervention: Review of recent Developments

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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. In this article, we describe various tips and tricks which can help in increasing the success rate of retrograde CTO PCI. Various complications, their preventions, and treatments, if they occur, have been described.

Introduction

It has been known that successful revascularization of chronic total occlusion (CTO) through percutaneous coronary intervention (PCI) renders substantial clinical benefits [1, 2]. Despite major advancements in technology over the past few decades, successful CTO PCI remains a difficult task in routine clinical practice and truly *represents* the "last frontier" of PCI [3]. Traditionally, with the antegrade approach, the procedure success rates have been low, typically 60–70% [4]. As a matter of interest, the retrograde approach via collateral channels overcomes the limitations of the traditional antegrade approach [5-7]. Nevertheless, the implementation of this approach is limited only to 15–30% of CTO PCI [8, 9].

Historical Outline

In 1990, Kahn and his coworker Hartzler [10] put forward the technique of retrograde CTO PCI, wherein a saphenous vein graft was utilized to perform PCI of the occluded left anterior descending artery. Six years later, Silvestri *et al.* [11] proposed retrograde revascularization of the left main artery using a saphenous vein graft. The technique of retrograde crossing via septal collateral channels was first described in 2006 by Surmely *et al.* [12] and his colleagues. Later on, the retrograde approach emerged to involve septal branch [13] and epicardial [14] collateral channels and aortocoronary bypass grafts [15]. Dash [16] postulated significant iteration and standardization of reverse controlled antegrade and retrograde tracking (rCART) to aid the implementation of the technique more effectively and safely, thus the CTO PCI success rate has raised up to 95% [17]. Retrograde CTO crossing of the distal CTO cap may be easier than the proximal cap due to being softer, often tapered, and less ambiguous. Moreover, it is not dependent upon the exact visualisation of the origin of the CTO.

Indications

The antegrade route is usually considered the preliminary

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approach on account of successful outcomes, and even if it fails, antegrade preparation will likely be needed to complete the retrograde crossing. Before all the CTO procedures, two pivotal aspects should be taken into consideration: a) Evaluation of the patient's eligibility and lesion for retrograde approach, and b) Be prepared to change the strategy. The most prevalent indication for the retrograde approach is the unsuccessful antegrade approach. Besides, an upfront (primary) retrograde approach may be necessary for selected lesions that are outlined in (Table 1) [18-24]. Dedicated equipment along with personal skills and appropriate collateral channels are the prerequisite to performing retrograde CTO PCI in the lesion subsets.

Angiographic evaluation of occluded vessel

Areas of focus in an angiogram of CTO lesion are depicted in (Table 2). Excellent pre-procedural diagnostic angiography is of paramount importance in CTO PCI. Dual injections from both left and right coronary ostia with complete filling of the distal collateral bed from all feeding sources need to be considered for optimal angiographic planning. Moreover, attempts should be made to illustrate the following: a) proximal cap morphology (blunt or tapered), b) the occlusion length, c) the quality of occluded vessel (i.e.,

tortuous, calcified, diffusely diseased, small), or d) the source and direction of flow of distal vasculature, if any, and the course of collateral channels supply and target vasculature beyond the occlusion. It is preferable to use a low magnification of 13 inches instead of 8. After collateral channel filling of the distal vessel, the donor vessel should be injected initially following the injection of the CTO vessel. Cine acquisitions must be long enough to allow for collateral channels and distal vessel filling, recognition of the distal cap, and be free of panning to aid the identification of collateral channels. Before each acquisition, the entire area subtended by the vessel of interest must be visible. Minimum two orthogonal images with key anatomic features should be obtained.

Table 1: Indications of retrograde recanalization of chronic total occlusion [18-24].

Failed antegrade approach
Flush aorto-ostial occlusion
CTO with proximal cap ambiguity
CTO with bifurcation at the distal cap
CTO with severe proximal tortuosity or calcification
CTO with diffuse disease or poorly visible distal vessel
CTO vessels that are difficult to engage, such as anomalous coronary arteries
† Key = CTO, Chronic total occlusion.

Table 2: Areas of focus in an angiogram of chronic total occlusion lesion [29].

Proximal cap: calcification, bifurcation, stump, tapered or blunt type
CTO body: occlusion length, microchannel, contrast pooling, calcification
Distal cap: calcification, tapered, diffuse plaque, bifurcation, stump
Distal segment: diameter, calcification, serial occlusions, diffuse disease
Extraluminal pathology (subintimal tract, calcification)
Collateral channels: entry, body and exit from the main vessel
† Key = CTO, Chronic total occlusion.

Selection of collateral channels for retrograde chronic total occlusion percutaneous coronary intervention

The retrograde approach can be performed through bypass grafts, septal, and epicardial collateral channels. Every collateral channel should be evaluated for size (which is usually estimated using the Werner classification), tortuosity, entry and exit angles, bifurcations, and distance between the collateral channels exit and the distal cap [5, 25]. Septal collateral channels are the safest and should be used as a default alternative whenever feasible. Severe septal tortuosity rather than size hampers navigation of the wire. In comparison to the epicardial route, several advantages are associated with the septal collateral channels route, which includes a shorter route to the recipient's vessel, less tortuous, and an injury to septal collateral channels is usually harmless. Besides, The septal collateral channels route can also be dilated using a small balloon (1.2–1.5mm), at very low pressure (2–4 atm) for smooth navigation of the catheter [26, 27].

Larger, non–tortuous collateral channels are most likely to be crossed easily, despite faintly visible or invisible (Werner class 0) septal collateral channels can frequently be crossed, particularly with "surfing" with the guidewire [26]. Collateral channels should be chosen following adequate vasodilation and using a proper angiographic projection (generally anteroposterior, or right anterior oblique with cranial angulation, for septal collateral channels that elongates the collateral channels at the entry and exit site). Not only the donor but also recipient vessel angles should be smaller than 90º, as well as entry of the collateral channels into the recipient artery should not be in proximity to the distal cap. It has been proposed that septal collateral channels (50–65%) are the most frequently used, followed by epicardial (25–38%) and bypass grafts (5–13%) [23]. Because of the large size, less tortuosity, and lack of side branches, saphenous vein grafts offer an excellent conduit for crossing. Owing to a lower success rate with a higher risk of perforation and tamponade, epicardial collateral channels are least preferred. Internal mammary artery grafts should be handled with caution because of the risks of vessel injury and hemodynamic compromise. Great care requires to be maintained while using internal mammary artery grafts to avoid hemodynamic compromise or damage to the vessel [28].

