

JACC STATE-OF-THE-ART REVIEW

Global Chronic Total Occlusion Crossing Algorithm

JACC State-of-the-Art Review



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ABSTRACT

The authors developed a global chronic total occlusion crossing algorithm following 10 steps: 1) dual angiography; 2) careful angiographic review focusing on proximal cap morphology, occlusion segment, distal vessel quality, and collateral circulation; 3) approaching proximal cap ambiguity using intravascular ultrasound, retrograde, and move-the-cap techniques; 4) approaching poor distal vessel quality using the retrograde approach and bifurcation at the distal cap by use of a dual-lumen catheter and intravascular ultrasound; 5) feasibility of retrograde crossing through grafts and septal and epicardial collateral vessels; 6) antegrade wiring strategies; 7) retrograde approach; 8) changing strategy when failing to achieve progress; 9) considering performing an investment procedure if crossing attempts fail; and 10) stopping when reaching high radiation or contrast dose or in case of long procedural time, occurrence of a serious complication, operator and patient fatigue, or lack of expertise or equipment. This algorithm can improve outcomes and expand discussion, research, and collaboration. (J Am Coll Cardiol 2021;78:840-853) © 2021 The Authors. Published by Elsevier on behalf of the American College of Cardiology Foundation. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

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ABBREVIATIONS AND ACRONYMS

ADR = antegrade dissection
and re-entry

APCTO = Asia Pacific CTO Club

CTO = chronic total occlusion

IVUS = intravascular
ultrasound

PCI = percutaneous coronary
intervention

The success of chronic total occlusion (CTO) percutaneous coronary intervention (PCI) significantly improved during the past decade from 50%-70% (1) to 85%-94% (2-7) at experienced centers. In addition to technological advances, this improvement was catalyzed by the widespread implementation of an algorithmic approach to CTO crossing. The first CTO crossing algorithm was the hybrid algorithm (8) (Figure 1A, Table 1), which emphasized the importance of dual angiography and careful angiographic review to guide the selection of initial and subsequent crossing strategies. The hybrid algorithm also recommended a prompt change of strategy in case of failure to achieve progress and awareness of radiation and contrast use and procedure time. These guiding principles were adopted and expanded in subsequent algorithms (Table 1). The Asia Pacific CTO Club (APCTO) algorithm (9) (Figure 1B) recommended intravascular ultrasound (IVUS) to resolve ambiguity in the location of the proximal cap of the CTO, use of the CrossBoss catheter (Boston Scientific) for in-stent CTOs, use of parallel wiring, and consideration of tortuosity, calcification, and ambiguity for

using a knuckle-wire technique. Similar algorithms were also published by the CTO Club China (10) (Figure 1C), the EuroCTO Club (11) (Figure 1D), and the Japan CTO Club (2). Existing algorithms have similarities but also significant differences (Table 1).

Recently, a global consensus document highlighted 7 key principles of CTO PCI (12), 1 of which is that all CTO crossing techniques are valuable in the right setting. Development of a unified global CTO crossing algorithm could significantly facilitate decision making and CTO PCI teaching across various geographies and improve the safety, reproducibility, and efficiency of the procedure (13). An initial document draft of a global CTO crossing algorithm (Central Illustration, Table 1) was created by a group of 4 CTO PCI experts from North America, Europe, and Asia. A total of 122 other CTO PCI experts from 50 countries were invited to participate, of whom 121 from 50 countries provided comments and approved this final document.

The global CTO crossing algorithm includes the following 10 steps.

STEP 1: DUAL ANGIOGRAPHY. Dual coronary angiography remains the cornerstone of CTO PCI and should be performed in nearly all cases unless the

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collateral circulation originates exclusively from ipsilateral vessels. Dual angiography, with nitroglycerin if needed, facilitates planning of CTO crossing and guides crossing attempts by helping determine the guidewire position and detecting potential complications. Coronary computed tomographic angiography can also provide important information on CTO anatomy and procedural planning (14).

Currently, most CTO techniques, including antegrade dissection and re-entry (ADR) techniques with the Stingray LP system (Boston Scientific) and simultaneous IVUS-controlled cap puncture or IVUS-guided wiring, can be performed with 7-F guide catheters using 7-F compatible equipment combinations, such as 5-F IVUS and low-profile microcatheters. Eight-French guide catheters are

