JACC: CARDIOVASCULAR INTERVENTIONS
© 2012 BY THE AMERICAN COLLEGE OF CARDIOLOGY FOUNDATION
PUBLISHED BY ELSEVIER INC.
VOL. 5, NO. 4, 2012
ISSN 1936-8798/$36.00
DOI: 10.1016/j.jcin.2012.02.006

STATE-OF-THE-ART PAPER

A Percutaneous Treatment Algorithm for Crossing Coronary Chronic Total Occlusions

CME

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CME Objective for This Article: At the end of this activity the reader would be able to: 1) discuss the strengths and limitations of different wire crossing strategies for coronary chronic total occlusions; 2) determine an optimal procedural planning strategy for crossing coronary chronic total occlusions by evaluating four key angiographic parameters; and 3) discuss the role and optimal use of various types of equipment that are available for facilitating crossing of coronary chronic total occlusions.

CME Editor Disclosure: *JACC: Cardiovascular Interventions* CME Editor Habib Samady, MB, ChB, FACC, has research grants from the Wallace H. Coulter Foundation, Volcano Corp., St. Jude Medical, Forrest Pharmaceuticals Inc., and Pfizer Inc.

Author Disclosure: Dr. Brilakis has received speaker honoraria from St. Jude Medical and Terumo; research support from Abbott Vascular and InfraReDx; and his spouse is an employee of Medtronic. Dr. Grantham has received grants and honoraria from Abbott Vascular, BridgePoint Medical, and Vascular Solutions, all paid directly to Saint Luke's Hospital Foundation. Dr. Rinfret has received honoraria for proctorship from Abbott Vascular and BridgePoint Medical and honoraria for conference from Terumo and BridgePoint Medical. Dr. Wyman is a consultant/honoraria from Abbott Vascular, BridgePoint Medical, Terumo, and Boston Scientific; and has equity in BridgePoint Medical. Dr. Burke is a consultant for BridgePoint Medical and Terumo Medical. Dr. Karmpaliotis is on the speaker's bureau of Abbott Vascular and Medtronic; and is a consultant for BridgePoint Medical. Dr. Lembo is on the speaker's bureau of Medtronic; he is on the advisory board of Abbott Vascular and Medtronic; and he is a proctor for BridgePoint Medical. Dr. Pershad has received speaker honoraria from Medtronic and Abbott Vascular; and consulting fees from BridgePoint Medical. Dr. Kandzari's institution (Piedmont Heart Institute) has received educational grants from BridgePoint Medical; and he has received research/grant support from and is a consultant for Abbott Vascular, Medtronic CardioVascular, and Boston Scientific. Dr. Buller is a consultant for Abbott Vascular and AstraZeneca. Dr. DeMartini is a consultant for and on the speaker's bureau of Abbott Vascular. Dr. Lombardi is a consultant for Abbott Vascular, BridgePoint Medical, and Medtronic; has received speaker honoraria from Abbott Vascular, Medtronic, Boston Scientific, and Terumo (all funds paid to his institution - PeaceHealth); and has equity in BridgePoint Medical. Dr. Thompson is a consultant for Abbott Vascular, BridgePoint Medical, Terumo, and Volcano; and has equity in BridgePoint Medical.

Medium of Participation: Print (article only); online (article and quiz).

CME Term of Approval:

Issue Date: April 2012
Expiration Date: March 31, 2013

JACC: CARDIOVASCULAR INTERVENTIONS, VOL. 5, NO. 4, 2012
APRIL 2012:367–79

A Percutaneous Treatment Algorithm for Crossing Coronary Chronic Total Occlusions

Coronary chronic total occlusions (CTOs) are frequently identified during coronary angiography and remain the most challenging lesion group to treat. Patients with CTOs are frequently left unrevascularized due to perceptions of high failure rates and technical complexity even if they have symptoms of coronary disease or ischemia. In this review, the authors describe a North American contemporary approach for percutaneous coronary interventions for CTO. Two guide catheters are placed to facilitate seamless transition between antegrade wire–based, antegrade dissection re-entry–based, and retrograde (wire or dissection re-entry) techniques, the "hybrid" interventional strategy. After dual coronary injection is performed, 4 angiographic parameters are assessed: 1) clear understanding of location of the proximal cap using angiography or intravascular ultrasonography; 2) lesion length; 3) presence of branches, as well as size and quality of the target vessel at the distal cap; and 4) suitability of collaterals for retrograde techniques. On the basis of these 4 characteristics, an initial strategy and rank order hierarchy for technical approaches is established. Radiation exposure, contrast utilization, and procedure time are monitored throughout the procedure, and thresholds are established for intraprocedural strategy conversion to maximize safety, efficiency, and effectiveness. (J Am Coll Cardiol Intv 2012;5:367–79) © 2012 by the American College of Cardiology Foundation

Percutaneous coronary intervention (PCI) of coronary chronic total occlusions (CTOs) has historically been limited by technical success rates of ~50% to 70%, despite being performed in highly selected cases (1–4). In the current era, however, operators and programs with higher CTO PCI–specific experience and modern techniques and technologies can consistently achieve technical success rates of ≥80% in a more unselected and complex population of CTO patients, as has been reported in Europe (5), Japan (6), the United States (7), and Canada (8). Although there are multiple reports on techniques that can result in successful CTO PCI, there is little published information on how these techniques can be used together, as part of a comprehensive procedural strategy. The goal of the present report is to propose an algorithmic approach to CTO PCI, in an attempt to demystify the field and create common ground among operators who are currently performing, or are interested in developing a CTO PCI program. The approach presented herein is based on the expert opinion of 13 high-volume North American CTO operators. The purpose of this proposed algorithm is to provide a consistent framework that can be used to evaluate patients considered for CTO PCI and provide a reproducible and teachable method to expand a base of interventionalists that perform safe, effective, and efficient CTO PCI.

Fundamentals and the Learning Curve

The current paper presupposes that experience with the requisite techniques and technologies has been established before applying the following algorithms. During the learning phase for CTO operators and CTO programs, these experiences may be more compartmentalized to certain

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Manuscript received December 1, 2011; revised manuscript received February 7, 2012, accepted February 9, 2012.

strategies, as there is often safety and technical equipoise between approaches. We recognize that it is not reasonable to propose algorithms that weigh toward methods that have not been accessible or employed by the emerging operators. Lifetime non-CTO PCI experience, although helpful, does not immediately translate to better CTO PCI techniques, as these techniques, wires, and devices are often employed in a manner that is counterintuitive to the standard PCI procedure. To this end, we strongly recommend local proctoring program and attendance at local and national CTO focused meetings to develop the didactic and clinical skill sets required for advanced CTO PCI. Although this paper cannot alleviate the need for proper proctorship of new CTO operators, it summarizes information often transmitted in teaching sessions in an organized manner. As the CTO PCI operator becomes more confident with wire selection, shaping, manipulation, device utilization, and advanced techniques (e.g., retrograde and antegrade re-entry techniques), a reasonable transition can occur to employ the following algorithms to optimize the CTO procedures in terms of efficiency, safety, and effectiveness. The learning curve and applications of the algorithms, however, need not be mutually exclusive in the proctored environment because the patient's anatomy will dictate strategies.

