Dissection and Re-entry Techniques for Chronic Total Occlusion Percutaneous Coronary Intervention

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Abstract

Despite early stagnation in success rates for percutaneous coronary intervention for chronic total occlusion with the traditional antegrade wiring approach, the introduction of dissection/re-entry techniques and the retrograde approach opened new avenues for operators to tackle more complex occlusions. Dissection/re-entry techniques (both antegrade and retrograde) are commonly used in angiographic scenarios characterised by long, tortuous and calcified occlusions, as well as in those with proximal cap ambiguity. Familiarity and comfort using the extraplaque space (with either an antegrade or retrograde approach) have become fundamental to achieving safe and effective recanalisation of complex chronic total occlusions. This review provides an overview of different contemporary antegrade and retrograde dissection re-entry techniques and their acute and longer-term outcomes.

Keywords

Chronic total occlusion, antegrade dissection re-entry, retrograde dissection re-entry, extraplaque, reverse controlled antegrade and retrograde subintimal tracking (CART), subintimal tracking and re-entry (STAR)

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Since the introduction of percutaneous coronary intervention (PCI) for chronic total occlusion (CTO), conventional antegrade wiring (AW) techniques (‘true-to-true lumen’ approach) have been the traditional approach to tackle most cases.[1,2] However, this has led to a premature plateau in success rates because this method is best suited for tackling simple-to-moderately complex occlusions. The introduction of subintimal tracking and re-entry (STAR) and the retrograde approach opened new avenues for operators to navigate beyond traditional intraplaque strategies. This allowed tackling occlusions previously deemed off limits or those that were usually unsuccessfully approached with conventional methods.[3,4] This review focuses on antegrade and retrograde dissection/re-entry techniques for CTO recanalisation, providing a description on their technical aspects, as well as acute and longer-term outcomes.

Antegrade Dissection/Re-entry: Indications and Technical Aspects

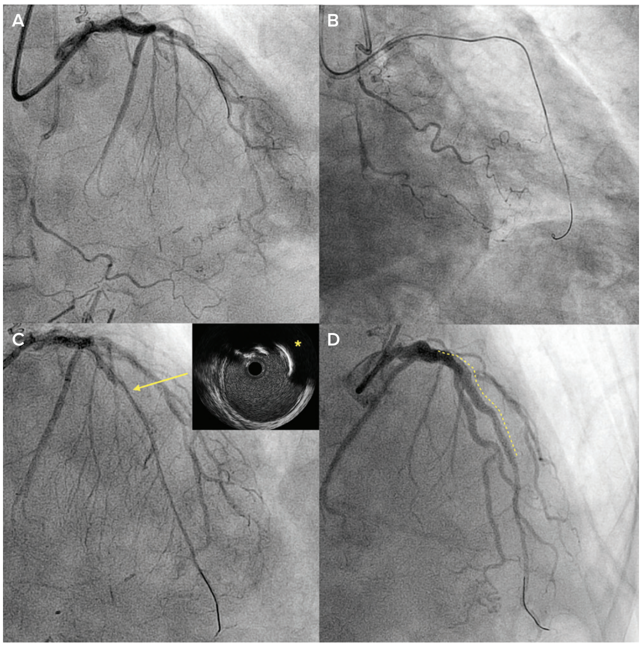
There is a widespread consensus that AW is the preferred technique for cases with a short tapered proximal cap occlusion with a clear course, and a distal vessel of good quality.[1,5,6] In fact, AW is the most frequently used and most frequently successful strategy across various practice patterns and approaches to PCI for CTO.[7] However, when AW fails to reach the distal true lumen and acquires an extraplaque situation, antegrade dissection/re-entry (ADR) becomes a valuable bailout option. ADR can also be used as a first-line strategy in case of long (>20 mm) occlusions with an ambiguous or impenetrable proximal cap or, again, in case of an ambiguous or tortuous vessel course.[1,3,5]

As its name implies, ADR involves two components: dissection and re-entry.

Dissection

Dissection may occur inadvertently by advancing a wire in the extraplaque space or intentionally by knuckling a polymer-jacketed wire. The wire is advanced against resistance until its tip folds upon itself, acquiring the shape of a knuckle (or the tip is purposefully shaped by the operator into a ‘J’ shape). Wire selection may vary, typically involving low-tip load polymer-jacketed wires (such as the Fielder XT family) or specialised guidewires (such as the Gladius Mongo, which features an abrupt core tapering 8 mm from its tip: ‘knuckle point’). Conversely, higher-tip load polymer-jacketed guidewires (e.g. Abbott Vascular Pilot 200, Asahi Intecc Gladius and Teleflex Raider) tend to create larger knuckles. Although smaller knuckles (e.g. Gladius Mongo) are generally suitable for both dissection and re-entry, larger knuckles may be preferred during the dissection phase, in cases where avoiding side branches is crucial (e.g. acute marginal branches in the right coronary artery) or where a higher tip load is instrumental in overcoming fibrocalcified tissue. Although

Figure 1: Subintimal Tracking and Re-entry-based Chronic Total Occlusion Recanalization



A: Proximal left anterior descending artery chronic total occlusion with an ambiguous course, length approximately 60 mm, severe calcification and epicardial collaterals from the right coronary artery. B: After failure of several different techniques, bailout subintimal tracking and re-entry was performed using a Gladius Mongo wire over a Corsair Pro microcatheter, which achieved successful re-entry. C: Final result, after extensive ballooning of the left anterior descending artery. Intravascular ultrasound shows the extraplaque track in the proximal half of the occlusion (the compressed true lumen is marked by the asterisk). D: The patient was brought back 6 weeks later, and two stents were implanted (dashed line), with good result.

knuckling is considered generally safe, caution is advised, emphasising stepwise advancement and vigilant tracking in orthogonal projections to ensure proper knuckle propagation along the expected course of the main vessel, and avoiding deep advancement into smaller branches.