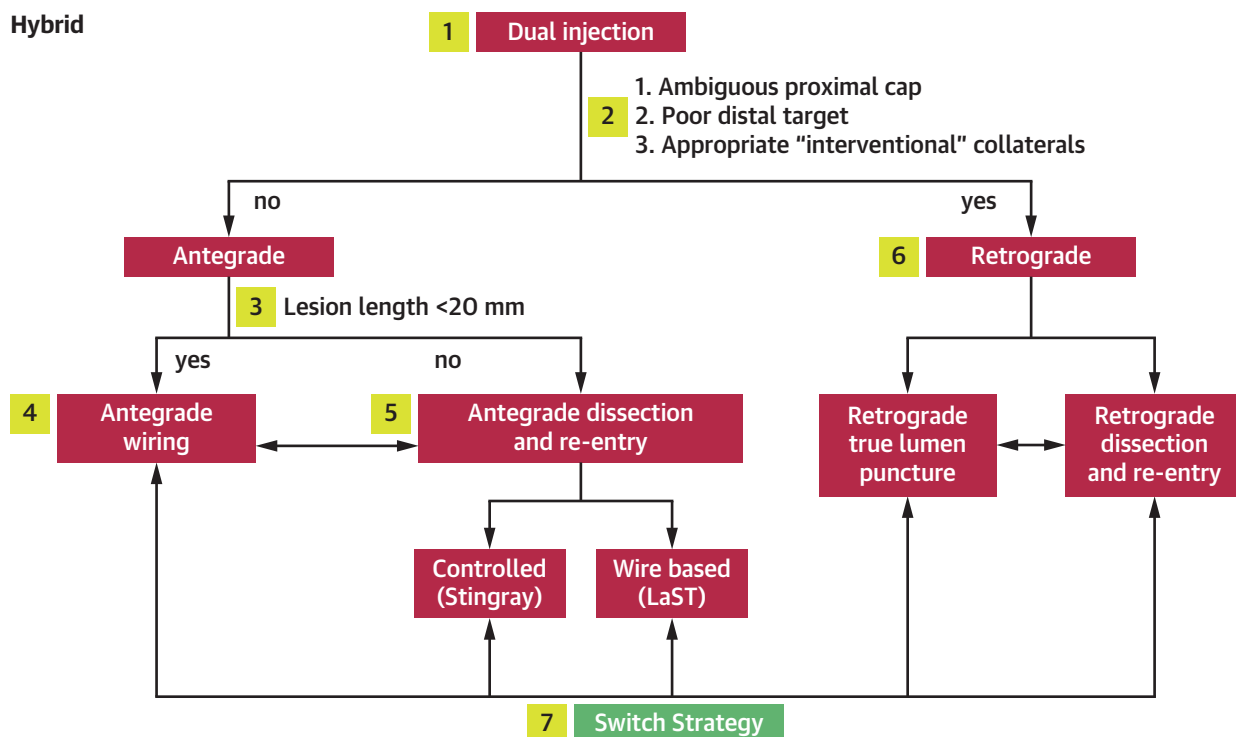
HIGHLIGHTS

- Several regional crossing algorithms for chronic total coronary artery occlusive lesions (CTO) have been published.
- The authors of these regional algorithms from 50 countries have collaborated in developing a global CTO crossing algorithm.
- This algorithm can encourage discussion, promote research collaboration, facilitate training and improve outcomes of percutaneous revascularization for patients with CTO.

FIGURE 1 Different CTO Crossing Algorithms

A

Hybrid



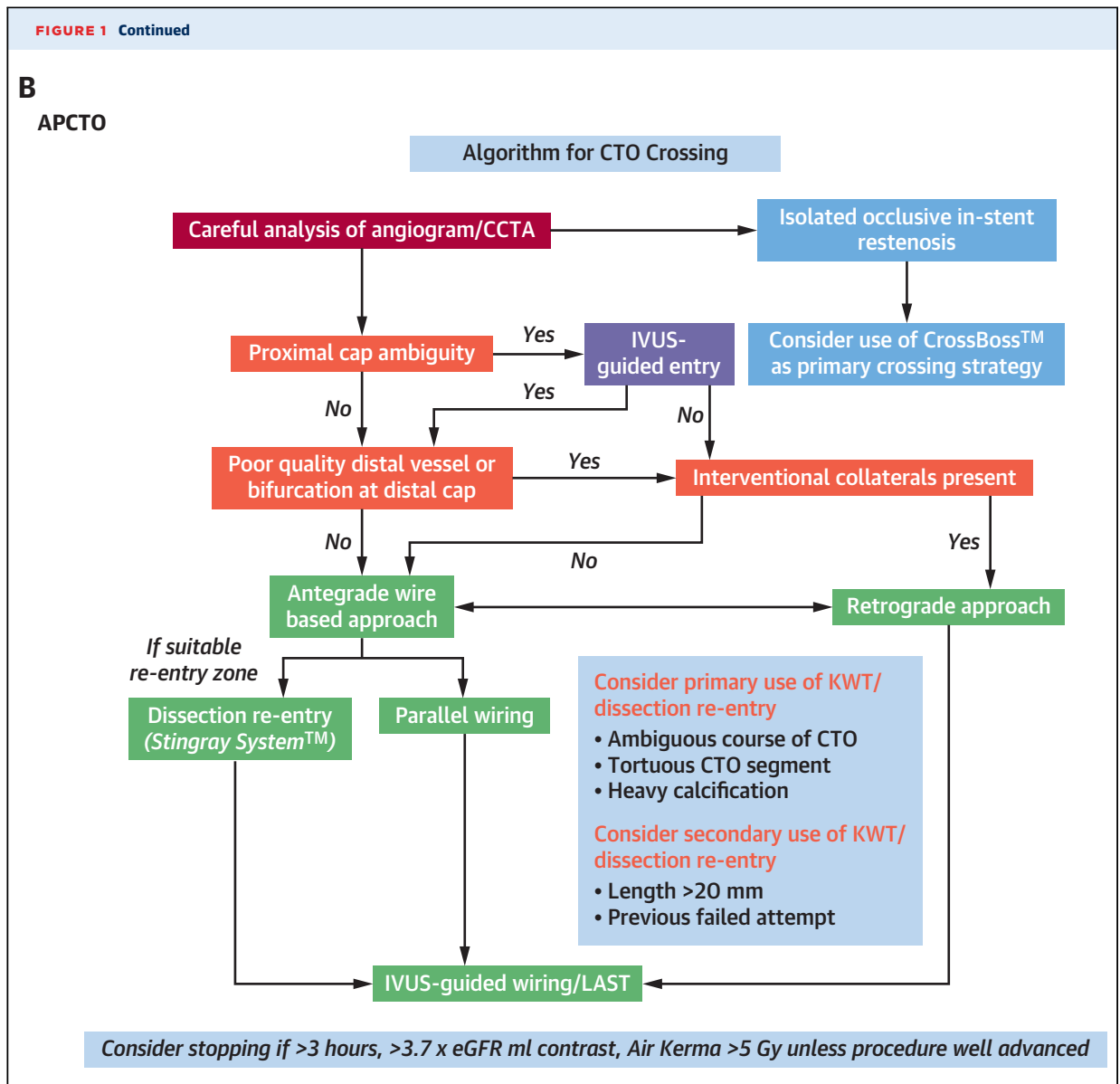
(A) The hybrid algorithm. Reprinted with permission from Brilakis et al (8). (B) The Asia Pacific CTO Club (APCTO) algorithm. Reprinted with permission from Harding et al (9). (C) CTO Club China algorithm. Reprinted with permission from Junbo (10). (D) EuroCTO Club algorithm. Reprinted with permission from Galassi et al (11). ADR = antegrade dissection and re-entry; AWE antegrade wire escalation; BASE = balloon-assisted subintimal entry; CAG = coronary angiography; CART = controlled antegrade and retrograde tracking; CCTA = coronary computed tomographic angiography; CTO = chronic total occlusion; eGFR = estimated glomerular filtration rate; IVUS = intravascular ultrasound; KWT = kissing wire technique; LaST = limited antegrade subintimal tracking; POBA = plain old balloon angioplasty; RWE = retrograde wire escalation; SB = side branch; STAR = subintimal tracking and re-entry.

