The Egyptian Heart Journal (2014) 66, 1–10

Egyptian Society of Cardiology

The Egyptian Heart Journal

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INVITED ARTICLE

Current technical and clinical features of the antegrade and retrograde approaches to percutaneous transluminal coronary intervention for chronic total occlusion – 2013 version

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Received 15 October 2013; accepted 16 October 2013
Available online 15 December 2013

KEYWORDS
Percutaneous transluminal coronary intervention;
Chronic total occlusion;
Retrograde approach

Abstract PCI for the treatment of CTO has made remarkable progress in recent years, and interventional cardiologists in Japan have made a great contribution to this progress. Innovative techniques, including the retrograde approach, are hot topics in the CTO field. The long-term prognosis after initial success is also attracting considerable attention. Strategies for treating CTO are continually evolving, and the author's strategy also continues to change over time. The author's strategy as of 2013 is described here.

1. Introduction

Percutaneous coronary intervention (PCI) for chronic total occlusion (CTO) has made great progress during the past few years, and Japanese interventional cardiologists have made a particularly important contribution. New innovative techniques, including the retrograde approach, are among the recent topics with regard to PCI for CTO. During the past year, several new devices have been developed and changes to some therapeutic strategies for CTO have occurred. Here, I will review recent advances in the treatment of CTO and also explain my current strategies for managing CTO lesions.

1.1. Approach and guiding catheters to use in PCI for CTO

The first step to achieving success with PCI for CTO is to perform appropriate coronary angiography (CAG) and to properly interpret the angiograms before starting the procedure. An important point when performing baseline CAG is to serially adjust the image size without panning. At our center, close-up images are obtained for detailed assessment of CTOs, while other images are obtained with a wider field of view to display the anatomy of collateral channels. For both purposes, at least three different views in which major branches are not superimposed should be obtained to show the pattern and length of the CTO, the course and branches of the occluded

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Peer review under responsibility of Egyptian Society of Cardiology.

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http://dx.doi.org/10.1016/j.ehj.2013.10.002

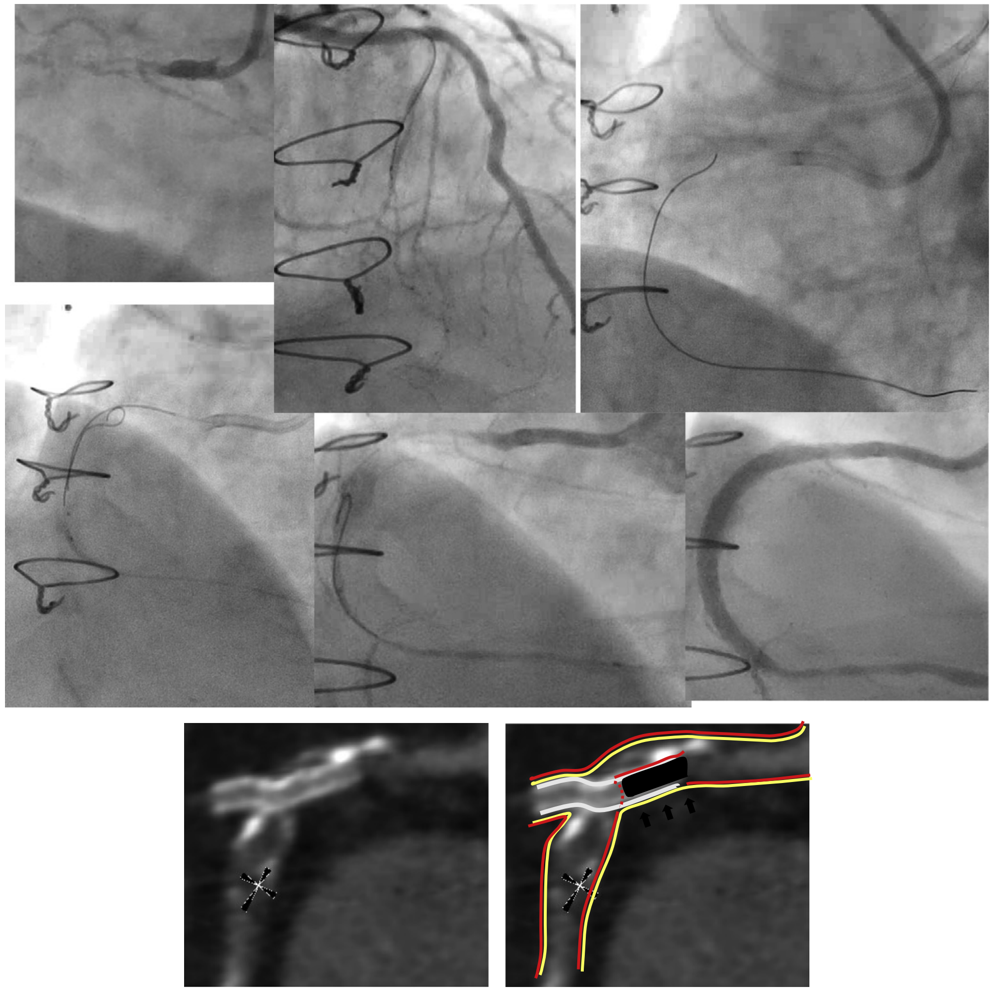


Figure 1 Retrograde PCI guided MSCT.

