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REVIEW
Coronary

Insights into the Global Total Occlusion Crossing Algorithm

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Abstract
An algorithmic approach to chronic total occlusion (CTO) percutaneous coronary intervention has led to an increase in the success rate and safety of the procedure. The global CTO crossing algorithm is a consensus document that was developed by 121 expert operators from 50 countries and published during the COVID-19 pandemic. It provides standardisation while allowing flexibility in CTO crossing strategy selection, and can facilitate teaching of CTO percutaneous coronary intervention across various regions of the world. In this review, the 10 steps of the global CTO crossing algorithm are discussed in detail.

Keywords
Chronic total occlusion, percutaneous coronary intervention, global crossing algorithm

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Developing a crossing algorithm has had a significant impact on the success and safety of chronic total occlusion (CTO) percutaneous coronary intervention (PCI). In 2012, the hybrid algorithm was published, followed by the Asia-Pacific CTO club algorithm in 2017, the CTO club China algorithm in 2018, the Japan CTO club algorithm in 2019 and the EuroCTO club algorithm also in 2019.[1–5] In 2021, during the COVID-19 pandemic, 121 expert operators from 50 countries published the global CTO crossing algorithm that provides standardisation while allowing flexibility in CTO crossing strategy selection and can facilitate teaching of CTO PCI across the world.[6]

The global CTO crossing algorithm has 10 steps, addressing all stages of the procedure (*Figure 1*).

Step 1: Dual Angiography

Dual (and sometimes triple, in patients with prior coronary artery bypass graft surgery) angiography is instrumental in CTO PCI.[7] It increases the likelihood of success and decreases the likelihood of complications. It allows visualisation of the distal true lumen, helps estimate the difficulty of the procedure during planning and enables assessment of equipment position during CTO crossing attempts. Dual angiography should be performed in all cases unless the distal vessel is solely supplied by ipsilateral collaterals or in flush aorto-ostial occlusions.

Dual angiography is performed by injecting the donor vessel first, followed by injection of the occluded vessel 2–3 seconds later. Optimal timing of the injections allows the contrast to reach the proximal and distal cap simultaneously, helping to optimally assess the CTO characteristics.

While dual angiography may increase the risk of vascular access complications, the gains in safety and success outweigh the risks. Use of (single or dual, distal or proximal) radial access and the use of state-of-the-art femoral access techniques (ultrasound, fluoroscopy, femoral angiography and use of vascular closure devices) may decrease the risk of vascular complications.[8] Two randomised controlled trials, the COLOR and FORT CTO trials, showed similar success rates with radial versus femoral access with lower incidence of arterial access complications in the radial artery group.[9,10] However, femoral access may be advantageous when trying to cross highly complex CTOs, such as in prior coronary artery bypass graft patients. Use of large (7 or 8 Fr) guide catheters improves visualisation and increases support during CTO crossing attempts.

