Techniques for Percutaneous Revascularization of Coronary CTOs

Necessary skillsets for a hybrid approach to CTO PCI.

BY CRAIG A. THOMPSON, MD, MMSc, AND DAVID V. DANIELS, MD

Percutaneous recanalization of coronary chronic total occlusions (CTOs) has historically been limited by the inability to consistently achieve wire positioning in the distal true lumen across the CTO segment. More contemporary technical methods have helped convert the traditional failure mode of subintimal wire/device position into a strategic advantage for procedural success in selected cases. Improved coronary guidewires and support catheters, dedicated lumen reentry devices, and retrograde methods for CTO percutaneous coronary intervention (PCI) have led to an expansion of CTO PCI. The hybrid approach for CTO PCI is predicated on an algorithm that is intended to create a process whereby trained operators may select and appropriately utilize any of the aforementioned methods. The expectation with this approach is technical success and efficiency in a robust and reproducible manner.

Successful PCI of coronary CTOs in selected patients is associated with reduced mortality and need for subsequent coronary artery bypass surgery, as well as improved angina, heart failure symptoms, and quality of life. Despite ample evidence to support promotion and education of this valuable therapy for patients, dissemination and uptake have historically been limited in broad clinical practice.

CLASSIC TECHNIQUE AND MYTH OF THE TRUE LUMEN

There has been great historical interest from many operators in making heroic efforts to stay in the true lumen when wiring the CTO segment. The primary cited reasons for this level of interest are a theoretic improvement in healing and a better safety-durability profile for drug-eluting stents placed during the procedure, along with safety concerns when exploiting the subadventitial space as a treatment pathway. It is the authors’ view that the practical ramifications of this philosophy as a dogmatic approach are reduced success rates and prolonged procedures. Furthermore, methodical wire technique is perhaps the most difficult of skillsets to teach and learn and cannot resolve the issue of which might be the best approach for highly complex anatomy. Techniques and technologies designed to cross the true lumen or provide subintimal return do not consistently cross the CTO by the intended mechanism (ie, intravascular ultrasound of wire only, true-to-true technique reveals subadventitial pathways ~30%–50% of the time, many “reentry procedures” represent sublesional redirection rather than subintimal reentry). Currently, no singular strategy, technique, or technology can consistently address all anatomies of CTO that exist in patients presenting with an appropriate need for percutaneous revascularization. This considered, an integrative, comprehensive strategy with multiple skillsets applied by operators/centers is required.

Physicians have a tendency to reflect to intellectual comfort zones in interventional cardiology; however, the management of CTOs challenges these constructs in several ways. Current technology and techniques for optimal CTO PCI can be counterintuitive to standard PCI procedures. For example, crossing catheters or looped wires in the subadventitial space provide greater safety than standard wire techniques, retrograde methods can be more safe and effective in selected patients than a standard antegrade approach, and Ellis grade 1 through 3 perforations are typically dissections and do not constitute a safety hazard or stopping point for many procedures. Another such construct is “the true lumen.” We recall learning about vascular morphology and biology and the classification of endothelial, intima, media, and adventitial layers and internal and external elastic membranes. Within
a completely occluded segment, histopathologic surveillance often demonstrates destruction of the integrity of these layers. The strength and elasticity of the adventitia make it the only layer in the vessel structure that provides security in preventing perforation.

If one can accept a clinical utility model with two effective layers in CTOs (adventitia and plaque), then therapeutic options abound, and opportunities to effectively manage patients will increase accordingly.

**SKILLSET DEVELOPMENT**

Four fundamental skillsets are needed to facilitate an “all-comers” approach for CTO PCI if the goal is to revascularize patients with clinical indications, irrespective of the complexity of anatomy: (1) antegrade wire crossing, (2) antegrade dissection reentry, (3) retrograde wire crossing, and (4) retrograde dissection reentry. These skillsets involve adoption of optimal techniques and technology to cross lesions using coronary guidewires or reentry methods in the antegrade or retrograde direction.

**Antegrade Wire Crossing**

The standard technical approach for patients undergoing CTO PCI is dual (common) or single (uncommon) vascular access, recognizing the need for imaging via contrast injection of the vessel proximal to the CTO and complete collateral bed filling to maximally opacify the vascular target bed distal to the occluded segment. Our practice is to use dual access and imaging when any degree of contralateral collateralization is present (> 90% of cases). Collateral pattern shifts frequently occur during CTO PCI, and even when ipsilateral collaterals are dominant on initial injections, the contralateral collaterals may become increasingly needed during the course of the procedure. It is a frequent error for inexperienced operators and programs not to use a second catheter or to wait too late into the procedure for that imaging to be useful. Patients should undergo adequate moderate sedation, as chest pain is easily produced during these procedures and should even be expected. Unfractionated heparin is the typical anticoagulant of choice, with a target activated clotting time of approximately 300 seconds for antegrade procedures and 350 seconds for retrograde procedures.

