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Mastering retrograde coronary chronic total occlusion intervention in 2021

Domínio da técnica de intervenção retrógrada para oclusão coronária crônica em 2021

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ABSTRACT – Chronic total occlusion recanalization still represents the last frontier in percutaneous coronary intervention. Retrograde recanalization is one of the most significant amendments of the technique, and has recently become an essential complement to the classical antegrade approach. It has a high success rate with a low complication profile, despite frequent utilization in the most complex patients. Since its initial description, important iterations have occurred and made the technique safer, faster and more successful.

Keywords: Percutaneous coronary intervention; Coronary occlusion; Coronary artery disease

RESUMO – A recanalização das oclusões coronárias crônicas ainda representa a última fronteira na intervenção coronária percutânea. A recanalização retrógrada é uma das alterações mais significativas da técnica e, recentemente, tornou-se um complemento essencial para a abordagem anterógrada clássica. Tem alta taxa de sucesso e baixo perfil de complicações, apesar de sua frequente utilização nos pacientes mais complexos. Desde sua descrição inicial, ocorreram adaptações importantes, que tornaram a técnica mais segura, rápida e bem-sucedida.

Descritores: Intervenção coronária percutânea; Oclusão coronária; Doença da artéria coronariana

INTRODUCTION

Successful percutaneous coronary intervention (PCI) of chronic total occlusion (CTO) can provide significant clinical benefits.^{1,2} Despite remarkable progress over the last decades, successful CTO PCI remains challenging and represents the final frontier of PCI.^{3,4} Historically, success rates have been limited to 60% to 70% with the antegrade approach.⁵ However, retrograde approach using collateral channels (CC) circumvents the limitations of the conventional antegrade technique. With increasing knowledge and expertise, it is expected to be a breakthrough to potentially improve the success rate of complex CTO PCI, when conventional antegrade approach is ineffective, unsafe or inefficient.^{6,7}

HISTORICAL PERSPECTIVE

The technique of retrograde CTO PCI was first reported in 1990, by Kahn and Hartzler, who used a saphenous vein graft to perform PCI of occluded left anterior descending artery.⁸ Silvestri et al. demonstrated retrograde stenting of the left main artery in 1996, using saphenous vein graft.⁹ In 2006, Surmely et al.¹⁰ first reported retrograde crossing via septal CC. The retrograde approach subsequently evolved to include septal¹¹ and epicardial¹² CCs, as well as aortocoronary bypass grafts.¹³ Dash reported important iteration and standardization of reverse controlled antegrade and retrograde tracking (rCART).¹⁴ The adoption of this technique has increased success

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rate of CTO PCI up to 95%.¹⁵ Retrograde penetration of the distal CTO cap may be easier because it is tapered and softer, and less ambiguous as compared to the proximal cap. Also, it is not reliant upon precise visualization of CTO origin.

INDICATIONS

The antegrade route is generally considered as the primary approach because it may be successful, and even if it fails, antegrade preparation will be required for completing the retrograde crossing. Prior to all the CTO procedures, it is essential to assess eligibility of the patient and lesion for a retrograde approach, to be prepared to change the strategy. The most common indication of this method is unsuccessful antegrade approach. An upfront (primary) retrograde approach may be necessary for selected lesions (Table 1), such as flush aorto-ostial CTO, CTO with proximal cap ambiguity, CTO with bifurcation at the distal cap, 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.^{7,15-17} Performing retrograde CTO PCI, in the above-mentioned lesion subsets, warrant dedicated equipment and expertise, as well as appropriate CC.

Table 1. Indications of retrograde recanalization of chronic total occlusion

Failed antegrade approach
Flush aorto-ostial occlusion
Ambiguous proximal cap
CTOs with bifurcation at the distal cap
CTOs with severe proximal tortuosity or calcification
CTOs with diffuse disease or poorly visible distal vessel
CTOs involving anomalous coronary artery

Source: Dash D. Treatment of chronic total occlusion. In: Nussinovitch U, ed. Emerging therapeutic technologies for heart diseases. UK: Elsevier; 2020. p. 587-621. Table 27.8, Indications of retrograde approach; p. 604.⁽¹⁸⁾
CTO: chronic total occlusion.

ANGIOGRAPHIC ASSESSMENT OF OCCLUDED VESSEL

Excellent pre-procedural diagnostic angiography (Table 2)¹⁸ is of critical importance in CTO PCI. Optimal angiographic planning requires dual injection technique, with complete filling of the distal collateral bed from all feeding sources. Efforts should be made to elucidate the following: proximal cap morphology (blunt or tapered); the occlusion length; the quality of occluded vessel (i.e. tortuous, calcified, diffusely diseased, small); the source and direction of flow of distal vasculature, if any, and the course of CC supply and target vasculature beyond

Table 2. Areas of focus in an angiogram of chronic total occlusion lesion

Proximal segment: tortuosity, calcification, bifurcation, anomaly of coronary origin
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 main vessel

Source: Dash D. Treatment of chronic total occlusion. In: Nussinovitch U, ed. Emerging therapeutic technologies for heart diseases. UK: Elsevier; 2020. p. 587-621. Table 27.3, Areas of focus in an angiogram of chronic total occlusion (CTO) lesion; p. 591.⁽¹⁸⁾
CTO: chronic total occlusion.

the occlusion. Use of low magnification (13 in. instead of 8 in.) is desirable. The donor vessel should be injected first, followed by injection of the CTO vessel, after the CC have filled the distal vessel. Cine acquisitions must be long enough to allow for CC and distal vessel filling, identification of the distal cap and be free of panning to facilitate the recognition of CC. The entire area subtended by the vessel of interest must be visible prior to each acquisition. At least two orthogonal images with key anatomic features should be obtained.