Reaching the Collateral Channel

The selected collateral channels are first wired proximally with a workhorse wire, shaped to navigate the donor vessel and to access the collateral channels. The retrograde guide catheter should ideally be short (*e.g.*, 90cm), especially while the distance between the ostium of the donor vessel and the ostium of the CTO vessel via the collateral channels is long. A workhorse guidewire advancement through a long (150cm or 155cm) microcatheter is mostly used for reaching the collateral channels. Task-specific guidewires are summarized in (Table 3) [29]. For entering septal collateral channels, a double bend on the guidewire or an angled tip microcatheter may be needed. When the guidewire enters the collateral channels, it is followed by a microcatheter. Microcatheters are selected based on the size and morphology of the collateral channels. Microcatheters used in CTO PCI are outlined in (Table 4).

Collateral Channel Navigation

Navigation of the guidewire starts with workhorse wire engagement of the target collateral channels with meticulously dedicated microcatheter advancement to its origin. The workhorse guidewire is then replaced with a non–tapered, low tip load, lubricious collateral channels crossing the

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Table 3: Compilation of guidewires according to specific task [29].

Task	Guidewire	Manufacturer	Coating	Tip morphology	Tip load (g)	Tip diameter (inches)	Usable length (cm)
Access (workhorse)	SION	Asahi	Hydrophilic, non-jacketed over spring coil and tip	Non tapered	0.7	0.014	180/300
	SION Blue	Asahi	Hydrophilic, non-jacketed over spring coil (18.5cm), hydrophobic tip	Non tapered	0.5	0.014	180/300
	Pilot 50	Abbott	Hydrophilic polymer jacket	Non tapered	1.5	0.014	190/300
	Whisper MS	Abbott	Hydrophilic polymer jacket	Non-tapered	1.0	0.014	180/300c
	BMW Universal II	Abbott	Hydrophilic coating	Non tapered with shaping ribbon	0.7	0.014	190/300
	Samurai	Boston Scientific	Hydrophilic, non-jacketed, reduced coating on distal 1cm	Non tapered	0.5	0.014	190/300
Microchannel crossing	Fielder XT	Asahi	Hydrophilic, full polymer jacket	Tapered	0.8	0.009 (0.014) *	190/300
	Fielder XT-A	Asahi	Hydrophilic, polymer jacket	Tapered	1.0	0.009 (0.014) *	180/300
	Pilot 50	Abbott	Hydrophilic polymer jacket	Non tapered	1.5	0.014	190/300
	Fighter	Boston Scientific	Hydrophilic, clear polymer jacket over spring coil & tip	Tapered	1.5	0.009 (0.014) *	190/300
Collateral crossing	Fielder FC	Asahi	Hydrophilic full polymer jacket	Non tapered	0.8	0.014	180/300
	Fielder XT-A	Asahi	Hydrophilic, polymer jacket	Tapered	1.0	0.009 (0.014) *	180/300
	Fielder XT-R	Asahi	Hydrophilic, polymer jacket	Tapered	0.6	0.009 (0.014) *	180/300
	Suoh	Asahi	Hydrophilic, non-jacketed over spring & coil tip	Non tapered	0.3	0.014	180/300
	SION Black	Asahi	Hydrophilic, full polymer jacket on distal 20cm	Non tapered	0.8	0.014	190/300
	Pilot 50	Abbott	Hydrophilic polymer jacket	Non tapered	1.5	0.014	190/300
	SION	Asahi	Hydrophilic, non-jacketed over spring coil and tip	Non tapered	0.7	0.014	180/300
	Samurai RC	Boston Scientific	Hydrophilic coating on distal 24cm	Non tapered	1.2	0.014	190/300
Knuckling	Fielder XT	Asahi	Hydrophilic, full polymer jacketed	Tapered	0.8	0.009 (0.014) *	190/300
	Fielder XT-A	Asahi	Hydrophilic, polymer jacketed	Tapered	1.0	0.009 (0.014) *	180/300
	Fighter	Boston Scientific	Hydrophilic, clear polymer jacket over spring coil & tip	Tapered	1.5	0.009 (0.014) *	190/300
	Pilot 150	Abbott	Hydrophilic, polymer jacketed	Non tapered	2.7	0.014	190/300
	Pilot 200	Abbott	Hydrophilic, polymer jacketed	Non tapered	4.1	0.014	190/300
Directed navigation	Fighter	Boston Scientific	Hydrophilic, clear polymer jacket over spring coil & tip	Tapered	1.5	0.009 (0.014) *	190/300
	Hornet	Boston Scientific	Hydrophilic coating over spring coil & tip	Tapered	1.0	0.008 (0.014) *	190/300
	Gaia First	Asahi	Hydrophilic, non-jacketed, tip hydrophilic	Tapered	1.5	0.010 (0.014) *	190
	Gaia Second	Asahi	Hydrophilic, non-jacketed, tip hydrophilic	Tapered	3.5	0.011 (0.014) *	190
	Gaia Third	Asahi	Hydrophilic, non-jacketed, tip hydrophilic	Tapered	4.5	0.011 (0.014) *	190
	Miracle 3	Asahi	Hydrophilic (silicone)	Non tapered	3.0	0.014	180
	Miracle 6	Asahi	Hydrophilic (silicone)	Non tapered	6.0	0.014	180
Directed penetration	Gaia Third	Asahi	Hydrophilic, non-jacketed, tip hydrophilic	Tapered	4.5	0.011 (0.014) *	190
	Miracle 6	Asahi	Hydrophilic (silicone)	Non tapered	6.0	0.014	180
	Miracle 12	Asahi	Hydrophilic (silicone)	Non tapered	12.0	0.014	180
	Conquest	Asahi	Hydrophobic (silicone)	Tapered	9.0	0.009 (0.014) * (20 cm) #	180
	Conquest Pro	Asahi	Hydrophilic non-jacketed over spring coil, hydrophobic tip & shaft	Tapered	9.0	0.009 (0.014) * (20 cm) #	180
	Conquest Pro 12	Asahi	Hydrophilic non-jacketed over spring coil, hydrophobic tip & shaft	Tapered	12.0	0.009 (0.014) *(20 cm) #	180
	Hornet 10	Boston Scientific	Hydrophilic over spring coil & tip	Tapered	10.0	0.008 (0.014) *	190/300
	Hornet 14	Boston Scientific	Hydrophilic over spring coil & tip	Tapered	14.0	0.008 (0.014) *	190/300
	Astato XS 20	Asahi	Hydrophilic non-jacketed over spring coil, hydrophobic tip & shaft	Tapered	20.0	0.009 (0.014) * (17 cm) #	180