In case of an ambiguous or impenetrable proximal cap, the so-called 'move-the-cap' techniques can be used, the goal of which is to 'go around' a hostile cap. These techniques include balloon-assisted subintimal entry (BASE) and scratch-and-go.[3] With BASE, balloon-induced intimal disruption is performed proximal to the proximal cap using a balloon sized 1:1 to the artery at high pressure. In case of significant fibrosis and/or calcification, speciality balloons can also be used, such as cutting/scoring balloons or even an intravascular lithotripsy balloon.[8] With the scratch-and-go technique, the extraplaque space is accessed using a highly penetrative wire, proximal to the proximal cap, and the microcatheter is advanced. In both cases, the goal is to create intimal disruption and access the extraplaque space, to then knuckle a polymer-jacketed wire. In the case of a particularly resistant proximal cap, the balloon used for BASE can be reinflated as soon as the microcatheter is advanced into the extraplaque space so as to anchor the microcatheter and thus give more penetrative power to the knuckle (BASE power knuckle).[9]

Notably, BASE should be preferred to the scratch-and-go technique, whenever feasible, because the latter is technically more challenging and potentially dangerous, as the penetrative wire can inadvertently perforate the vessel. Finally, another approach to deal with a very resistant proximal cap is the gentle injection of a small amount of contrast via the microcatheter tip after nosing it inside the cap (Carlino technique), which will modify plaque compliance.[3,10]

Re-entry

Re-entry in the true lumen has been the holy grail of PCI for CTO ever since the introduction of ADR and is still the subject of intensive technical and technological research efforts. Re-entry can be achieved through various methods, which can be classified as wire-based (with or without intravascular imaging guidance) or device-based.

Wire-based Antegrade Dissection/Re-entry: Subintimal Tracking and Re-entry and Limited Antegrade Subintimal Tracking

Historically, the first approach to re-entry consisted of simply continuing to advance the knuckle until it re-entered the true lumen. This technique was called STAR and was introduced by Colombo et al. in 2005.[11] However, this technique was associated with very high rates of restenosis on short-term follow-up due to extensive dissection planes, loss of significant side branches and poor run-off.[12,13] Subsequent modifications of the technique with novel wires (mini-STAR) or contrast injection to achieve hydraulic dissection of the vessel (contrast-guided STAR) were not able to significantly improve the outcomes.[14] As such, STAR currently only serves as last bailout strategy in case of impending failure, with the goal of performing an investment procedure (*Figure 1*).[15] Patients are typically brought back approximately 6–8 weeks later for a staged reattempt, allowing the dissection planes to heal before further intervention.[16,17] This deferred stenting strategy has been associated with improved patency rates on follow-up.[17,18]

Another technique that is only rarely used nowadays in the context of wire-based ADR is limited antegrade subintimal tracking (LAST; 11.1% of ADR cases in PROGRESS-CTO).[19] The primary goal of the LAST technique is to achieve a wire-based re-entry as close as possible to the distal cap by using a high-tip load and torqueable guidewire with a sharp bend at its tip.[3] However, the LAST technique remains less predictable and reproducible, with lower technical success than device-based techniques.[19–21]

Intravascular Imaging-guided Re-entry

A modification of the LAST technique involves incorporating live intravascular ultrasound (IVUS) interrogation to guide re-entry. This is achieved via either a single 8-Fr guide catheter or a second guide catheter (Ping Pong or dual-guide technique).[22–24] Very recently, a first-in-man case with a novel optical coherence tomography (OCT)-guided CTO re-entry device was reported, enabling real-time high-resolution visualisation with graphical augmentation and thus allowing precision steering and advancement of a guidewire.[25]

Device-based Antegrade Dissection/Re-entry: Antegrade Fenestration and Re-entry and Subintimal Antegrade Fenestration and Re-entry

The antegrade fenestration and re-entry (AFR) and subintimal antegrade fenestration and re-entry (SAFER) techniques aim to establish connections between the extraplaque space of a CTO segment and the distal true lumen through balloon-induced fenestrations. This is achieved by balloon dilation, and then guiding a wire through these openings. In AFR, a balloon sized 1:1 to the artery is advanced onto a first (extraplaque) guidewire and inflated across the distal cap. This will create transient fenestrations between the extraplaque space and the true lumen, and targeted re-entry into the true lumen can be achieved by engaging these fenestrations with a (second) polymer-jacketed guidewire.[26] After its initial formulation, AFR showed moderate success rates of 65.9% in a multicentre registry.[27] A more recent modification of AFR, called SAFER, involves the creation of larger and longer-lasting fenestrations between the false and true lumens through multiple inflations of the balloon along the entire occlusion, not just at the distal cap.[28] Multicentre validation of SAFER is eagerly awaited.