SELECTING THE COLLATERAL CHANNEL

The retrograde approach can be performed via bypass grafts, septal, and epicardial CCs. Every CC¹⁹ should be assessed for size (which is usually evaluated using the Werner classification);²⁰ tortuosity; angles of entry to and exit; bifurcations; and distance from the CC exit to the distal cap. Septal CC are the safest and should be the default choice whenever possible. Severe septal tortuosity rather than size impedes the wire navigation. Compared with the epicardial, the septal CC is a shorter route to the recipient vessel, is less tortuous, an injury to septal CC is usually harmless. It can also be dilated using a small balloon (1.20mm to 1.5mm), at very low pressure (2atm to 4atm) for smooth navigation of the catheter.^{6,7}

Larger, non-tortuous CC are easier to cross, although faintly visible or invisible (Werner class 0) septal CC can often be crossed, especially with “surfing” with the guidewire.⁶ Selecting the CC should be performed after sufficient vasodilation and using an appropriate angiographic projection (usually anteroposterior, or right anterior oblique with cranial angulation, for septal CC that elongates the CC at the entry and exit site). Both the donor and recipient vessel angles should be less than 90°, and entry of the CC into the recipient artery should not be close to the distal cap. Septal CC are most commonly used (50% to 65%),

followed by epicardial (25% to 38%) and bypass grafts (5% to 13%).²¹⁻²³ Saphenous vein grafts provide excellent conduit for crossing because of the large size, less tortuosity, and lack of side branches.²⁴ Epicardial CC are the least preferred due to lower success rate and higher risk of perforation and tamponade.²⁵ Internal mammary artery grafts should be used with caution due to risk of vessel injury and hemodynamic compromise.²⁶

REACHING THE COLLATERAL CHANNEL

The selected CC is first wired proximally with a workhorse wire, shaped to navigate the donor vessel and to access the CC. The retrograde guide catheter should ideally be short (e.g., 90cm), especially when the distance between the ostium of the donor vessel and the ostium of the CTO vessel through the CC is long. Reaching the CC is usually achieved using a workhorse guidewire (Table 3), advanced

Table 3. Task specific guidewires

Task	Name	Company	Properties	Coating	Tip load
Access (workhorse)	SION	Asahi	Non-tapered tip 0.014", 180/300cm	Hydrophilic, non-jacketed over spring coil and tip	0.7
	SION Blue	Asahi	Non-tapered tip 0.014", 180/300cm	Hydrophilic, non-jacketed over spring coil (18.5cm), hydrophobic tip	0.5
	Pilot 50	Abbott	Non-tapered tip 0.014", 190/300cm	Hydrophilic polymer jacket	1.5
	Whisper MS	Abbott	Non-tapered tip 0.014", 180/300cm	Hydrophilic polymer jacket	1.0
	BMW Universal II	Abbott	Non-tapered tip with shapping ribbon 0.014", 190/300cm	Hydrophilic coating	0.7
	Samurai	Boston Scientific	Non-tapered tip 0.014", 190/300cm	Hydrophilic, non-jacketed, reduced coating on distal 1cm	0.5
Microchannel crossing	Fielder XT	Asahi	Tapered tip 0.009", shaft 0.014", 190/300cm	Hydrophilic, full polymer jacket	0.8
	Fielder XT-A	Asahi	Tapered tip 0.009", shaft 0.014", 180/300cm	Hydrophilic, polymer jacket	1.0
	Pilot 50	Abbott	Non-tapered tip 0.014", 190/300cm	Hydrophilic polymer jacket	1.5
	Fighter	Boston Scientific	Tapered tip 0.009", shaft 0.014", 190/300cm	Hydrophilic, clear polymer jacket over spring coil & tip	1.5
Collateral crossing	Fielder FC	Asahi	Non-tapered tip 0.014", 180/300cm	Hydrophilic full polymer jacket	0.8
	Fielder XT-A	Asahi	Tapered tip 0.009", shaft 0.014", 180/300cm	Hydrophilic, polymer jacket	1.0
	Fielder XT-R	Asahi	Tapered tip 0.009", shaft 0.014", 180/300cm	Hydrophilic, polymer jacket	0.6
	Suoh	Asahi	Non-tapered tip 0.014", 180/300cm	Hydrophilic, non-jacketed over spring & coil tip	0.3
	SION Black	Asahi	Non-tapered tip 0.014", 190/300cm	Hydrophilic, full polymer jacket on distal 20cm	0.8
	Pilot 50	Abbott	Non-tapered tip 0.014", 190/300cm	Hydrophilic polymer jacket	1.5
	SION	Asahi	Non-tapered tip 0.014", 180/300cm	Hydrophilic, non-jacketed over spring coil and tip	0.7
	Samurai RC	Boston Scientific	Non-tapered tip 0.014", 190/300cm	Hydrophilic coating on distal 24cm	1.2
Knuckling	Fielder XT	Asahi	Tapered tip 0.009", shaft 0.014", 190/300cm	Hydrophilic, full polymer jacketed	0.8
	Fielder XT-A	Asahi	Tapered tip 0.009", shaft 0.014", 180/300cm	Hydrophilic, polymer jacketed	1.0
	Fighter	Boston Scientific	Tapered tip 0.009", shaft 0.014", 190/300cm	Hydrophilic, clear polymer jacket over spring coil & tip	1.5
	Pilot 150	Abbott	Non-tapered tip 0.014", 190 & 300cm	Hydrophilic, polymer jacketed	2.7
	Pilot 200	Abbott	Non-tapered tip 0.014", 190 & 300cm	Hydrophilic, polymer jacketed	4.1
Directed navigation	Fighter	Boston Scientific	Tapered tip 0.009", shaft 0.014", 190/300cm	Hydrophilic, clear polymer jacket over spring coil & tip	1.5
	Hornet	Boston Scientific	Tapered tip 0.008", shaft 0.014", 190/300cm	Hydrophilic coating over spring coil & tip	1.0
	Gaia First	Asahi	Tapered tip 0.010", shaft 0.014", 190cm	Hydrophilic, non-jacketed, tip hydrophilic	1.5
	Gaia Second	Asahi	Tapered tip 0.011", shaft 0.014", 190cm	Hydrophilic, non-jacketed, tip hydrophilic	3.5
	Gaia Third	Asahi	Tapered tip 0.011", shaft 0.014", 190cm	Hydrophilic, non-jacketed, tip hydrophilic	4.5
	Miracle 3	Asahi	Non-tapered tip 0.014", 180cm	Hydrophilic (silicone)	3.0
	Miracle 6	Asahi	Non-tapered tip 0.014", 180cm	Hydrophilic (silicone)	6.0
Directed penetration	Gaia Third	Asahi	Tapered tip 0.011", shaft 0.014", 190cm	Hydrophilic, non-jacketed, tip hydrophilic	4.5
	Miracle 6	Asahi	Non-tapered tip 0.014", 180cm	Hydrophilic (silicone)	6.0
	Miracle 12	Asahi	Non-tapered tip 0.014", 180cm	Hydrophilic (silicone)	12.0
	Conquest	Asahi	Tapered tip 0.009", shaft 0.014", 180cm shaft, spring coil 20cm	Hydrophobic (silicone)	9.0
	Conquest Pro	Asahi	Tapered tip 0.009", shaft 0.014", 180cm shaft, spring coil 20cm	Hydrophilic non-jacketed over spring coil, hydrophobic tip & shaft	9.0
	Conquest Pro 12	Asahi	Tapered tip 0.009", shaft 0.014", 180cm shaft, spring coil 20cm	Hydrophilic non-jacketed over spring coil, hydrophobic tip & shaft	12.0
	Hornet 10	Boston Scientific	Tapered tip 0.008", shaft 0.014", 190/300cm	Hydrophilic over spring coil & tip	10.0
	Hornet 14	Boston Scientific	Tapered tip 0.008", shaft 0.014", 190/300cm	Hydrophilic over spring coil & tip	14.0
	Astato XS 20	Asahi	Tapered tip 0.009", shaft 0.014", 180cm shaft, spring coil 17cm	Hydrophilic non-jacketed over spring coil, hydrophobic tip & shaft	20.0
Fenestration re-entry	Conquest Pro	Asahi	Tapered tip 0.009", shaft 0.014", 180cm shaft, spring coil 20cm	Hydrophilic non-jacketed over spring coil, hydrophobic tip & shaft	12.0
	Hornet 14	Boston Scientific	Tapered tip 0.008", shaft 0.014", 190/300cm	Hydrophilic over spring coil & tip	14.0
	Astato XS 20	Asahi	Tapered tip 0.009", shaft 0.014", 180cm shaft, spring coil 17cm	Hydrophilic non-jacketed over spring coil, hydrophobic tip & shaft	20.0
	Stingray™ Wire				
Externalization	RG 3	Asahi	Non-tapered tip. Tip shaft 0.010"	Hydrophilic over spring coil & tip	
	R 350	Vascular Solutions	Non-tapered tip, 0.013" shaft, 5mm platinum coil, 350cm length	Hydrophilic over spring coil & tip	

