

Subintimal Dissection/Reentry Strategies in Coronary Chronic Total Occlusion Interventions

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Percutaneous coronary intervention (PCI) of chronic total occlusions (CTO) is a rapidly evolving field. Subintimal dissection/reentry techniques were initially used for crossing peripheral arterial CTOs¹ but have been increasingly used in coronary arteries, especially since the development of specialized equipment.² However, there is confusion on the terminology and coronary application of such techniques and limited data on outcomes, especially long-term.

In this review we will (1) describe the CTO subintimal dissection/reentry techniques and clarify the related terminology, (2) summarize published studies on this area, and (3) provide practical recommendations on how to implement these techniques and identify areas in need for further evaluation.

STAR-CART-LAST: Clarifying the Terminology

CTO crossing can occur either in the antegrade or the retrograde direction. In either direction, crossing can be achieved either from true-to-true lumen or by first entering the subintimal space, followed by reentry into the true lumen (dissection/reentry strategies) (Figure 1).

In the antegrade direction, dissection can be achieved by one of the following procedures:

1. Using a knuckle wire, usually formed by pushing a polymer jacketed guide wire, usually a Fielder XT (Asahi Intecc, Nagoya, Japan) or Pilot 200 (Abbott Vascular, Santa Clara, CA), until it forms a tight loop at its tip that is advanced subintimally through the occlusion.
2. Using the CrossBoss catheter (Bridgepoint Medical, Minneapolis, MN), which is a blunt microdissection catheter with a 1-mm metal tip that is rapidly rotated (fast-spin technique) by the operator (Figures 2 and 3).²

In the antegrade direction, reentry can be achieved by the following:

1. Continuing to advance the knuckled guide wire until it spontaneously reenters the true lumen (usually at a distal bifurcation). This technique is called subintimal tracking and reentry (STAR).³ A modification of the STAR technique called contrast-guided STAR uses subintimal

contrast injection through a microcatheter positioned at the proximal cap to create/visualize a dissection plane and guide wire advancement (Figure 4).⁴

2. Intentionally reentering the true lumen as early as possible distal to the occlusion, which can be achieved by the mini-STAR⁵ or the limited antegrade subintimal tracking (LAST) (Figure 5)⁶ technique. In mini-STAR, reentry is achieved by advancing the loop of a Fielder FC or XT wire (Asahi Intecc) distal to the lesion, whereas, in LAST, reentry is achieved by using a Pilot 200 (Abbott Vascular) or a Confianza Pro 12 (Asahi Intecc) guide wire with an acute distal bend, occasionally with the help of a Venture catheter (Vascular Solutions, Maple Grove, MN).
3. Using the Stingray (Bridgepoint Medical) balloon and guide wire (Figures 2 and 3). The Stingray balloon is 2.5 mm in diameter and 10 mm in length and has a flat shape with 2 side exit ports: upon low-pressure (2–4 atm) inflation it orients 1 exit port automatically toward the true lumen. The Stingray guide wire is a stiff guide wire with a 20-cm distal radiopaque segment and a 0.009-inch tapered tip with a 0.0035-inch distal taper. The Stingray guide wire can be directed toward 1 of the 2 side ports of the Stingray balloon under fluoroscopic guidance to reenter the distal true lumen.^{7–9}

In the retrograde direction, dissection is usually performed using a knuckle wire, whereas reentry can be achieved by one of 2 techniques:^{10,11}

1. Inflating a balloon over the retrograde guide wire, followed by advancement of the antegrade guide wire into the distal true lumen (controlled antegrade and retrograde tracking and dissection[CART] , Figure 6).¹²
2. Inflating a balloon over the antegrade guide wire, followed by advancement of the retrograde guide wire into the proximal true lumen (reverse CART, Figure 6).

Several variations of the CART techniques have been reported, such as the intravascular ultrasound (IVUS)-guided CART¹³ and the confluent balloon¹⁴ technique (Figures 6 and 7).

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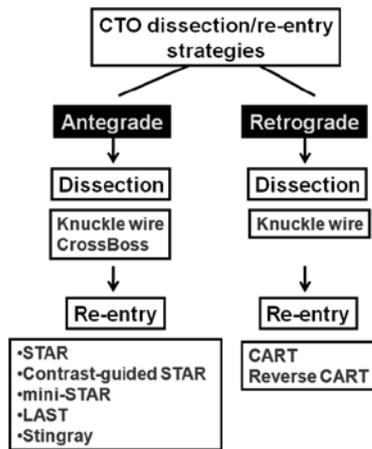


Figure 1. Classification of the chronic total occlusion dissection/reentry strategies. CTO, chronic total occlusion; STAR, subintimal tracking and reentry; LAST, limited antegrade subintimal tracking; and CART, controlled antegrade and retrograde tracking and dissection.

Published Studies

Several studies have reported mainly acute procedural outcomes after CTO PCI using dissection/reentry techniques, as summarized in Tables 1 and 2.