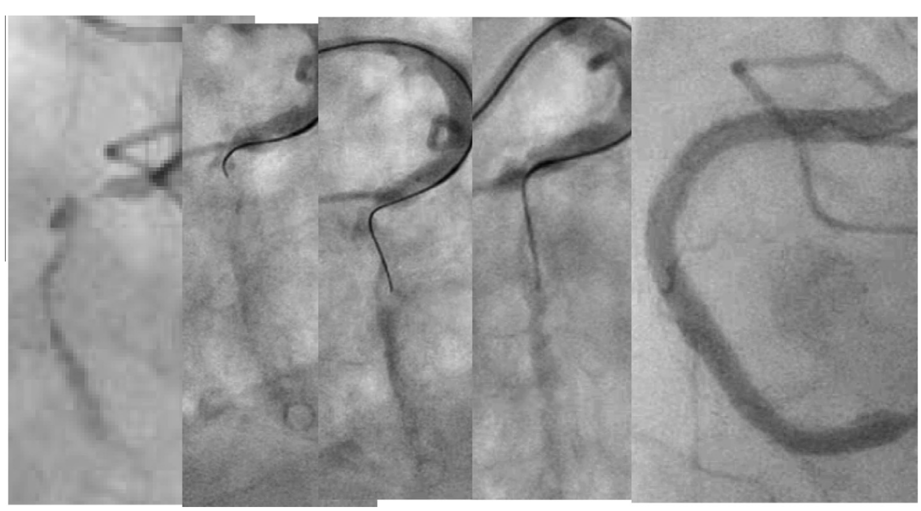


Figure 2 Bend CTO crossed by Miracle guidewire.

artery, the anatomy of the arteries distal to the CTO, and the extent of vascular calcification. The features to be checked for a collateral channel include the extent of its development, its origin and course, and the entry point of the channel into the artery distal to the CTO. The RAO caudal, RAO, RAO cranial, and lateral views are necessary to delineate a septal channel, which is the type of channel most commonly used for the retrograde approach. However, use of epicardial channels has been increasing recently and these include apical, AC, and ipsilateral channels. In general, LAO and RAO cranial views are appropriate to display an apical channel, while a spider view is needed to properly show an AC channel, and an RAO cranial view is required for an ipsilateral channel. Important tips for imaging a collateral channel are to adjust the image size to cover its entire course, avoid panning during imaging, and use a sufficient volume of contrast medium to demonstrate collateral flow into the coronary artery distal to the CTO.

Baseline multislice CT (MSCT) of the heart is routinely performed at our center because it is also useful for understanding the plaque structure of the CTO and the anatomy of the occluded artery. In a patient with CTO located at the ostium of the right coronary artery (RCA), baseline MSCT showed that a previously implanted stent was in a conus branch. This information allowed successful performance of PCI for the CTO by the retrograde approach (Fig. 1).

The second important step toward achieving success with PCI for CTO is selection of the optimum PCI system. In principle, guiding catheters should be at least 7 Fr in size to ensure delivery of sufficient back-up force. Supportive guiding catheters should be used, such as those of the AL type for insertion into the RCA and those of the XB or EBU type for insertion into the left coronary artery (LCA). However, a supportive guiding catheter can easily cause injury to the proximal coronary artery due to deep engagement of its tip, so care should be taken to avoid this. In principle, I use guiding catheters with a side hole to avoid coronary artery injury by the catheter tip and excessive pressure. It is essential for guiding catheters to be inserted into both the RCA and the LCA for angiographic confirmation of collateral channels. It may be sufficient to insert a diagnostic catheter into the donor artery if the retrograde approach is not being specifically targeted, but just inserting a guiding catheter into the affected artery is only acceptable if there is an ipsilateral collateral pathway. Intervention for CTO without confirmation of a collateral pathway to the coronary artery distal to the occlusion should be avoided as it leads to a far lower success rate and an increased risk of complications.

1.2. Antegrade approach

1.2.1. Tapered guidewires

Tapered guidewires are currently the first choice for the antegrade approach, including the Fielder XT (0.009 inch, Asahi Intecc), Wizard 78 (0.078 inch, Lifeline), and Equation (0.008 inch, Johnson & Johnson). Recently, new tapered guidewires such as the Gaia 1st (0.10 inch, Lifeline) have been developed and are gaining acceptance. These tapered guidewires are not intended for intentional crossing of the CTO by wiring and are designed for microchannel tracking, which may occasionally result in incidentally crossing the CTO. Therefore, tapered guidewires are not used to treat a CTO without microchannels and are unlikely to pass through tortuous or kinked microchannels. Tapered guidewires are also unsuitable for the treatment of CTOs that require good guidewire trackability. However, tapered guidewires are safer than other types of wires because of being floppy. Another advantage of using a tapered guidewire is that the time required for PCI can be shortened if the wire passes through a microchannel. Therefore, about 10–15 min is the optimal time to attempt manipulation of a tapered guidewire. If the tapered guidewire cannot be passed through a microchannel within this period, it should be promptly exchanged for another wire.

1.2.2. Intermediate guidewires

If the affected artery is tortuous, a tapered guidewire should be switched to an immediate type of wire. The Miracle 3 g, 4.5 g, and 6 g guidewires are representative wires for this purpose, while the recently introduced Ultimate bro 3 g shows better trackability. Guidewires of this type may be used if the target artery makes an acute angle just proximal to the CT, so that it is difficult to keep a soft guidewire coaxial with the lesion (Fig. 2).

Figure 3 Bend CTO crossed by Gaia 2nd guidewire.

The Gaia 2nd guidewire (0.011 inch, Lifeline) was developed recently and it has attracted the attention of leading interventional cardiologists. Because of its excellent torque transmission, the Gaia 2nd is particularly efficient at passing along tortuous arteries and entering fine channels. Fig. 3 shows successful use of a Gaia 2nd wire to treat a patient with CTO of a tortuous RCA.

1.2.3. Stiff guidewires

To recanalize a CTO in a relatively straight artery, I often directly exchange a tapered guidewire for a stiff wire rather than an intermediate one because this strategy saves time and reduces cost. The Conquest Pro is a representative stiff guidewire with better penetration than the other guidewires in this class. However, use of the Conquest Pro is associated with an increased risk of coronary artery injury, so the operator must make all possible efforts to keep the guidewire within the vessel lumen and should not choose this wire if the course of the vessel is difficult to visualize or predict. More precisely, I think that attempting the antegrade approach is not appropriate in the absence of data on the vascular anatomy around the CTO. If the CTO is too dense to cross, the guidewire should be exchanged for one with a stiffer tip such as a Conquest Pro 12 g or 20 g. However, guidewires of the Miracle series or the Gaia 2nd wire are better than the Conquest wires for crossing a CTO in a tortuous artery.