Fenestration re-entry	Conquest Pro	Asahi	Hydrophilic non-jacketed over spring coil, hydrophobic tip & shaft	Tapered	12.0	0.009 (0.014) (20 cm) #	180
	Hornet 14	Boston Scientific Asahi	Hydrophilic over spring coil & tip	Tapered	14.0	0.008 (0.014)	190/300
	Astato XS 20	Boston Scientific Asahi	Hydrophilic non-jacketed over spring coil, hydrophobic tip & shaft	Tapered	20.0	0.009 (0.014) (17cm) #	180
	Stingray™ Wire			Tapered	–	–	–
Externalization	RG 3	Asahi	Hydrophilic over spring coil & tip	Non tapered	–	0.010	–
	R 350	Vascular Solutions	Hydrophilic over spring coil & tip	Non tapered	–	0.013, 5mm platinum coil	350

† * Shaft diameter; # spring coil.

Table 4: Microcatheters utilized in chronic total occlusion percutaneous coronary intervention [29].

Manufacturer	Catheter	Shaft Length (cm) and distal and proximal outer diameter (F)	Properties	Recommendations
Terumo	FineCross®	150/1.8/2.6	Stainless steel shaft, hydrophilic coating	Very low profile, good deliverability with limited push ability or ability to spin. Good for small and straight collateral channel
Asahi	Corsair®	135/150/2.6/2.8	Double layer braided stainless steel, kink resistant flexible tip (composed of tungsten powder)	Low profile, easily, deliverable, pushable. Used for traversing and dilating collateral channel. Provides good wire backup and spinning
Vascular Solutions	Turnpike®	135/150/2.6/3.1	Hybrid of braid & a double layer coil encapsulated between 2 polymer layers (5 layers total)	Workhorse catheter that performs well in most chronic total occlusion cases
	Turnpike® Spiral	135/150/2.6/3.1	Similar construction	Spiral enhances trackability
	Turnpike® Gold	135/3.2/3.1	Similar construction	Tip on tip Gold enhances forward movement
	Turnpike® PB	135/15/2.2/2.9	Similar construction with thinner tip braiding for lowering profile	Excellent for very tortuous or epicardial collateral channel
Roxwood Medical	Micro14	155/1.9/2.5	Variable pitch braided shaft, torquable	Very low profile for the fine and tortuous collateral channel. Micro 14es has an extra-supportive tip profile for enhanced push ability
Asahi	Caravel®	135/1.9/2.6	ACT-one core precision braided shaft, hydrophilic coating	Low crossing profile, excellent for tortuous collateral channel
Asahi	Tornus® 2 sizes	135/Tappered/2.1 or 135/2.6/3.0	Stainless steel braided catheter	Available in 2.1 & 2F. Used as support and collateral channel dilator

guidewire, with an extremely small curve (<1mm, 45° angle). Once the microcatheter reaches in septal, either of two techniques can be employed for the subsequent crossing: a) “surfing” or b) “contrast guided”.

In the surfing technique, a guidewire is advanced rapidly with simultaneous rotation, until it either buckles or slips into the distal target vessel. If the guidewire buckles, it is promptly retracted back and redirected to find alternative collateral channels, if resistance is encountered. Even though premature ventricular contractions may be faced rarely, their frequent or runs during crossing the collateral channels imply suboptimal tip position, myocardial irritability, and herald collateral channels injury. While surfing is successful in most cases, forceful guidewire navigation should be avoided to prevent perforation and to make the septal collateral channels unusable [28].

In the contrast–guided technique, a 3–cc Luer–Lock syringe with 100% contrast is linked to the microcatheter hub and blood is aspirated, secondary to contrast injection under cine angiography outlining the collateral channels course. Once collateral channels are determined to be suitable for usage, the microcatheter is advanced after flushing. After visualization of a clear connection, the guidewire is advanced toward the collateral channels. Epicardial collateral channel crossing should always be promoted by contrast guidance. Surfing is not recommended due to the increased risk of perforation. The guidewire should be rotated, not pushed in tortuous segments. The crossing may be easier during diastole. Divergence from the observed path may result in perforation. Both arterial and saphenous venous grafts pose a leading challenge of steering the guidewire via acute angulation at the distal anastomosis. The most frequently used guidewires for collateral channel crossing are the Fielder XT-R, SION, SION Black, and Suoh 03 (Asahi Intecc, Aichi, Japan).