Antegrade Strategies

STAR

The STAR technique was initially described by Colombo et al in 2005.³ It was used in 31 consecutive patients with native coronary artery CTOs (87% in the right coronary artery) in whom conventional crossing failed; 21 patients (87%) had failed prior CTO PCI attempts. Procedural success was achieved in 30 patients (97%), 21 of whom had complete success (defined as *Thrombolysis in Myocardial Infarction* 3 flow in most distal branches). Three patients had a perforation (requiring implantation of a covered stent in 1 patient) and 1 patient had acute stent thrombosis 2 hours after the procedure requiring repeat PCI. Five patients (16%) had periprocedural myocardial infarction. Angiographic follow-up was performed in 21 patients (68%) during a mean follow-up of 5.1 ± 3.7 months, and 11 of those patients (52%) required repeat intervention of the target vessel because of nonocclusive ($n=6$) or occlusive ($n=5$) restenosis. However, 5 of those 11 patients had initially received bare-metal stents. In summary, in the initial publication of the STAR technique, excellent procedural success was obtained, despite of limited use of dual coronary injection (used in only 4 patients); however the restenosis rate (including occlusive restenosis) was high, in part because of the use of bare-metal stents in some patients. As a result, the authors recommended using this technique as a last resort, when other techniques and devices fail to cross the CTO. Moreover, they recommended not using it in vessels with major side branches that could be compromised with subintimal dissection, such as in the left anterior descending artery.

Contrast-Guided STAR

The contrast-guided STAR technique was initially described by Carlino et al⁴ in 2008 in an attempt to simplify the STAR technique. In this technique, a stiff guide wire is used to puncture the proximal CTO cap sufficiently to insert the distal tip of

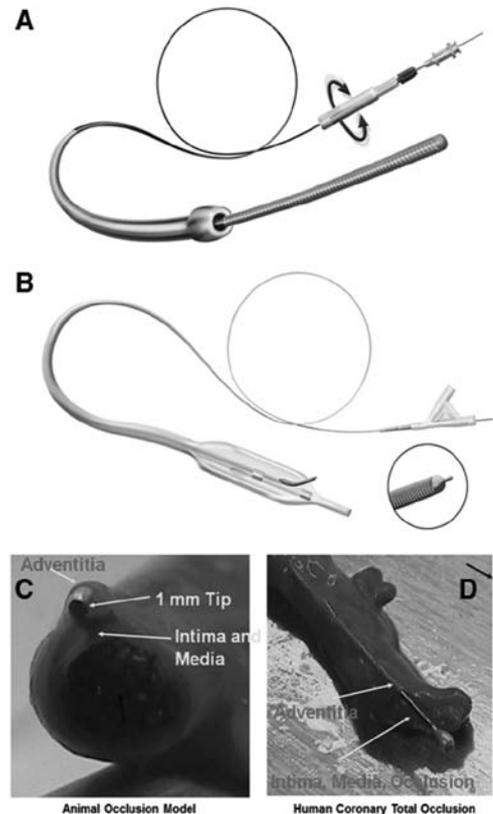


Figure 2. A, Illustration of the CrossBoss Catheter, which is an over-the-wire device (0.014" guide wire compatible) with a 1-mm rounded tip, a coiled shaft, and a moveable proximal torque device that releases under high torque to prevent product damage. B, Illustration of the Stingray chronic total occlusion (CTO) reentry system, with its 2 components: the Stingray CTO orienting balloon catheter and the Stingray CTO reentry guide wire. The Stingray balloon has 2 side exit ports located on diametrically opposite balloon surfaces immediately proximal to 2 radiopaque markers (yellow bands in the Figure). The flat shape of the Stingray balloon orients 1 exit port automatically toward the vessel true lumen upon low-pressure inflation (2–4 atm). The Stingray guide wire has a 0.0035-inch distal taper (image insert) allowing it to reenter the true vessel lumen through the exit port of the Stingray balloon after subintimal passage of the guide wire. C and D, Illustration of the CrossBoss catheter use in an animal (C) or human (D) occlusion specimens. (Provided by Bridgepoint Medical, Minneapolis, MN.)

an over-the-wire balloon or microcatheter into the lesion. After removing the guide wire, 1 to 2 mL of contrast are injected into the CTO leading to 3 possible outcomes: (1) visualization of the distal true lumen, in which case a floppy guide wire is used to cross the occlusion; (2) no distal visualization and resistance to injection, in which case a guide wire is used to further advance the balloon deeper into the lesion with repeat contrast injection; and (3) visualization of a dissection, which could be of 2 types: tubular dissection and storm cloud dissection. When tubular dissection (linear contrast opacification consistent with the vessel outline) is observed, further contrast injections are performed to open the dissection into the distal true lumen; but if this is not successful, a polymer jacketed knuckle wire is inserted and advanced until it enters the distal true lumen. If storm cloud dissection is observed (diffuse staining of contrast media), the authors recommended stopping in most cases, or trying to convert the storm cloud into