A useful tip for manipulating a guidewire toward and through a CTO is to coordinate rotational movements made with the right hand and forward/backward movements made by the left hand. Particular care should be taken when manipulating a wire at the entry site to a CTO. If it is advanced too vigorously at the entry, the guidewire can easily be deflected into a subintimal space. If the guidewire remains in the intimal space after passing the entry site of a CTO, this can be recognized by the unique tactile sensation and the guidewire can be advanced relatively easily to reach the coronary artery lumen distal to the CTO. The operator should not rotate the guidewire excessively as this may enlarge the subintimal space. If a guidewire enters a subintimal space, the wire will feel "trapped" and this can be confirmed by frequently performing alternating withdrawal/advancement. After a subintimal space has been excessively enlarged, the "trapped" feeling is abolished and the tip of the guidewire rotates easily while advancing. Whether or not the guidewire has entered a subintimal space should be determined as soon as possible since this situation can probably be corrected at an early stage. As entry of a guidewire into the subintimal space often occurs at the proximal cap of a CTO, the situation may be corrected by withdrawing the wire and attempting re-wiring. To manipulate a guidewire back from the subintimal space to the intimal space, the strategies that should be adopted in order are the parallel wiring technique, the intravascular ultrasound (IVUS)-guided technique, and other techniques. When performing the parallel wiring technique, it is important to position the two guidewires in the same plane. To achieve this, the operator should superimpose the two guidewires on each other in a certain view and then obtain another view at an angle of 90° to the first view. If this can be achieved, a simple two-dimensional movement will theoretically lead the first guidewire back into the intimal space (Fig. 4).

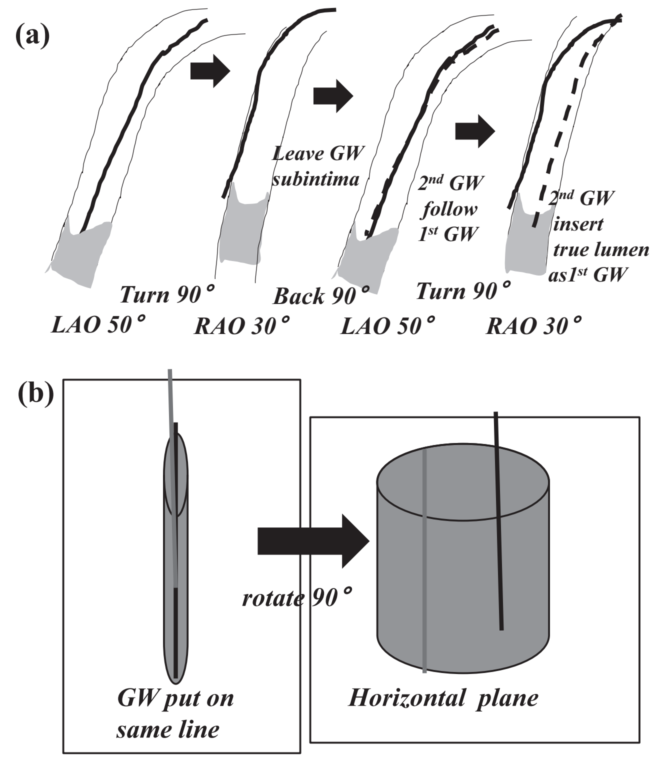


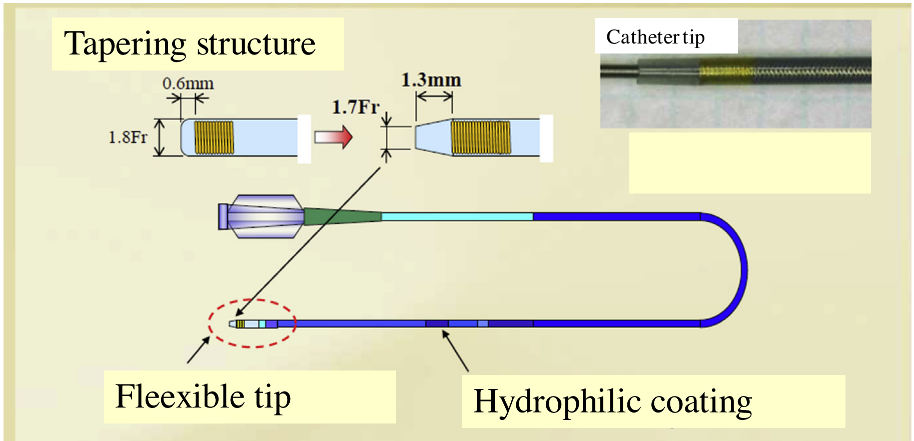
Figure 4 Theory of Parallel wire technique.

In general, more skill is needed to get a guidewire to re-enter the intimal space from a subintimal space than to navigate a wire into the intimal space from the beginning. Therefore, the maximum effort should be made to ensure that the wire goes into the intimal space. Of course, the operator should not forget to check multiple views of the CTO while attempting to cross the lesion. Ideally, a bi-plane angiographic apparatus should be available. If only a single-plane apparatus is available, it is important to check the CTO in two views so as to keep the guidewire within the intimal space. Continuing to advance a guidewire without realizing that it has entered a subintimal space may result in coronary artery perforation and should be avoided at all costs.