Source: Dash D. Treatment of chronic total occlusion. In: Nussinovitch U, ed. Emerging therapeutic technologies for heart diseases. UK: Elsevier; 2020. p. 587-621. Table 27.5, Task specific guidewires; p. 594.^[18]

through a long (150cm or 155cm) microcatheter. A double bend on the guidewire or an angled-tip microcatheter may be required for entering septal CC. A microcatheter

follows once the guidewire enters the CC. The size and morphology of the CC dictate the choice of microcatheters (Table 4).

Table 4. Microcatheters used in chronic total occlusion percutaneous coronary intervention

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

Source: Dash D. Treatment of chronic total occlusion. In: Nussinovitch U, ed. Emerging therapeutic technologies for heart diseases. UK: Elsevier; 2020. p. 587-621. Table 276. Microcatheters used in CTO PCI; p. 596.¹⁸
OD: outer diameter; CC: collateral channel; CTO: chronic total occlusion.

NAVIGATING THE COLLATERAL CHANNEL

The guidewire navigation begins with workhorse wire engagement of the target CC with careful dedicated microcatheter advancement to its origin. The workhorse guidewire is then exchanged with non-tapered, low tip load, lubricious CC crossing guidewire (Table 3), with extremely small curve (<1mm, 45° angle). Once the microcatheter is in septal, either “surfing” or “contrast guided” technique can be employed for subsequent crossing.

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 quickly retracted back and redirected to find an alternative CC, in case of resistance. Although occasional premature ventricular contractions may be encountered, frequent or runs of PVC while crossing the CC indicate suboptimal tip position, myocardial irritability, and herald CC injury.

While surfing is successful in most cases,²⁶ forceful navigation of the guidewire should be avoided, since it may lead to perforation, making the septal CC unusable.

In the contrast-guided technique, a 3-cc Luer-Lock syringe with 100% contrast is connected to the microcatheter hub and blood is aspirated, followed by contrast injection under cineangiography delineating the CC course. Once CC is found to be suitable for use, the microcatheter is advanced after flushing. After visualization of a clear connection, the guidewire is advanced toward the CC. Epicardial CC crossing should always be facilitated by contrast guidance. Surfing is not advisable in view of high 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 lead to perforation. Both arterial and saphenous venous grafts pose a major challenge of steering the guidewire through

acute angulation at the distal anastomosis. The most commonly used guidewires for CCs crossing are the Fielder XT-R, SION, SION Black, and Suoh 03 (Asahi Intecc, Aichi, Japan).

CROSSING THE COLLATERAL CHANNEL WITH THE MICROCATHETER

After apparent guidewire crossing, retrograde vessel angiography should be performed before advancing the microcatheter, to confirm that the guidewire has entered into the distal true lumen. Following confirmation of the target zone, the microcatheter is carefully negotiated through the CC to the distal guidewire tip, thereby establishing the retrograde base of operation (BO).

The microcatheter can be advanced either by push or by rotation, depending on its construction. Various techniques can be used to facilitate delivery if the microcatheter fails to advance, such as increasing support (deep throating, side branch anchor or a guide catheter extension), or using a different or shorter microcatheter.

Septal CC can be dilated at low pressure (2atm to 4atm) using a small (1.0mm to 1.5mm) balloon, whereas epicardial collaterals should never be dilated, for fear of perforation. Alternatively, retrograde guidewire crossing can be attempted without advancing the retrograde microcatheter (especially for short occlusions), or the retrograde guidewire may serve as a marker to facilitate antegrade crossing. If all attempts fail, retrograde crossing may be attempted through another CC.

CROSSING THE CHRONIC TOTAL OCCLUSION

Once the CC has been navigated successfully and retrograde microcatheter advanced to the distal cap, there are various options to cross the lesion.