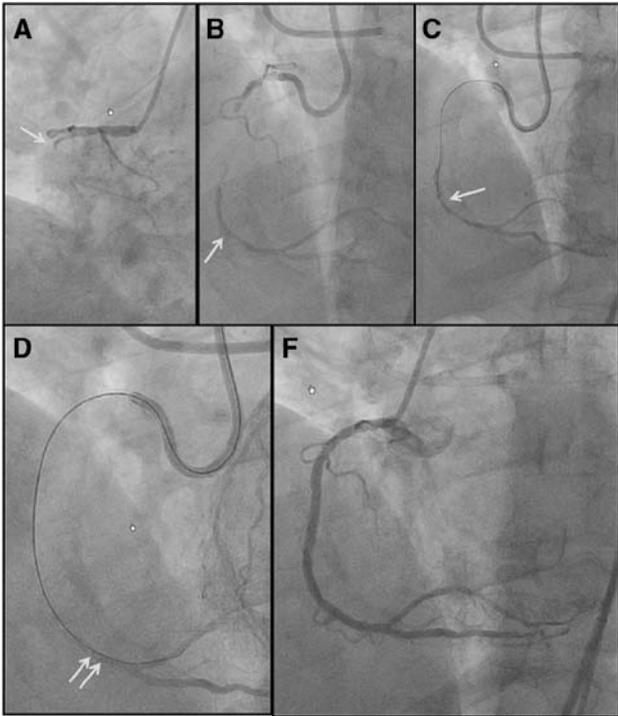


Figure 3. Use of the CrossBoss catheter (Bridgepoint Medical), knuckle wire, and Stingray balloon and wire (Bridgepoint Medical) for subintimal crossing. Chronic total occlusion of the proximal right coronary artery (arrow; **A**) with distal filling via collaterals from the left anterior descending artery (arrow; **B**). Using a CrossBoss catheter (Bridgepoint Medical) and a knuckle wire (arrow; **C**) the lesion was crossed subintimally. Using the Stingray balloon (arrows; **D**) and wire (Bridgepoint Medical) the wire was advanced into the distal right coronary artery, as confirmed by contralateral injection (**D**), with an excellent angiographic result after stent implantation (**E**).

tubular dissection when the dissection is not too large and the lumen of the vessel distal to the dissection can be identified.

The contrast-guided STAR technique was used in 68 consecutive patients with native coronary artery CTOs (79% in the right coronary artery), after a conventional technique resulted in a dissection (in 69%) or as a primary strategy (in the remaining 31%).⁴ Angiographic success was achieved in 55 patients (81%), 48 of whom had complete recanalization. Five patients (7%) had a perforation that was treated conservatively in all patients but required discontinuation of the procedure in 3 patients. One patient had ventricular fibrillation 2 hours after the procedure requiring repeat PCI to treat residual dissection. During a median follow-up of 7 months, 38 patients had angiographic follow-up showing restenosis

in 17 (45%), which was occlusive in 6 of those 17 patients (35%). The frequency of target lesion revascularization was 29% among patients who had received drug-eluting stents. In a subsequent publication from the same group, during a median follow-up of 2.1 years of 74 patients who underwent treatment with the contrast-guided STAR technique the restenosis rate was 54%, compared with 30% in patients undergoing conventional antegrade CTO recanalization.¹⁵ Approximately 40% of restenosis in both groups was occlusive and on multivariable analysis, stent length was the only independent predictor of restenosis.

Hence, the contrast-guided STAR technique is subject to relatively high rates of perforation and restenosis, even with drug-eluting stent use, likely because of the need for stenting long coronary artery segments. That is why STAR and contrast-guided STAR are only recommended after the failure of standard antegrade and retrograde techniques.⁴

The Mini-STAR and LAST Techniques

A second modification of the STAR technique is the mini-STAR technique, which was recently described by Galassi et al.⁵ A Fielder FC or XT guide wire (Asahi Intecc) is used. In contrast to the STAR and guided-STAR technique, in which an umbrella handle wire configuration is made before insertion through the microcatheter, in the mini-STAR technique 2 curves are placed on the wire, a small first curve (40°–50°) at the distal end (1–2 mm proximal to the tip) and second curve (15°–20°) 3 to 5 mm proximal to the tip. The wire is advanced toward the CTO resulting either in distal true lumen crossing or the wire forms a J-loop that is advanced for subintimal penetration of the CTO, followed by efforts to reenter the true lumen as proximally as possible limiting the length of the dissection plane.

The mini STAR technique was used in 42 of 225 consecutive CTO procedures, in which a first antegrade or retrograde approach had failed. Recanalization was successful in 41 of 42 patients (98%).⁵ In contrast, success was only 52% among patients in whom conventional crossing strategies (such as parallel wire, STAR, microchannel technique, IVUS-guidance, and anchor balloon) were used. Four patients treated with mini-STAR developed a perforation, but only 1 patient had tamponade requiring pericardiocentesis, and 1 patient had a periprocedural myocardial infarction. There are no long-term published data on the outcomes after use of the mini-STAR technique.

The LAST⁶ technique is similar to mini-STAR; however, instead of advancing a Fielder FC or XT wire (Asahi Intecc) to reenter the distal true lumen (which can be challenging in large vessels), a Confianza Pro 12 (Asahi Intecc) or Pilot 200

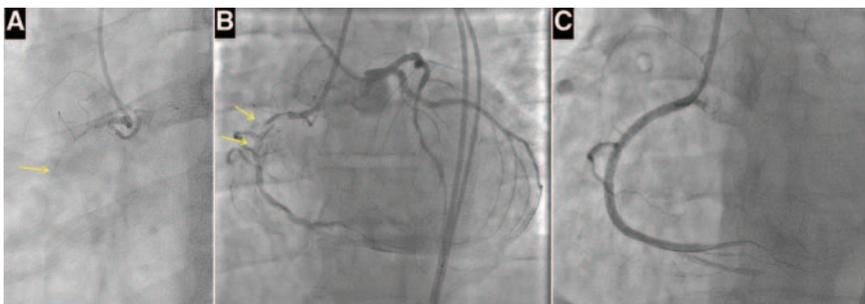


Figure 4. Contrast-guided subintimal tracking and reentry technique. Chronic total occlusion of the proximal right coronary artery (arrow; **A**), treated with injection of contrast via a microcatheter resulting in subintimal contrast entry (arrows; **B**) into the distal true lumen, with successful recanalization after stenting (**C**).