Even after a guidewire has successfully crossed a CTO, it is often difficult to pass a balloon catheter through the lesion. In Japan, low-profile balloon catheters specifically designed for the treatment of CTO have recently been developed and come into clinical use. Such balloon catheters that are currently available in Japan include the Tazuna 1.25-mm (Terumo), Ikazuchi (Kaneka), and RAXA (Goodman). If a CTO cannot be crossed even by these low-profile balloon catheters, the anchor technique or the mother-daughter catheter technique should be used. If the latter technique is attempted, the daughter catheter can be chosen from among the KIWAMI (Terumo), the KOKATE (Asahi Intecc), and the Dio (Goodman) catheters.

2. Uses of different microcatheters

Microcatheters facilitate guidewire exchange in the coronary artery lumen during PCI. When used to support the advance of a guidewire across a CTO in the intimal space, a microcatheter



	External			Internal		length
	Entry	Tip	Prox	Tip	Prox	
FINECROSS GT	1.7Fr. (0.57mm)	1.8Fr (0.60mm)	2.6Fr (0.87mm)	0.45mm	0.55mm	130cm 150cm
FINECROSS MG	1.8Fr (0.60mm)					

Figure 5 Spec of finecross GT microcatheter.

can be employed to stabilize the guidewire and reduce the risk of it entering a subintimal space. A microcatheter can also straighten a curved and/or tortuous coronary artery proximal to the CTO and increase the guidewire torque so that it is close to 1:1. The most commonly used microcatheter is the Finecross (Terumo). Its small tip (1.8 Fr) and M-coating enable it to advance smoothly through a narrow space in a CTO and to provide good support. The recently introduced Finecross GT microcatheter (Terumo) has a tapered tip and can thus advance through finer vascular lumens and is also better for tracking tortuous vessels (Fig. 5).

The Tornus microcatheter (Asahi Intecc) is specifically designed to cross a CTO. This microcatheter is the first choice for crossing a very hard CTO that cannot be entered even by a balloon catheter. The Corsair microcatheter was originally designed for locating a collateral channel via the retrograde approach, but is also a useful antegrade microcatheter. In terms of pushability as an antegrade microcatheter, the Corsair is slightly inferior to Tornus but better than the Finecross. The Corsair is more flexible than the Tornus so that it is less likely to cause vascular wall injury, even in very fine vessels.

My current strategy for CTO is to attempt the antegrade approach first while considering the optimal timing for making the switch to the retrograde approach. Generally, I try to advance a tapered wire antegradely and then employ a stiff wire with or without the parallel wire technique for about 30 min. If this is not successful, I then switch to the retrograde approach. Expending too much effort and time on the antegrade approach, i.e., using too many devices and too much contrast medium (excessive radiation exposure), at the first step of PCI limits subsequent performance of the retrograde approach.

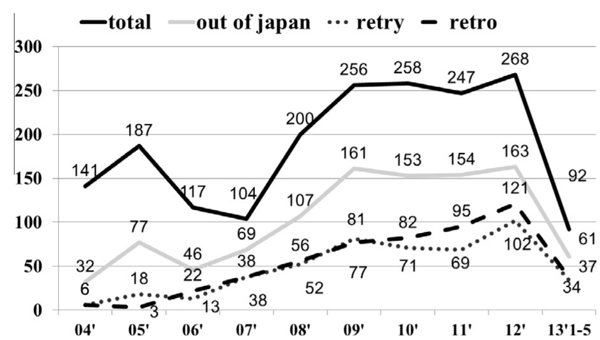


Figure 6 Number of CTO lesion.

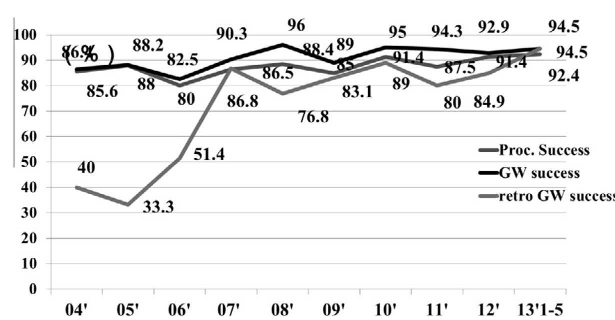


Figure 7 Success rate and retrograde approach for CTO.

2.1. Retrograde approach

The retrograde approach is chiefly indicated if success with the antegrade approach is prevented by failure to locate the entrance of the CTO, severe calcification of the lesion, or some other factor.

2.1.1. My experience with the retrograde approach

My first experience with the retrograde approach was treating a CTO that was reached via a bypass graft. In recent years, however, it has become common to use a native channel for

Table 1 Backgroud of retrograde approach.	
N	534
Re-try	402
Unknown entry	112
Abrupt	16
Diffuse	12
Septal channel	372
Epicardial channel	162

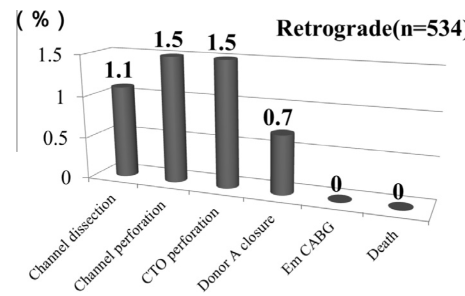


Figure 9 Complication of retrograde approach for CTO.

the retrograde approach to a CTO. At our center, the retrograde approach was introduced in January 2004, and PCI devices and techniques for the retrograde approach have since been refined. I recently reviewed the outcome of the retrograde approach and the procedural changes over the past 9 years at our center.