Indications for CTO PCI

A detailed, in-depth clinical assessment is critical before proceeding with CTO PCI. CTO PCI should only be performed if it carries a favorable risk/benefit ratio. CTO PCI can provide angina relief (9), improve exercise tolerance (10) and left ventricular function (11), improve tolerance of a future acute coronary syndrome (12), reduce the need for coronary artery bypass graft surgery (13), and possibly improve survival if successful (especially for PCI of left anterior descending artery CTOs) (2,14). Moreover, CTO PCI carries similar risk to non-CTO PCI (1). As with any type of coronary revascularization, CTO PCI will mostly benefit patients who have angina refractory to optimal medical management (15) and those with large ischemic burden.

Pre-Procedure Angiographic Review, Arterial Access, and the Role of Dual Selective Angiography for CTO PCI

Careful study of the target CTO lesion cannot be overemphasized: 20 min of pre-procedure review of the angiogram is often required to fully understand the CTO anatomy and collateral circulation. We discourage routine "ad hoc" CTO PCI because pre-planning facilitates a thoughtful procedural approach and estimation of the risk–benefit ratio in this complex lesion/patient subset. Understanding the vessel course and the presence, quality, and location of collateral vessels can allow rapid adjustments and change of strategies during the procedure and maximizes the likelihood of procedural success.

In the current report, we advocate a routine 2 guide catheter strategy, with a shortened (~90 cm long) catheter in the retrograde vessel to allow for seamless, efficient transition between antegrade and retrograde techniques in eligible patients. Long (35 to 45 cm) sheaths and large-bore guide catheters (7- to 8-F) are preferred for providing additional support and options, although experienced transradial operators can successfully perform CTO using smaller 6-F catheters (8). Dual arterial access is commonly used (bifemoral, biradial, femoral–radial). Alternative methods to augment guide catheter support include "mother and child" extensions, such as the GuideLiner catheter (Vascular Solutions, Minneapolis, Minnesota) (16) and various balloon anchoring techniques (17–19).

Dual injection is critical for performing CTO PCI and should be performed in every case where contralateral collaterals exist (20). Nonsimultaneous, single-catheter injection frequently provides suboptimal visualization of the CTO segment and limited ability to assess the proximal and distal caps, and distal vessel beyond the CTO, due to collateral competitive flow. In addition, single-catheter antegrade injection during dissection/re-entry techniques may result in hydraulic enlargement of the subintimal space and reduce the chances of successful re-entry. Filling the collateral bed with dual injection reduces non-contrast-containing competitive flow and provides optimal visualization of the CTO vessel. Furthermore, the collateral flow direction and strength of flow can shift from 1 source to another during the course of a procedure, likely due to collateral compromise as well as potential activation of vasoactive substances during intervention.

Abbreviations and Acronyms

CART = controlled antegrade and retrograde tracking

CTO = chronic total occlusion

LaST = limited antegrade subintimal tracking

OTW = over the wire

PCI = percutaneous coronary intervention

RAO = right anterior oblique

Dual injection is performed through selective coronary angiography from the CTO PCI target vessel and through another vessel (the contralateral coronary artery or a bypass graft) that provides collaterals to the distal target vessel. Dual injection is crucial for determining the lesion length and the size and location of the distal target vessel, evaluating whether there is a significant bifurcation at the distal cap, and for deciding on the optimal CTO PCI strategy (20). Occasionally, dual injection will reveal that the "CTO" may actually not be a total occlusion, but rather a "functional" occlusion with a central patent microchannel. Dual injection can reveal the presence, size, and tortuosity of collateral vessels and help determine whether a retrograde approach is feasible. Dual injection is also critical for clarifying the location of the angioplasty wire or other equipment during CTO crossing attempts.

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Dual injection is best performed at low magnification, with prolonged imaging exposure, and without table panning, to allow for optimal delineation of the CTO segment and collateral vessel location and course. To minimize radiation exposure, the donor vessel (vessel that supplies the territory distal to the CTO) is injected first, followed by injection of the occluded vessel (20). Bridging collaterals are important to recognize and avoid during both antegrade and retrograde crossing attempts to minimize the risk of vessel perforation, especially when advancing microcatheters and balloons. Septal collaterals are best visualized from a right anterior oblique (RAO) cranial view, or straight RAO view, whether the donor vessel is the posterior descending coronary artery or the left anterior descending coronary artery. Epicardial collaterals often need tailored views to assess their course, as they are often from diagonal, left circumflex, and right coronary posterolateral territories; the left anterior oblique and RAO cranial views are often the best to image distal lateral wall collaterals between obtuse marginal arteries and posterolateral arteries and diagonal to diagonal/obtuse marginal connections; and the RAO and anteroposterior caudal views are preferred for collaterals connecting the more proximal obtuse marginal arteries and those arising in the atrioventricular groove between the circumflex and right coronary arteries.

In patients with only ipsilateral collaterals, dual arterial access and dual injection may not be required, although in some cases, contralateral collaterals may appear if ipsilateral collaterals are compromised during CTO crossing attempts. Moreover, 2 guide catheters may be required if retrograde CTO crossing is performed via ipsilateral collaterals: 1 guide catheter is used to advance the retrograde guidewire, and a second one is used for externalizing the retrograde guidewire and/or antegrade wiring. Engagement of the target coronary artery is alternating between the antegrade and the retrograde guide catheter in a "ping-pong" fashion, enabling lesion crossing and equipment delivery (21).

The "Base of Operations"

The first goal of the proposed algorithm is to safely and efficiently establish guidewire and microcatheter position in the lesion segment known as the "base of operations." The purpose is to spend procedure time, radiation, and contrast focused on final recanalization of a short, isolated segment. The base of operations is typically at or near the distal cap for the antegrade direction and at or near the proximal cap for retrograde direction procedures. It is important to realize that this effective working segment may need to be shifted to a different location within the vessel, for example, beyond the distal cap for re-entry, or elsewhere in the CTO segment for controlled antegrade retrograde tracking (CART), reverse CART, and limited antegrade subintimal tracking (LaST), if refractory situations occur. The flexibility in the base of operations as well as strategic changes are critical to the application of the "hybrid" CTO PCI technique. We define the "hybrid" approach to CTO PCI, as the approach that focuses on opening the occluded vessel, using all feasible techniques (antegrade, retrograde, true-to-true lumen crossing or re-entry) in the most safe, effective, and efficient way.

Anatomy Dictates Initial Strategy

In the proposed algorithm, 4 angiographic characteristics determine the initial procedural approach in patients having CTO PCI:

1. Proximal cap location and morphology. This characteristic refers to the ability to unambiguously localize the entry point to the CTO lesion by angiography and/or intravascular ultrasound and to be able to properly engage the lesion considering bridging collaterals, as well as side branches, with appropriate wire/device support (which can be complicated in ostial locations).
2. Lesion length. Lesions are dichotomized to $<$20 versus $\geq$20 mm. CTO PCI on lesions $\geq$20 mm in length tends to have lower success rates and longer procedure times using standard antegrade wire escalation (22), and may be best approached with early adoption of alternative techniques, such as primary antegrade dissection and re-entry, or retrograde techniques. As noted in the previous text, in most cases, this characteristic can only be accurately assessed by using dual injections.
3. Target coronary vessel at the distal cap. This refers to the size of the lumen, to the presence of significant side branches, to the relative angiographic health of the vessel at the reconstitution point, and importantly, to the ability to adequately angiographically visualize this segment.
4. Size and suitability of collateral circulation for retrograde techniques. Optimal collateral vessels for retrograde CTO PCI are sourced from a healthy (or repaired) donor vessel, can be easily accessed with wires and microcatheters, have minimal tortuosity, are not the only source of flow to the CTO segment (with risk for intraprocedural ischemia), and enter the CTO vessel well beyond the distal cap. More favorable collateral circulation characteristics lower the barriers to utilizing retrograde techniques as an initial strategy or early crossover strategy.