Wire shaping and selection is critical for these procedures. Because the occluded coronary is a potential space that may be inadvertently enlarged, large tip bends used in standard PCI are counterproductive for optimal torque and manipulation in the CTO. The typical wire bend is 30° approximately 1 mm from the tip, which can only be created manually from a straight-tipped wire placed through the introducer needle and gently bent with the fingertip.

We endorse three fundamental wire classes to accomplish lesion crossing in a wire escalation strategy: (1) a soft (approximately < 1-g tip load), tapered, polymer-jacketed wire for lesion exploration and loose tissue tracking; (2) a moderately stiff, polymer-jacketed wire to cross long or tortuous lesions and negotiate a complex dissected environment; and (3) a tapered, stiff wire for a penetration technique.

We encourage use of an over-the-wire, support microcatheter to augment wire manipulation and strength and serve as a platform to freely switch wires and change tip shapes during the wiring process. Intralesional wire modifications or changes are frequently needed. In general, a dedicated support catheter is superior to an over-the-wire balloon with respect to support, torque control, and deliverability.

Typically, in antegrade or retrograde wire-based approaches, the lesion is initially probed with a soft wire, with escalation to a penetration wire if the vessel course is known or to a stiff polymer-jacketed wire if the anatomy is unknown, long, or tortuous. We reemphasize that the effective working length for a penetration strategy is approximately 10 to 20 mm. If crossing needs are for longer lesions, it is generally wise to exchange the penetration stiff wire for another wire that is more suited for crossing and reinsert it if penetration is required again at the distal cap. In general, however, lesions > 20 mm are usually best treated with a dissection reentry approach.

**Antegrade Dissection Reentry**

The primary historical mode of failure for CTO PCI has been subintimal wire positioning and dissection with an inability to predictably correct the wire location to the true lumen. Multiple wire strategies (eg, parallel wire, see-saw wire) have been utilized, but the likelihood of wire redirection to the true lumen is unpredictable at best, and the ability to broadly educate the interventional community on the nuances of these techniques has been limited.

More recently, a reentry balloon catheter (Stingray, Boston Scientific Corporation, Natick, MA) has fundamentally transformed the ability to convert the dissection space from failure to a predictable, reproducible therapeutic pathway. The Stingray is a flat, over-the-wire balloon that orients, when inflated, to lay flat along the artery (Figure 1). It has 180° opposed exit ports proximal to visible fluoroscopic markers. One port will always be oriented toward the true lumen and the other toward the adventitia. The target artery can be then reentered via the lumen port with the dedicated Stingray guidewire (a 0.014-inch, tapered penetration wire with a tip probe). A variety of techniques have been developed to accomplish lesion crossing and reentry predicated on this platform technology. Appropriate situations for antegrade reentry include existing wire failure in the subintimal...
space, complex lesions in which wire-based crossing is unlikely or unsafe, and failing retrograde procedures. In this way, antegrade dissection and reentry can be used either as a primary or provisional strategy as dictated by the CTO anatomy.

Retrograde Wire Crossing

The retrograde technique involves crossing the collateral circulation from the donor vascular bed to the distal CTO segment with a guidewire and specialty microcatheter. In the typical retrograde procedure, a shortened (90-cm) guide is placed in the donor vessel. Collaterals are typically septal artery connections between the left anterior descending coronary artery and posterior descending artery/posterolateral circulation, or epicardial connections (typically connecting lateral wall branches [left anterior descending coronary artery to diagonal, diagonal to obtuse marginal, obtuse marginal to posterolateral], or atrioventricular groove circumflex to right coronary). The most commonly used guidewires for collateral crossing are soft, polymer-jacketed wires (eg, Fielder FC, Asahi Intecc, Nagoya, Japan; or Sion, Asahi Intecc). The Sion is a unique guidewire with a soft tip, hydrophilic coating, and dual-core technology to negotiate tortuosity. The most common crossing microcatheter is the Corsair device (Asahi Intecc). Corsair is an approximate 2.7-F, bidirectionally braided, over-the-wire microcatheter with a soft, tapered distal tip. This catheter technology has been revolutionary and transformative for safe, effective, and predictable retrograde procedures.

Once in the CTO target artery in a position near the distal cap, wire escalation is performed in the same manner with the same wires as previously described in the antegrade wire escalation section. When the lesion is crossed in the retrograde direction, the wire is typically placed at the antegrade guide catheter followed by the Corsair. The wire can then be exchanged for a long wire (eg, RG3, Asahi Intecc; R350, Vascular Solutions, Inc., Minneapolis, MN; ViperWire Advance, Cardiovascular Systems, Inc., St. Paul, MN) that can be externalized from the antegrade guide to provide the platform for subsequent PCI.