Continued on the next page

FIGURE 1 Continued

B

APCTO



still needed for more complex antegrade IVUS controlled re-entry cases and for ipsilateral single-guide retrograde cases with simultaneous IVUS guidance. Access choice depends on the balance of risk for vascular complication against potential benefits, especially in more complex CTO procedures.

STEP 2: CAREFUL ANGIOGRAPHIC REVIEW. The coronary angiogram (most recent as well as prior angiograms) should be reviewed in detail, focusing on the following 4 characteristics.

Proximal cap morphology. Clear understanding of proximal cap location is critical for safely attempting antegrade CTO crossing recanalization. Proximal cap ambiguity is a key parameter in the global CTO

crossing algorithm. CTOs with ambiguous proximal caps may be approached using the retrograde approach or IVUS or the “move-the-cap” subintimal crossing techniques, such as balloon-assisted subintimal entry or scratch and go (15).

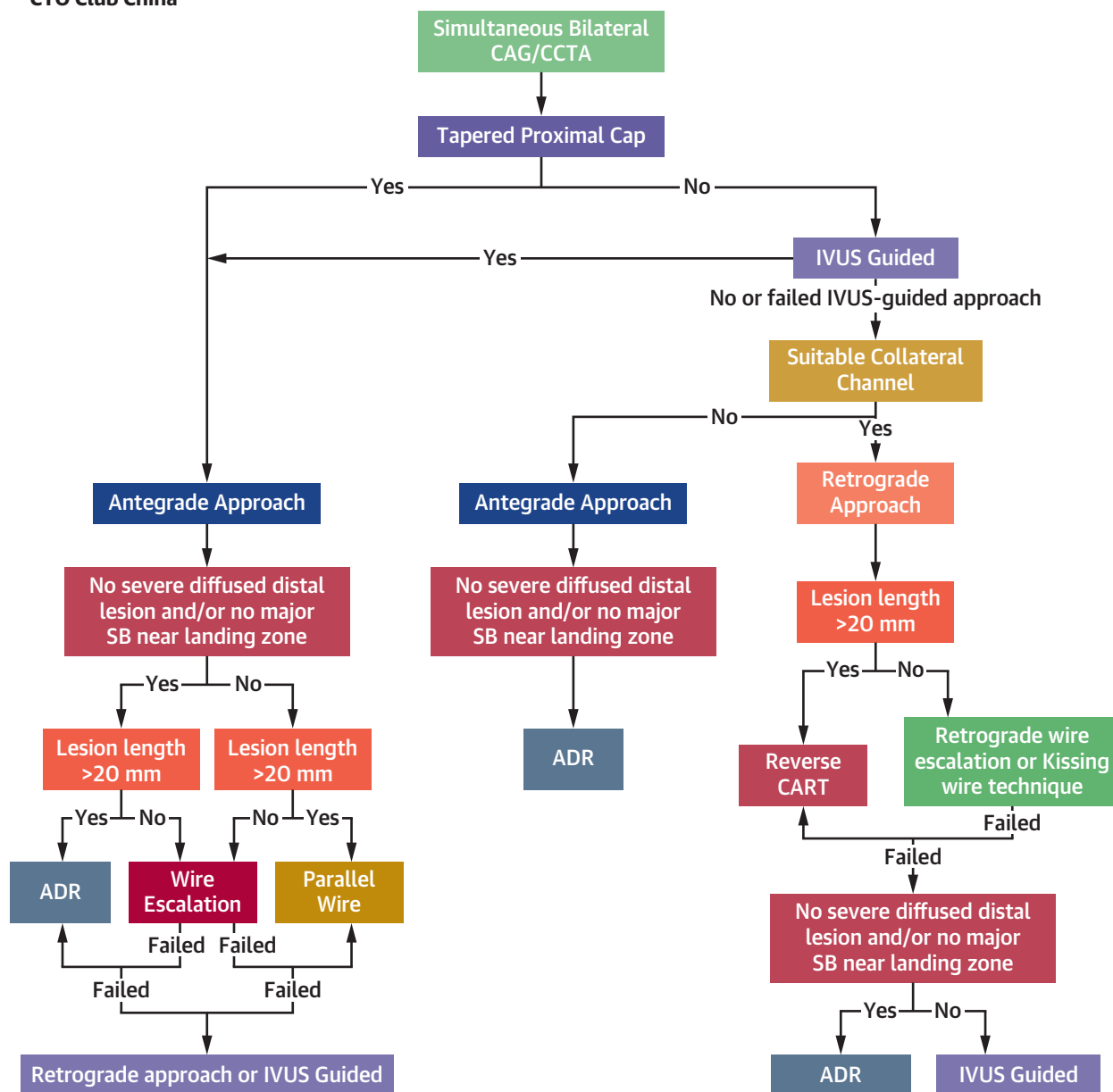
CTO lesion length and composition. Dual injection is necessary for estimating the occlusion length, as it allows visualization of the distal vessel and the distal cap. Calcification and tortuosity of the occluded segment increase the difficulty of CTO crossing and favor use of subintimal crossing techniques.