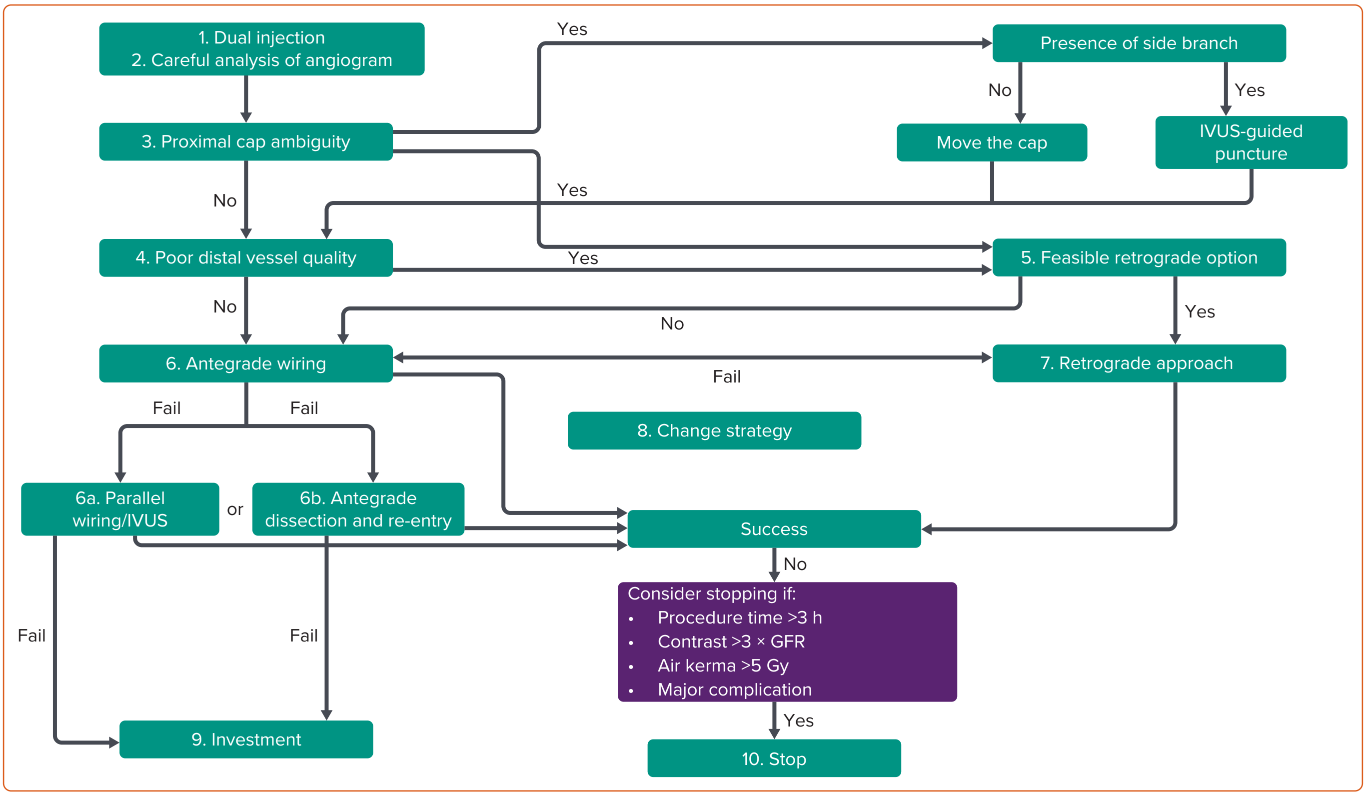
Coronary computed tomography angiography (CCTA) is increasingly being performed for planning CTO PCI, and can be extremely useful for procedural planning, especially in more complex cases. In the CT-CTO trial, pre-procedural coronary CCTA guidance resulted in higher success rates with numerically fewer immediate periprocedural complications, driven by higher success in more complex CTO lesions (those with Japanese CTO score of ≥2).[11]

Step 2: Careful Angiographic Review

Detailed analysis of the dual angiography is key for planning and performing CTO PCI. Angiographic review should focus on four areas (*Figure 2*):

1. Proximal cap: understanding the location and morphology of the proximal cap is key for selecting the initial and subsequent crossing strategies.
2. Occlusion: dual angiography helps determine occlusion length, course, presence of tortuosity and calcifications. Longer occlusions with severe tortuosity and calcification are associated with lower success and are

Figure 1: The Global Chronic Total Occlusion Crossing Algorithm



GFR = glomerular filtration rate; IVUS = intravascular ultrasound.

more likely to require advanced crossing strategies, such as antegrade dissection and re-entry (ADR) and the retrograde approach.[12,13]

3. Distal vessel quality: a large distal vessel that is free of disease increases the likelihood of successful antegrade techniques when compared with a small and diffusely diseased distal vessel.
4. Collateral circulation: multiple aspects of the collateral circulation should be evaluated, such as the course (septal, bypass graft, epicardial), angle of entry and exit, size, tortuosity, distance to distal cap, and dominance (one single dominant collateral versus multiple) before determining the feasibility of the retrograde approach (*Figure 3*). Selective injections through a guide catheter extension or a microcatheter can be performed to improve visualisation of the collateral circulation. In general, bypass grafts and septal collaterals are safer than epicardial collaterals. Large collaterals without severe tortuosity are associated with higher likelihood of successful wiring.[14]