Retrograde intraplaque (true-to-true) crossing

The fastest way is when a retrograde guidewire is directly passed into the proximal true lumen known as intraplaque crossing. This can be attempted in short occlusions (<20mm), especially when the distal cap is tapered, but it is successful in less than 30% of cases. A directed penetration or directed navigation wire (Table 3) is used to breach the distal cap and advance through the occlusion. Once the true lumen position of the wire is confirmed in 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 a long externalization wire which is retracted from

the hemostatic valve of the antegrade guide. 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, to facilitate crossing of the occlusion with the microcatheter. The probability of retrograde guidewire crossing can be enhanced by maneuvers, such as inflating a retrograde balloon for more support (coaxial anchor) and using a stiffer, tapered-tip, and/or hydrophilic wires. Antegrade intravascular ultrasound (IVUS) is an important tool to guide retrograde guidewire into proximal true lumen.⁶

Kissing wire technique

The kissing wire technique involves navigation of antegrade guidewire into true lumen, when the retrograde wire is utilized as a guide or marker for manipulations with the antegrade one. Two different angiographic projections should be obtained to check the position of the retrograde guidewire and to confirm that it meets the antegrade guidewire at a single point. If the two guidewires fail to overlap precisely, one of them may have entered a subintimal space. Antegrade wiring should be initiated from a site proximal to the retrograde wire, so that the tips of the two guidewires can meet at a single point.¹⁸

Retrograde dissection and reentry

In case of failed true lumen recanalization, dissection and reentry techniques, such as the standard controlled antegrade and retrograde subintimal tracking (CART) technique or the reverse CART (rCART) are attempted. Subsequently, there are four possible fates for both antegrade and retrograde wire requiring different strategies (Table 5).²⁷ The most favorable scenario arises when both guidewires from antegrade and retrograde direction are subintimal. The two sides are usually connected when antegrade space is enlarged with balloon inflation. This is most widely used retrograde dissection re-entry technique called as rCART. The least favorable scenario arises when antegrade wire is intimal and retrograde wire subintimal. The solution is to create a space by aggressive antegrade dilatation of CTO body, for successful navigation of retrograde wire. When both the antegrade and retrograde wire are intimal, either wire is advanced antegradely or retrogradely, with the opposing wire as a landmark, towards the opposite channel – called as kissing wire technique. Antegrade balloon dilatation is the next strategy for retrograde navigation of wire. If this fails, the author purposefully embarks on antegrade or retrograde subintimal tracking. A CART procedure has been advocated when the antegrade wire is subintimal and retrograde wire intimal.

Table 5. Successful retrograde guidewire crossing by connecting antegrade and retrograde channels

Guidewire position	Preferred strategy
Intimal position of both antegrade and retrograde guidewire	1. Kissing wire technique 2. Antegrade balloon dilatation 3. Antegrade or retrograde subintimal tracking
Subintimal (most favourable) position of both antegrade and retrograde guidewire	1. rCART
Antegrade guidewire intimal and retrograde subintimal	1. Aggressive antegrade balloon dilatation for CTO body disruption and opening of a passage
Antegrade guidewire subintimal and retrograde intimal	1. rCART 2. CART as second line, with caution

Source: adapted from Touma G, Ramsay D, Weaver J. Chronic total occlusions - Current techniques and future directions. *Int J Cardiol Heart Vasc.* 2015;7:28-39. <https://doi.org/10.1016/j.ijcha.2015.02.002>. Table 3, 3A: An overview of connecting antegrade and retrograde channels for successful retrograde cross; p. 35.²⁷ rCART: reverse controlled antegrade and retrograde tracking; CTO: chronic total occlusion; CART: controlled antegrade and retrograde subintimal tracking.

STANDARD CART

The standard CART (Figure 1) involves creation of a connection between the subintimal space and the distal true lumen, by the retrograde balloon dilation in the case of an inadvertent subintimal position of the antegrade guidewire. While the balloon is being deflated, the antegrade

Source: Dash D. Iteration of reverse controlled antegrade and retrograde tracking for coronary chronic total occlusion intervention: a current appraisal. *Korean Circ J.* 2020;50(10):867-79. <https://doi.org/10.4070/kcj.2020.0156>. Figure 1, Schematic illustration of CART (A) and reverse CART (B); p. 868.⁽¹⁴⁾

Figure 1. Schematic illustration of controlled antegrade and retrograde subintimal tracking (CART) (A) and reverse CART (B). (A) Antegrade navigation of guidewire through the coronary chronic total occlusion into distal true lumen, through a local subintimal dissection created by retrograde balloon (pink arrow indicates retrograde balloon). (B) Retrograde navigation of a guidewire through a subintimal space created by antegrade balloon (pink arrow indicates antegrade balloon).

wire is negotiated further along the deflated balloon into the distal true lumen.²⁸ The advantage of this technique is the minimization of length of the subintimal tracking. The standard CART technique was replaced by rCART (Figure 1) with the advent of dedicated microcatheters. The standard CART technique is still employed 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 CCs and enlarged heart).^{6,18,29}

rCART

rCART is the most widely employed retrograde dissection re-entry technique. A balloon is inflated over the antegrade guidewire, followed by retrograde guidewire advancement into the space created by the balloon. In case of failure, larger antegrade balloons are used. The author proposes several important iterations which would further facilitate its adoption with more efficacy and safety.¹⁴

Conventional rCART

A longitudinal overlap of the antegrade and retrograde guidewires is the first step of conventional rCART (Figure 2). The conventional wiring in both an antegrade and a retrograde fashion is easier to make an overlap with unambiguous course of the CTO segment. With CTO vessel course ambiguity, severe tortuosity or heavy calcification, conventional wiring is not only inconvenient, but also carries the risk of vessel perforation. This warrants 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). An appropriate guidewire with or without a knuckle (an umbrella-type bend or loop), is advanced via the microcatheter through CTO body, within the subintimal space, to establish retrograde BO. An antegrade BO is established by positioning a microcatheter at proximal cap, using a low to intermediate penetration force guidewire to breach the proximal cap to enter subintimal space. Then an appropriately sized antegrade balloon is negotiated into the CTO segment to the point of guidewire overlap and inflated, which creates or enlarges intimal/subintimal dissection and makes a connection between the spaces, known as common subintimal space (CSS) within which both guidewires are positioned.^{14,16,30} In the conventional rCART technique, a large size antegrade balloon (Table 4) is chosen to maximize the chance of CSS formation. Usually, a low to intermediate penetration force wire is used as the retrograde guidewire to track the created connection. However, in case of 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.³⁰

Source: Dash D. Iteration of reverse controlled antegrade and retrograde tracking for coronary chronic total occlusion intervention: a current appraisal. *Korean Circ J.* 2020;50(10):867-79. <https://doi.org/10.4070/kcj.2020.0156>. Figure 3, Schematic illustration of the conventional reverse CART technique; p. 872.⁽¹⁴⁾

Figure 2. Schematic illustration 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) Creation of a connection is between the spaces (common subintimal space) containing both the guidewires. (E) Navigation of the retrograde guidewire through the common subintimal space. (F) The subsequent advancement of the retrograde guidewire into the proximal true lumen.