Distal vessel quality. A distal vessel of large caliber (≥ 2.0 mm) that fills well, does not have significant

FIGURE 1 Continued

C

CTO Club China



disease, and is free from major branches facilitates CTO recanalization. Conversely, small, diffusely diseased distal vessels with significant bifurcations are more challenging to recanalize, especially after subintimal guidewire entry.

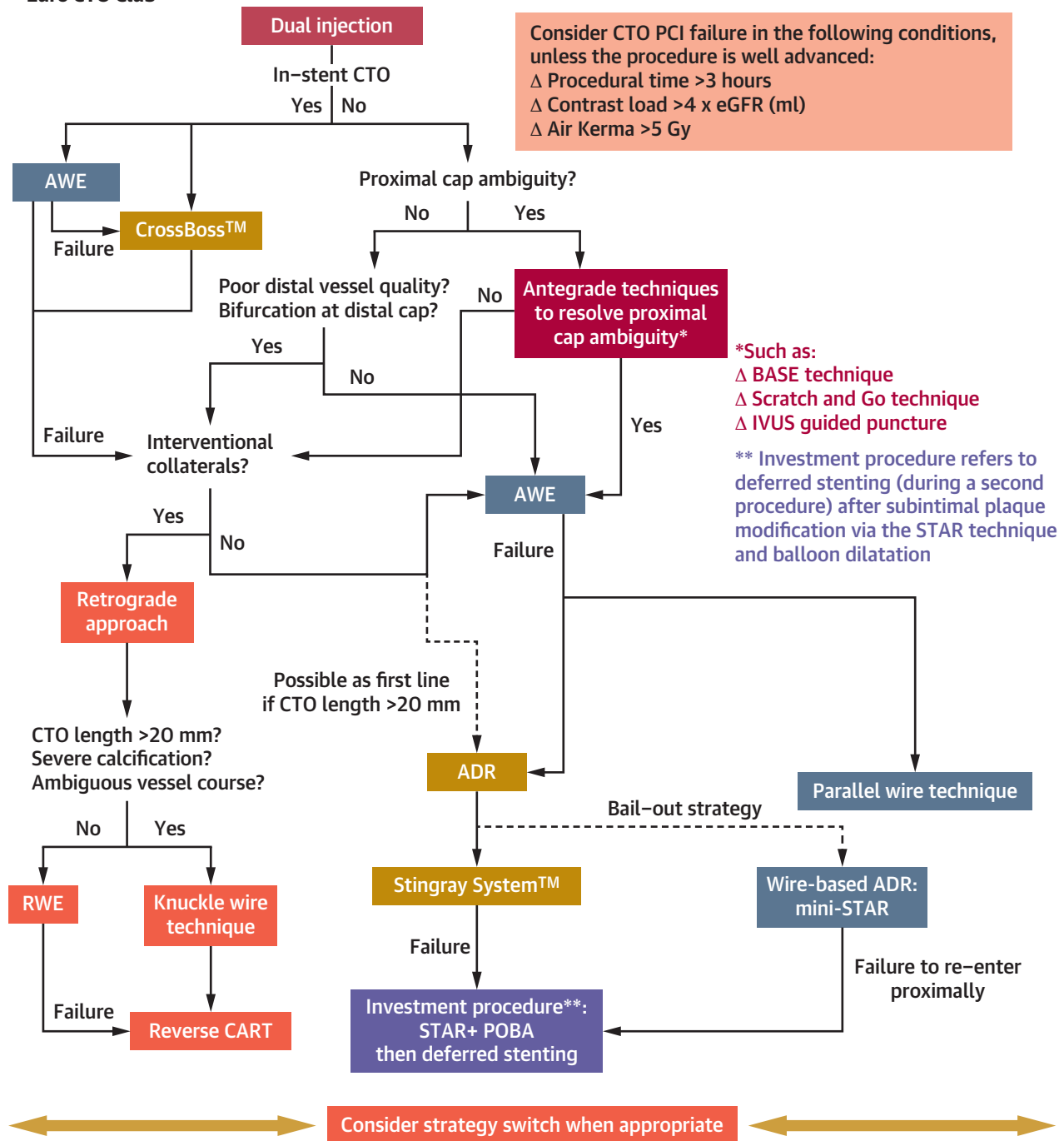
Collateral circulation. Evaluation of the collateral circulation helps determine the feasibility of the retrograde approach. Retrograde access to the distal vessel can be obtained via septal collateral

vessels, epicardial collateral vessels, or (patent or occluded) coronary bypass grafts. When assessing collateral vessels, it is important to consider size, tortuosity, bifurcations, angle of entry to and exit from the channel, and distance between the collateral exit and the distal cap. Larger collateral size and lack of tortuosity are associated with easier crossing by a guidewire and microcatheter (16,17).