Step 3: Approaching Proximal Cap Ambiguity

Inability to accurately pinpoint the proximal cap location is associated with lower success and higher complication rates.[15] Obtaining better-quality angiograms using large guide catheters and projections with extreme angulations can sometimes clarify the location of the proximal cap, as can the use of CCTA. If the cap remains ambiguous, the global CTO crossing algorithm suggests three strategies to resolve the ambiguity: intravascular ultrasound (IVUS)-guided puncture, 'move the cap' techniques and the retrograde approach.

Feasibility and safety should be taken into consideration when choosing between these techniques. For example, IVUS-guided puncture can be used if there is a suitable side branch at the proximal cap, but may not be useful in the presence of severe calcification. In contrast, if IVUS fails to resolve the ambiguity or there is no significant side branch at the proximal cap, then the retrograde approach should be considered in patients with appropriate collaterals. The 'move the cap' techniques (starting a dissection proximal to the proximal cap) can be used if there are no major side branches at the proximal and distal caps, and if the distal vessel is of good quality to increase the likelihood of successful re-entry.

Whether a proximal cap is ambiguous or not depends heavily on operator experience and expertise, on the quality of coronary angiography, and on use of CCTA. What appears to be an ambiguous proximal cap to an inexperienced operator may be clear to an experienced operator and vice versa.

Step 4: Approaching Poor Distal Vessel Quality or Bifurcation at the Distal Cap

A poor-quality distal vessel decreases the likelihood of successful antegrade techniques. It is associated with overall lower success rate, higher complications rate and longer procedure time.[15] The global algorithm recommends the retrograde approach when feasible in lesions with a poor-quality distal vessel or a bifurcation at the distal cap.

Quite often, the distal vessel may appear small and diffusely diseased due to poor filling, but may significantly grow in size after successful recanalisation. Sometimes, the distal vessel may be poorly or not visible if the collaterals are not filled with contrast; for example, in patients with a left anterior descending artery CTO that is filling via a Vieussens' collateral from a conus branch that is not selectively engaged by the right coronary artery guide catheter.

Step 5: Feasible Retrograde Options

Assessing the collateral circulation is a critical step in the global algorithm when contemplating use of the retrograde approach. CTOs with interventional collaterals (i.e. collaterals considered feasible to cross by the operator) are associated with higher success rates because the retrograde approach can be used to resolve proximal cap ambiguity and a poor-quality distal vessel.[16]

Operator experience is critical for determining whether a collateral connection is interventional or not. Two aspects need to be taken into consideration: safety and likelihood of wiring. In general, bypass grafts and septal collaterals are safer than epicardial connections. Bigger collaterals with less tortuosity are more likely to be successfully wired. Wiring a large, dominant collateral (usually epicardial) may lead to ischaemia of the target vessel, causing chest pain, electrocardiographic changes, and sometimes hypotension and arrhythmias.

Step 6: Antegrade Wiring Strategies

Antegrade wiring should be used as the initial strategy in most CTOs, except those with proximal cap or course ambiguity where antegrade wiring can cause perforations, or cases with poor quality distal vessel and bifurcation at the distal cap. Most wire escalation algorithms recommend starting with a low tip, tapered polymer jacketed wire, followed by stiff polymer jacketed wires. High tip load, penetrative wires can be used to advance through calcified and resistant proximal caps, followed by de-escalation to a softer wire. If the initial wire goes extraplaque, then parallel wiring with a second, usually stiffer, wire or IVUS-guided wiring can be attempted to find the distal true lumen. With development of more torqueable and penetrative wires, the success of antegrade wiring has increased in recent years.[17]