Crossing the Collateral Channel with the Microcatheter

Following apparent guidewire crossing, retrograde vessel angiography should be carried out before advancing the microcatheter, to validate the entrance of the guidewire into the distal true lumen, the microcatheter is carefully negotiated through the collateral channels to the distal guidewire tip after confirmation of the target zone, thus establishing the retrograde base of operation. According to the construction of the microcatheter, it can be advanced by either pushing or rotating. Whenever the microcatheter fails to advance, several approaches like increasing support (deep throating, side branch anchors, or a guide catheter extension), or using a different or shorter microcatheter can be utilized to aid the delivery. Septal collateral channels can be dilated with a small size balloon (1.0 mm x 1.5 mm) at low pressure of 2 atm to 4 atm, whereas epicardial collaterals should never be dilated, for risk of perforation. Alternatively, retrograde guidewire crossing can be endeavored without advancing the retrograde microcatheter (particularly for short occlusions), or the retrograde guidewire may act as a marker that aids the crossing of antegrade wire. If all approaches fail, retrograde crossing may have been attempted via other collateral channels.

Crossing the Chronic Total Occlusion

Once the successful navigation of collateral channels and advancement of retrograde microcatheter to the distal cap has been performed, there are many alternatives for crossing the lesion.

Retrograde true-to-true crossing or intraplaque crossing

The fastest means is to pass a retrograde guidewire directly into the proximal true lumen, a procedure referred to as intraplaque crossing. This can be ventured in short occlusions (less than 20mm), particularly when the distal cap is tapered, however, it is successful in only below 30% of cases. A directed penetration or directed navigation wire is employed to breach the distal cap and advance via the occlusion. Once the true lumen position of the wire is confirmed in the proximal vessel, both the wire and retrograde microcatheter are moved forward into the antegrade guiding catheter. At this stage, this retrograde guidewire is exchanged for the wire to be externalized which is retracted from the haemostatic valve of the antegrade guide. To aid the crossing of the occlusion using the microcatheter, the retrograde guidewire into the aorta or the antegrade guide can be anchored by inflating a small balloon (2.5mm) within the antegrade guide catheter. Manoeuvres like inflating a retrograde balloon for further support (coaxial anchor) and using stiffer, tapered tip, and/or hydrophilic wires might increase the likelihood of retrograde guidewire crossing. Antegrade intravascular ultrasound (IVUS) can provide valuable information for guiding a retrograde guidewire into the proximal true lumen [30].

Kissing wire technique

Whilst the retrograde wire is utilized as a guide or marker for manipulations with the antegrade one, the kissing wire technique comprises navigation of antegrade guidewire into the true lumen. To check the position of the retrograde guidewire and to confirm that it meets the antegrade guidewire at a single point, two different angiographic projections should be obtained. If the two guidewires fail to overlap accurately, one of them may have reached a subintimal space. Antegrade wiring should be started from a location adjacent to the retrograde wire thus the tips of the two guidewires can meet at a single point [29].

Retrograde dissection and re-entry

When true lumen recanalization is failed, dissection and re-entry techniques like the standard controlled antegrade and retrograde subintimal tracking (CART) technique or the reverse CART (rCART) are attempted. As a result, there are four possible scenarios for both antegrade and retrograde wire that needs diverse strategies (Table 5) [31]. The most favourable scenario occurs while both guidewires from antegrade and retrograde directions are subintimal. Whilst antegrade space is enlarged by inflating a balloon, the two sides are usually connected. This is an extensively used retrograde dissection re-entry technique known as rCART.

Table 5: Successful retrograde guidewire crossing by connecting antegrade and retrograde channels [31].

Guidewire position	Preferred strategy
Intimal position of both antegrade and retrograde guidewire	Kissing wire technique Antegrade balloon dilatation Antegrade or retrograde subintimal tracking
Subintimal (most favorable) position of both antegrade and retrograde guidewire	rCART
Antegrade guidewire intimal and retrograde subintimal	Aggressive antegrade balloon dilatation for CTO body disruption and opening of a passage
Antegrade guidewire subintimal and retrograde intimal	rCART CART as the second line, with caution

† CART, Controlled antegrade and retrograde subintimal tracking; rCART; Reverse.
CART.

When the antegrade wire is intimal and retrograde wire subintimal, the least favorable situation occurs. The optimal solution for this problem is to create a space by aggressive antegrade dilatation of the CTO body, for successful navigation of retrograde wire. When both the antegrade and retrograde wire is intimal, the kissing wire technique is used, in which either wire is advanced anterogradely or retrogradely using the opposing wire as a landmark, towards the opposite channel. The next approach for retrograde navigation of wire is antegrade balloon dilatation. If this fails, the author intentionally sheds light on antegrade or retrograde subintimal tracking. When both the antegrade and retrograde wires are intimal, the kissing wire technique is used to advance one wire antegrade Ly or retrogradely towards the opposite channel, using the opposing wire as a landmark. The next method for retrograde wire navigation is antegrade balloon dilatation. If this fails, the author engages in antegrade or retrograde subintimal tracking on purpose. A CART procedure has been recommended when the antegrade wire is subintimal and retrograde wire intimal.

Standard controlled antegrade and retrograde subintimal tracking (cart) technique

In the case of an inadvertent subintimal guidewire position, the standard CART (Figure 1) [16] comprises the creation of a connection between the subintimal space and the distal true lumen, through the retrograde balloon dilation While the balloon is being deflated, the antegrade wire is negotiated further along with the deflated balloon into the distal true lumen [9]. The antegrade wire is advanced further along with the deflated balloon into the distal true lumen. The main benefit of this technique is to minimize the length of the subintimal tracking. With the introduction of dedicated microcatheters, the traditional CART technique was superseded by rCART. Despite this, the conventional CART technique is still used in some cases of ostial CTO, heavily calcified CTO, and when the retrograde equipment is not long enough to reach antegrade guiding catheter (with long epicardial collateral channels and enlarged heart) [29, 32].

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Reverse controlled antegrade and retrograde subintimal tracking (rCART)

The most extensively used retrograde dissection re-entry technique is rCART. A balloon is inflated over the antegrade guidewire following the advancement of the retrograde guidewire into the space created by the balloon. Larger antegrade balloons are utilized in case of failure. The author suggests some key iterations that would aid its adoption easier with greater efficacy and safety [16].