Assisted rCART

When the retrograde guidewire fails to navigate in the antegrade guide even after few tissue ablations, a guide-extension catheter (Guideliner, Vascular Solutions, Minneapolis, MN, USA; Guidezilla, Boston Scientific) can be deployed in the subintimal space to facilitate the process (mother-child rCART). Alternative strategies include IVUS-assisted rCART, use of larger balloon to achieve greater tissue ablation, the use of smaller balloons with retrograde navigation of Gaia series of wires (contemporary rCART), deployment of stent in antegrade subintimal space

for successful retrograde navigation of wire (stent-assisted rCART) or movement of base of operation overlap zone to a different location (shifting rCART).^{14,16}

IVUS-assisted rCART

Intravascular ultrasound is a useful imaging tool to estimate optimal size of antegrade balloon. It can prevent the risk of development of medial disruption and CSS recoil. Re-dilation with a larger balloon may be indicated if the CSS recoils. Intravascular ultrasound is also able to monitor the position and movement of the retrograde guidewire in the subintimal space.^{31,32} This retrograde guidewire is better navigated into the proximal true lumen under IVUS guidance. Further treatment is dictated by presence or absence of connection between antegrade and retrograde guidewire and position of antegrade guidewire.

Stent-facilitated rCART

A stent is deployed from the antegrade true lumen into the subintimal space created by antegrade balloon inflation. It forms a clear open target, enabling 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 via antegrade fashion. However, this technique is by nature an irreversible procedure as once the stent is deployed, it cannot be removed. Therefore, the failure to complete rCART after stent implantation might lead to stent thrombosis due to proximal thrombus propagation.^{14,16}

Mother-child rCART

The mother-child concept, an elegant modification of rCART, involves the use of a guide-extension catheter such as Guideliner (Vascular Solutions), Guidezilla (Boston Scientific) into antegradely created subintimal space to facilitate retrograde guidewire navigation into proximal true lumen. Unlike a stent, the guide extension device may be removed or repositioned once there is failure of connection between the antegrade and retrograde true lumen.^{16,33}

Contemporary rCART

The undesirable intentional intimal/subintimal dilatation with a large balloon in the conventional rCART technique may lead to distal propagation of the subintimal haematoma and vessel perforation. Some reports indicate that the CART and conventional rCART techniques could be associated with subsequent coronary artery aneurysm formation, and increased risk for target vessel revascularization due to longer stent length.^{34,35} Moreover, excessive manipulation of the retrograde guidewire, or use of a knuckle wire technique to achieve guidewire overlap, can

enlarge a space around the retrograde guidewire, that may be an obstacle for the precise directional control of the same guidewire. Although this challenge may be overcome with inflation of a larger antegrade balloon and tracking with low to intermediate penetration force guidewires, it is often cumbersome and time consuming. The contemporary rCART technique aims to minimize trauma to the vessel wall, and to make the procedure more efficient through a precise directional control by efficient use of deflection mechanisms of the retrograde guidewire (Gaia series). The key steps of this technique are antegrade preparation; 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).^{14,16}

This technique commences with simultaneous dual contrast injection from the antegrade and retrograde guiding catheters, and navigation of an antegrade guidewire through the occlusion with the support of a microcatheter to within 5mm to 10mm of the distal cap. It is taken care not to advance the antegrade guidewire beyond the CTO segment to minimize the risk of formation of distal hematoma. Next, the microcatheter is exchanged for a small balloon (2.0mm diameter in most cases) which is advanced towards the tip of the guidewire. Except for an ambiguous proximal cap or uncertainty of CC crossing, antegrade preparation first is preferable, since it reduces donor artery risk and ischemic time of the CTO territory, and encourages going directly to rCART after retrograde CC crossing.

The retrograde approach is then commenced with CC crossing by guidewire supported by microcatheter. The retrograde CTO segment wiring is performed using a guidewire with good torque control and high penetration efficiency (Gaia series). This retrograde guidewire should be navigated without excessive torqueing and directed towards the antegrade balloon, so that the shaft of the antegrade balloon and the retrograde wire are 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 recommended to confirm the positional relation between the retrograde guidewire and the antegrade balloon. After gently pushing the retrograde guidewire, the antegrade balloon is deflated, allowing the retrograde guidewire to slip into the space created by the antegrade balloon.

The contemporary rCART is considered unsuitable in CTO cases with ambiguous proximal cap, severe tortuosity, and heavy calcification, because this technique requires antegrade preparation before embarking on retrograde CTO segment wiring, and the knuckle wire technique cannot be contemplated to advance the antegrade or retrograde gui-

Source: Dash D. Iteration of reverse controlled antegrade and retrograde tracking for coronary chronic total occlusion intervention: a current appraisal. Korean Circ J. 2020;50(10):867-79. <https://doi.org/10.4070/kcj.2020.0156>. Figure 6, Schematic illustration of contemporary reverse CART; p. 874.⁽¹⁴⁾

Figure 3. Schematic illustration of contemporary reverse controlled antegrade and retrograde tracking (rCART). (A) Antegrade preparation depicting navigation of an antegrade guidewire, through 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 gentle push of the retrograde guidewire towards the inflated antegrade balloon catheter (retrograde wire is lateral to balloon in this figure). (E) Navigation of the retrograde guidewire into the space (created by the balloon) after balloon deflation. (F) Negotiation of the retrograde guidewire into the proximal true lumen with sequential antegrade balloon inflation within the chronic total occlusion segment proximal to the connecting point.

dewire, since it is likely to create large spaces around the guidewires resulting in reduced retrograde wire control. Also, short segment (<15mm) CTO are not suitable for the contemporary rCART, because of difficulty in embarking on antegrade preparation without propagating the hematoma beyond the distal cap.²⁹ Short CTO are best dealt with antegrade or retrograde wire escalation.