Device Platforms to Support CTO PCI

We favor a selected device portfolio to support coronary CTO PCI to streamline decision trees, develop operator device-specific expertise, and manage catheterization laboratory and procedure costs. We do recognize the utility of other wires and devices, as well as novel technologies currently in development, but the following support most of our current PCI procedures:

Four-wire strategy:

1. A hydrophilic and/or polymer-jacket 0.014-inch guidewire, low gram-force, with tapered 0.009-inch tip, for antegrade microchannel or soft tissue probing and also for knuckle techniques. Examples include the Fielder XT wire (Asahi Intecc, Nagoya, Japan) and Runthrough taper wire (Terumo Corporation, Tokyo, Japan).
2. A nontapered, polymer-jacket hydrophilic 0.014-inch guidewire for collateral channel crossing in retrograde procedures. Examples include the Fielder FC wire (Asahi Intecc) and Pilot 50 wire (Abbott Vascular, Santa Clara, California).
3. A moderately high–gram-force (4 to 6 g), polymer-jacket, nontapered 0.014-inch guidewire for complex lesion crossing, long lesions, knuckle technique, and dissection/re-entry, such as the Pilot 200 guidewire (Abbott Vascular). This wire is particularly useful for long lesions and complex lesions, and performs well in very tortuous segments with an ambiguous course.
4. A high–gram-force 0.014-inch guidewire, with a tapered 0.009-inch nonjacketed tip for penetration techniques, cap puncture, complex lesion crossing, and lumen re-entry techniques. An example is the Confianza Pro 12 wire (Asahi Intecc). This wire and similar devices are best used when the vessel pathway and location target coronary segment are well understood.

Guidewire selection and utilization is independent of whether an antegrade or retrograde approach is used. Most wires should be shaped by inserting the wire through an introducer tool and placing a shallow 30° to 45° bend no more than 1 mm from the tip. Occasionally, a secondary bend is required to allow for proper orientation in the vessel. Finally, a more acute bend, 2 to 3 mm from the tip, may be required for high–gram-force wires when wire-based lumen re-entry is contemplated. Coronary guidewires commonly used for CTO PCI are listed in Table 1.

Microcatheters:

1. Corsair microcatheter (Asahi Intecc). This is a 2.7-F catheter with a lubricious outer coating, a bidirectional wire braiding for torque transmission, and an inner polymer lumen with soft tip for optimal wire control. At present, this device is unique in providing a reliable platform to cross collateral channels and provides the primary basis for conventional retrograde procedures (23). This microcatheter can also be used in the antegrade direction for wire support and exchange as well as lesion crossing, although we usually employ smaller outer diameter microcatheters for these purposes. The Corsair catheter is advanced by rotation in either direction. The Corsair should not be over-rotated (>10 consecutive turns without release) as over-rotation could cause catheter kinking. Contrast can be injected through the Corsair for distal vessel visualization, but the catheter should subsequently be flushed to minimize the risk for guidewire "stickiness" and entrapment.
2. Small outer diameter, over-the-wire (OTW) microcatheters. Examples include the Finecross (Terumo Corporation) and Quick-Cross (Spectranetics Corporation, Colorado Springs, Colorado) catheter for wire support and exchange.
3. Small OTW balloons for wire support and exchange.
4. Tornus microcatheter (Asahi Intecc). This is a braided-wire mesh OTW microcatheter with left-handed thread allowing for channel preparation and lesion crossing in resistant occlusions. The Tornus is advanced using counterclockwise rotation and removed using clockwise rotation. A coronary guidewire should remain within the Tornus inner lumen during manipulations, and over-rotation should be avoided to minimize the risk of kinking. Contrast injections should not be performed through the Tornus, as the contrast escapes through the wire braid and does not reach the catheter tip.

Lesion crossing and lumen re-entry technologies:

1. CrossBoss catheter (BridgePoint Medical, Plymouth, Minnesota). This is a metal OTW microcatheter with a rounded tip to prevent vessel exit (24). This device is rotated rapidly, in either direction, using a "fast spin" technique (rapid rotation of the catheter using both hands) and can advance forward through a CTO without the wire in the lead. If a subintimal/subadventitial position is obtained beside the true lumen, re-entry is performed.
2. Stingray balloon and Stingray guidewire systems (BridgePoint Medical). The Stingray balloon is a 1-mm flat balloon with 3 exit ports connected to the same guidewire lumen (24). The distal exit port is used to place the balloon in position. The other 2 ports are 180° opposed, so that when inflated, 1 is oriented to the lumen and the other toward the adventitia. Using fluoroscopy for directional orientation, the Stingray guidewire (a 0.014-inch high–gram-force guidewire with a distal tapered "probe" to grab tissue) is used to penetrate the distal true lumen and gain guidewire position.

Safety devices: CTO PCI catheterization laboratories should be equipped with a selection of covered stents (25), embolization coils and delivery systems, pericardiocentesis trays to manage perforation (26), and thrombectomy devices

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Table 1. Description of Coronary Guidewires Commonly Used in CTO PCI

Wire Category	Tip Style	Commercial Name	Tip Stiffness	Manufacturer	Properties
Polymer covered	Tapered	Fielder XT*	1.2 g	Asahi Intecc	Frontline wire for antegrade crossing. Can also be used for creating knuckle wire and for retrograde crossing
	Straight (nontapered), low tip stiffness	Fielder FC* Whisper LS, MS, ES Pilot 50 Choice PT Floppy	1.6 g 0.8, 1.0, 1.2 g 1.5 g 2.1 g	Asahi Intecc Abbott Vascular Abbott Vascular Boston Scientific	Used to cross through collateral vessels during the retrograde approach
	Straight (nontapered), high tip stiffness	Pilot 150/200* Crosswire NT PT Graphix Intermediate PT2 Moderate Support Shinobi Shinobi Plus	2.7 g/4.1 g 7.7 g 1.7 g 2.9 g 7.0 g 6.8 g	Abbott Vascular Terumo Boston Scientific Boston Scientific Cordis Cordis	Antegrade crossing, especially when the course of the occluded vessel is unclear. Also useful for knuckle wire formation and for re-entry into true lumen during LaST technique
Open coil (no polymer jacket)	Straight, low tip stiffness	SION (hydrophilic)	0.8	Asahi Intecc	
	Tapered, low tip stiffness	Cross-it 100XT (0.010-inch) Runthrough NS tapered (0.008-inch)	1.7 g 1.0 g	Abbott Vascular Terumo	
	Tapered, high tip stiffness, hydrophilic coating	Confianza Pro 9, 12* (0.009-inch) PROGRESS 140T, 200T (0.0105-inch, 0.009-inch) Persuader 9 (0.011-inch) ProVia 9, 12 (0.009-inch)	9.3, 12.4 g 12.5, 13.3 g 9.1 g 11.8, 13.5 g	Asahi Intecc Abbott Vascular Medtronic Medtronic	Antegrade crossing when vessel course known
	Straight tip, high tip stiffness	MiracleBros 3, 4.5, 6 MiracleBros 12 PROGRESS 40, 80, 120 Persuader 3 and 6 (hydrophilic and -phobic) Provia 3, 6 (hydrophilic and -phobic)	3.9, 4.4, 8.8 g 13.0 g 5.5, 9.7, 13.9 g 5.1, 8.0 g 8.3, 9.1 g	Asahi Intecc Asahi Intecc Abbott Vascular Medtronic Medtronic	Antegrade crossing when vessel course is known
	Tapered, high tip stiffness, hydrophobic coating	Confianza 9 (hydrophobic) Persuader 9 (hydrophobic) ProVia 9, 12 (hydrophobic)	8.6 g 9.1 g 11.8, 13.5 g	Asahi Intecc Medtronic Medtronic	Antegrade crossing when vessel course is known
Externalization wires		Viper* RG3 RotaWire Floppy and Extra Support	3.6 g	CSI Asahi Intecc Boston Scientific	335 cm in length 330 cm in length 325 cm in length

*Most commonly used guidewires.
CTO = chronic total occlusion; LaST = limited antegrade subintimal tracking; PCI = percutaneous coronary intervention.

to manage thrombotic complications. Hemodynamic support system availability is a prerequisite as well.