Traditional reverse controlled antegrade and retrograde subintimal tracking (rCART)

The first step of conventional rCART is a longitudinal overlap of the antegrade and retrograde guidewires (Figure 2) [16]. The conventional wiring in both antegrade and re- retrograde fashion is easier to make an overlap with the unambiguous course of the CTO segment. Conventional wiring is not only cumbersome but also carries an inherently increased risk of vessel perforation with CTO vessel course ambiguity, severe tortuosity, or heavy calcification.

This needs more efficient and safer knuckle wiring with low (Fielder XTA, Asahi Intecc) to intermediate penetration force polymer–jacketed guidewires (Gaia Second/Third, Asahi Intecc; Pilot 200, Abbott Vascular, Santa Clara, CA, USA). To create retrograde base of operation, an appropriate guidewire with or without a knuckle (an umbrella-type bend or loop) is advanced through the microcatheter via the CTO body, within the subintimal space. An antegrade base of operation is created by placing a microcatheter at the proximal cap, using a low to intermediate penetration force guidewire to breach the proximal cap to enter subintimal space. Next, an appropriately sized antegrade balloon is negotiated into the CTO segment to the point of guidewire overlap and inflated forming or enlarging intimal/subintimal dissection and creates a connection among the spaces, referred to as common subintimal space within which both guidewires are positioned [16, 33, 34]. In the conventional rCART technique, a large size antegrade balloon is preferred to maximize the possibility of the formation of common subintimal space. Generally, a low to intermediate penetration force wire is employed as the retrograde guidewire for tracking the formed connection. Nonetheless, in the case of the subintimal position of antegrade guidewire and intimal position of the retrograde wire, a high penetration force guidewire (Gaia Third, Conquest 12, Asahi Intecc; Hornet 14, Boston Scientific, United States), may be required to advance through the intimal plaque into the subintimal space (16, 17).

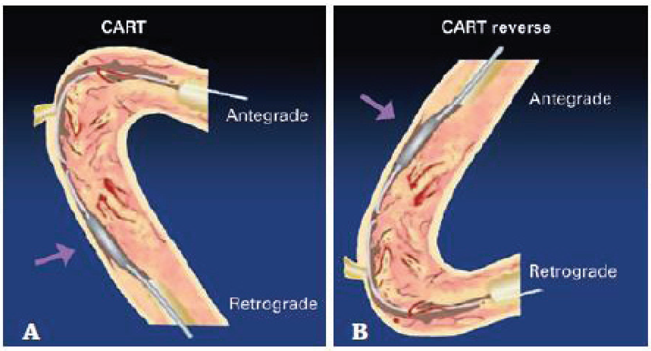

Figure 1: Diagram representation of controlled antegrade and retrograde subintimal tracking (CART) (a) A guidewire is navigated anterogradely via the coronary chronic total occlusion into the distal true lumen via a local subintimal dissection formed by retrograde balloon (pink arrow designates retrograde balloon). (b) A guidewire is navigated retrogradely via a subintimal space formed by the antegrade balloon (pink arrow shows antegrade balloon). (Redrawn from Dash [16]).

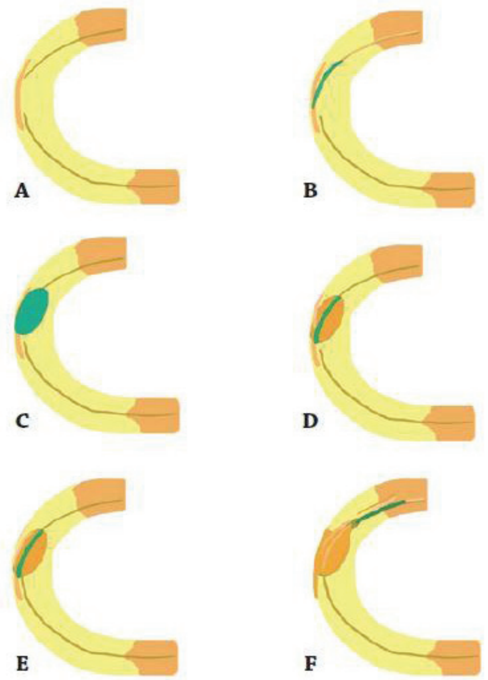

Figure 2: Diagram representation of the conventional reverse controlled antegrade and retrograde tracking (rCART) technique.
(a) A longitudinal overlap of the antegrade and retrograde guidewires in a case of proximal right coronary artery chronic total occlusion.
(b) Delivery of a balloon over the antegrade guidewire to the point of guidewire overlap.
(c) Inflation of the balloon.
(d) The formation of a connection between the spaces (common subintimal space) comprising both the guidewires.
(e) The retrograde guidewire is then advanced into the proximal real lumen.
(f) The subsequent advancement of the retrograde guidewire into the proximal true lumen. (Redrawn from Dash [16]).

Assisted reverse controlled antegrade and retrograde subintimal tracking (rCART)

A guide-extension catheter (Guideliner, Vascular Solutions, Minneapolis, MN, USA; Guidezilla, Boston Scientific) can be deployed in the subintimal space to aid the process (mother-child rCART) while the retrograde guidewire fails to navigate in the antegrade guide even after some tissue ablations. The IVUS assisted rCART, use of larger balloon to gain greater tissue ablation, the use of smaller balloons with re–retrograde navigation of Gaia series of wires (contemporary rCART), deployment of the stent in antegrade subintimal space are other alternative techniques for successful retrograde guidewire navigation (stent-assisted rCART) or movement of the base of operation overlap zone to a distinct location (shifting rCART) [16, 34].

Intravascular ultrasound (IVUS) assisted reverse controlled antegrade and retrograde subintimal tracking (rCART)

The IVUS is an important imaging tool for determining the optimal size of the antegrade balloon. It can counteract the risk of the developmental disruption of medial and common subintimal space recoil. Whenever, the common subintimal space recoils, re-dilation with a larger balloon may be suggested. The IVUS plays a critical role in monitoring the position as well as the movement of the retrograde guidewire in the subintimal space [35, 36]. Under the guidance of IVUS, this retrograde guidewire is better navigated into the proximal true lumen. The presence or absence of connection between the antegrade and retrograde guidewire as well as the position of the antegrade guidewire aids the determination of the further course of therapy.