Shifting rCART

The shifting rCART technique involves shifting or extension of the intimal/subintimal dissection beyond the CTO segment (Figure 4). The antegrade balloon dilatation is undertaken outside the CTO segment (either proximal or distal), which is followed by navigation of retrograde guidewire through the connection created between the proximal true lumen and the retrograde intimal/subintimal space. The shifting rCART technique is useful in cases where antegrade preparation or retrograde cap penetration is not

possible, and where there are no significant side branches close to the site of the rCART technique.^{14,30}

GUIDEWIRE EXTERNALIZATION

The guidewire and microcatheter are advanced further into the antegrade guide, the retrograde guidewire is removed, and a long, especially designed externalization wire is navigated until it exits from the Y connector of the antegrade guide catheter. The two currently available externalization wires are the RG3 (Asahi Intecc; 330cm long, 0.010") or R350 (Vascular Solutions; 350cm long, 0.013"). The CC always need to be protected by a microcatheter during advancement or withdrawal of the externalization wire, and a torquer 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 cannot reach the antegrade guide, the tip-in wire rendezvous method may be employed for bailout.³⁶

TREATING THE CHRONIC TOTAL OCCLUSION

After disengaging the retrograde guide catheter to avoid inadvertent deep seating and dissection of the donor vessel, PCI of the CTO is performed over the externalized guidewire. With loop wire condition, the tip of the delivery device comes to inner curve of the coronary artery which provides 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 protect the CC until the soft wire tip is back in the CC. Both antegrade and retrograde guiding catheters are disengaged from the coronary ostium and pulled back 3cm to 4cm into the aorta to avoid ostial dissection, because of 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). After establishing guiding catheter control, the externalized wire is withdrawn gradually, synchronized with the heart beat, taking care not to kink it. Then the retrograde microcatheter is withdrawn into the donor vessel leaving the retrograde wire in the CC. The dye is injected into retrograde guide to ensure that there is no injury to the CC.⁶

COMPLICATIONS OF THE RETROGRADE APPROACH

The retrograde approach carries a higher risk of complications compared with antegrade-only crossing.³⁷ The retrograde CTO PCI were longer, associated with higher

Source: Dash D. Iteration of reverse controlled antegrade and retrograde tracking for coronary chronic total occlusion intervention: a current appraisal. *Korean Circ J.* 2020;50(10):867-79. <https://doi.org/10.4070/kcj.2020.0156>. Figure 8, Schematic illustration of shifting reverse CART; p. 877.⁽¹⁴⁾

Figure 4. Schematic illustration of shifting reverse controlled antegrade and retrograde tracking (rCART). (A) Navigation of a retrograde guidewire 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) Negotiation of an antegrade balloon to the planned connecting point. (C) Inflation of the antegrade balloon in an attempt to create a medial dissection. (D) Creation of a connection between the retrograde subintimal space and the proximal true lumen after balloon deflation. (E) Navigation of the retrograde guidewire into the proximal true lumen through the created connection. (F) Performance of the guidewire externalization and balloon dilatation.

contrast volume and fluoroscopy time, and higher risk of complications, such as pericardiocentesis, periprocedural myocardial infarction and contrast-induced nephropathy,³⁸ in a meta-analysis with more than 7,000 patients. In the same study, retrograde CTO PCI was associated with worse long-term outcomes, including target lesion revascularization, target vessel revascularization, and myocardial infarction, compared with antegrade over four years. Two complications of the retrograde approach must be highlighted due to their extreme hazard - CC perforation and donor vessel troubles.

Collateral channels perforation

Septal CC perforations are, in most cases, benign. However, they can rarely lead to septal hematomas, impeding ventricular filling.⁶ In contrast, epicardial CC perforations can lead to cardiac tamponade and require prompt treatment, by sealing both sides of the perforation, usually with coils, thrombin, or subcutaneous fat although absorbable sutures have also been used.^{39,40} Perforations in prior coronary artery bypass graft surgery patients pose more risks, for they can lead to loculated hematomas and dry tamponade, which may be very challenging to treat.⁴¹

Donor vessel complications

Donor vessel trouble (thrombus, dissection) is a dreadful complication of retrograde strategy.^{39,40} Guide catheter induced dissection can occur during antegrade equipment delivery over the externalized wire, and, therefore, it is essential to disengage the retrograde guide during this step. Donor vessel thrombosis can occur during prolonged procedures with equipment in the donor vessel, particularly

if this is a highly dominant artery, with a large supplied area. This may lead to hemodynamic disaster, which cannot be bailed-out in all of the cases. For this reason, activated clotting time should be frequently checked (every 20 to 30 minutes) with a target of >350 seconds. Frequent flushing of the retrograde system with saline is also necessary. The donor artery should be stented in case of dissection. Aspiration thrombectomy and additional heparin may be required for donor artery thrombosis.

CONCLUSION

Huge progresses in techniques and technologies make chronic total occlusion-percutaneous coronary intervention an essential option for any modern coronary catheterization laboratory. The retrograde approach has become an integral part of the contemporary chronic total occlusion percutaneous coronary intervention armamentarium. The rCART is the most frequently used technique and can be used as primary retrograde approach, or an alternative to an unsuccessful antegrade approach. The proposed iteration of rCART by the author would motivate the interventional cardiologists to appropriately adopt wire crossing strategies, and also facilitate communication and teaching of the rCART techniques. The global approach by putting it all together has further transformed chronic total occlusion percutaneous coronary intervention (Figure 5). This plan of incorporating integration of skillsets is flexible and allows several alternative scenarios. Favorable evidence from future randomized trials may encourage the interventional cardiologists to further adopt this challenging endeavor.

Source: adapted from Dash D. "Putting it all together": A global approach to chronic total occlusion revascularization. *J Indian Coll Cardiol.* 2016;6(3-4):152-7. <https://doi.org/10.1016/j.jicc.2016.12.003>. Figure 1, Algorithm global approach to CTO PCI; p. 153.

MDCT: multiple detector computed tomography; IVUS: intravascular ultrasound; rCART: reverse controlled antegrade and retrograde subintimal tracking; CART: controlled antegrade and retrograde subintimal tracking.

Figure 5. Algorithm of global approach to chronic total occlusion percutaneous coronary intervention.

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CONFLICTS OF INTEREST

The authors declare there are no conflicts of interest.

CONTRIBUTION OF AUTHORS

Conception and design of the study: DD; data collection: DD; data interpretation: DD; text writing: DD; approval of the final version to be published: DD.