During the period from January 2004 to May 2013, 1870 patients with CTO were treated by PCI at our center. I retrospectively reviewed the initial success rate, the frequency of employing the retrograde approach, and the outcome of treatment. The number of patients treated for CTO has increased every year. In recent years, about 200–250 patients have been treated annually, and the number of patients treated overseas has exceeded the number of Japanese patients. There has been an associated increase of re-try cases (currently accounting for about 30–40% of all CTO cases) and an increase of patients treated via the retrograde approach (currently about 40% of all CTO cases) (Fig. 6). Both the procedural and guidewire success rates were about 90% throughout the entire period reviewed and both have exceeded 90% since 2010 (Fig. 7). The most common reason for employing the retrograde approach was "re-try", which was reported in 179 patients. The most common collateral channel used for the retrograde approach was a septal branch (n = 372) (Table 1). The outcome of the retrograde approach for treatment of CTO was analyzed in 237 patients. Retrograde channel tracking was successful in 82.5% of the patients, and retrograde crossing of the CTO was achieved in 298 patients. In 90 patients for whom retrograde channel tracking was unsuccessful, the antegrade approach was attempted again, but the resultant guidewire success rate was only 50%. After successful crossing of the CTO with a retrograde guidewire, the kissing wire technique (KWT) was tried in 218 patients and an antegrade guidewire crossed the CTO in 167 of them. A retrograde balloon catheter crossed the CTO in 65 patients. The CART technique was used in 22 patients, while the reverse CART technique was employed in 80 patients. A Corsair microcatheter was tried in 248 patients and procedure success was 81.1% (n = 433) (Fig. 8). Complications related to the retrograde approach were collateral channel dissection (1.1%), channel perforation (1.5%), CTO perforation (1.5%), and donor artery thrombosis (0.7%). However, none of the patients treated by the retrograde approach required surgical intervention (CABG) and there were no cardiac deaths (Fig. 9). The incidence of channel perforation has decreased recently, while other complications such as CTO perforation or donor artery thrombosis still occur occasionally (Fig. 10).

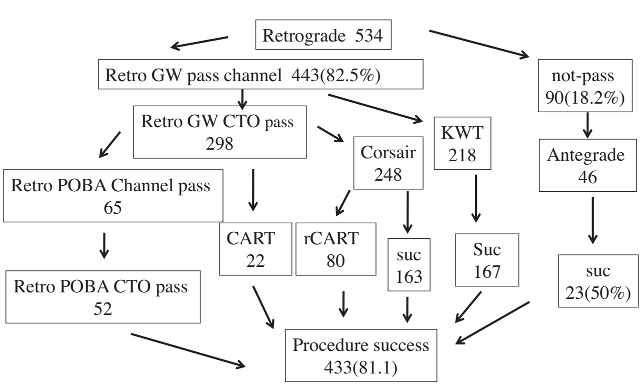


Figure 8 Flow chart of retrograde approach for CTO.

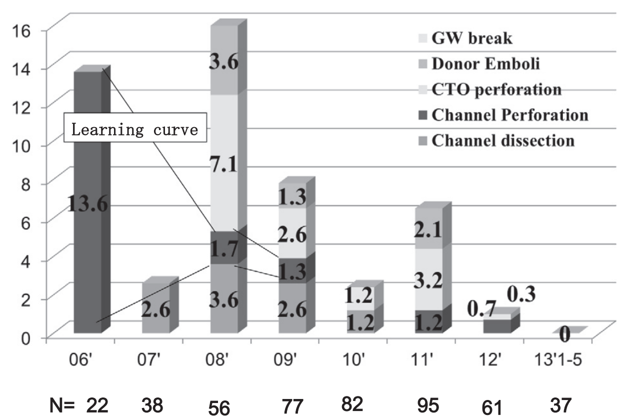


Figure 10 Chronological change of complication related with retrograde approach.

2.1.2. Negotiating a collateral channel with a retrograde guidewire

The first step in performing the retrograde approach is to identify a suitable collateral channel. CAG should be performed in at least two fixed views that focus on the collaterals. A large and straight septal channel is most desirable, but such ideal channels are uncommon. Some channels that seem to be ideal have an unexpected bend or tortuosity that makes it hard for a guidewire to pass through. Relatively straight collateral channels are easier to cross, even if they do not have a large diameter. I classify septal channels into the following 5 groups in the order of increasing difficulty of tracking: Group I: channel diameter >1 mm and bends $<90°$; Group II: channel diameter $\leqslant 1$ mm and bends $<90°$; Group III: channel diameter >1 mm and bends $\geqslant 90°$; Group IV: channel diameter $\leqslant 1$ mm and bends $\geqslant 90°$; and Group V: broom-shaped.

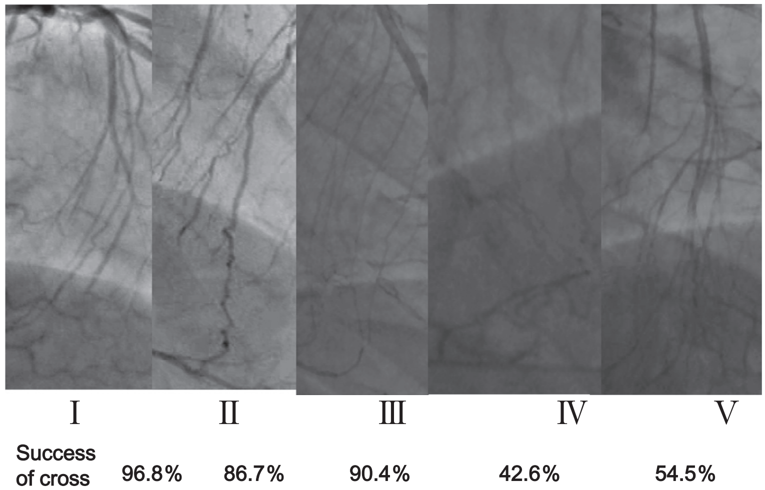


Figure 11 Classification of septal collateral way.