Initial Strategy—Algorithm

All cases are planned as previously discussed in anticipation of both antegrade and retrograde approaches (the so-called "hybrid" procedure). The initial directional strategy of antegrade or retrograde is dependent on the anatomy confirmed by dual angiography as described with 4 primary variables considered: 1) ability to identify and safely and effectively engage the proximal cap; 2) lesion length; 3) significant branches, size and quality of the target at the distal cap; and 4) suitability and anticipated ease of retrograde "interventional" collaterals. The goal is to safely and efficiently recanalize the ischemic bed and provide a "quality result" while maintaining patency of pertinent side branches and outflow vessels.

The combinations of these simple factors can determine the primary strategy for most procedures (Fig. 1) and identify subsequent secondary and tertiary bailout techniques, should the primary strategy fail. In summary, short lesions (<20 mm) with clearly identified proximal caps and good distal vessel targets are initially approached with an antegrade wire escalation strategy. A lesion length <20 mm has been identified as a predictor of rapid CTO crossing in the Japan CTO Registry (Multicenter CTO Registry in Japan) (22). Longer and complex lesions with clearly identified proximal caps and distal target favor a primary dissection re-entry approach. Other complex lesions with poor distal targets or ambiguous access points may favor an initial retrograde approach. The threshold for dissection/re-entry or retrograde technique as an initial strategy is lowered in reattempt procedures.

General Considerations for Strategic Changes and Procedural Efficiency

The new, hybrid CTO PCI strategy places emphasis, not only on procedural success, but also on procedural efficiency, aiming to successfully recanalize the CTO in the shortest

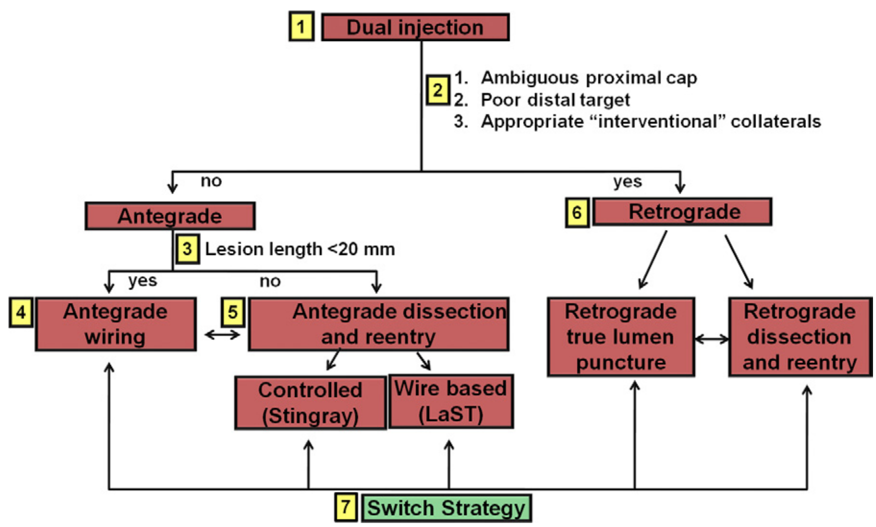

Figure 1. Algorithm for Crossing CTOs

The algorithm starts with dual coronary injection **(box 1)** to allow assessment of several angiographic parameters **(box 2)** and allow selection of a primary antegrade **(boxes 3 to 5)** or primary retrograde **(box 6)** strategy. Strategy changes are made **(box 7)**, depending on the progress of the case. CTO = chronic total occlusion; LaST = limited antegrade subintimal tracking.

possible period and using the least amount of radiation, contrast, and equipment. The optimal techniques and technologies are applied during the specific time of the procedure when they are most likely to be effective. The practical ramifications of this method are that changes of strategy should occur very early, and often cycle rapidly, to maximize the likelihood of early successful crossing. Far too often in conventional CTO PCI, standard strategies are pursued beyond the point of diminishing return, and bailout techniques are applied when their utility is greatly reduced. An intended by-product of the hybrid CTO PCI approach is to reduce procedure time, patient and staff radiation exposure, and contrast utilization. Although there are no universally accepted time limits for each of the steps described in the algorithm (Fig. 1), the recommendation is to stop pursuing a technique that has not resulted in any significant progress during a reasonable period. At this point, which is sooner than traditional PCI, a different technique (such as new guidewire, new microcatheter, the retrograde approach, and so on) should be tried. Generally, no more than 5 to 10 min should be spent in a stagnant mode without minor or major technique adjustments being made.

Careful attention to fluoroscopy use throughout the case is important to minimize the risks associated with radiation exposure. Use of >5-Gy air kerma dose can lead to skin injury, and >10 Gy significantly increase this possibility, therefore the procedure should usually be stopped before exceeding 10 Gy, unless lesion crossing has occurred and little extra time is needed to complete the procedure (27). Minimizing fluoroscopy time, routine utilization of non-magnified viewing, decreasing frame rate, coning, fluoroscopy storage (in lieu of cine acquisition), and image intensifier positional adjustment/rotation can limit skin exposure to radiation at each entry point (27). Radiation dosing, monitored closely during the procedure, is a pre-eminent factor in strategic intraprocedural strategy changes in addition to case time and lack of progress.

Unfractionated heparin is the anticoagulation of choice for CTO PCI, as it can be reversed in case of significant perforation. At the present time, we strongly discourage the use of bivalirudin, low-molecular-weight heparin, or glycoprotein IIb/IIIa inhibitors. Finally, the contrast load administered should be monitored closely during the procedure, and pre-procedural hydration is encouraged.

Hybrid Techniques

The technical executions within the hybrid CTO PCI procedure are wire escalation (similar in either antegrade or retrograde direction) and dissection/re-entry (Stingray device or wire [the LaST technique] in antegrade direction and CART or reverse CART in retrograde direction).