Retrograde Dissection Reentry

After crossing the collateral bed with a guidewire and microcatheter, as previously described, if the wire is unable to cross into the proximal true lumen, or if the lesion complexity makes wiring unlikely or unsafe, retrograde reentry can be performed. The most common method is using the reverse CART (Controlled Antegrade and Retrograde Tracking) technique. The fundamental steps to this technique involve bringing a balloon catheter antegrade and dilating it adjacent to the retrograde microcatheter. This is safe and effective as long as care is taken to ensure that both antegrade and retrograde systems are in the architecture of the vessel.

This is best assessed by observing the “dance” (phasic movement of the antegrade and retrograde) of equipment that are moving in phase in multiple views. In most circumstances, irrespective of whether both antegrade and retrograde systems are in the subintimal or plaque segment of the CTO, balloon dilation can create a common connection that can be subsequently wired. Because the distal true lumen is controlled with the retrograde microcatheter, once stenting is performed, there is true lumen inflow and outflow and good clinical success. This is conceptually, and practically, the same outcome as performing reentry from the antegrade direction. The most important aspect of either approach is to provide significant blood flow to the ischemic territory and outflow branches in a safe and predictable manner.

INTEGRATING THE SKILLSETS: THE HYBRID APPROACH

Once these skillsets are developed, the practical question is “which approach do I perform when?” and “what method next, if that fails?” The hybrid method has been developed in an attempt to optimally integrate these skillsets based on simple anatomic assessment and to optimize provisional strategy workflow. The goal has been to standardize the CTO PCI procedure, increase consistency between operators, and improve outcomes by exploiting conditional probabilities of leveraging approaches when they are most likely to be safe and successful. Four questions are reviewed on the initial angiogram: (1) is the proximal cap of the CTO apparent by angiography or adjunctive intravascular ultrasound? (2) is the lesion length < 20 mm or ≥ 20 mm? (3) what is the quality of the distal target (size, visibility, involve-
ment of meaningful outflow branches)? and (4) what is the suitability of collaterals for retrograde intervention (for the operator in question)? Based on these answers, the initial and provisional strategies can be determined (Figure 2).

The technical merits and emphasis are on procedural success and, importantly, procedural efficiency with an acceptable safety profile. Efficient procedures and processes can help to drive CTO PCI adoption (and therefore lead to the primary initiative of more open arteries), reduce complications specific to radiation and contrast exposure, and perhaps reduce bleeding/thrombotic complications that have higher frequency rates in prolonged cases. The hybrid approach has been compared to other approaches in contemporary registries and is associated with a higher success rate in complex lesions. The hybrid video registry was recently reported, with a 93% success rate in complex CTO lesions, whereas success rates were between 73% and 79% in comparator registries.

It should be noted that the driver for the primary retrograde technique is ambiguity of the proximal cap and poor target for antegrade wiring or reentry in patients with suitable collaterals. Nuanced methods to troubleshoot patients who do not fit the prespecified anatomic criteria according to the hybrid approach exist but are outside the scope of this article.

Secondary strategies are developed in advance in anticipation of failed or failing primary strategies. Generally, the secondary strategy for antegrade or retrograde wire escalation is the dissection-reentry method in the same direction. Remember that the initial directional choice was determined by characteristics favoring success and efficiency.

CONCLUSION
Coronary CTO PCI has historically been limited by poor success rates and clinical uptake. Recent advances in technique and technology have provided a platform to create a systematic method to improve success rates and efficiency and, importantly, to extend therapy to a broader group of patients by addressing consistency and training needs and overcoming anatomic hurdles. Although CTO PCI is rapidly evolving, and these methods may, in turn, adapt over time, the methods we describe can provide a starting point to expand the pool of operators and, ideally, achieve the goal of more open arteries worldwide.

Craig A. Thompson, MD, MMSc, is Director, Cardiovascular Catheterization and Intervention at Yale New Haven Hospital, Yale University School of Medicine in New Haven, Connecticut. He has disclosed that he has consulting relationships with Bridgepoint Medical, Asahi Intecc, and Boston Scientific; has an equity position in Bridgepoint Medical; and is employed by Boston Scientific (2014).

David V. Daniels, MD, is Associate Director, Cardiac Catheterization Laboratory, Mills Peninsula Health Services in Burlingame, and is an interventional cardiologist at Palo Alto Medical Foundation in Palo Alto, California. He has disclosed that he is a consultant-educator for Boston Scientific. Dr. Daniels may be reached at danield2@pamf.org.