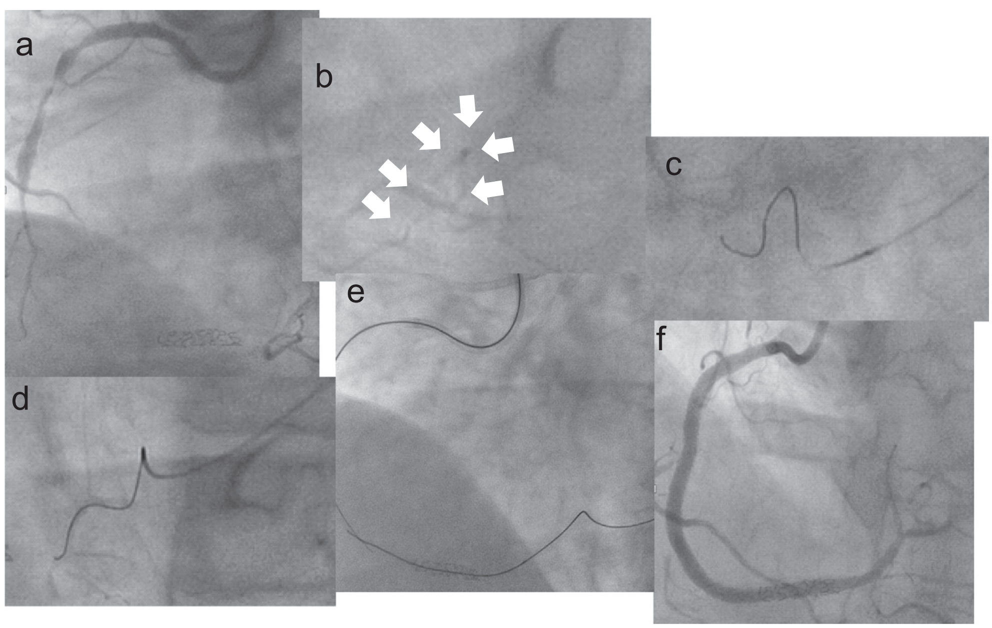


Figure 12 Change microcatheter from Corsair to finecross.

A broom-shaped septal channel appears to have many sub-channels, but each of them is very fine and difficult to pass through. Thus, careful consideration is needed before attempting the retrograde approach via a septal channel of this type. The success rate is as low as 42.6% for Group IV and 54.5% for Group V compared with 96.8% for Group I (Fig. 11).

Epicardial channels are usually large, but are often tortuous. Sometimes the collateral channel has an unexpected origin, so angiograms should be interpreted carefully. I often use the Finecross catheter to track an epicardial channel because this fine catheter is less likely to cause ischemia during passage through a large but tortuous epicardial channel (Fig. 12). I select the optimal catheter according to the morphology of the channel. For example, I choose the Corsair microcatheter when good pushability is required.

Regarding the technique of wiring a collateral channel, a short guiding catheter should be inserted retrogradely and a soft guidewire should be used with microcatheter support to locate a collateral pathway. A guiding catheter at least 7 Fr in size should be used to navigate a Finecross or Corsair microcatheter into a collateral channel, and tip injection from a 3-ml syringe should be done to confirm the course of the channel. Before performing contrast injection, it is safer to confirm backflow of blood into the syringe under negative pressure. For the purpose of locating a collateral channel, I have recently been using the Sion guidewire (Asahi Intecc) as the first choice. This guidewire can be advanced smoothly to safely locate a collateral channel because of its coated tip and 0.5 g load. In contrast, the Sion Blue guidewire (Asahi Intecc) does not have a coated tip, but torque control is better than with the Sion guidewire. Therefore, the Sion Blue may be effective for tracking arteries with three-dimensional tortuosity, although I have not used it so frequently in recent times. Even finer collateral channels can effectively be located by using the Fielder XTR guidewire (Asahi Intecc). The Fielder XTR has a slightly larger tip (0.010 inch) than the Fielder XT and torque control is better. I usually employ a different soft guidewire first to navigate a microcatheter into the collateral channel and then exchange it for a Sion guidewire. This is because the tip of the Sion only has a small curve that is generally compatible with the course of the collateral channel. If the channel shows marked curvature, however, the tip of the guidewire should be curved accordingly.

For tracking a collateral channel, the guidewire should be manipulated in a completely different manner from that employed when crossing a CTO. It is desirable to gently rotate the guidewire in order to straighten the artery while minimizing forward/backward movement so that the wire can be smoothly advanced through the collateral channel without creating significant friction. Since a single view is often insufficient to understand the detailed anatomy of a collateral channel, multiple views (e.g., RAO cranial, RAO caudal, and lateral) should be obtained during collateral channel tracking to provide precise information about vascular tortuosity. Needless to say, continuing to advance a guidewire despite perceiving resistance under angiographic guidance with a single view can easily result in channel dissection or perforation. If resistance to the guidewire is felt, I usually confirm the anatomy of the target channel by obtaining additional angiographic views to avoid blind wiring and to ensure safe location of the channel. When performing additional angiography for this purpose, it is important to withdraw the microcatheter back from the channel to the main trunk in order to enhance the contrast effect. Again, a single view is often insufficient to confirm the anatomy of a target channel. The anatomy of a septal channel should be confirmed by using clear RAO cranial, RAO caudal, and lateral views to facilitate precise guidewire manipulation.

After a guidewire has been passed through the collateral channel, the passage of a microcatheter should be attempted next. The Corsair microcatheter is often the first choice for this purpose, while the Finecross microcatheter may be selected for a very tortuous epicardial channel. The Corsair microcatheter is sometimes blocked by severe tortuosity of a collateral channel. If this happens, the Corsair should be exchanged for a Finecross microcatheter or a 1.25-mm OTW balloon catheter. The recently developed Finecross GT is useful for locating a channel with many small bends. Exchanging the Finecross for another Corsair microcatheter may sometimes be successful, because the tip of the Corsair is delicate and likely to be damaged during the procedure or by vascular tortuosity. Microcatheter exchange requires strong support from a retrograde guiding catheter, but the guiding catheter sometimes deviates from the coronary artery, resulting in destruction of the entire PCI system. If a microcatheter cannot be advanced through the channel by trying all these strategies, many difficulties will be encountered with the subsequent steps of the procedure. Accordingly, the operator should no longer persist with such a channel and should seek another channel.