Wire Escalation

As noted in Figure 1, this is the initial strategy of choice in a <20-mm CTO with reasonably definable proximal cap and distal target. The initial wire to probe the CTO is typically a low–gram-force, polymer-jacket wire, unless the proximal cap is clearly blunt, calcified, or ambiguous. We favor a tapered wire in the antegrade direction (such as the

Fielder XT, Asahi Intecc) and nontapered in the retrograde direction (as this wire is available having been used to cross the collateral vessels). The lesion is probed with a soft sliding technique, with soft drilling and emphasis in keeping the tip free and with appropriate shape on fluoroscopy. If the wire buckles, the OTW support catheter is advanced to support column strength at the tip. Probing is again performed. If the wire demonstrates lack of progress, goes offline, or buckles, it is determined to be ineffective and wire exchange is performed. In our experience, this series of maneuvers can be accomplished within a few minutes and, therefore, initial probing is not intended to be an extensive, time-consuming effort. The subsequent wire is determined by lesion characteristics. If the crossing distance is long, uncertain, or tortuous, we favor a moderately high–gram-force, nontapered, polymer-jacket wire, such as the Pilot 200 (Abbott Vascular). This platform is optimal for tracking the vessel structure and rarely exits the wall of the CTO segment. If the lesion distance is short and its course well understood, a stiff, tapered penetration wire (such as the Confianza Pro 12, Asahi Intecc) is chosen, employing a focused, directional penetration technique. Each of these wire platforms will serve as the subsequent bailout for the other. If the wires fail to progress (Fig. 2, Online Videos 1, 2, 3, 4, and 5), or enter the subintimal space (remaining within the vessel wall), conversion to dissection re-entry techniques is performed.

Dissection Re-Entry Techniques

Antegrade dissection. Antegrade dissection occurs when a guidewire or crossing catheter advances antegradely within the subintimal space (inside the vessel wall but outside the limits of what formerly was the true lumen). This can be achieved by using a CrossBoss catheter (BridgePoint Medical) or a knuckle wire technique (28–30). In the latter approach, a looped, polymer-jacket wire (knuckle wire) is advanced without rotation in the direction of the distal CTO segment. Typically, the leading end of the knuckle wire will be the stiff-to-floppy transition point near the ribbon/coils of the guidewire. Although it may seem counterintuitive, this approach has been tested to be a much safer way to advance through the course of an ambiguous CTO segment than with stiffer guidewires. The reason relates to adventitial distensibility. Blunt objects can be accommodated within the adventitia without perforation. Stiff guidewires, by contrast, may penetrate the adventitia because more force is directed to the relatively small area of the tip. In addition, the knuckled wire is less likely to be directed into and subsequently perforate small branches. It is important to manage the size of the knuckle with a diameter that matches the expected vessel size and ensure that it extends longitudinally within the vessel structure. This knuckle wire technique, or alternatively, the blunt-tipped CrossBoss catheter (BridgePoint Medical) are effective ways to move forward within the CTO segment when wire methods are considered inefficient or less safe. The CrossBoss catheter has the advantage of creating a smaller subadventitial space, which is less likely to accumulate blood. Such features can facilitate use of the Stingray system, as false lumen hematoma may decrease vessel wall contact with the Stingray balloon and wire and thus hinder re-entry attempts. In addition, a dissection/hematoma that is too large can impinge upon the true lumen, making re-entry more difficult.

Re-entry techniques. After subintimal crossing, 2 primary methods can be used for re-entering the lumen: 1) wire-based (LaST method) (31); or 2) device-based (Stingray balloon and guidewire, BridgePoint Medical).

The LaST Method

When antegrade wiring fails and Stingray-based re-entry or retrograde techniques are not an option or have failed, and alternate bailout strategy is the LaST technique. Once a microcatheter is positioned near the re-entry point, the knuckle wire is withdrawn and a stiff polymer jacket and/or a stiff tapered guidewire is inserted and directed into the distal true lumen (31).

The Stingray System

The Stingray system (BridgePoint Medical) consists of a balloon that assumes a flat shape when inflated at 3 to 4 atm, and a guidewire with an extreme 0.0025-inch tapered distal tip (24,30). The Stingray balloon has 2 exit ports that are diametrically opposed. Each port is proximal to a radio-opaque marker. The Stingray guidewire is advanced through the luminal exit port of the Stingray balloon until the wire crosses into the true lumen, which needs to be confirmed by contralateral injection, or by visualization though ipsilateral collaterals (Fig. 3, Online Videos 6, 7, 8, 9, 10, and 11). Sometimes the Stingray wire may fail to advance into the distal true lumen despite effective re-entry, as it tends to catch tissue and re-exit in a false channel. In such cases, the Stingray wire should be exchanged for a plastic-jacket guidewire, which can be readvanced into the same puncture hole created by the Stingray guidewire, and then more easily positioned in the distal vessel. This later technique has emerged as a very effective and efficient variant to avoid further damage to the distal vessel ("stick and switch" technique), especially when diseased and/or negatively remodeled.

Retrograde Dissection Re-Entry

Reverse CART. The most commonly used method to connect the proximal and distal true lumen in retrograde CTO PCI procedures if retrograde true lumen crossing attempts