Stent-facilitated reverse controlled antegrade and retrograde subintimal tracking (rCART)

Stent-facilitated rCART technique entails deployment of a stent from the antegrade true lumen into the subintimal space created by antegrade balloon inflation. It creates a clear open target, aids rapid advancement of retrograde guidewire into the proximal true lumen. Once the retrograde guidewire engages the proximal true lumen, the approach is conventional rCART with externalization of a long wire and PCI through antegrade fashion. Nevertheless, this technique is by nature an irreversible procedure because once the stent is deployed, it cannot be removed. As a consequence, the failure to complete rCART following the implantation of the stent could result in-stent thrombosis on account of proximal thrombus propagation (16, 17).

Mother-child reverse controlled antegrade and retrograde subintimal tracking (rCART)

The mother-child concept is an elegant modification of rCART that includes the use of a guide-extension catheter like Guideliner (Vascular Solutions), Guidezilla (Boston Scientific) into antegradely created subintimal space to aid navigation of retrograde guidewire into the proximal true lumen. Unlike a stent, the guide extension device may be removed or repositioned in case of failure of connection between the antegrade and retrograde true lumen [34, 36].

Contemporary reverse controlled antegrade and retrograde subintimal tracking (rCART)

In the traditional rCART technique, the undesirable intentional intimal/subintimal dilatation with a large balloon may result in distal propagation of the subintimal haematoma and vessel perforation. Several findings signify that the CART and conventional rCART techniques could be correlated with subsequent coronary artery aneurysm formation, and enhanced risk of target vessel revascularization on account of longer stent length [37, 38]. Furthermore, extreme manipulation of the retrograde guidewire, or use of a knuckle wire technique to obtain guidewire overlap, expanding a space throughout the retrograde guidewire, might be an impede for the exact control of direction with the same guidewire. The present rCART technique intends to reduce trauma to the vessel wall, as well as to make the procedure more efficient by precise control of direction by efficient use of deflection mechanisms of the retrograde guidewire (Gaia series).

The basic step of this technique is antegrade preparation; the use of a small antegrade balloon as a target for the retrograde wire and retrograde intentional vessel tracking using a guidewire with high torque control (Figure 3**)** [16, 24]. This technique begins with simultaneous dual contrast injection from the antegrade and retrograde guiding catheters, and then an antegrade guidewire is navigated via the occlusion with the support of a microcatheter to within 5mm to 10mm of the distal cap. To reduce the risk of the development of distal hematoma, the antegrade guidewire should not be advanced beyond the CTO segment. The microcatheter is then exchanged for a small balloon (typically 2.0 mm in diameter) which is advanced towards the tip of the guidewire. Except for an ambiguous proximal cap or uncertainty of collateral channels crossing, antegrade preparation is the first choice as it reduces donor artery risk and ischemic time of the CTO territory and promotes going directly to rCART following retrograde CC crossing.

The retrograde approach is then begun with collateral channels crossing via guidewire supported by microcatheter. A guidewire with good torque control and high penetration efficiency is used to retrograde wiring of the CTO segment (Gaia series). This retrograde guidewire should be navigated without excessive torquing and directed towards the antegrade balloon so the shaft of the antegrade balloon and the retrograde wire is as coaxial as possible at the point of puncture. The retrograde puncture should aim towards the end of the balloon first (end balloon wiring technique) and, if this fails, towards the lateral side of the balloon. Fluoroscopy in two orthogonal projections is advocated to validate the positional relation between the retrograde guidewire and

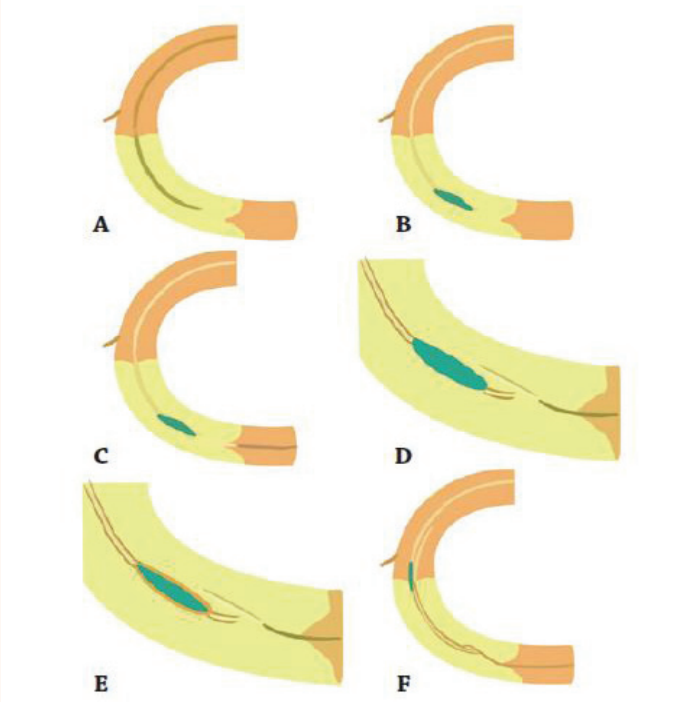

Figure 3: Diagram representation of contemporary reverse controlled antegrade and retrograde tracking (rCART). (A) Antegrade preparation describing navigation of an antegrade guidewire via the occlusion until 5mm to 10mm proximal to the distal cap, with the support of a microcatheter in a case of mid-right coronary artery chronic total occlusion. (b) Advancement of a small balloon to the tip of the antegrade guidewire. (c) Navigation of the retrograde guidewire towards the antegrade balloon after the collateral channel crossing by a guidewire and a microcatheter. (d) The manipulation and the gentle push of the retrograde guidewire towards the inflated antegrade balloon catheter (retrograde wire is lateral to balloon in this figure). (e) The retrograde guidewire is navigated into the space (created by the balloon) following the deflation of the balloon. (f) The retrograde guidewire is navigated into them proximal true lumen with sequential antegrade balloon inflation within the chronic total occlusion segment proximal to the connecting point. (Redrawn from Dash [1]).