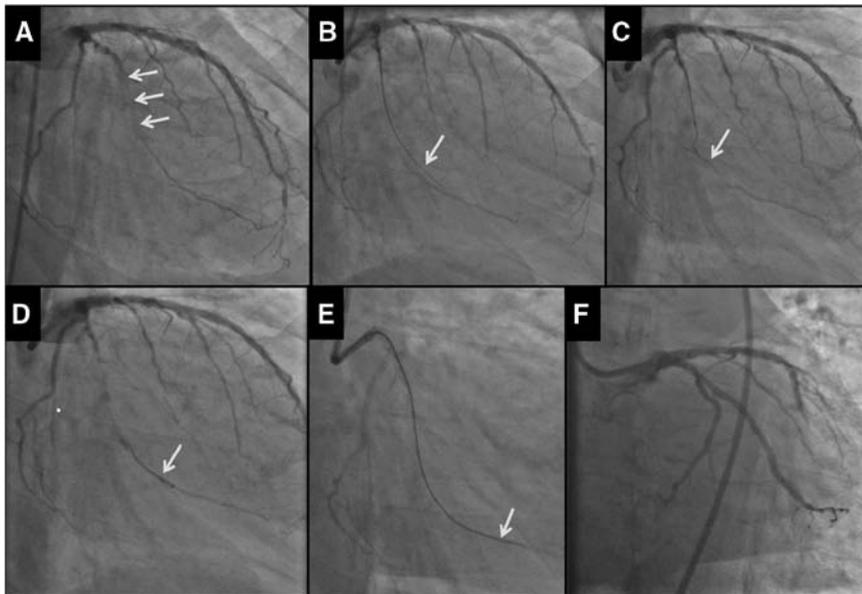


Figure 5. Use of the limited antegrade subintimal tracking (LAST) technique. Chronic total occlusion of the ramus intermedius branch (arrows; **A**). Crossing attempts with a Confianza Pro 12 wire (Abbott Vascular) failed (arrow; **B**). A Fielder XT wire (Asahi Intecc) remained intraluminal but could not cross the occlusion (arrow; **C**). The Fielder XT wire was advanced until a knuckle formed at its tip (arrow; **D**) that crossed the CTO into the subintimal space. A Confianza Pro 12 guide wire was used to reenter into the distal true lumen (arrow; **E**), with an excellent final angiographic result after stenting (**F**).

(Abbott Vascular) wire with an acute distal bend is used. There are no published data on the short and long-term outcomes of this technique.

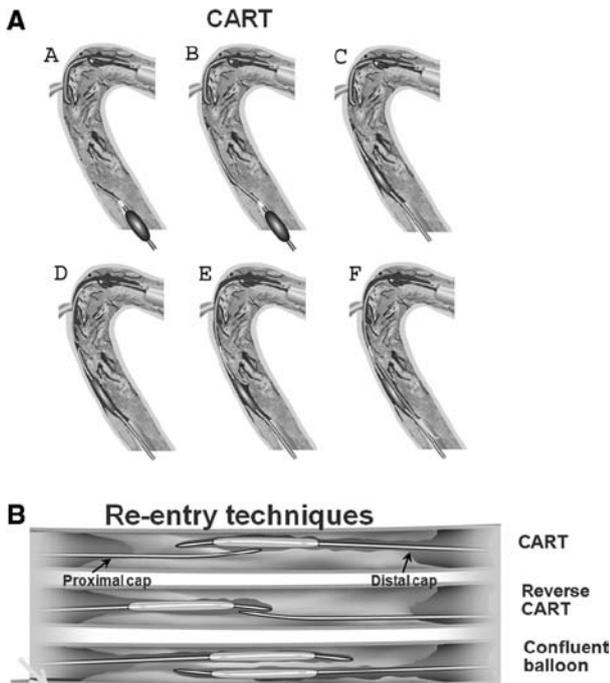


Figure 6. Illustration of reentry techniques used during retrograde chronic total occlusion (CTO) interventions. **1.** Step-by-step illustration of the controlled antegrade and retrograde tracking and dissection technique (reproduced with permission from Surmely et al).¹² The retrograde guide wire reaches the distal CTO cap (**1A**) and is advanced into the chronic total occlusion (CTO) subintimal space (**1B**). A balloon is advanced over the retrograde guide wire into the subintimal space (**1C**) where it is inflated (**1D**), enabling advancement of the antegrade guide wire into the space created by the balloon (**1E**), which communicates with the distal true lumen (**1F**). **2.** Illustration of the controlled antegrade and retrograde tracking and dissection (CART), reverse CART, and confluent balloon techniques (reproduced with permission from Brilakis et al).¹⁰

The Bridgepoint System for Antegrade Crossing and Reentry

In contrast to the above-described techniques that are based on using commercially available guide wires and microcatheters for subintimal crossing and reentry of CTOs, there is currently an Food and Drugs Administration–approved system, specifically designed for CTO crossing and reentry. The CrossBoss catheter (Bridgepoint Medical) is a stiff, metallic, over-the-wire catheter with a 1-mm blunt, hydrophilic-coated distal tip that can advance through the occlusion when the catheter is rotated rapidly using a proximal torque device (fast-spin technique). If the catheter enters the subintimal space, it creates a limited dissection plane making reentry into the distal true lumen easier. The risk of perforation is low provided that the CrossBoss catheter (Bridgepoint Medical) is not advanced into the side branches. If the CTO is crossed subintimally the Stingray balloon and guide wire (Bridgepoint Medical) can be used to assist with reentry into the distal true lumen, as described above.⁷⁻⁹

In the Facilitated Antegrade Steering Technique in Chronic Total Occlusions (FAST-CTOs) trial, the Bridgepoint system was used in 147 patients with 150 refractory CTOs with 77% crossing success: the CrossBoss crossed into the distal true lumen in 56 lesions and the Stingray balloon and wire facilitated distal true lumen reentry in 59 lesions.² In a series of 42 patients at 4 European centers, successful true lumen distal wire passage was achieved in 67% without any severe device-related complications.¹⁶ Whitlow et al reported successful reentry in 16 of 19 cases with subintimal wire entrapment using the Stingray system with one grade 1 perforation that did not require any treatment.³⁵