Device-Based Re-entry: STINGRAY LP System and ReCross Microcatheter

A device-based approach aims to enhance the efficacy and reproducibility of re-entry procedures. The STINGRAY LP (Boston Scientific) was the first of such devices, featuring a flat balloon with two side exit ports positioned 180° apart, alongside a distal exit port. Upon gentle inflation, the STINGRAY self-aligns one of its ports with the true lumen. An angiographic projection parallel to the device is then sought. Subsequently, a highly penetrative tapered wire (e.g. Astato XS 20) is guided through the side port closer to the true lumen, facilitating successful re-entry (*Figure 2*).[3,5] The same wire used to re-enter the lumen can then be advanced to the distal true lumen using a 'stick-and-drive' technique or, alternatively, it can be exchanged with a polymer-jacketed wire (e.g. Pilot 200) using a 'stick-and-swap' method (which is particularly useful in case of a diseased distal vessel). One challenge of this procedure is haematoma formation in the extraplaque space, which can be mitigated by burying a guide extension at the proximal cap before starting dissection manoeuvres. This issue can also be addressed by the subintimal transcatheter withdrawal (STRAW) technique, which involves attaching the over-the-wire STINGRAY port to a syringe and applying negative suction, which will evacuate the haematoma.

The ReCross microcatheter (IMDS) is uniquely designed as an oval-shaped microcatheter featuring two over-the-wire lumens and a total of three exit ports. The white hub connects to two of these ports: the distal one and the more proximal of two ports positioned 180° apart. The blue hub allows access to the second exit port (between those accessible via the white hub). The ReCross microcatheter can be used for device-based ADR, as well as for parallel wiring or as a conventional microcatheter.[29]

Retrograde Dissection Re-entry: Indications and Technical Aspects

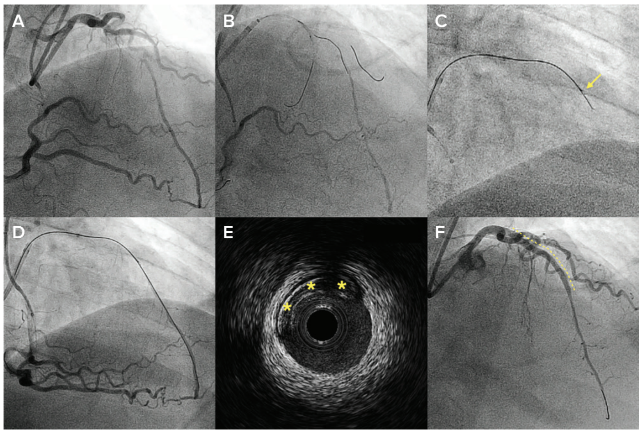
Procedural algorithms favour the retrograde approach in the presence of interventional collaterals, an ambiguous proximal cap, a distal vessel of poor quality, a significant bifurcation at the distal cap or failure of antegrade techniques.[3,30,31] Once collateral crossing is achieved, there are several options to complete CTO crossing. However, retrograde dissection/re-entry (RDR) is the most commonly used approach (63% in the PROGRESS-CTO registry).[32]

Although in one-third of cases operators may use retrograde wiring or a 'true-to-true lumen' approach (direct passage of the retrograde wire into the proximal true lumen without antegrade or retrograde balloon dilatation), this is often unsuccessful due to the high lesion complexity that dictated resorting to the retrograde approach in the first place.[31,32] Therefore, in most cases, balloon dilatation is required to create a connection between the antegrade and retrograde systems. Two RDR techniques are available: controlled antegrade and retrograde subintimal tracking (CART) and reverse CART.

Controlled Antegrade and Retrograde Subintimal Tracking

CART was the first RDR technique to be introduced in 2005 by Katoh et al.[33] With CART, an over-the-wire balloon was used to support retrograde guidewire crossing into the distal CTO vessel. Subsequently, retrograde

Figure 2: STINGRAY-based Chronic Total Occlusion Recanalization



A: Mid-left anterior descending artery chronic total occlusion with an ambiguous proximal cap, length approximately 25 mm and epicardial collaterals from the right coronary artery. B: Extraplaque situation at the distal cap with a Gladius wire over a Sasuke dual-lumen catheter (a blocking balloon was inflated in a septal branch to prevent the Gladius entering it). C: STINGRAY-based antegrade dissection: stick-and-drive with an Astato XS 20. The arrow indicates the STINGRAY balloon. D: Re-entry in the true lumen. E: Extraplaque recanalisation on intravascular ultrasound (the compressed true lumen is marked by asterisks). F: Good final result after the implantation of one stent.

balloon dilatation would facilitate antegrade wire crossing into the distal true lumen. CART was limited by the high crossing profile and the relative propensity of the over-the-wire balloons to kink. In fact, even in experienced hands, success rates were modest (40.8% in a single-centre study).[34]

The retrograde approach evolved over the following years and, in 2010, the Corsair microcatheter was introduced. With its ability to dilate retrograde channels, Corsair allowed a marked increase in the success rates of retrograde CTO recanalisation.[4] This also allowed the introduction of reverse CART (described in the next section). Consequently, CART use dropped significantly, and reverse CART became the dominant retrograde CTO crossing technique.[31,32,35]

However, there are still situations where the original CART technique remains valuable:

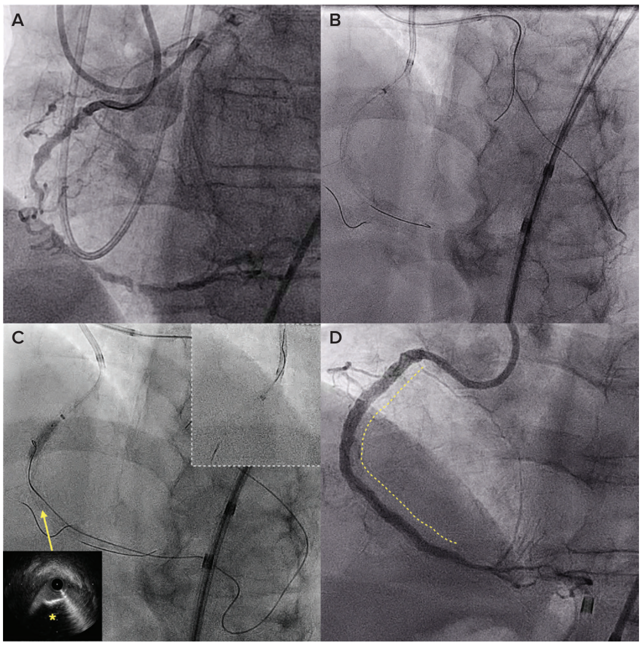
- aorto-ostial occlusions with difficult guide engagement
- impenetrable proximal cap or any cases where the antegrade equipment cannot be advanced to overlap with the retrograde system
- failure of reverse CART; and
- when the retrograde equipment is not long enough to reach the antegrade guide catheter.[36]

In a contemporary single-centre registry, CART was used in a minority of very challenging (mean [±SD] J-CTO score 3.6±0.9) retrograde cases (7.5% of the overall retrograde cohort), most often in the context of impenetrable CTOs, as described above.[36] The CART success rate was 73.3%, and overall technical/procedural success was observed in 82.2% of cases. Major adverse cardiovascular events (MACE) were observed in only 2.2% of cases (due to tamponade), with no fatalities, indicating the overall safety and efficacy of this technique in the hands of expert operators.[36]

Conventional Reverse Controlled Antegrade and Retrograde Subintimal Tracking

As discussed above, after the introduction of dedicated microcatheters,

Figure 3: Guide Catheter Extension-facilitated Reverse Controlled Antegrade and Retrograde Subintimal Tracking-based Recanalization of Chronic Total Occlusion



A: Mid-RCA chronic total occlusion with an ambiguous proximal cap, length approximately 15 mm, severe calcification and epicardial collaterals from the circumflex and diagonal systems. B: After failure of antegrade techniques (extraplaque situation at the distal cap), the retrograde approach was performed with a Sion Black wire over a Corsair Pro XS microcatheter, which crossed into the distal RCA. C: Reverse controlled antegrade and retrograde subintimal tracking was performed in the mid-RCA with a 4.5-mm non-compliant balloon and a retrograde Gladius wire. The inset shows entry of the retrograde wire into the antegrade guide extension. Intravascular ultrasound was subsequently performed and showed the extraplaque situation in a calcified area of the mid-RCA (the calcified compressed true lumen is marked by an asterisk). D: Good final result after implantation of three stents. RCA = right coronary artery.

balloon dilatation of the occlusion could subsequently be performed in an antegrade manner, because retrograde wire manipulation and collateral channel and occlusion crossing were greatly facilitated by the microcatheter. The retrograde wire could then be advanced into the true lumen towards the antegrade guide catheter, the retrograde microcatheter was advanced into the antegrade guide catheter and externalisation of a >300-cm-long wire would follow. There are several other variations of reverse CART, which are discussed below.[32]

Intravascular Ultrasound-guided Reverse Controlled Antegrade and Retrograde Subintimal Tracking

Beyond determining the ideal balloon size to connect compartments effectively, IVUS proves helpful in evaluating antegrade and retrograde wire position within CTO segments for reverse CART troubleshooting.[37] It can also provide live visualisation of the retrograde wire to assist in crossing and confirm wire location into the same space as the antegrade gear.[38]

Guide Extension-facilitated Reverse Controlled Antegrade and Retrograde Subintimal Tracking

Advancing a guide catheter extension can provide an easier target for retrograde wire re-entry (*Figure 3*). This technique is routinely used (e.g. in one-fifth of retrograde cases in PROGRESS-CTO) and is particularly useful in the following scenarios:

- diffuse disease in the proximal vessel
- a retrograde microcatheter that cannot reach the antegrade guide catheter
- managing ostial left anterior descending artery or left circumflex CTOs to reduce the risk of extraplaque crossing into the left main coronary artery.[32,39]

Contemporary/Directed Reverse Controlled Antegrade and Retrograde Subintimal Tracking

Japanese operators advocate for a contemporary or directed approach to reverse CART, with the goal of achieving the least amount of vascular manipulation possible (under the belief of better long-term stent patency rates).[40] In a directed approach, the goal is to achieve close proximity between the antegrade and retrograde systems, and for this purpose reliance is placed on highly torqueable wires (such as the Gaia family). A small balloon is advanced and inflated on the antegrade wire in the CTO segment and the retrograde wire aims at it.[40] However, this technique may not be feasible in the presence of ambiguity of the vessel course or proximal cap, severe tortuosity or heavy calcification of the CTO vessel.

Extended Reverse Controlled Antegrade and Retrograde Subintimal Tracking

In this iteration, the operational base is relocated either proximal or distal to the CTO segment, and ballooning in those segments is performed to facilitate entry of the retrograde wire into the lumen.[40] A potential drawback involves extending the dissection planes and the requirement for longer stents. Nonetheless, this approach can prove beneficial, particularly in the context of an impenetrable proximal or distal cap, especially in the absence of significant side branches.