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the antegrade balloon. After gently pushing the retrograde guidewire, the antegrade balloon is deflated, allowing the retrograde guidewire to slip into the space produced by the antegrade balloon.

The contemporary rCART is regarded as unsuitable in CTO cases with ambiguous proximal cap, severe tortuosity, and heavy calcification as this technique needs antegrade preparation before embarking on retrograde CTO segment wiring, and the knuckle wire technique cannot be considered to advance the antegrade or retrograde guidewire, because it is more prone to form large spaces around the guidewires results in reduced control of retrograde wire. As well, short segment (<15mm) CTO are inappropriate for the contemporary rCART due to the challenge of embarking on antegrade preparation without propagating the hematoma beyond the distal cap (32). Wire escalation, either antegrade or retrograde, is the best way to deal with short CTO.

Shifting reverse controlled antegrade and retrograde subintimal tracking (rCART)

The shifting rCART technique entails shifting or extension of the intimal/subintimal dissection beyond the CTO segment (Figure 4) [16]. The antegrade balloon dilatation is carried out outside the CTO segment (either proximal or distal) following navigation of retrograde guidewire via the connection formed between the proximal true lumen and the retrograde intimal/subintimal space. When antegrade preparation or retrograde cap penetration is not possible, the shifting rCART technique is beneficial in cases, and where there are no notable side branches adjacent to rCART technique site [16, 33].

Guidewire Externalization

The guidewire and microcatheter are advanced further into the antegrade guide, the retrograde guidewire is removed, and a long, specially designed externalization wire is navigated until it exits from the Y connector of the antegrade guide catheter. RG3 (Asahi Intecc; 330cm long, 0.010”) or R350 (Vascular Solutions; 350cm long, 0.013”) are the two externalisation wires available at present. During advancement or withdrawal of the externalization wire, the collateral channels always require to be guarded by a microcatheter and a torque should be placed on the retrograde end of the wire to prevent excessive pull of the wire from the antegrade side. If the retrograde microcatheter is unable to reach the antegrade guide, the tip in the wire rendezvous method may be used for a bailout [39].

Treating the Chronic total Occlusion

Following disengaging the retrograde guide catheter to reduce unintentional deep seating and dissection of the donor artery, PCI of the CTO is performed over the externalized guidewire. With loop wire condition, the tip of the delivery device meets the inner curve of the coronary artery yielding the strongest support for the devices.

Removal of retrograde gear

After the completion of PCI, the retrograde microcatheter is readvanced into the antegrade guide, unless resistance is encountered. It must shield the collateral channels until the soft wire tip is back in the collateral channels. Both antegrade and retrograde guiding catheters are disengaged from the coronary ostium and drawn back 3 to 4cm into the aorta to prevent ostial dissection, due to externalized wire retraction (antegrade guide is disengaged by pushing the externalized wire and the retrograde guide by fixing the microcatheter using it as rail for guide retraction) [26].

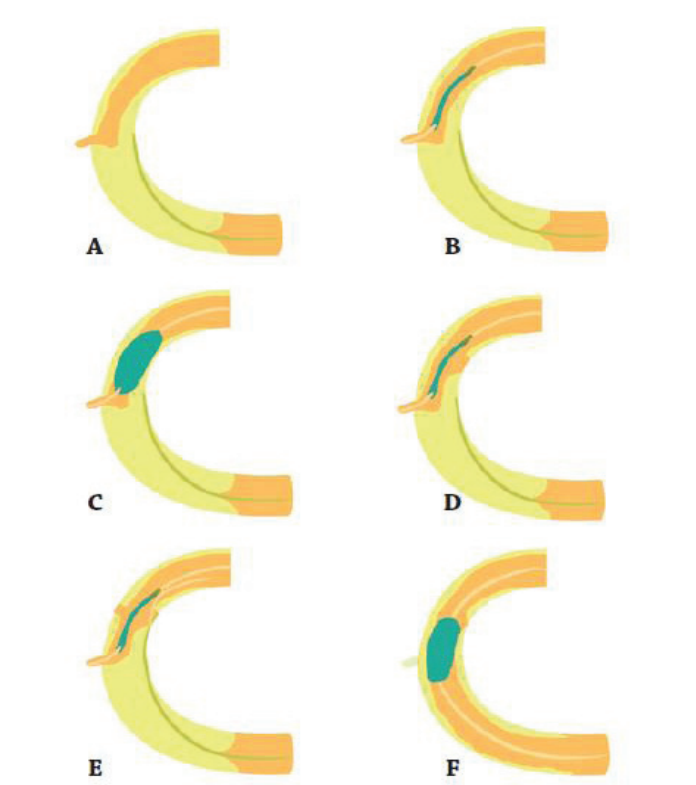

Figure 4: Diagram representation of shifting reverse controlled antegrade and retrograde tracking (rCART). (a) A retrograde guidewire is navigated into the subintimal space in a case of mid-right coronary artery chronic total occlusion with a small side branch around the proximal cap. (b) An antegrade balloon is negotiated to the plan connecting point. (c) The antegrade is inflated in an endeavour to form a medial dissection. (d) A connection between the retrograde subintimal space and the proximal true lumen after balloon deflation is created. (e) A retrograde guidewire is navigated into the proximal true lumen via the created connection. (f) Performance of the guidewire externalization and balloon dilatation. (Redrawn from Dash [1]).