ADR can be useful in long (>20 mm), calcified, tortuous occlusions with a good-quality distal vessel and without major side branches, especially when the retrograde approach is not feasible. ADR in such cases can decrease the risk of complications associated with antegrade wiring. Dissection is frequently started using a knuckled wire. A polymer jacketed wire is looped to create a dissection and is advanced across the occlusion. The size of the loop or the knuckle is usually reflective of the vessel diameter. Stiff polymer jacketed wires, such as the Pilot 200 (Abbott), create large knuckles, which is useful in avoiding side branches, but may enlarge the extraplaque space. Softer wires, such as Fielder XT (Asahi Intecc), create small knuckles, which results in smaller extraplaque space, but can track side branches.[1]

Dissections can also be started using balloon-assisted subintimal entry (inflation of a balloon proximal to the proximal cap to create a dissection, followed by staged or simultaneous advancement of a polymer-jacketed guidewire into the extraplaque space) or the side-balloon-assisted subintimal entry technique (same as balloon-assisted subintimal entry with the balloon being halfway into a side branch at the proximal cap). Once the occlusion is traversed with a knuckled polymer-jacketed wire, re-entry should be performed as close as possible to the distal cap to minimise the risk of losing side branches. This can be achieved using specific devices, such as the STINGRAY balloon (Boston Scientific) and the ReCross microcatheter (Biotronik), with newer intravascular imaging-guided devices currently in development.[18]

Tip detection ADR is a new method originating from Japan that allows controlled and accurate re-entry under live intravascular ultrasound guidance.[19,20] Subintimal antegrade fenestration and re-entry is a new technique that uses multiple inflations of a 1:1 sized balloon in the extraplaque space at the preferred re-entry site to create fenestrations and tears in the dissection flaps. These connections are then traversed

Figure 2: Dual Angiogram Can Help with the Assessment of Proximal Cap, Occlusion Length, Distal Vessel Quality and Collateral Circulation

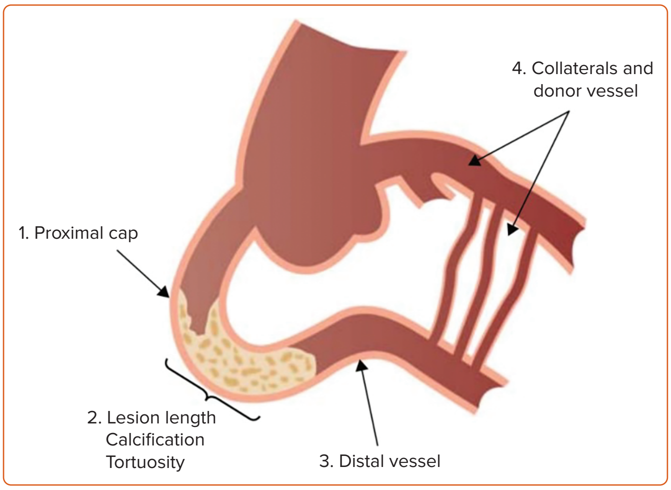


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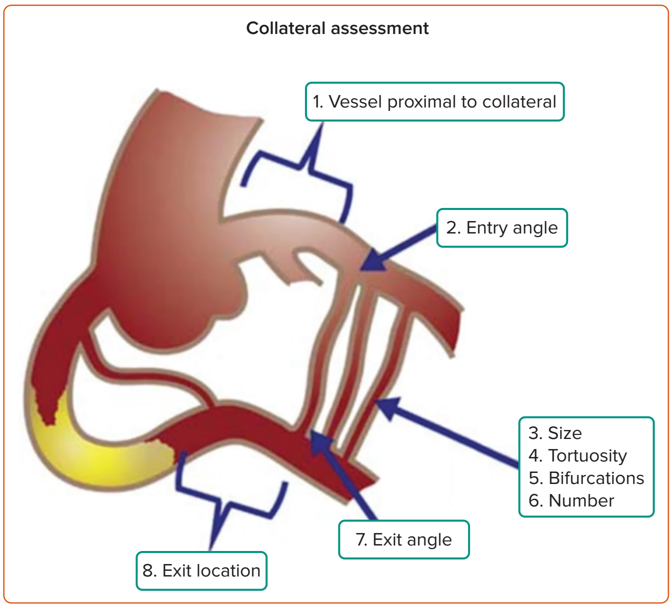
Figure 3: Assessment of the Collateral Circulation



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back into the true lumen using a polymer jacketed wire.[21] The Triumph microcatheter (Teleflex) is a new catheter with six exit ports that allows re-entry and superior haematoma evacuation through these ports, but it is not commercially available yet.