Effect of Intraplaque versus Extraplaque Tracking on Vessel Patency Rates

The subject of intense debate has been whether intraplaque versus extraplaque tracking during CTO recanalisation has a long-term effect on vessel patency rates. For many years, Japanese authors have, in fact, defended the importance of pursuing intraplaque tracking much as possible, due to the alleged impact on distal run-off and preservation of side branches. As such, their algorithm emphasises intentional wiring approaches.[41] However, it is important to highlight that the intended use of dissection/re-entry techniques does not equate to extraplaque tracking, and even the intended use of a 'true-to-true lumen' approach does not necessarily lead to intraplaque tracking. In fact, IVUS studies have revealed that extraplaque tracking was observed in 27.9% of cases using an antegrade wiring approach, whereas intraplaque tracking occurred in 15.0% of cases using dissection/re-entry techniques.[42] However, because intravascular imaging-based evaluation of wire tracking is not consistently performed in PCI for CTO literature, our discussion will sometimes have to take a simplified approach and compare dissection/re-entry techniques versus 'true-to-true lumen' wiring. A summary of the available literature on this topic is presented in *Table 1*.[20,21,43–51]

In a meta-analysis by Megaly et al., extraplaque tracking was more often used in complex CTO lesions and was associated with a higher risk of MACE (OR 1.50; 95% CI [1.10–2.06]; p=0.01), driven by a higher risk of target vessel revascularisation (OR 1.69; 95% CI [1.15–2.48]; p=0.01) at 1 year.[49] However, there were no differences in terms of death or MI between extraplaque and intraplaque tracking.[49]

Similarly, other studies have reported a higher occurrence of target vessel

Table 1: Studies Comparing Antegrade/Retrograde Dissection Re-entry with True-to-True Approaches

Authors	No. Patients	J-CTO score (mean ± SD)	In-hospital outcomes	Follow-up (months)	Follow-up Findings	Comments
Muramatsu et al. 2014[44]	163	–	–	12	No difference in TVR, greater late loss in subintimal group (0.71 ± 0.98) versus intimal group (0.29 ± 0.63) at angiographic follow-up	Multivariate analysis identified preprocedural reference diameter as a predictor of subintimal tracking
Amsavelu et al. 2016[46]	185	2.34 ± 1.04	–	12	Death (2.5%), MI (4.9%) and composite of ACS/TVR (24.4%) were similar between intimal and subintimal crossing strategies	Use of ADR and RDR was associated with bifurcation at distal cap, longer CTO occlusion length and longer stent length
Azzalini et al. 2016[21]	223	2.3 ± 1.2	Perforation s/p intervention (2.2%), stroke (0.5%) without differences between groups	24	Higher MACE with STAR (15.4%) and LAST (17.5%) versus CrossBoss/ STINGRAY (4.3%), driven by TVR	Wire-based ADR and total stent length were independent predictors of MACE
Wilson et al. 2017[45]	929	2.4 ± 1.4	MACE (death, MI, TVR; 1.8%), perforation s/p pericardiocentesis (1.6%), without differences between groups	12	Composite of death, MI, TVR in 8.6% (10.3% in DART group, 7.0% in wire-based cases)	ADR and RDR were used in cases with greater disease burden, but the only independent predictor of the primary endpoint was lesion length
Azzalini et al. 2017[20]	924	1.9 ± 1.2		12	Composite of cardiac death, target vessel MI and TVR was higher with old DART (22.1%) versus modern DART (8.9%) and a true-to-true strategy (9.1%)	Old but not modern DART techniques were associated with a higher adjusted risk of MACE compared with true lumen
Hasegawa et al. 2017[49]	323	–	–	12	Higher rates of MACE (death, MI, TVR, thrombosis) in the subintimal (11.3%) than intimal (4.8%) group	Subintimal tracking resulted in increased TVR in the retrograde, but not antegrade, group
Finn et al. 2018[50]	157	2.1 ± 1.1	–	12	Higher rate of TVF in DART group versus the wiring strategies group (17.9% versus 6.9%), driven by periprocedural MI and TVR	In patients with J-CTO scores ≥2, there was no significant association between strategy used and the unadjusted 1-year TVF or MACE
Xhepa et al. 2019[43]	75	2.5 ± 1.9	–	6	No differences in percentage diameter stenosis, comparable strut coverage but significantly higher strut malapposition after DART on OCT	DART independently correlated with the presence of strut malapposition
Walsh et al. 2020[47]	231	2.4 ± 1.3	Perforation (2.4%), pericardiocentesis (1%)	24	1-year TVF 5.7% and MACE 10%, not influenced by crossing techniques	No difference at 1 year in OCT-assessed intravascular healing between DART and intimal strategies
Xhepa et al. 2021[42]	473	1.9 ± 0.9	DART versus intraplaque: perforation 5.7 versus 1.2%, pericardiocentesis 3 versus 0%	12	No differences in MACE or composite of death or MI between subintimal and intraplaque	Crossing technique, in-stent CTO and post-procedural percentage diameter stenosis were independent predictors of MACE
Megaly et al. 2022[48]	2,982	2.3 ± 1.2	–	12	Higher MACE in extraplaque tracking versus intraplaque tracking (13.3% versus 9.8%), driven by TVR (7.5% versus 4.9%)	Extraplaque tracking was associated with higher J-CTO score, longer lesion and stent length and severe calcification

ACS = acute coronary syndrome; ADR = antegrade dissection; CTO = chronic total occlusion; DART = dissection and re-entry techniques; LAST= limited antegrade subintimal tracking; MACE = major adverse cardiovascular events; OCT = optical coherence tomography; RDR = retrograde dissection/re-entry; s/p = status post; STAR = subintimal tracking and re-entry; TVF = target vessel failure; TVR = target vessel revascularization.