The CrossBoss catheter may be useful for crossing CTO because of in-stent restenosis, as the preexisting stent may prevent the CrossBoss catheter from entering the subintimal space, facilitating true-to-true lumen recanalization.³⁶ Although the Stingray balloon and wire can be used for distal reentry after knuckle wire crossing,⁹ use with the CrossBoss catheter is preferred, as it limits the extent of subintimal

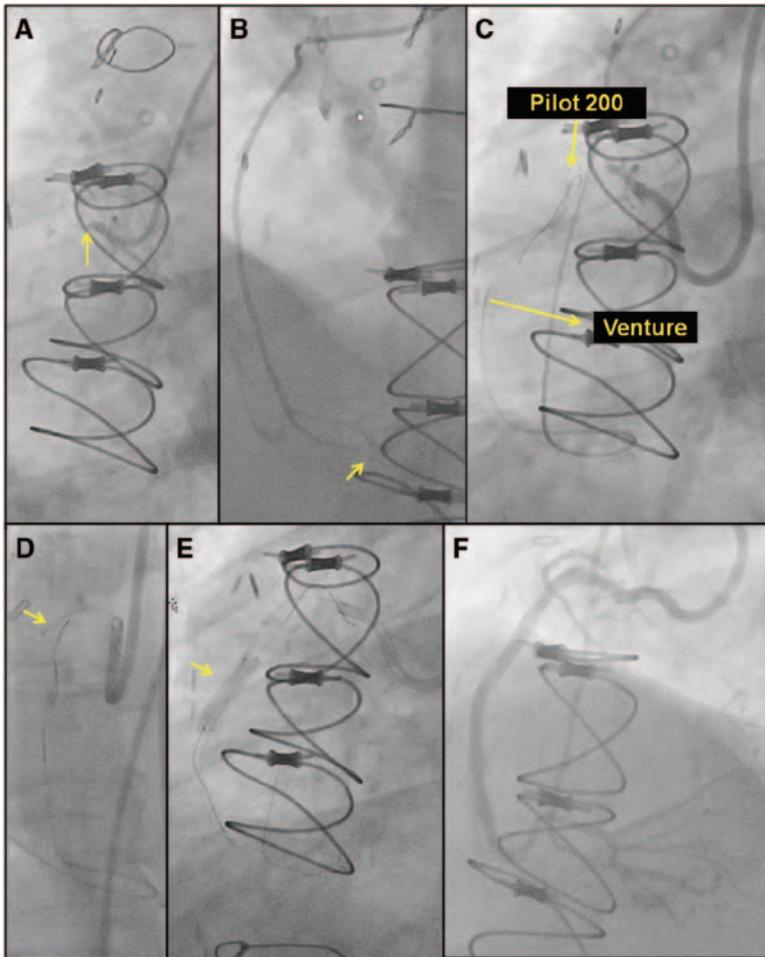


Figure 7 .Illustration of the confluent balloon technique. Chronic total occlusion of the proximal right coronary artery (arrow; **A**) with filling of the right posterior descending artery via a diffusely diseased saphenous vein graft with a distal anastomotic lesion (arrow, **B**). Using a Venture catheter (St. Jude Medical) and a Pilot 200 wire (Abbott Vascular) formed into a knuckle (arrow; **C**), the chronic total occlusion (CTO) was crossed subintimally. A CrossBoss catheter (Bridgepoint Medical) was used for antegrade crossing (arrow; **D**), followed by the inflation of two 2.5-mm balloons (1 advanced over the antegrade and 1 over the retrograde guide wire (arrow; **E**) (confluent balloon technique) the CTO was successfully crossed with an excellent result after stent implantation (**F**).

dissection that could compress the distal true lumen and hinder reentry efforts. There are currently no long-term follow-up data with use of the Bridgepoint system. Hence, although the Bridgepoint system is an important addition to the CTO toolbox the available data supporting its use is limited.

Studies reporting on antegrade CTO dissection/reentry strategies are summarized in Table 1.^{3-6,15,16}

Retrograde Strategies

Although the retrograde guide wire may cross into the proximal true lumen in 15%–40% of the cases, more commonly it enters the subintimal space. Techniques similar to those used for antegrade dissection/reentry can also be used for retrograde dissection/reentry (except use of the Bridgepoint system, which is too stiff and bulky to be advanced through collaterals). Moreover, specialized techniques have been developed for reentry into the true lumen during retrograde CTO PCI.¹⁰⁻¹⁴

CART

CART technique for coronary CTO recanalization was originally described by Surmely et al in 2006.¹² A wire is advanced in the antegrade direction from the proximal true lumen into the subintimal space at the CTO site. Another wire is advanced in the retrograde direction via a collateral vessel into the distal true lumen and then into the CTO subintimal space. A balloon is advanced in retrograde fashion into the CTO

subintimal space and is inflated enlarging the space that is subsequently entered by advancement of the antegrade guide wire. However, retrograde balloon advancement through a collateral vessel can be challenging and may require multiple low-pressure small balloon inflations for septal collateral vessel dilation. Occasionally larger diameter balloons may fail to cross the collateral vessel. Saito et al reported proximal true lumen reentry in 30% and CART in 27% of 45 consecutive retrograde CTO PCI patients.¹⁹ Similarly, Rathore et al used retrograde true lumen puncture in 25% and CART in 41% of 157 consecutive retrograde CTO PCI procedures.²⁰ Bufo et al used reverse CART in 36%, retrograde true lumen puncture in 18%, and CART in 14% of 56 retrograde CTO PCI.³²