2.1.3. Handling the retrograde guidewire after passing the channel

2.1.3.1. Direct retrograde wiring. After the coronary artery lumen distal to the CTO has been reached, a soft guidewire such as a Fielder XT (Asahi Intecc) should be used to attempt direct retrograde crossing of the CTO. When manipulated retrogradely, a guidewire can more easily enter a CTO and will often cross it directly because the distal fibrous cap of a CTO is softer than its proximal fibrous cap. If the Fielder XT guidewire cannot cross the CTO, it should be exchanged for an Ultimate BrO 3 (Asahi Intecc). The recently introduced Gaia 2nd guidewire is effective for retrograde tracking of the true lumen. If the CTO is severely calcified, the guidewire is most appropriately exchanged for a Conquest Pro (Asahi Intecc) or a Pilot 200 (Abbott). If direct retrograde wiring is successful, the guidewire should then be advanced into the antegrade guiding catheter. If a microcatheter can also be fed into the antegrade guiding catheter, it can be exchanged for a 3-m guidewire that is withdrawn from the contralateral femoral sheath to allow antegrade passage of a balloon catheter (externalization). If the guidewire is anchored by a 2.5-mm balloon inflated in the guiding catheter, the microcatheter can easily be advanced into the guiding catheter. The RG3 long guidewire is specifically designed for externalization, and it has made this process smoother and more rapid. Caution should be exercised when navigating a microcatheter (e.g., a Corsair) into an antegrade guiding catheter as microcatheter movement pulls the guiding catheter into the coronary artery. Conversely, advancing an antegrade device into a CTO or partial withdrawal of a retrograde microcatheter (e.g., a Corsair) pulls the retrograde guiding catheter into the coronary artery.

2.1.3.2. Kissing wire technique. If direct retrograde wiring is impossible or a microcatheter fails to negotiate the collateral channel and reach the coronary artery lumen distal to the CTO, the antegrade guidewire should be manipulated while using the retrograde guidewire as the landmark (kissing wire technique). The retrograde guidewire can serve as a good landmark that facilitates manipulation of the antegrade guidewire.

2.1.4. If the retrograde guidewire fails to cross the CTO

2.1.4.1. CART technique. Following the introduction of the Corsair microcatheter, the reverse CART technique has become relatively unpopular and the reverse CART technique has gained wider acceptance instead. If a retrograde guidewire is blocked, an antegrade guidewire should be manipulated while using the retrograde guidewire as a landmark. If the two guidewires exist within the same subintimal space, the CART technique can be tried.

2.1.4.2. Reverse CART technique. If direct retrograde wiring and the kissing wire technique are impracticable, use of the reverse CART technique should be considered. When both the antegrade and retrograde guidewires have entered a subintimal space and cannot be manipulated further, an IVUS catheter should be inserted antegradely. If this is impossible, a 2.0-mm balloon should be inflated to dilate the proximal space. The IVUS findings should be used to estimate the vessel diameter, after which a balloon catheter of an appropriate size should be selected and inserted antegradely to dilate the subintimal space. I generally use a 2.5–3.0 mm balloon for an RCA

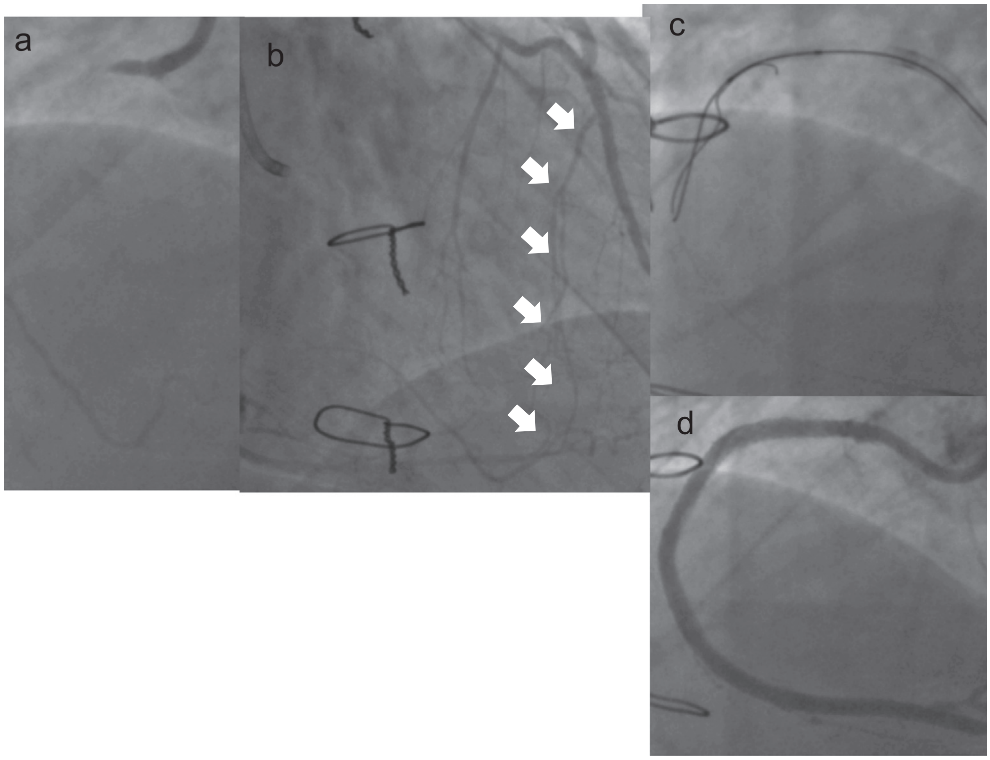


Figure 13 Knuckle plus r-CART technique.