revascularisation with extraplaque tracking, particularly in the RDR group, but not in the ADR group.[48,50,51] Conversely, in the prospective CONSISTENT-CTO study, MACE rates at the 2-year follow-up were similar between dissection/re-entry and the 'true-to-true lumen' approaches.[48]

In an ADR approach, device-based re-entry, specifically using the CrossBoss/STINGRAY system, was associated with lower MACE rates compared with wire-based ADR techniques.[20,21]

Conclusion

Antegrade and retrograde dissection/re-entry techniques greatly expand and enhance the array of techniques available to CTO operators, offering solutions for challenging occlusions that were previously deemed too difficult to tackle or in which PCI was unsuccessfully attempted. Proficiency and ease in navigating the extraplaque space are imperative to ensuring a safe, effective and efficient approach to CTO revascularisation. ❑

1. Brilakis ES, Grantham JA, Rinfret S, et al. A percutaneous treatment algorithm for crossing coronary chronic total occlusions. *JACC Cardiovasc Interv* 2012;5:367–79. https://doi.org/10.1016/j.jcin.2012.02.006; PMID: 22516392.
2. Brilakis ES, Banerjee S, Karmpaliotis D, et al. Procedural outcomes of chronic total occlusion percutaneous coronary intervention: a report from the NCDR (National Cardiovascular Data Registry). *JACC Cardiovasc Interv* 2015;8:245–53. https://doi.org/10.1016/j.jcin.2014.08.014; PMID: 25700746.
3. Azzalini L, Carlino M, Brilakis ES, et al. Subadventitial techniques for chronic total occlusion percutaneous coronary intervention: the concept of 'vessel architecture'. *Catheter Cardiovasc Interv* 2018;91:725–34. https://doi.org/10.1002/ccd.27025; PMID: 28303648.
4. Azzalini L, Vo M, Dens J, Agostoni P. Myths to debunk to improve management, referral, and outcomes in patients with chronic total occlusion of an epicardial coronary artery. *Am J Cardiol* 2015;116:1774–80. https://doi.org/10.1016/j.amjcard.2015.08.050; PMID: 26434510.
5. Azzalini L, Karmpaliotis D, Santiago R, et al. Contemporary issues in chronic total occlusion percutaneous coronary intervention. *JACC Cardiovasc Interv* 2022;15:1–21. https://doi.org/10.1016/j.jcin.2021.09.027; PMID: 34991814.
6. Wu EB, Brilakis ES, Mashayekhi K, et al. Global chronic total occlusion crossing algorithm: JACC state-of-the-art review. *J Am Coll Cardiol* 2021;78:840–53. https://doi.org/10.1016/j.jacc.2021.05.055; PMID: 34412818.
7. Masoomi R MS, Hirai T, Azzalini L. Antegrade techniques for chronic total occlusion percutaneous coronary intervention. *Prog Cardiovasc Dis* 2024. https://doi.org/10.1016/j.pcad.2024.07.001; epub ahead of press.
8. Azzalini L, Kearney KE, Lombardi WL. Intravascular lithotripsy-facilitated balloon-assisted subintimal entry for chronic total occlusion percutaneous coronary intervention. *Can J Cardiol* 2024. https://doi.org/10.1016/j.cjca.2024.01.014; PMID: 38244987.
9. Riley RF, Walsh SJ, Kirtane AJ, et al. Algorithmic solutions to common problems encountered during chronic total occlusion angioplasty: the algorithms within the algorithm. *Catheter Cardiovasc Interv* 2019;93:286–97. https://doi.org/10.1002/ccd.27987; PMID: 30467958.
10. Carlino M, Azzalini L. Letter: What is the Carlino technique? *EuroIntervention* 2023;18:e1388–9-e1389. https://doi.org/10.4244/EIJ-D-22-00838; PMID: 37025084.
11. Colombo A, Mikhail GW, Michev I, et al. Treating chronic total occlusions using subintimal tracking and reentry: the STAR technique. *Catheter Cardiovasc Interv* 2005;64:407–11; discussion 412. https://doi.org/10.1002/ccd.20307; PMID: 15789384.
12. Carlino M, Figini F, Ruparelia N, et al. Predictors of restenosis following contemporary subintimal tracking and reentry technique: the importance of final TIMI flow grade. *Catheter Cardiovasc Interv* 2016;87:884–92. https://doi.org/10.1002/ccd.26103; PMID: 26308750.
13. Valenti R, Vergara R, Migliorini A, et al. Predictors of reocclusion after successful drug-eluting stent-supported percutaneous coronary intervention of chronic total occlusion. *J Am Coll Cardiol* 2013;61:545–50. https://doi.org/10.1016/j.jacc.2012.10.036; PMID: 23273395.
14. Galassi AR, Tomasello SD, Costanzo L, et al. Mini-STAR as bail-out strategy for percutaneous coronary intervention of chronic total occlusion. *Catheter Cardiovasc Interv* 2012;79:30–40. https://doi.org/10.1002/ccd.22998; PMID: 21956876.
15. Carlino M, Godino C, Latib A, et al. Subintimal tracking and re-entry technique with contrast guidance: a safer approach. *Catheter Cardiovasc Interv* 2008;72:790–6. https://doi.org/10.1002/ccd.21699; PMID: 19006242.
16. Ybarra LF, Rinfret S, Brilakis ES, et al. Definitions and clinical trial design principles for coronary artery chronic total occlusion therapies: CTO-ARC consensus recommendations. *Circulation* 2021;143:479–500. https://doi.org/10.1161/CIRCULATIONAHA.120.046754; PMID: 33523728.