REFERENCES

- Ivanhoe RJ, Weintraub WS, Douglas JS Jr, Lembo NJ, Furman M, Gershony G, et al. Percutaneous transluminal coronary angioplasty of chronic total occlusions. Primary success, restenosis, and long-term clinical follow-up. *Circulation.* 1992;85(1):106-15. <https://doi.org/10.1161/01.cir.85.1.106>
- Suero JA, Marso SP, Jones PG, Laster SB, Huber KC, Giorgi LV, et al. Procedural outcomes and long-term survival among patients undergoing percutaneous coronary intervention of a chronic total occlusion in native coronary arteries: a 20-year experience. *J Am Coll Cardiol.* 2001;38(2):409-14. [https://doi.org/10.1016/s0735-1097\(01\)01349-3](https://doi.org/10.1016/s0735-1097(01)01349-3)
- Hoye A, van Domburg RT, Sonnenschein K, Serruys PW. Percutaneous coronary intervention for chronic total occlusions: the Thoraxcenter experience 1992-2002. *Eur Heart J.* 2005; 26(24):2630-6. <https://doi.org/10.1093/eurheartj/ehi498>
- Saito S, Tanaka S, Hiroe Y, Miyashita Y, Takahashi S, Satake S, et al. Angioplasty for chronic total occlusion by using tapered-tip guidewires. *Catheter Cardiovasc Interv.* 2003;59(3):305-11. <https://doi.org/10.1002/ccd.10505>
- Joyal D, Afilalo J, Rinfret S. Effectiveness of recanalization of chronic total occlusions: a systematic review and meta-analysis. *Am Heart J.* 2010;160(1):179-87. <https://doi.org/10.1016/j.ahj.2010.04.015>
- Dash D. A step-by-step guide to mastering retrograde coronary chronic total occlusion intervention in 2018: The author's perspective. *Indian Heart J.* 2018;70 Suppl 3(Suppl 3):S446-S455. <https://doi.org/10.1016/j.ihj.2018.08.011>
- Dash D. Retrograde coronary chronic total occlusion intervention. *Curr Cardiol Rev.* 2015;11(4):291-298. <https://doi.org/10.2174/1573403X11666150909110300>
- Kahn JK, Hartzler GO. Retrograde coronary angioplasty of isolated arterial segments through saphenous vein bypass grafts. *Cathet Cardiovasc Diagn.* 1990;20(2):88-93. <https://doi.org/10.1002/ccd.1810200205>
- Silvestri M, Parikh P, Roquebert PO, Barragan P, Bouvier JL, Comet B. Retrograde left main stenting. *Cathet Cardiovasc Diagn.* 1996;39(4):396-9. [https://doi.org/10.1002/\(SICI\)1097-0304\(199612\)39:4<396::AID-CCD15>3.0.CO;2-B](https://doi.org/10.1002/(SICI)1097-0304(199612)39:4<396::AID-CCD15>3.0.CO;2-B)
- Surmely JF, Tsuchikane E, Katoh O, Nishida Y, Nakayama M, Nakamura S, et al. New concept for CTO recanalization using controlled antegrade and retrograde subintimal tracking: the CART technique. *J Invasive Cardiol.* 2006;18(7):334-8. PMID: 16816442.