Reverse CART

The reverse CART technique is similar to CART, except that a balloon is advanced to the proximal part of the occlusion over the antegrade guide wire and the retrograde wire crosses into the proximal true lumen. Since the development of the Corsair catheter (Asahi Intecc), reverse CART has become the most commonly used retrograde reentry technique, as retrograde balloon access is not required.²⁸ In a series of 93 consecutive patients in whom the Corsair catheter was used, reverse CART was used in 61%, CART in 11%, and wire-based crossing only in the remaining 28%.²⁸ In contrast, in 93 CTO PCI performed during the period preceding use of the Corsair, CART was used in 64%, reverse CART in 4%, and wire-based crossing only in

Table 1. Published Studies on Antegrade Subintimal Dissection/Reentry Strategies for Coronary Chronic Total Occlusion Recanalization

Author	Year	N	Technique	Acute Results	FU Outcomes
Colombo et al ³	2005	31	STAR	Success: 96.8% Acute stent thrombosis: 1 pt (3.2%) NSTEMI: 5 pts (16%) CABG: 0 Death: 0	30 d: no MACE During a mean FU of 5 mo, all remained symptom free but angiographic FU showed in-stent restenosis requiring TLR in 52%
Carlino et al ⁴	2008	68	Contrast-guided STAR	Success: 80.9% NSTEMI: 7 pts (10%) Perforation: 3 pts (4.4%) CABG: 0 Death: 0	During a median FU of 7 mo 1 pt died. Angiographic FU in 38 pts (56%) showed 45% in-segment angiographic restenosis.
Lombardi et al ⁶	2009	0	(LAST)	Technical description only, no patient data published	NA
Godino et al ¹⁵	2011	74	Contrast-guided STAR	Only cases with successful CTO recanalization were included in this FU study.	Median FU of 26 mo Death: 3 pts (4.1%) MI: 2 (2.7%) CABG: 2 (2.7%) TVR: 35 (47.9%)
Werner et al ¹⁶	2011	42	CrossBoss+Stingray (Bridgepoint Medical)	Success: 67% MI: 2 pts (4.7%) Perforation: 0 CABG: 0 Death: 0	NA
Galassi et al ⁵	2012	42	Mini-STAR	Success: 97.6% MI: 1 pt (2.4%) Coronary perforation type III: 1 pt (2.4%) CABG: 0 Death: 0	NA
Whitlow ²	2012	147 patients-150 CTO	CrossBoss+Stingray (Bridgepoint Medical)	Success: 77% Coronary perforation: 14 patients (14.3%) Tamponade:) CABG: 0 Periprocedural MI: 6 patients (4.1%) Death at 30 days: 2 (unrelated to CTO intervention)	Long-term FU: NA

FU indicates follow-up; STAR, Subintimal tracking and reentry; NSTEMI, non-ST segment elevation acute myocardial infarction; CABG, coronary artery bypass graft surgery; MACE, major adverse cardiac events; NA, not available; TLR, target lesion revascularization; LAST, limited antegrade subintimal tracking; TVR, target vessel revascularization; and CTO, chronic total occlusion.

the remaining 33%. Procedural success was higher when the Corsair catheter was used and fluoroscopy time was lower.²⁸

Rinfret et al used reverse CART in 60% of 42 consecutive CTO PCI cases done using bilateral radial access.²² The CART registry is the largest reported experience with the retrograde approach from 2 highly-skilled CTO operators from Japan. In 224 consecutive patients in whom a retrograde approach was used between 2005 and 2008, the CART or reverse CART technique was used in 62.6% of cases and the final procedural success rate was 92.4%.²² The complication rate was low with 3.1% incidence of perforations, 1 death (because of renal artery rupture from a guide wire), and 1 emergency coronary artery bypass graft surgery because of coronary rupture after use of rotational atherectomy.

Intravascular Ultrasound-Guided Reverse Controlled Antegrade and Retrograde Tracking—the IVUS-Guided Reverse CART

Rathore et al described a modification of the reverse CART technique by using IVUS (IVUS-guided reverse CART).¹³ After initial antegrade balloon inflation with a small-size

(usually 2.0 mm) balloon, an IVUS catheter is advanced in the antegrade direction into the CTO segment, allowing selection of an adequate sized balloon based on the vessel size and the presence of calcification (smaller balloons are used in calcified vessels to reduce the risk of perforation). After balloon dilation, IVUS is used to visualize the connecting channel and if recoil is observed a wire snare can be used to keep the connecting channel open.¹³ IVUS can then be used to visualize and confirm crossing of the retrograde guide wire into the proximal true lumen. IVUS-guided reverse CART was used in a series of 31 consecutive patients, 22 of whom (71%) had prior failed CTO PCI attempts) with 100% procedural success and no major complications.¹³

Confluent Balloon Technique

The confluent balloon technique, which was described by Wu et al in 2009, is a modification of the reverse CART and CART techniques in which antegrade and retrograde balloons are inflated simultaneously to create a common subintimal space which will allow wire crossing into the true lumen.¹³

Table 2. Published Studies (Including ≥10 Patients) on Retrograde Subintimal Dissection/Reentry Strategies for Coronary Chronic Total Occlusion Recanalization