17. Goleski PJ, Nakamura K, Liebeskind E, et al. Revascularization of coronary chronic total occlusions with subintimal tracking and reentry followed by deferred stenting: experience from a high-volume referral center. *Catheter Cardiovasc Interv* 2019;93:191–8. https://doi.org/10.1002/ccd.27783; PMID: 30411863.
18. Visconti G, Focaccio A, Donahue M, Briguori C. Elective versus deferred stenting following subintimal recanalization of coronary chronic total occlusions. *Catheter Cardiovasc Interv* 2015;85:382–90. https://doi.org/10.1002/ccd.25509; PMID: 24740711.
19. Karacsonyi J, Kostantinis S, Simsek B, et al. Use of the limited antegrade subintimal tracking technique in chronic total occlusion percutaneous coronary intervention. *JACC Cardiovasc Interv* 2022;15:2284–93. https://doi.org/10.1016/j.jcin.2022.08.052; PMID: 36423972.
20. Azzalini L, Dautov R, Brilakis ES, et al. Impact of crossing strategy on midterm outcomes following percutaneous revascularisation of coronary chronic total occlusions. *EuroIntervention* 2017;13:978–85. https://doi.org/10.4244/EIJ-D-16-01010; PMID: 28242587.
21. Azzalini L, Dautov R, Brilakis ES, et al. Procedural and longer-term outcomes of wire- versus device-based antegrade dissection and re-entry techniques for the percutaneous revascularization of coronary chronic total occlusions. *Int J Cardiol* 2017;231:78–83. https://doi.org/10.1016/j.ijcard.2016.11.273; PMID: 27887799.
22. Huang WC, Teng HI, Hsueh CH, et al. Intravascular ultrasound guided wiring re-entry technique for complex chronic total occlusions. *J Interv Cardiol* 2018;31:572–9. https://doi.org/10.1111/joic.12518; PMID: 29726047.
23. Suzuki S, Okamura A, Nagai H, Iwakura K. Tip detection-antegrade dissection and reentry using intravascular ultrasound in chronic total occlusion intervention: first human case report. *Eur Heart J Case Rep* 2022;6:ytac233. https://doi.org/10.1093/ehjcr/ytac233; PMID: 35757584.
24. Tanaka K, Okamura A, Tsuchikane E, et al. New antegrade dissection re-entry technique with tip detection method and new puncture wire in CTO-PCI. *JACC Cardiovasc Interv* 2023;16:1546–8. https://doi.org/10.1016/j.jcin.2023.04.019; PMID: 37380241.
25. Sandesara PB, Robertson GC, Chan KF, et al. Clinical experience of a novel optical coherence tomography-guided coronary chronic total occlusion re-entry device. *JACC Case Rep* 2023;26:102041. https://doi.org/10.1016/j.jaccas.2023.102041; PMID: 38094175.
26. Carlino M, Azzalini L, Mitomo S, Colombo A. Antegrade fenestration and re-entry: a new controlled subintimal technique for chronic total occlusion recanalization. *Catheter Cardiovasc Interv* 2018;92:497–504. https://doi.org/10.1002/ccd.27470; PMID: 29314567.
27. Azzalini L, Alaswad K, Uretsky BF, et al. Multicenter experience with the antegrade fenestration and reentry technique for chronic total occlusion recanalization. *Catheter Cardiovasc Interv* 2021;97:E40–50. https://doi.org/10.1002/ccd.28941; PMID: 32320133.
28. Carlino M, Uretsky BF, Azzalini L, et al. STAR procedure becomes SAFER: first-in-man case series of a new antegrade dissection re-entry technique. *Catheter Cardiovasc Interv* 2023;102:577–84. https://doi.org/10.1002/ccd.30789; PMID: 37522283.
29. Garbo R, Iannaccone M, Sanz Sánchez J, et al. The ReCross dual-lumen microcatheter versatility during percutaneous coronary intervention of chronic total coronary occlusions. REC Interv Cardiol 2022;4:67–69. https://doi.org/10.24875/RECICE.M21000211.
30. Michael TT, Papayannis AC, Banerjee S, Brilakis ES. Subintimal dissection/reentry strategies in coronary chronic total occlusion interventions. *Circ Cardiovasc Interv* 2012;5:729–38. https://doi.org/10.1161/CIRCINTERVENTIONS.112.969808; PMID: 23074346.
31. Galassi AR, Sianos G, Werner GS, et al. Retrograde recanalization of chronic total occlusions in Europe: procedural, in-hospital, and long-term outcomes from the multicenter ERCTO registry. *J Am Coll Cardiol* 2015;65:2388–400. https://doi.org/10.1016/j.jacc.2015.03.566; PMID: 26046732.
32. Allana SS, Kostantinis S, Rempakos A, et al. The retrograde approach to chronic total occlusion percutaneous coronary interventions: technical analysis and procedural outcomes. *JACC Cardiovasc Interv* 2023;16:2748–62. https://doi.org/10.1016/j.jcin.2023.08.031; PMID: 38030360.
33. Surmely JF, Tsuchikane E, Katoh O, et al. New concept for CTO recanalization using controlled antegrade and retrograde subintimal tracking: the CART technique. *J Invasive Cardiol* 2006;18:334–8. PMID: 16816442.