FIGURE 1 Continued

D

Euro CTO Club



STEP 3: APPROACHING PROXIMAL CAP AMBIGUITY. Proximal cap ambiguity is inability to confidently determine the location of the proximal cap and is common in CTOs with a side branch at the proximal

cap. A stiff-tip guidewire should not be used to puncture caps with proximal cap ambiguity. In some patients, proximal cap ambiguity can be resolved by performing angiography in different projections and

TABLE 1 Comparison of Various CTO Crossing Algorithms

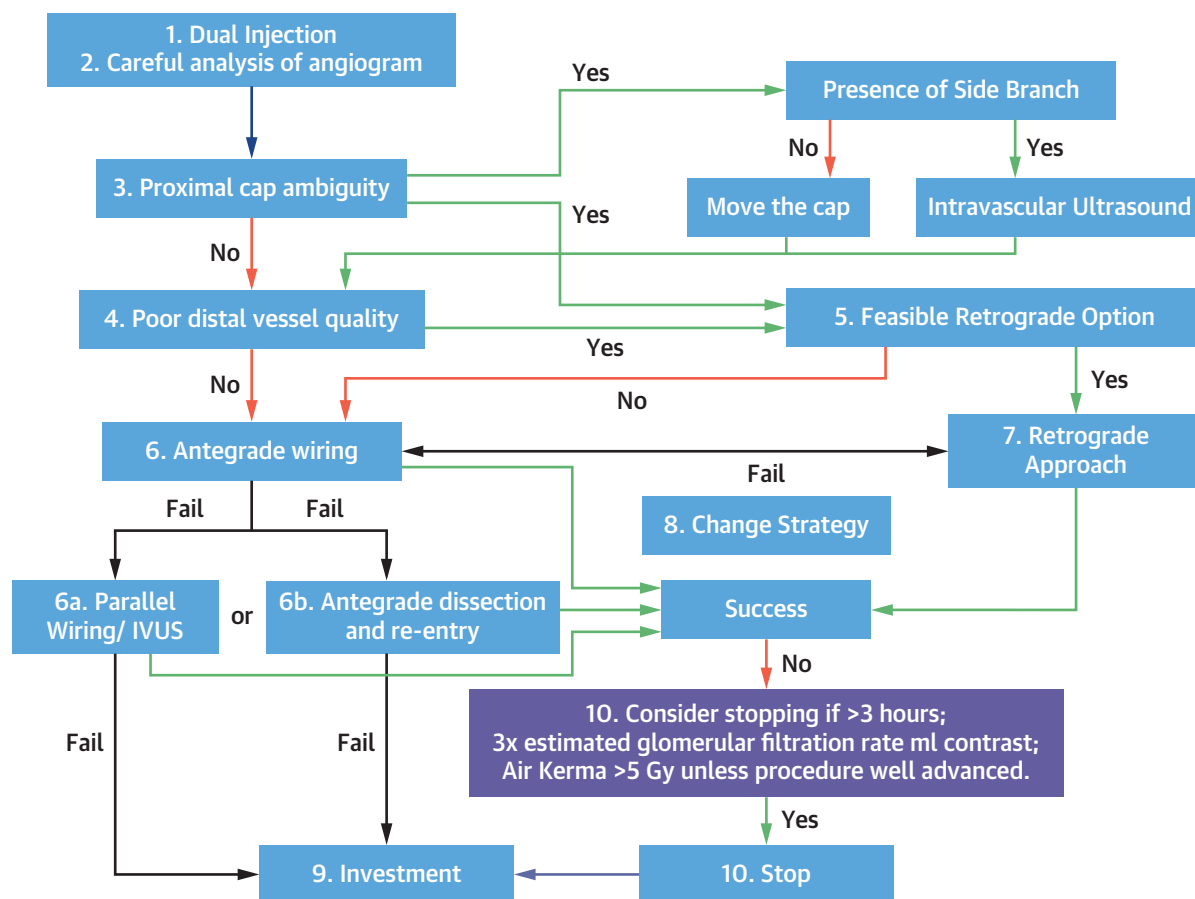
	Hybrid	Asia Pacific CTO Club	EuroCTO Club	CTO Club China	Japan CTO Club	Global
1. Dual angiography	+	+	+	+	+	+
1b. CTA		+		+		+
2. Careful angiographic review	+	+	+	+	+	+
ISR	No specific recommendation	+(CrossBoss)	+(CrossBoss)	+(CrossBoss)	Antegrade	No specific recommendation; assess lesion characteristics and treat accordingly
3. Proximal cap ambiguity	+	+	+	+	+	+
3b. Solutions to proximal ambiguity	Retrograde	Retrograde, IVUS	Retrograde, IVUS, move the cap	Retrograde, IVUS, move the cap	Retrograde	IVUS, retrograde, move the cap
4. Poor distal vessel bifurcation distal cap	+(retrograde)	+(retrograde)	+(retrograde)	+(retrograde)		+(retrograde)
5. Retrograde option	+	+	+	+	+	+
6. Antegrade wiring strategies	ADR for length ≥ 20 mm	AWE, parallel wiring Primary ADR for ambiguous CTO course, tortuous CTO segment, heavy calcification Secondary ADR: length ≥ 20 mm, prior failed attempt	AWE preferred; ADR possible as first line if length ≥ 20 mm	ADR preferred if severe diffuse distal disease and major side branch near landing zone	ADR or parallel wiring after AWE failure	AWE preferred
7. Retrograde	Ambiguous proximal cap, poor distal vessel + interventional collateral vessels	Ambiguous proximal cap (if IVUS fails), poor distal vessel + interventional collateral vessels	Ambiguous proximal cap, poor distal vessel + interventional collateral vessels	Ambiguous proximal cap + no or failed IVUS-guided approach + interventional collateral vessels	Reattempt, CTO length of ≥ 20 mm, and no stump + interventional collateral vessels	Ambiguous proximal cap, poor distal vessel + feasible retrograde option
7b. RDR preferred over RWE	Length ≥ 20 mm	Length ≥ 15 mm	Length ≥ 20 mm Severe calcification Ambiguous vessel course	Length ≥ 20 mm		Length ≥ 20 mm Severe calcification Ambiguous vessel course
7c. RDR preferred technique	Reverse CART	Contemporary reverse CART	Reverse CART	Reverse CART		Reverse CART
8. Change	+	+	+	+	After 20-min wire manipulation time	+
9. Investment			+			+
10. When to stop	Air kerma >10 Gy	Procedure duration >3 h Air kerma >5 Gy Contrast $>3.7 \times$ eGFR	Procedure duration >3 h Air kerma >5 Gy Contrast $>4 \times$ eGFR		Procedure duration >3 h	Procedure duration >3 h Air kerma >5 Gy Contrast $>3 \times$ eGFR Complication

ADR = antegrade dissection and re-entry; AWE = antegrade wire escalation; CART = controlled antegrade and retrograde tracking; CTA = computed tomographic angiography; CTO = chronic total occlusion; eGFR = estimated glomerular filtration rate; ISR = in-stent restenosis; IVUS = intravascular ultrasound; RDR = retrograde dissection and re-entry; RWE = retrograde wire escalation.

in others by contrast injection through a micro-catheter near the suspected proximal cap. Coronary computed tomographic angiography can also help resolve proximal cap ambiguity.