No.	Author	Year	N	Technique	Acute Results	FU Outcomes
1	Surmely et al ¹²	2006	10	CART: 100%	Success: 100% No complications.	NA
2	Di Mario et al ¹⁷	2007	17	CART: 24% knuckle: 12% Retrograde true lumen puncture: 41%	Success: 88.2% No complications (no myocardial infarction, in-hospital death or pericardial effusion).	NA
3	Sianos et al ¹⁸	2008	175	CART: 34% Marker wire/knuckle: 48% Retrograde true lumen crossing: 28%	Success: 83.4% Septal rupture and hematoma: 6.9% MI: 4% Transient ischemic attack=0.6% Wire entrapment=0.6%	NA
4	Saito et al ¹⁹	2008	45	CART: 27% Just landmark: 32% Proximal true lumen puncture: 30%	Success: 84% STEMI: 1 pt (2.2%) Ventricular fibrillation: 1 pt (2.2%) Acute heart failure: 1 pt (2.2%) Tamponade: 1 pt (2.2%) Dissection: 1 pt (2.2%)—treated by stenting. All complications occurred during antegrade crossing attempts	NA
5	Rathore et al ²⁰	2009	157	CART: 40.8% Retrograde true lumen crossing: 24.8%	Success: 85% Q-wave MI: 1 pt Non-Q-wave MI: 5 pts Urgent CABG: 1 pt Death: 0	NA
6	Chung et al ²¹	2009	28 pts/31 lesions	CART: 3.2% Loop method: 16.1% Marker wire: 16.1% Kissing wire: 45.2%	Success: 64.5% Non-Q-wave MI: 1 pt Death: 1 pt Urgent revascularization: 1 pt	NA
7	Kimura et al ²²	2009	224	CART: 62.6%	Success: 90.6% Complications MACE: 4 pts (1.8 %) Q-wave MI: 2 pts (0.9%) Non-Q-wave MI: 8 pts (3.6%) Perforation: 8 pts (3.1%) CABG: 1 pt (1%) (because of coronary rupture) Death: 1 pt (0.4%) (renal artery rupture by tip of guidewire)	NA
8	Tsujita et al ²³	2009	25/48	IVUS comparison of retro vs ante approach for CTO PCI	Success: 100% No complications	NA
9	Thompson et al ²⁴	2009	122/636	CART: 15% Reverse CART: 9% Kissing wire: 32% Retrograde true lumen puncture: 25%	Success: 81.1% Complications not reported separately for retrograde procedures	NA
10	Rathore et al ²⁵	2009	83	CART:100%	Success: 86.2% Q-wave MI: 0 Non-Q-wave MI: 4 (4.5%) Tamponade: 1 (1.1%) CABG: 0 Death: 0	NA
11	Hsu et al ²⁶	2009	50	Use of retrograde dissection/reentry techniques was not reported	Success: 80% NSTEMI: 6% Death: 0	NA
12	Ge et al ²⁷	2010	42	CART: 8.8% Reverse CART: 83.8% Kissing wire: 35.3% Retrograde wire crossing: 2.9%	Success: 88% Non-Q wave MI: 4 pts (7.7%) Emergent CABG: 0 Death: 0	NA
13	Tsuchikane et al ²⁸	2010	93	CART: 10.9% Reverse CART: 60.9% Retrograde wire crossing: 20.6% Kissing wire: 7.6%	Success: 96.8% Non-Q wave MI: 4 pts (5.4%) Tamponade: 0 Emergent CABG: 0 Death: 0	NA

(continued)

Table 2. (Continued)

No.	Author	Year	N	Technique	Acute Results	FU Outcomes
14	Rathore et al ¹³	2010	31	CART: 6.5% Reverse CART: 93.5% (IVUS guided)	Success: 100%. Perforation: 3 pts (9%) Tamponade: 0 CABG: 0 Death: 0	NA
15	Morino et al ²⁹	2010	136	Multicenter CTO registry in Japan: 136 of 528 pts underwent retrograde CTO PCI. Frequency of dissection/reentry techniques not reported	Success: 79.2% Complications not reported separately for retrograde procedures	NA
16	Lee et al ³⁰	2010	24	CART: 22% Reverse CART: 11% Retrograde wire crossing: 44% Kissing wire: 22%	Success: 88%. Tamponade: 1 pt (4.2%)—because of epicardial collateral perforation Donor vessel stent thrombosis: 1 pt (4.2%) Donor vessel dissection: 3 pts (12.5%)	During a median FU of 10.3 mo overall MACE rate was 18%
17	Galassi et al ³¹	2011	234	CART: 31.8% Knuckle: 8.7% Retrograde wiring: 37.2% Touching wire: 22.3%	Success: 64.5% Perforation: 11 (4.7%) Tamponade: 2 (0.8%) Non-Q-wave MI: 5 (2.1%) Q-wave MI: 1 (0.4%) CABG: 0 Death: 1 pt (0.4%)	NA
18	Bufe et al ³²	2011	56	CART: 14.3% Reverse CART: 35.7% Retrograde wiring: 17.9% Marker wire: 17.9%	Success: 62.5% Complications not reported separately for retrograde procedures	NA
19	Wu et al ³³	2011	85	Bilateral radial approach. CART: 29.4% Reverse CART: 8.2% Marker/kissing wire: 43.5% Knuckle: 5.9%	Success: 87%. Tamponade: 3 pts (3.5%) Donor vessel dissection: 3 pts (3.5%) Collateral perforation: 7 pts (8.2%) Emergent CABG: 0 Death: 0	NA
20	Rinfret et al ³⁴	2011	42	Bilateral transradial approach. Reverse CART: 60%	Success: 88% Coronary perforation type 1: 5 pts (12%) Coronary perforation type 2: 1 pt (2%) Donor artery thrombosis: 1 pt (2%) Donor vessel dissection: 1 pt (2%) Mild tamponade: 1 pt (2%)—treated conservatively	NA

FU indicates follow-up; CART: Controlled Antegrade and Retrograde Tracking and Dissection; MI, myocardial infarction; STEMI, ST-segment elevation acute myocardial infarction; CABG, coronary artery bypass graft surgery; MACE, major adverse cardiac events; NA, not available; NSTEMI, non-ST segment elevation acute myocardial infarction; CTO, chronic total occlusion; pt, patient; IVUS, intravascular ultrasound; pt, patient; and PCI percutaneous coronary intervention.