If crossing attempts fail, the subintimal tracking and re-entry technique can be used to achieve re-entry. Stenting should be deferred when the subintimal tracking and re-entry technique is used. In a recent publication, ADR was used in 18.6% of CTO PCI performed at experienced, high-volume centres in complex CTOs (mean Japanese CTO score of 2.94).[22] Use of ADR has overall been decreasing, with subintimal tracking and re-entry overtaking Stingray as the most common ADR technique in 2023.

Step 7: Retrograde Approach

A primary retrograde approach (i.e. the retrograde approach used as the first CTO crossing strategy) is used to resolve proximal cap ambiguity or when there is a poor-quality distal vessel with a bifurcation at the distal cap. After wiring the collateral connections, the occlusion can be crossed via retrograde wiring or retrograde dissection and re-entry. Like ADR, retrograde dissection and re-entry is usually performed in long occlusions with ambiguous course, calcification and tortuosity. Reverse controlled antegrade and retrograde tracking (reverse controlled antegrade and retrograde tracking) is the preferred method to achieve re-entry. The original controlled antegrade and retrograde tracking technique can also be used to form a connection between the antegrade and retrograde wires; however, it is currently used in few patients.[23]

In flush aorto-ostial occlusions when stiff guidewires fail to cross into the aorta, the electrocautery-assisted re-entry technique has been used to facilitate re-entry into the aorta by delivering electrical energy through a coronary guidewire.[24] In a recent publication, the retrograde approach was attempted in 34.4% of CTO PCIs performed in high-volume centres worldwide. True lumen crossing was used in 37%, and retrograde dissection and re-entry in 63% of these cases.[25]

Step 8: Change

Changing to a new strategy is recommended after failure of the initial and subsequent crossing strategies. How long to persist with the originally selected strategy and when to change to a new strategy depends on how much progress has been made and the operator's experience. In a study of 1,079 CTO PCIs, crossing over to a new approach was necessary in 19, 46 and 35% of the cases when primary antegrade, retrograde and ADR were used, respectively.[22]

Step 9: Investment Procedure

CTO modification with balloon angioplasty after failed crossing into the distal true lumen can create small channels and fenestrations that can facilitate recanalisation during subsequent attempts.[26] A drug-coated balloon has been used in such cases to preserve vessel patency with encouraging results.[27] It is recommended to return for a second attempt approximately 8 weeks after the investment procedure. Invest-CTO is a single-arm, ongoing study that is examining the outcomes of a subsequent completion PCI after 8–12 weeks of a planned investment procedure in CTOs with high-risk anatomy.[28]

Step 10: When to Stop

Operators should continually monitor radiation dose and contrast volume during the procedure. Moreover, patient and operator fatigue play an integral role in deciding when to stop further crossing attempts. The global crossing algorithm recommends stopping after 3 h of procedure time, contrast volume greater than threefold the glomerular filtration rate or air kerma (kinetic energy released per unit mass radiation) dose of >5 Gy. The procedure should be stopped earlier after a failed antegrade crossing attempt if the operator is inexperienced in advanced crossing strategies, such as ADR and retrograde.

The procedure should also be stopped if a major complication, such as perforation, equipment entrapment and acute closure of the donor vessel, occurs, unless continuing is important for managing the complication.[29] For example, dissection of the donor vessel early during the case should be stented and further attempts to recanalise the CTO should be stopped. In contrast, perforation within the CTO body might require the retrograde approach to seal the perforation using retrograde dissection techniques.[29]

The global, the hybrid and all other CTO crossing algorithms were developed by consensus. Use of actual procedural data can help improve the algorithm, and can be facilitated by use of artificial intelligence. In the meantime, thoughtful application of the algorithm can facilitate teaching, research and collaboration between operators from different regions of the world. ❑

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