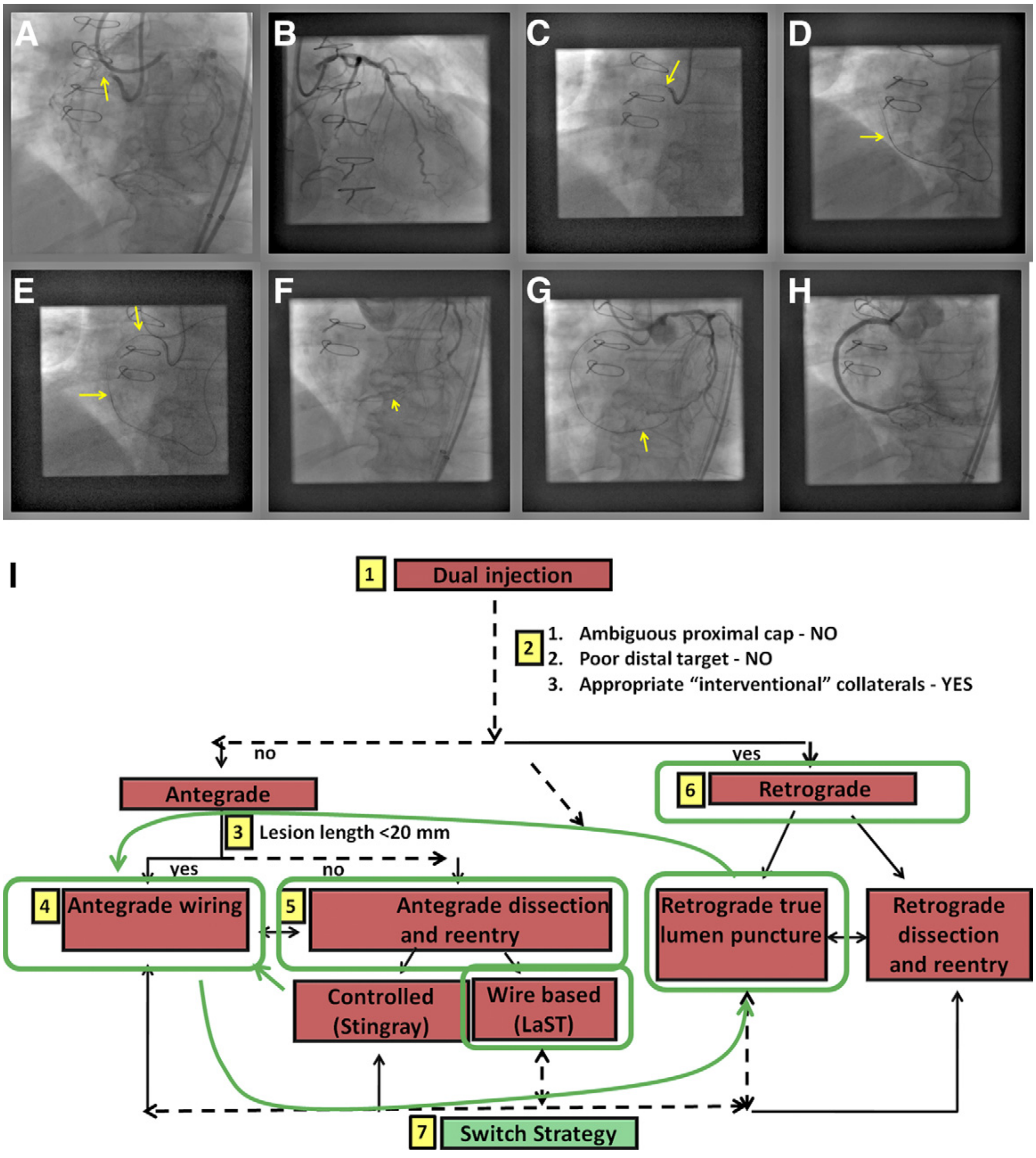

Figure 2. Complex Antegrade and Retrograde Intervention of a Right Coronary Artery CTO

Bilateral coronary angiography demonstrating a proximal right coronary artery chronic total occlusion (CTO) due to in-stent restenosis **(arrow, A)** (see Online Video 1). The right posterior descending coronary artery filled by septal collaterals from the left anterior descending coronary artery **(B)** (see Online Video 2). Angiographic characteristics included defined proximal cap, good distal target, long lesion length, and appropriate retrograde "interventional collaterals." Antegrade crossing attempts using a CrossBoss catheter (BridgePoint Medical) **(arrow, C)** and antegrade wire escalation failed. A Corsair microcatheter **(arrow, D)** (see Online Video 3) was advanced retrograde via a septal collateral to the mid right coronary artery over a nontapered polymer-jacket guidewire, but attempts to cross the occlusion retrograde failed **(E)**. Repeat antegrade crossing attempts with a moderately stiff, nontapered polymer-jacket wire (Pilot 200 wire, Abbott Vascular, Santa Clara, California) using limited subintimal tracking technique were successful in subintimal advancement of the wire **(arrow, F)** (see Online Video 4). After a GuideLiner catheter (Vascular Solutions, Minneapolis, Minnesota) **(arrowhead, G)** was advanced into the proximal right coronary artery a Confianza Pro 12 wire (Abbott Vascular) **(arrow, G)** successfully crossed the occlusion into the distal true lumen. After implantation of multiple drug-eluting stents an excellent angiographic result was achieved **(H)** (see Online Video 5). This case highlights the importance of multiple modifications in the procedural plan **(I)**, and "switching" strategies to be adaptive during chronic total occlusion percutaneous coronary interventions. LaST = limited antegrade subintimal tracking.

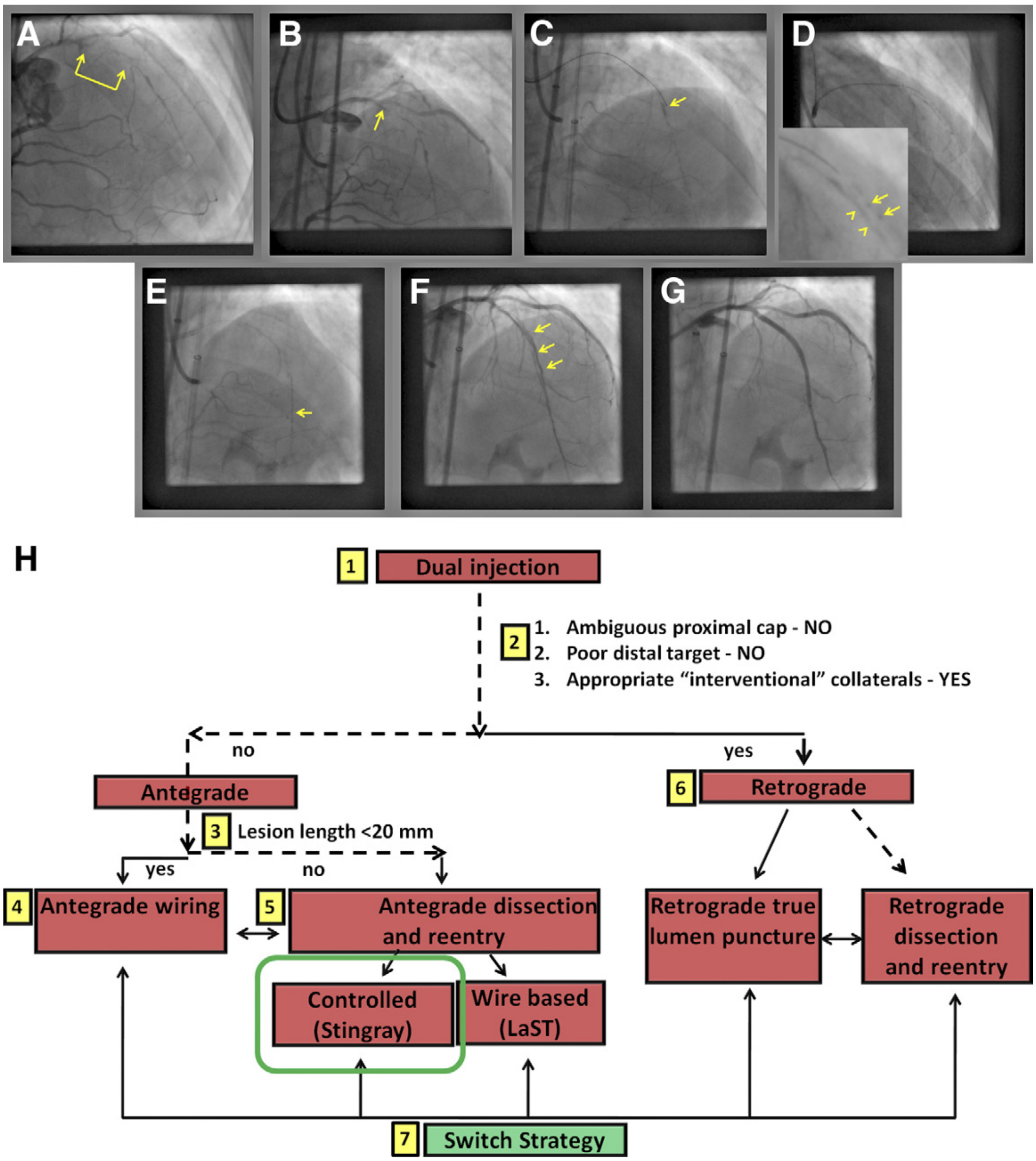

Figure 3. Antegrade Crossing—Provisional Re-Entry

Coronary angiography demonstrating a chronic total occlusion of the mid left anterior descending artery **(arrows, A)** (see Online Video 6). Angiographic characteristics included well-visualized proximal cap, good distal target, and lesion length >20 mm **(H).** A CrossBoss catheter (BridgePoint Medical, Plymouth, Minnesota) was advanced to the proximal cap **(arrow, B)** (see Online Video 7). With the fast spin technique, the catheter crossed the occlusion subintimally into the mid left anterior descending coronary artery **(arrow, C)** (see Online Video 8). The CrossBoss catheter was exchanged for a Stingray balloon (BridgePoint Medical) **(arrows D)** (see Online Video 9), located adjacent to the true lumen **(arrowheads, D)**. A Stingray guidewire **(arrow, E)** (see Online Video 10) successfully crossed into the distal true lumen. Angiography after predilation showed (as expected) dissection at the area of subintimal crossing **(arrows, F).** After implantation of multiple drug-eluting stents, an excellent angiographic result was achieved **(G)** (see Online Video 11).