All current CTO crossing algorithms recommend a stepwise approach to proximal cap ambiguity: the hybrid algorithm recommends retrograde crossing, the APCTO algorithm recommends IVUS first followed by retrograde crossing if IVUS cannot clarify the anatomy, and the EuroCTO Club algorithm recommends IVUS or the “move-the-cap” subintimal techniques first, followed by retrograde crossing attempts.

The global CTO crossing algorithm supports all 3 strategies (IVUS-guided puncture, “move-the-cap” techniques, and retrograde crossing) for approaching proximal cap ambiguity without prioritizing one strategy over another (Figures 2 and 3). Instead, the strategy that optimizes safety and increases the likelihood of success should be selected on the basis of CTO anatomy. For example, in cases of proximal cap ambiguity without an appropriate side branch for IVUS but with excellent septal collateral vessels, retrograde could often be the initial crossing strategy. In contrast, in proximal caps with a favorable side branch, IVUS-guided proximal cap puncture may be

CENTRAL ILLUSTRATION The Global Chronic Total Occlusion Crossing Algorithm

Wu, E.B. et al. J Am Coll Cardiol. 2021;78(8):840-853.

Flow of chronic total occlusion crossing procedure. Yes or presence of feature or success indicated by **green arrow**; no or absence of feature indicated by **red arrow**; failure indicated by **black arrow**; progression to next step indicated by **blue arrow**.

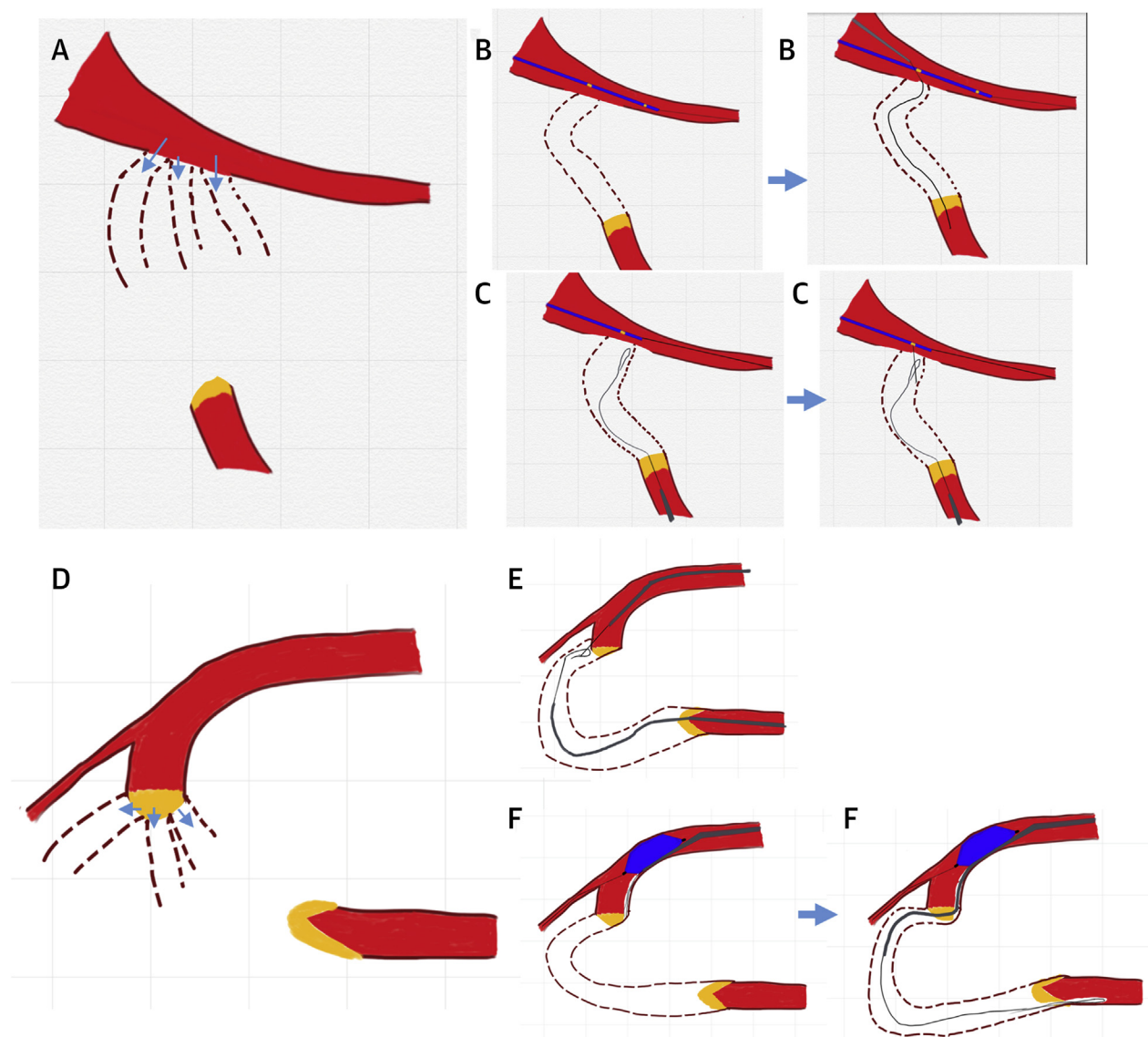
preferred. The “move-the-cap” techniques could be used if there are no significant side branches at the proximal or distal cap, as the intentional dissection can lead to occlusion of those branches, but should be avoided in patients with small and diffusely diseased distal vessels in whom re-entry into the distal true lumen may be challenging.