Complications of the Retrograde Approach

In comparison with antegrade-only crossing, the retrograde approach carries a higher risk of complications [40]. In a meta-analysis of over 7,000 patients, the retrograde CTO PCI was found to be longer, related to higher contrast volume and fluoroscopy time, and higher risk of complications like pericardiocentesis, periprocedural myocardial infarction, and contrast-induced nephropathy [41]. Moreover, this study also reported an association of retrograde CTO PCI with worse long-term outcomes, including target lesion revascularization, target vessel revascularization, and myocardial infarction when compared with antegrade over four years. It is prudent to embark upon two complications of the retrograde approach on account of their extreme hazard-collateral channels perforation and donor vessel troubles.

Collateral channels perforation

Septal collateral channels perforations are benign in almost all cases. Nevertheless, on a rare occasion, they can result in septal hematomas, obstructing ventricular filling. On the other hand, epicardial collateral channels perforations can cause cardiac tamponade and need immediate treatment, which usually includes sealing both sides of the perforation with coils, thrombin, or subcutaneous fat, though, absorbable sutures have also been used [42]. Perforations in patients who have previously undergone coronary artery bypass graft surgery are more dangerous as they can progress to loculated hematomas and dry tamponade, which can be difficult to treat [43].

Donor vessel complications

A dreadful complication of retrograde strategy is donor vessel trouble (thrombus, dissection). Guide catheter induced dissection can occur during antegrade equipment delivery over the externalized wire, and, hence, it is mandatory to disengage the retrograde guide during this step [42]. Donor vessel thrombosis can occur during prolonged procedures with equipment in the donor vessel, especially when an artery is a highly predominant artery, with a large, supplied area. This may result in a hemodynamic disaster that cannot be bailed out in all cases. Due to this reason, activated clotting time should be often checked (every 20 to 30 minutes) with a target of >350 seconds. Frequent flushing of the retrograde system with saline is also important. The donor artery should be stented in case of dissection. Aspiration thrombectomy and additional heparin may be needed for donor artery thrombosis.

Conclusion

Due to tremendous progress in techniques and technologies, CTO PCI has become a vital option for any modern coronary cath lab. The retrograde approach has become a fundamental part of the contemporary CTO PCI armamentarium. The rCART is the most used technique and can be used as a primary retrograde approach, or an option to an unsuccessful antegrade approach. The recommended iteration of rCART by the author would encourage the interventional cardiologists to properly adopt wire crossing strategies and aid communication and teaching of the rCART techniques. In brief, the global approach has further modified CTO PCI **(**Figure 5**)** [44]. This strategy for incorporating the integration of skillsets is adaptable and enables a variety of alternative scenarios. Promising evidence from future randomized trials may motivate the interventional cardiologists to further implement this challenging attempt.

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Author Contributions

The lead author of the case report is Dr Rohit Mody. Dr Debabrata Dash, Dr Bhavya Mody had equal and substantial contributions in the formation of this case report. 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.

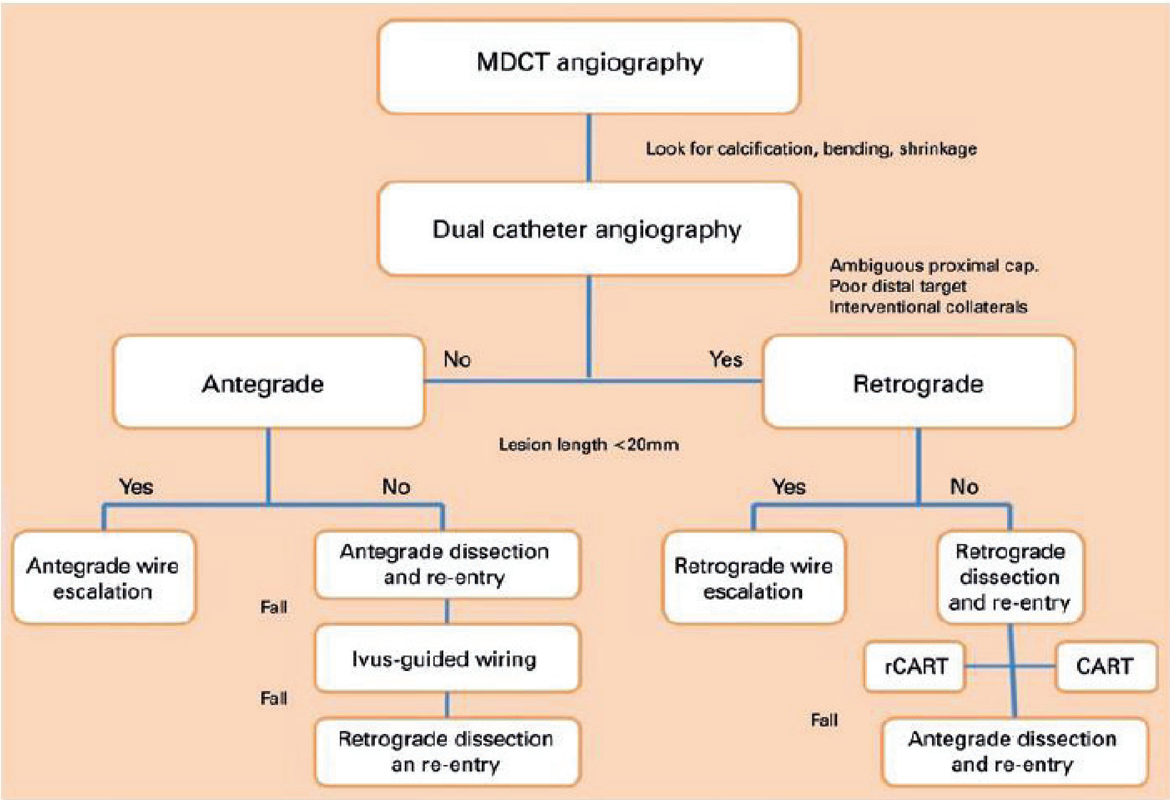

Figure 5: Flowchart illustrating the worldwide approach to chronic total occlusion percutaneous coronary intervention. (Redrawn from Dash [1]).

Consent for Publication

Written consent has been obtained to publish the case report from the guardian. The consent copy is available with the authors and ready to be submitted if required.

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