34. Rathore S, Katoh O, Matsuo H, et al. Retrograde percutaneous recanalization of chronic total occlusion of the coronary arteries: procedural outcomes and predictors of success in contemporary practice. *Circ Cardiovasc Interv* 2009;2:124–32. https://doi.org/10.1161/CIRCINTERVENTIONS.108.838862; PMID: 20031705.
35. Tsuchikane E, Yamane M, Mutoh M, et al. Japanese multicenter registry evaluating the retrograde approach for chronic coronary total occlusion. *Catheter Cardiovasc Interv* 2013;82:E654–61. https://doi.org/10.1002/ccd.24823; PMID: 23404874.
36. Moscardelli S, Kearney KE, Lombardi WL, Azzalini L. Controlled antegrade and retrograde subintimal tracking (CART) for recanalization of chronic total occlusions. *EuroIntervention* 2024;20:571–8. https://doi.org/10.4244/eij-d-23-01082; PMID: 38726716.
37. Fan Y, Maehara A, Yamamoto MH, et al. Outcomes of retrograde approach for chronic total occlusions by guidewire location. *EuroIntervention* 2021;17:e647–55. https://doi.org/10.4244/EIJ-D-20-01169; PMID: 33589409.
38. Rathore S, Katoh O, Tuschikane E, et al. 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. *JACC Cardiovasc Interv* 2010;3:155–64. https://doi.org/10.1016/j.jcin.2009.10.030; PMID: 20170872.
39. Mozid AM, Davies JR, Spratt JC. The utility of a guideliner catheter in retrograde percutaneous coronary intervention of a chronic total occlusion with reverse cart-the 'capture' technique. *Catheter Cardiovasc Interv* 2014;83:929–32. https://doi.org/10.1002/ccd.25205; PMID: 24089343.
40. Matsuno S, Tsuchikane E, Harding SA, et al. Overview and proposed terminology for the reverse controlled antegrade and retrograde tracking (reverse CART) techniques. *EuroIntervention* 2018;14:94–101. https://doi.org/10.4244/EIJ-D-17-00867; PMID: 29360064.
41. Tanaka H, Tsuchikane E, Muramatsu T, et al. A novel algorithm for treating chronic total coronary artery occlusion. *J Am Coll Cardiol* 2019;74:2392–404. https://doi.org/10.1016/j.jacc.2019.08.1049; PMID: 31699280.
42. Song L, Maehara A, Finn MT, et al. Intravascular ultrasound analysis of intraplaque versus subintimal tracking in percutaneous intervention for coronary chronic total occlusions and association with procedural outcomes. *JACC Cardiovasc Interv* 2017;10:1011–21. https://doi.org/10.1016/j.jcin.2017.02.043; PMID: 28521919.
43. Xhepa E, Cassese S, Ndrepepa G, et al. Clinical and angiographic outcomes of crossing techniques for coronary chronic total occlusions: the ISAR-CTO registry. *EuroIntervention* 2021;17:e656–63. https://doi.org/10.4244/EIJ-D-20-01248; PMID: 33646124.
44. Xhepa E, Cassese S, Rroku A, et al. Subintimal versus intraplaque recanalization of coronary chronic total occlusions: mid-term angiographic and OCT findings from the ISAR-OCT-CTO registry. *JACC Cardiovasc Interv* 2019;12:1889–98. https://doi.org/10.1016/j.jcin.2019.04.049; PMID: 31521651.
45. Muramatsu T, Tsuchikane E, Oikawa Y, et al. Incidence and impact on midterm outcome of controlled subintimal tracking in patients with successful recanalisation of chronic total occlusions: J-PROCTOR registry. *EuroIntervention* 2014;10:681–8. https://DOI.ORG/10.4244/EIJV10I6A119; PMID: 25330501.
46. Wilson WM, Walsh SJ, Bagnall A, et al. One-year outcomes after successful chronic total occlusion percutaneous coronary intervention: the impact of dissection re-entry techniques. *Catheter Cardiovasc Interv* 2017;90:703–12. https://doi.org/10.1002/ccd.26980; PMID: 28296045.
47. Amsavelu S, Christakopoulos GE, Karatasakis A, et al. Impact of crossing strategy on intermediate-term outcomes after chronic total occlusion percutaneous coronary intervention. *Can J Cardiol* 2016;32:1239.e1–7. https://doi.org/10.1016/j.cjca.2016.01.020; PMID: 27006316.
48. Walsh SJ, Hanratty CG, McEntegart M, et al. Intravascular healing is not affected by approaches in contemporary CTO PCI: the CONSISTENT CTO study. *JACC Cardiovasc Interv* 2020;13:1448–57. https://doi.org/10.1016/j.jcin.2020.03.032; PMID: 32553333.
49. Megaly M, Buda K, Karacsonyi J, et al. Extraplaque versus intraplaque tracking in chronic total occlusion percutaneous coronary intervention. *Catheter Cardiovasc Interv* 2022;100:1021–9. https://doi.org/10.1002/ccd.30403; PMID: 36168859.
50. Hasegawa K, Tsuchikane E, Okamura A, et al. Incidence and impact on midterm outcome of intimal versus subintimal tracking with both antegrade and retrograde approaches in patients with successful recanalisation of chronic total occlusions: J-PROCTOR 2 study. *EuroIntervention* 2017;12:e1868–73-e1873. https://doi.org/10.4244/EIJ-D-16-00557; PMID: 27802928.
51. Finn MT, Doshi D, Cleman J, et al. Intravascular ultrasound analysis of intraplaque versus subintimal tracking in percutaneous intervention for coronary chronic total occlusions: one year outcomes. *Catheter Cardiovasc Interv* 2019;93:1048–56. https://doi.org/10.1002/ccd.27958; PMID: 30489684.