11. Ozawa N. A new understanding of chronic total occlusion from a novel PCI technique that involves a retrograde approach to the right coronary artery via a septal branch and passing of the guidewire to a guiding catheter on the other side of the lesion. *Catheter Cardiovasc Interv.* 2006;68(6):907-13. <https://doi.org/10.1002/ccd.20882>
12. Lane RE, Ilesley CD, Wallis W, Dalby MC. Percutaneous coronary intervention of a circumflex chronic total occlusion using an epicardial collateral retrograde approach. *Catheter Cardiovasc Interv.* 2007;69(6):842-4. <https://doi.org/10.1002/ccd.20979>
13. Rosenmann D, Meerkin D, Almagor Y. Retrograde dilatation of chronic total occlusions via collateral vessel in three patients. *Catheter Cardiovasc Interv.* 2006;67(2):250-3. <https://doi.org/10.1002/ccd.20597>
14. Dash D. Iteration of reverse controlled antegrade and retrograde tracking for coronary chronic total occlusion intervention: a current appraisal. *Korean Circ J.* 2020;50(10):867-79. <https://doi.org/10.4070/kcj.2020.0156>
15. Dash D. Guidewire crossing techniques in coronary chronic total occlusion intervention: A to Z. *Indian Heart J.* 2016 May-Jun;68(3):410-20. <https://doi.org/10.1016/j.ihj.2016.02.019>
16. Dash D. Retrograde coronary chronic total occlusion intervention using a novel reverse controlled antegrade and retrograde subintimal tracking. *J Interv Cardiol.* 2016;29(1):70-4. <https://doi.org/10.1111/joic.12268>
17. Dash D. Deja Vu of retrograde recanalization of coronary chronic total occlusion: A tale of a journey from Japan to India. *Indian Heart J.* 2016;68(4):584-5. <https://doi.org/10.1016/j.ihj.2016.05.008>
18. Dash D. Treatment of chronic total occlusion. In: Nussinovitch U, ed. *Emerging therapeutic technologies for heart diseases.* UK: Elsevier; 2020. p. 587-621.
19. Huang CC, Lee CK, Meng SW, Hung CS, Chen YH, Lin MS, et al. Collateral Channel Size and Tortuosity Predict Retrograde Percutaneous Coronary Intervention Success for Chronic Total Occlusion. *Circ Cardiovasc Interv.* 2018;11(1):e005124. <https://doi.org/10.1161/CIRCINTERVENTIONS.117.005124>
20. Werner GS, Ferrari M, Heinke S, Kuethe F, Surber R, Richartz BM, et al. Angiographic assessment of collateral connections in comparison with invasively determined collateral function in chronic coronary occlusions. *Circulation.* 2003;107(15):1972-7. <https://doi.org/10.1161/01.CIR.0000061953.72662.3A>
21. Tajti P, Xenogiannis I, Gargoulas F, Karpaliotis D. Contemporary outcomes of the retrograde approach to chronic total occlusion interventions: insights from an international CTO registry. *Euro Intervention.* 2019;pii:EIJ-D-19-00441. <https://doi.org/10.4244/eij-d-19-00441>
22. Tanaka H, Ohya M, Kubo S, Miura K, Otsuru S, Habara S, et al. Impact of retrograde approach on long-term clinical outcomes of patients undergoing coronary chronic total occlusion interventions. *Euro Intervention.* 2018;14:e1183-e1191. <https://doi.org/10.4244/EIJ-D-18-00534>
23. Lee CK, Chen YH, Lin MS, Yeh CF, Hung CH, Kao HL, et al. Retrograde approach is as effective and safe as antegrade approach in contemporary percutaneous coronary intervention for chronic total occlusion: a taiwan single-center registry study. *Acta Cardiol Sin.* 2017;33(1):20-7. <https://doi.org/10.6515/acs20160131a>
24. Dautov R, Manh Nguyen C, Altisent O, Gibrat C, Rinfret S. Recanalization of chronic total occlusions in patients with previous coronary bypass surgery and consideration of retrograde access via saphenous vein grafts. *Circ Cardiovasc Interv.* 2016;9(7):e003515. <https://doi.org/10.1161/CIRCINTERVENTIONS.115.003515>
25. Tajti P, Karatasakis A, Karpaliotis D, Alaswad K, Jaffer FA, Yeh RW, et al. Retrograde CTO-PCI of native coronary arteries via left internal mammary artery grafts: insights from a multicenter U.S. registry. *J Invasive Cardiol.* 2018;30(3):89-96. PMID: 29138364.
26. Dautov R, Urena M, Nguyen CM, Gibrat C, Rinfret S. Safety and effectiveness of the surfing technique to cross septal collateral channels during retrograde chronic total occlusion percutaneous coronary intervention. *Euro Intervention.* 2017;12(15):e1859-e1867. <https://doi.org/10.4244/EIJ-D-16-00650>
27. Touma G, Ramsay D, Weaver J. Chronic total occlusions - Current techniques and future directions. *Int J Cardiol Heart Vasc.* 2015;7:28-39. <https://doi.org/10.1016/j.ijcha.2015.02.002>
28. Yamane M. Current percutaneous recanalization of coronary chronic total occlusion. *Rev Esp Cardiol (Engl Ed).* 2012;65(3):265-77. <https://doi.org/10.1016/j.recesp.2011.10.026>
29. Sumitsuji S, Inoue K, Ochiai M, Tsuchikane E, Ikeno F. Fundamental wire technique and current standard strategy of percutaneous intervention for chronic total occlusion with histopathological insights. *JACC Cardiovasc Interv.* 2011;4(9):941-51. <https://doi.org/10.1016/j.jcin.2011.06.011>
30. Matsuno S, Tsuchikane E, Harding SA, Wu EB, Kao HL, Brilakis ES, et al. Overview and proposed terminology for the reverse controlled antegrade and retrograde tracking (reverse CART) techniques. *Euro Intervention.* 2018;14(1):94-101. <https://doi.org/10.4244/EIJ-D-17-00867>
31. Dash D, Li L. Intravascular ultrasound guided percutaneous coronary intervention for chronic total occlusion. *Curr Cardiol Rev.* 2015;11(4):323-27. <https://doi.org/10.2174/1573403X11666150909105827>
32. Rathore S, Katoh O, Tsuchikane E, Oida A, Suzuki T, Takase S. A novel modification of the retrograde approach for the recanalization of chronic total occlusion of the coronary arteries intravascular ultrasound-guided reverse controlled antegrade and retrograde tracking. *J Am Coll Cardiol Interv.* 2010;3(2):155-64.
33. Dash D. Reverse controlled antegrade and retrograde subintimal tracking for chronic total occlusion intervention: my approach in 2017. *SL Clin Exp Cardiol.* 2017;1:1-6.
34. Kim U, Seol SH, Kim DI, Kim DK, Jang JS, Yang TH, et al. Clinical outcomes and the risk factors of coronary artery aneurysms that developed after drug-eluting stent implantation. *Circ J.* 2011;75(4):861-7. <https://doi.org/10.1253/circj.cj-10-0635>
35. Hasegawa K, Tsuchikane E, Okamura A, Fujita T, Yamane M, Oikawa Y, et al. Incidence and impact on midterm outcome of intimal versus subintimal tracking with both antegrade and retrograde approaches in patients with successful recanalization of chronic total occlusions: J-PROCTOR 2 study. *Euro Intervention.* 2017;12(15):e1868-e1873. <https://doi.org/10.4244/EIJ-D-16-00557>
36. Yamane M. "Tip-in" method: a novel, wire rendez-vous method in need of retrograde CTO PCI. *Srce i krvni sudovi.* 2015;34:9-13.
37. Karpaliotis D, Karatasakis A, Alaswad K, Jaffer FA, Yeh RW, Wyman RM, et al. Outcomes with the use of the retrograde approach for coronary chronic total occlusion interventions in a contemporary multicenter US registry. *Circ Cardiovasc Interv.* 2016;9(6):10.1161/CIRCINTERVENTIONS.115.003434 e003434. <https://doi.org/10.1161/CIRCINTERVENTIONS.115.003434>
38. Megaly M, Ali A, Saad M, Omer M, Xenogiannis I, Werner GS, et al. Outcomes with retrograde versus antegrade chronic total occlusion revascularization. *Catheter Cardiovasc Interv.* 2020;96(5):1037-43. <https://doi.org/10.1002/ccd.28616>
39. Dash D. Problems encountered in retrograde recanalization of coronary chronic total occlusion: Should we lock the backdoor in 2018? *Indian Heart J.* 2018;70(1):132-4. <https://doi.org/10.1016/j.ihj.2017.11.014>
40. Dash D. Complications encountered in coronary chronic total occlusion intervention: Prevention and bailout. *Indian Heart J.* 2016;68(5):737-46. <https://doi.org/10.1016/j.ihj.2016.03.009>
41. Karatasakis A, Akhtar YN, Brilakis ES. Distal coronary perforation in patients with prior coronary artery bypass graft surgery: The importance of early treatment. *Cardiovasc Med.* 2016;17(6):412-7. <https://doi.org/10.1016/j.carrev.2016.05.014>
42. Dash D. "Putting it all together": A global approach to chronic total occlusion revascularization. *J Indian Coll Cardiol.* 2016;6(3-4):152-7. <https://doi.org/10.1016/j.jicc.2016.12.003>