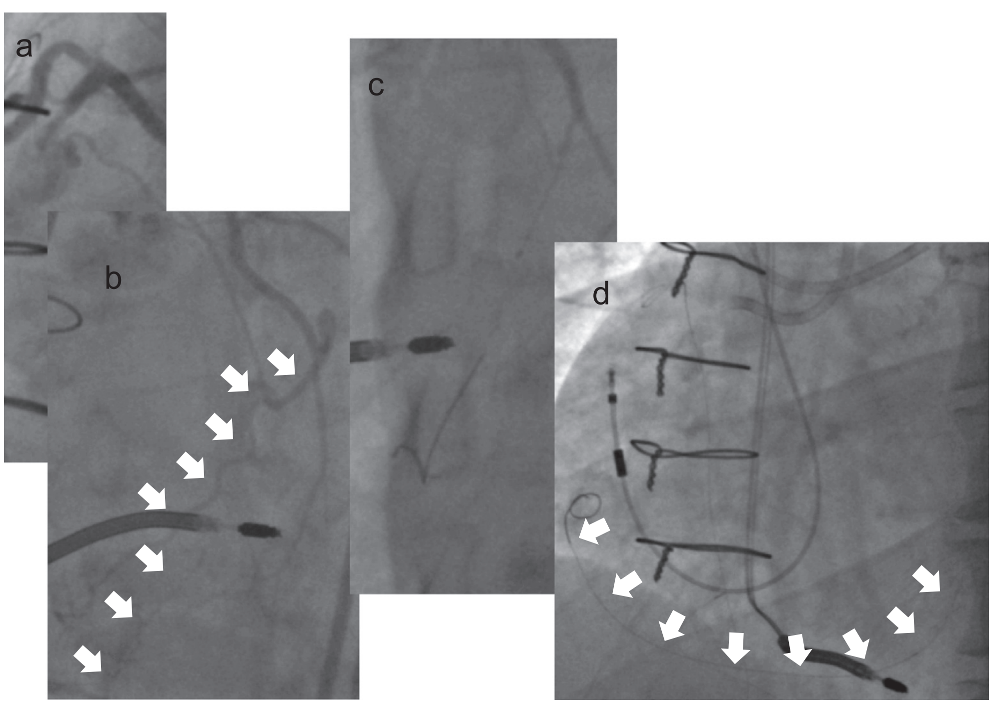


Figure 14 Break guidewire through tourtous channel.

lesion and a 2.5 mm balloon for a lesion of the left anterior descending artery. Ideally, the balloon should be inflated within the subintimal space when it is near or across the retrograde guidewire. If this does not help the retrograde guidewire pass the lesion, a larger balloon should then be inflated to further dilate the subintimal space. Balloon sizing should be based on IVUS data. If the subintimal space becomes large enough for the retrograde guidewire to cross the CTO and the retrograde guidewire can then be fed into the antegrade guiding catheter, the reverse CART technique is successfully achieved.

However, it is often difficult to advance a retrograde guidewire smoothly. If it cannot be manipulated well, the guidewire should be exchanged for a Fielder FC or XT, because this will facilitate crossing the CTO with a retrograde guidewire and its introduction into an antegrade guiding catheter. Excessive test injection should be avoided as this may enlarge the subintimal space.

2.1.4.3. Knuckle wire plus reverse CART technique. The knuckle wire technique has the same indications as the reverse CART technique and refers to advancing a guidewire with a knuckled tip into a subintimal space. This technique is primarily effective when a retrograde guidewire has been blocked in a subintimal space. In some cases, knuckled wires are advanced both antegradely and retrogradely. Guidewires such as the Fielder XT and Fielder FC are suitable for the knuckle wire technique. Combining the knuckle wire and reverse CART techniques will ensure adequate enlargement of the subintimal space (Fig. 13).

2.1.4.4. Knuckle wire technique combined with Finecross GT tracking. If the CTO is too hard to attempt CTO crossing by the reverse CART technique or subintimal tracking by the knuckle wire technique, combined use of the Finecross GT with a knuckled wire is a good solution. The flexible tip of the Finecross GT will improve the trackability of the knuckled wire and ensure the safety of subintimal tracking.

2.1.5. Complications of the retrograde approach

The most common complications of the retrograde approach are collateral channel dissection and perforation. However, severe complications are uncommon provided a septal channel is used for the retrograde approach. Even if channel perforation occurs, it usually results in bleeding into the ventricle, which may only require monitoring. If channel perforation causes intramyocardial hemorrhage, however, the hematoma will gradually enlarge and hemostasis is required. Collateral channel dissection and perforation can occur due to injury by a guidewire or a catheter shaft. If an epicardial channel is used for the retrograde approach, channel perforation will directly lead to pericardial hemorrhage and hemostatic measures will be required. More serious complications include acute obstruction of the donor artery due to thrombosis or dissection. This is a critical situation because there is a CTO in the target artery. To prevent this serious complication, we should always check the position of the guiding catheter so as to avoid deep engagement, use an 8-Fr guiding catheter that can accommodate more than one microcatheter, and measure the activated clotting time every hour and maintain it at $\geqslant 300$ s. If the collateral channel is too fine and/or tortuous, the guidewire or catheter may become kinked or difficult to withdraw from the channel. Accordingly, it is better to avoid using channels that are too fine or tortuous (Fig. 14).

3. Conclusions

Primarily due to the efforts of pioneering Japanese interventional cardiologists, PCI for CTO has been acknowledged worldwide as an advanced medical treatment that improves the long-term survival of patients with CTO. In the future, more interventionists will acquire knowledge and skills about the handling of CTO and will contribute to further progress in this field. PCI for CTO is the last major challenge for coronary intervention. If you wish to try PCI for CTO, you should have an adventurous spirit and more importantly, should be able to carefully review your previous procedures and properly weigh your skills against the difficulty of treating each lesion in order to avoid unnecessary complications.

Conflict of interest

None declared.