are unsuccessful is the reverse CART (17,23,32) technique (Fig. 4, Online Videos 12, 13, 14, 15, 16, and 17). In this method, a microcatheter (often Corsair microcatheter, Asahi Intecc) is placed across a collateral vessel from the donor artery and into the CTO segment over a guidewire. An antegrade wire is advanced into the CTO segment alone or in combination with a crossing catheter or a balloon. An angioplasty balloon is approximated over the antegrade wire

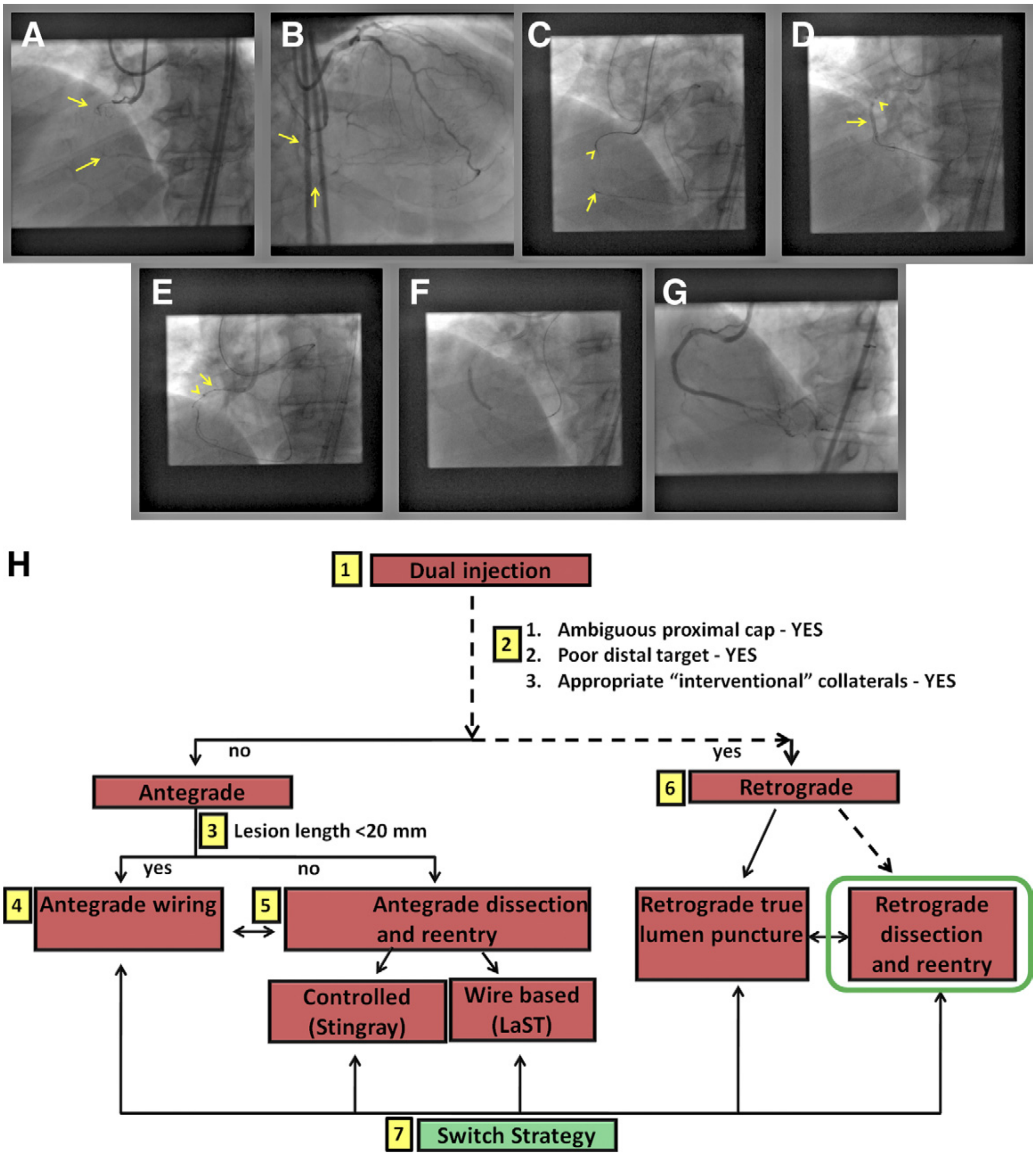

Figure 4. Primary Retrograde PCI to a Right Coronary Artery CTO

Dual coronary angiography demonstrating a chronic total occlusion (CTO) of the proximal right coronary artery **(arrows, A and B)** (see Online Videos 12 and 13) with distal filling via collaterals from the left anterior descending coronary artery. The angiographic characterization was poorly identified proximal cap, long lesion, diffusely diseased distal target, and good interventional collaterals **(H)**. A Corsair microcatheter (Asahi Intecc, Nagoya, Japan) **(arrow, C)** (see Online Video 14) was advanced retrogradely via a septal collateral over a polymer-jacket, nontapered guidewire, to the distal right coronary artery. A second Corsair microcatheter **(arrowhead, C)** was advanced antegradely to the mid right coronary artery. After antegrade insertion of a GuideLiner catheter (Vascular Solutions, Minneapolis, Minnesota) **(arrowhead, D)** (see Online Video 15), a 2.5 × 20-mm balloon was inflated over the antegrade guidewire in the mid right coronary artery **(arrow, D)**, and reverse controlled antegrade and retrograde tracking and dissection was performed, followed by successful advancement of a retrograde Pilot 200 guidewire (Abbott Vascular, Santa Clara, California) **(E)** (see Online Video 16) into the antegrade GuideLiner **(arrowhead, E).** A ViperWire Advance 335-cm guidewire (Cardiovascular Systems, St. Paul, Minnesota) was externalized followed by pre-dilation of the right coronary artery **(F)** and implantation of multiple drug-eluting stents, restoring Thrombolysis In Myocardial Infarction flow grade 3 antegrade flow **(G)** (see Online Video 17). LaST = limited antegrade subintimal tracking; PCI = percutaneous coronary intervention.

adjacent to the retrograde microcatheter and inflated. Before this, the antegrade and retrograde systems may reside in the same subadventitial space, within the CTO plaque, or in combination. However, if both systems are within the vessel structure, relative locations become less material because balloon angioplasty creates a connection between the 2 spaces. A retrograde wire can then be passed into the proximal vessel, and wire externalization (which involves externalizing the tip of a long, 300-cm or more guidewire at the antegrade hemostatic valve) or retrograde balloon angioplasty can be performed. The ViperWire Advance guidewire (CSI, St. Paul, Minnesota) is 335 cm long, provides excellent support, and is currently the preferred wire for externalization (32,33) where available. Intravascular ultrasonography guidance can facilitate performance of reverse CART, by allowing selection of the appropriate balloon size (34). In certain circumstances, the classic CART technique can be performed with retrograde dilation with a Corsair catheter or OTW balloon and advancement of an antegrade wire to the distal true lumen. We recently published detailed practical descriptions of the retrograde technique (32,33).