STEP 4: APPROACHING POOR DISTAL VESSEL QUALITY OR BIFURCATION AT THE DISTAL CAP. In patients with poor distal vessel quality or bifurcation at the distal cap, the retrograde approach may be safer and more efficient for operators experienced in this technique (10). In patients with bifurcation at the distal cap, use of a dual-lumen microcatheter is recommended for advancing a guidewire into the side branch to prevent side branch occlusion after balloon

angioplasty and stenting. If the CTO crossing guide-wire position is unclear, IVUS should be performed before stent placement to avoid side branch occlusion due to subintimal position of the main branch wire at the bifurcation.

STEP 5: FEASIBLE RETROGRADE OPTION. The term “interventional” collateral has been used for retrograde collateral vessels considered appropriate for crossing by the operator (8). Coronary bypass grafts, whether patent or occluded, are often used for the retrograde approach, even though bypass grafts are not truly “collateral” vessels. We introduce the term “feasible retrograde option” to describe the presence of any retrograde route considered appropriate for retrograde CTO PCI. Bypass grafts and septal collateral vessels are preferred over epicardial collateral

FIGURE 2 Approaches to Proximal Cap Ambiguity



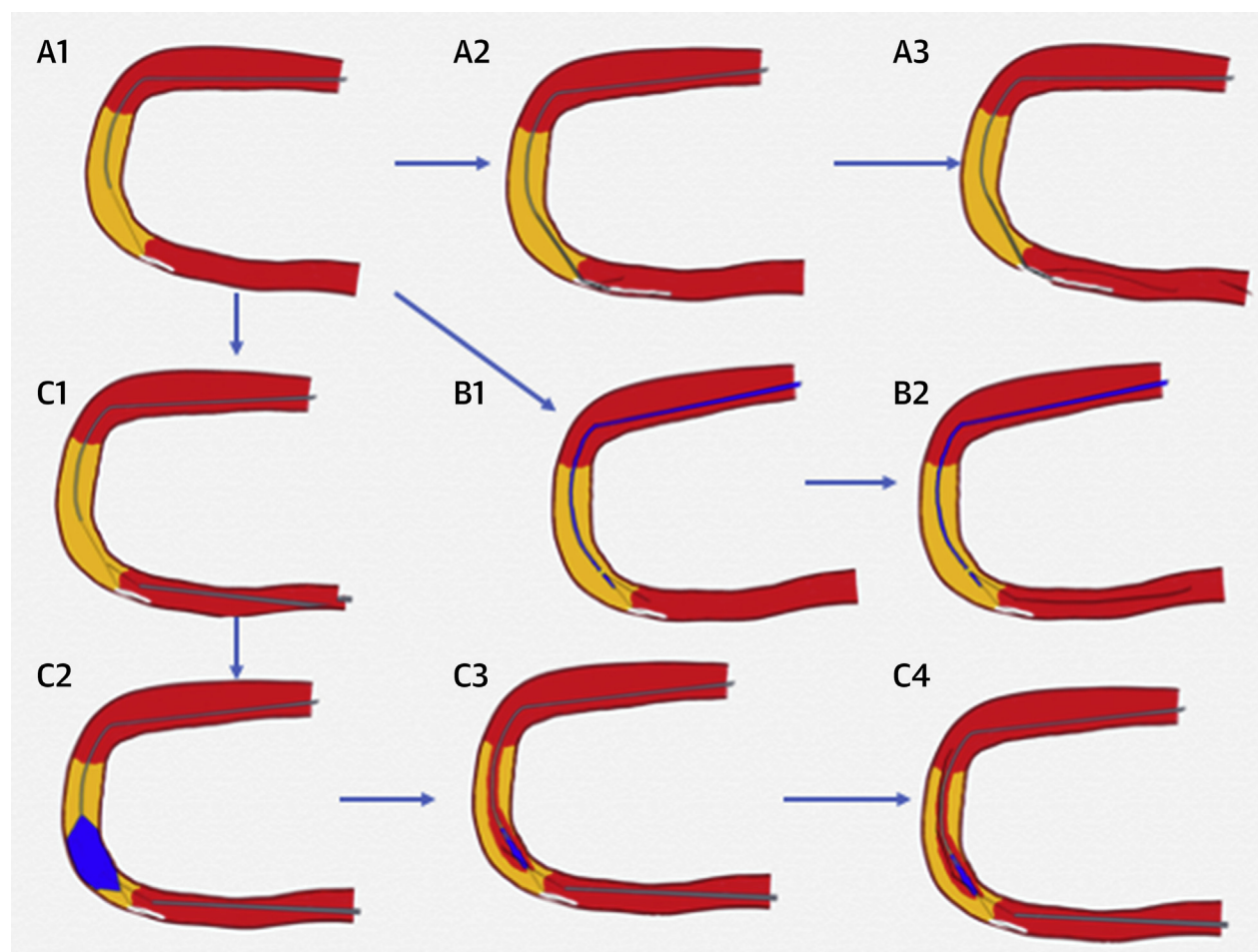
(A) Three possible position of proximal cap and vessel course of CTO (arrows). **(B)** True location of proximal cap revealed by IVUS and successful wiring of CTO. **(C)** Retrograde knuckle wire reveals proximal cap location, enabling successful antegrade puncture of the proximal cap. **(D)** Three possible positions (arrows) of the CTO proximal cap. **(E)** True location of proximal cap revealed by a retrograde knuckled wire and successful antegrade puncture into the cap. **(F)** Balloon-assisted subintimal entry, followed by subintimal crossing of the occlusion and distal re-entry. Abbreviations as in Figure 1.

vessels, as perforation of the latter is more likely to cause tamponade or potentially life-threatening loculated hematomas in patients with prior coronary artery bypass graft surgery.