Studies using various retrograde dissection/reentry strategies are summarized in Table 2.^{12, 13, 17–34}

Application of Subintimal/Dissection Techniques and Future Directions

Currently, use of antegrade subintimal dissection and reentry techniques is recommended by most operators as a second or third line strategy once conventional antegrade or retrograde crossing attempts fail. Some operators, however, advocate early use of antegrade dissection/reentry strategies for long lesions, in which true-to-true lumen crossing is unlikely, suggesting that early use of such techniques may be associated with higher likelihood of successful crossing without excessive use of fluoroscopy and contrast.³⁷ This approach is facilitated by the availability of dedicated dissection/reentry devices (CrossBoss catheter and Stingray

balloon and wires), which can make the procedure faster and safer.

Although use of antegrade dissection reentry techniques appears safe, they still carry risk for perforation (ranging from 0.4%–5.0%), which may not become evident until after stent implantation is performed and may be Ellis grade 3 requiring placement of a covered stent. These techniques may also carry higher risk for periprocedural myocardial infarction (Table 1), likely because of occlusion of coronary side branches. Occasionally side branch occlusion may result in ST-segment elevation if there is no collateral circulation to these areas of the myocardium (Figure 8). Dissection/reentry is especially challenging in patients with a bifurcation at the distal cap, as reentry can usually be achieved in only 1 of the branches, requiring additional techniques (such as retrograde crossing) for restoring patency of the other branch.

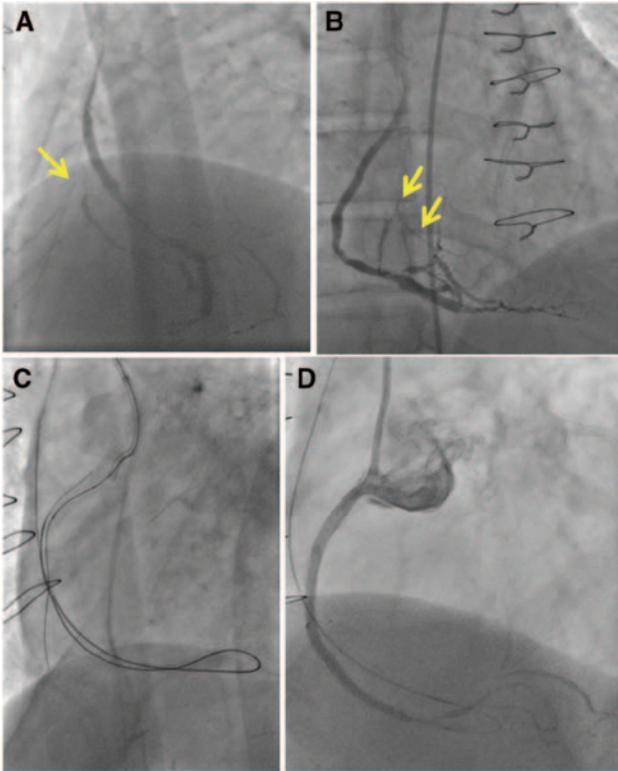


Figure 8. Acute side branch occlusion during a retrograde chronic total occlusion (CTO) intervention. Chronic total occlusion of the mid-right coronary artery that filled by a diffusely diseased saphenous vein graft (A). A large acute marginal branch originated at the distal CTO cap (arrow, A; and arrows, B). Successful retrograde recanalization was achieved using a retrograde true lumen puncture technique (C). After stent placement antegrade flow to the distal right coronary artery was restored, but the acute marginal branch became occluded leading to inferolateral ST-segment elevation and postprocedural acute myocardial infarction.

Occlusion of side branches can also lead to reduced outflow increasing the risk for restenosis, including occlusive restenosis. Use of extensive dissection/reentry is less optimal in the left anterior descending artery because of the numerous septal and diagonal side branches. Dissection crossing techniques can cause subintimal hematomas that may compress the distal true lumen and hinder reentry attempts. Aspiration through a microcatheter may decompress the hematoma and allow reexpansion of the distal true lumen (Subintimal TRANscatheter Withdrawal [STRAW] technique). Whether use of limited dissection/reentry (mini-STAR, LAST, Bridgepoint Medical system) will be associated with lower restenosis rates compared with more extensive dissection/reentry strategies (STAR and contrast-guided STAR) remains to be determined. Also, the risk for less frequent complications, such as aneurysm formation (which theoretically would be higher with dissection/reentry techniques), is still poorly studied.³⁸ Aneurysm formation could also result in blood pooling and predispose to stent thrombosis or restenosis.

Similarly, although retrograde dissection/reentry techniques have become a critical part of retrograde CTO PCI procedures (with reverse CART being used in approximately half of retrograde CTO PCI cases), the long-term outcomes of retrograde dissection/reentry techniques are poorly studied.

Hence, long-term clinical and angiographic follow-up of patients undergoing dissection/reentry CTO PCI (both antegrade and retrograde) is needed to assess the long-term safety and efficacy of these approaches.

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