Conclusions

The presented procedural algorithm can provide a useful working and training framework for operators performing CTO PCI and may help increase attempt and success rates, improve efficiency, and minimize complications. Further studies are needed to validate this approach.

Acknowledgments
The authors would like to acknowledge the tremendous assistance of Todd Tourand, Nancy Morris, and Chad Harshman-Smith in preparing Table 1.

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REFERENCES

1. Grantham JA, Marso SP, Spertus J, House J, Holmes DR Jr., Rutherford BD. Chronic total occlusion angioplasty in the United States. J Am Coll Cardiol Intv 2009;2:479–86.
2. Joyal D, Afilalo J, Rinfret S. Effectiveness of recanalization of chronic total occlusions: a systematic review and meta-analysis. Am Heart J 2010;160:179–87.
3. Prasad A, Rihal CS, Lennon RJ, Wiste HJ, Singh M, Holmes DR Jr. Trends in outcomes after percutaneous coronary intervention for chronic total occlusions: a 25-year experience from the Mayo Clinic. J Am Coll Cardiol 2007;49:1611–8.
4. Mehran R, Claessen BE, Godino C, et al. Long-term outcome of percutaneous coronary intervention for chronic total occlusions. J Am Coll Cardiol Intv 2011;4:952–61.
5. Galassi AR, Tomasello SD, Reifart N, et al. In-hospital outcomes of percutaneous coronary intervention in patients with chronic total occlusion: insights from the ERCTO (European Registry of Chronic Total Occlusion) registry. EuroIntervention 2011;7:472–9.
6. Morino Y, Kimura T, Hayashi Y, et al. In-hospital outcomes of contemporary percutaneous coronary intervention in patients with chronic total occlusion insights from the J-CTO Registry (Multicenter CTO Registry in Japan). J Am Coll Cardiol Intv 2010;3:143–51.
7. Thompson CA, Jayne JE, Robb JF, et al. Retrograde techniques and the impact of operator volume on percutaneous intervention for coronary chronic total occlusions: an early U.S. experience. J Am Coll Cardiol Intv 2009;2:834–42.
8. Rinfret S, Joyal D, Nguyen CM, et al. Retrograde recanalization of chronic total occlusions from the transradial approach; early Canadian experience. Catheter Cardiovasc Interv 2011;78:366–74.
9. Grantham JA, Jones PG, Cannon L, Spertus JA. Quantifying the early health status benefits of successful chronic total occlusion recanalization: results from the FlowCardia's Approach to Chronic Total Occlusion Recanalization (FACTOR) trial. Circ Cardiovasc Qual Outcomes 2010;3:284–90.
10. Finci L, Meier B, Favre J, Righetti A, Rutishauser W. Long-term results of successful and failed angioplasty for chronic total coronary arterial occlusion. Am J Cardiol 1990;66:660–2.
11. Baks T, van Geuns RJ, Duncker DJ, et al. Prediction of left ventricular function after drug-eluting stent implantation for chronic total coronary occlusions. J Am Coll Cardiol 2006;47:721–5.
12. Claessen BE, van der Schaaf RJ, Verouden NJ, et al. Evaluation of the effect of a concurrent chronic total occlusion on long-term mortality and left ventricular function in patients after primary percutaneous coronary intervention. J Am Coll Cardiol Intv 2009;2:1128–34.
13. Noguchi T, Miyazaki S, Morii I, Daikoku S, Goto Y, Nonogi H. Percutaneous transluminal coronary angioplasty of chronic total occlusions. Determinants of primary success and long-term clinical outcome. Catheter Cardiovasc Interv 2000;49:258–64.
14. Safley DM, House JA, Marso SP, Grantham JA, Rutherford BD. Improvement in survival following successful percutaneous coronary intervention of coronary chronic total occlusions: variability by target vessel. J Am Coll Cardiol Intv 2008;1:295–302.
15. Boden WE, O'Rourke RA, Teo KK, et al. Optimal medical therapy with or without PCI for stable coronary disease. N Engl J Med 2007;356:1503–16.
16. Luna M, Holper E, Banerjee S, Brilakis ES. Transfemoral use of the GuideLiner catheter in complex coronary and bypass graft interventions. Catheter Cardiovasc Interv 2011 Jul 29 [E-pub ahead of print].
17. Hirokami M, Saito S, Muto H. Anchoring technique to improve guiding catheter support in coronary angioplasty of chronic total occlusions. Catheter Cardiovasc Interv 2006;67:366–71.
18. Di Mario C, Ramasami N. Techniques to enhance guide catheter support. Catheter Cardiovasc Interv 2008;72:505–12.
19. Mahmood A, Banerjee S, Brilakis ES. Applications of the distal anchoring technique in coronary and peripheral interventions. J Invasive Cardiol 2011;23:291–4.
20. Singh M, Bell MR, Berger PB, Holmes DR Jr. Utility of bilateral coronary injections during complex coronary angioplasty. J Invasive Cardiol 1999;11:70–4.
21. Brilakis ES, Grantham JA, Banerjee S. "Ping-pong" guide catheter technique for retrograde intervention of a chronic total occlusion through an ipsilateral collateral. Catheter Cardiovasc Interv 2011;78:395–9.
22. Morino Y, Abe M, Morimoto T, et al. Predicting successful guidewire crossing through chronic total occlusion of native coronary lesions within 30 minutes: the J-CTO (Multicenter CTO Registry in Japan) score as a difficulty grading and time assessment tool. J Am Coll Cardiol Intv 2011;4:213–21.
23. Tsuchikane E, Katoh O, Kimura M, Nasu K, Kinoshita Y, Suzuki T. The first clinical experience with a novel catheter for collateral channel tracking in retrograde approach for chronic coronary total occlusions. J Am Coll Cardiol Intv 2010;3:165–71.
24. Werner GS. The BridgePoint devices to facilitate recanalization of chronic total coronary occlusions through controlled subintimal reentry. Expert Rev Med Dev 2011;8:23–9.

25. Romaguera R, Waksman R. Covered stents for coronary perforations: is there enough evidence? Catheter Cardiovasc Interv 2011; 78:246–53.
26. Ben-Gal Y, Weisz G, Collins MB, et al. Dual catheter technique for the treatment of severe coronary artery perforations. Catheter Cardiovasc Interv 2010;75:708–12.
27. Chambers CE, Fetterly KA, Holzer R, et al. Radiation safety program for the cardiac catheterization laboratory. Catheter Cardiovasc Interv 2011;77:546–56.
28. 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.
29. 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.
30. Brilakis ES, Badhey N, Banerjee S. "Bilateral knuckle" technique and Stingray re-entry system for retrograde chronic total occlusion intervention. J Invasive Cardiol 2011;23:E37–9.
31. Lombardi WL, Retrograde PCI: what will they think of next? J Invasive Cardiol 2009;21:543.
32. Brilakis ES, Grantham JA, Thompson CA, et al. The retrograde approach to coronary artery chronic total occlusions: a practical approach. Catheter Cardiovasc Interv 2012;79:3–19.
33. Joyal D, Thompson CA, Grantham JA, Buller CEH, Rinfret S. The retrograde technique for recanalization of chronic total occlusions: a step-by-step approach. J Am Coll Cardiol Intv 2012;5:1–11.
34. Rathore S, Katoh O, Tuschikane 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 Intv 2010;3:155–64.

Key Words: chronic total occlusion ■ devices ■ percutaneous coronary intervention.

APPENDIX

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