STEP 6: ANTEGRADE WIRING STRATEGIES. Antegrade wiring is the most commonly used CTO crossing strategy and should be performed in most cases, unless there is proximal cap ambiguity or poor quality

distal vessel. Antegrade wiring usually starts with a low-tip-load, tapered, polymer-jacketed guidewire, followed by escalation to a stiffer polymer jacketed or a higher tip load, tapered guidewire if there is resistance to crossing (18,19). Escalation is usually followed by de-escalation to a softer tip, torquable guidewire after advancing through the area of resistance, especially when the vessel course is ambiguous

FIGURE 3 Approaches to Subintimal Guidewire Entry



When antegrade wire escalation strategy fails and the first wire enters the subintimal space next to the distal cap, subsequent wiring options include **(A1)** antegrade wire in subintimal space, **(A2)** antegrade dissection and device-based re-entry using the Stingray balloon, **(A3)** successful wiring of distal true lumen with use of Stingray, **(B1)** parallel wiring, **(B2)** successful wiring of distal true lumen with parallel wiring, **(C1)** retrograde approach, **(C2)** reverse controlled antegrade and retrograde tracking, **(C3)** successful crossing of retrograde wire into antegrade balloon space, and **(C4)** successful wiring of proximal true lumen via retrograde.

(20). If antegrade wiring fails to enter the distal true lumen, either antegrade (parallel wiring, device-based re-entry [such as use of the Stingray system], IVUS-guided antegrade wiring), or the retrograde approach can be used (Figure 3).

In ADR, the subintimal space is entered, followed by subintimal crossing of the CTO with re-entry into the distal true lumen. ADR may be intentional or unintentional during antegrade wiring attempts. The hybrid algorithm uses occlusion length alone (≥ 20 mm) to determine whether to use wire escalation or ADR, whereas the APCTO and EuroCTO Club algorithms use a combination of length and other

factors, such as tortuosity, calcification, and proximal cap ambiguity.

In the global CTO crossing algorithm, the following 4 parameters favor the use of ADR: ≥ 20 mm occlusion length, calcification, tortuosity, and presence of an appropriate re-entry zone of large caliber and without major side branches. ADR may be less desirable in long left anterior descending coronary artery CTOs with multiple branches (septal and diagonal) at risk for occlusion. Re-entry should be performed as close to the distal cap as possible, which may be best achieved by using a dedicated re-entry device, such as the Stingray balloon. Stenting should be avoided if

the subintimal tracking and re-entry technique is used, as it is associated with high rates of restenosis and reocclusion (21).

STEP 7: RETROGRADE APPROACH. The primary retrograde approach should be considered when retrograde is the best option to resolve proximal cap ambiguity, when there is a bifurcation in the distal cap, or when antegrade approach is completely impossible. Similar to antegrade wiring, retrograde crossing can be achieved via retrograde wiring versus retrograde dissection and re-entry, with the latter favored in cases with long occlusion length (≥ 20 mm), severe tortuosity, and calcification and lack of large side branches that could be compromised with use of dissection techniques. Reverse controlled antegrade and retrograde tracking is the most commonly used retrograde crossing technique (22) and can be facilitated by use of guide catheter extensions and IVUS (23).

STEP 8: CHANGE. Similar to all CTO crossing algorithms, the global CTO crossing algorithm recommends a change of strategy if the initially or subsequently selected strategies fail to achieve progress. The Japanese CTO algorithm recommends changing from antegrade to retrograde crossing after 20 minutes of guidewire manipulation, but the threshold for change varies depending on CTO anatomy and local expertise in various crossing techniques (2).

STEP 9: INVESTMENT PROCEDURE. If CTO crossing attempts fail, a variety of investment procedures should be considered if the anticipated benefit exceeds the potential harm (24-26). For example, if an antegrade guidewire has been advanced intraplaque through an ambiguous proximal cap, balloon angioplasty of the proximal cap is recommended. Repeat CTO crossing attempts are usually performed after ≥ 2 months to allow healing of any created dissections.

STEP 10: WHEN TO STOP. Deciding when to stop the CTO crossing attempts depends on the dynamic balance between the likelihood of success and patient safety. The global CTO algorithm recommends stopping the CTO PCI procedure if the procedure time is > 3 hours, if contrast volume is > 3 times the estimated glomerular filtration rate, or if the air kerma radiation dose is > 5 Gy, unless the procedure is well advanced. Even lower contrast volume thresholds may be used in patients with chronic kidney disease and comorbidities, such as diabetes (27). The procedure should also be stopped if it becomes evident that advanced crossing strategies, such as retrograde crossing or

ADR, are needed for successful crossing but the operator does not have expertise in those techniques or there is significant operator or patient fatigue. In such cases, referral to a CTO expert center or repeat attempt with a proctor could be considered. In most cases, occurrence of a serious complication should lead to discontinuation of CTO crossing attempts.

Optimal implementation of the global CTO algorithm is dependent on operator expertise in all CTO crossing strategies and techniques. Expertise can be developed in several ways, such as studying, attending meetings, and proctorship. Proctoring may not only improve an operator's CTO PCI skills but can also improve the safety of the CTO procedure, especially for highly complex lesions and patients.

CONCLUSIONS

CTO crossing algorithms are useful tools for optimizing the success and safety of CTO PCI. The global CTO crossing algorithm reflects the consensus of several experienced operators from multiple countries around the world and could help further improve the outcomes of these challenging procedures. This algorithm could help expand discussion, research, collaboration, and training in CTO PCI.

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