11.Basic Wire-Handling Strategies for CTOs

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1. Introduction

Fifteen years have passed since the first Interventional procedures to treat chronic total occlusions (CTOs) but in all that time no new device has emerged to revolutionize the field in the way that has happened in other areas of Coronary Intervention. The emergence of stents, the rotablator and DCA has meant that patients for whom treatment would previously have ended without optimal dilatation being achieved, are now seeing optimal results obtained and reocclusion rates reduced. It goes without saying, though, that the most important thing in revascularizing CTOs, is how to get the wire across the occlusion. In this sense, the lack of a revolutionary new device for CTOs means that strategy depends to a large extent on the experience, expertise and instincts of the operator and requires a considerable amount of precise and delicate work. This is not to say that experience and instinct are everything in Intervention for CTOs, as the breadth of the cardiologist's knowledge and the strategy selected are vitally important, too, in getting a better acute result. One very important development has been the availability, since the early 1990s of wires offering greater control of the wire tip inside the lesion, which has meant that other PTCA modalities can now be applied to CTOs that previously they would never have been indicated for, while the degree of expertise required for the rising number of treatable cases in this context of improved wire control has continued to rise, taking initial success rates up to previously uncharted ground (Fig. 1).

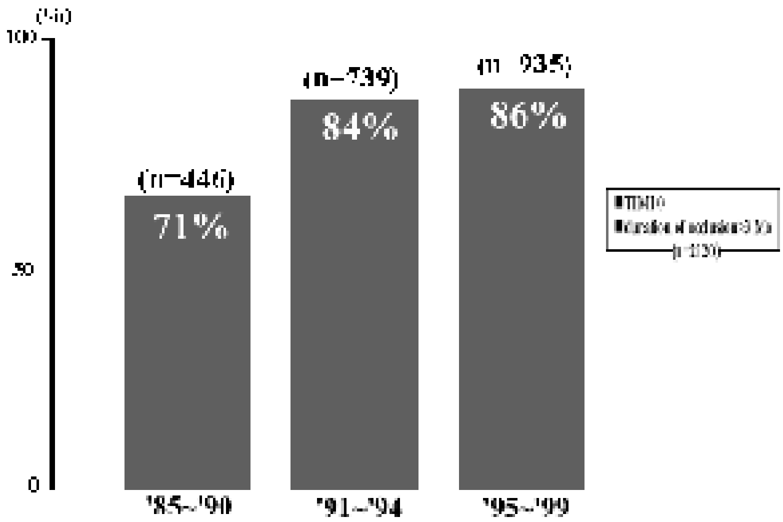


Figure 1: Success rates over the years
The graph shows the author's own success rates, which passed 80% in 1992, stabilizing at about 85% since 1993.

In this text, I would like to set out, as specifically as possible, the basics of interventional strategy for CTOs. It has been said that wire-handling is everything in Intervention for CTOs, but in order to get the best from your wire, I would like to stress the importance of evaluating the lesion before Intervention and identifying the most suitable approach, as well as choosing the best treatment option once the lesion has been assessed and the wire passed across it. Another thing I would like to stress, is that physicians attempting Intervention for CTOs often make the mistake of thinking that the procedure depends solely on their own sensitivity to what the wire is doing. This is not the case. All CTO procedures require endless delicacy and patience, which is what differentiates them from other lesions, even if the simplest available strategy will often be the best treatment option. Even in non-CTO lesions, there are always a number of factors about each specific lesion and its situation that need to be considered, but recent advances in device-quality and operator-skill, allied with the refinement and simplification of best-strategy have largely overcome the individual challenges presented by these lesions. It follows that individual lesion characteristics no longer have much direct influence on the success or failure of an Interventional procedure in other lesions. This can not be said of CTOs, however, where the greater range of factors in play means that the specific characteristics of each lesion can have a direct bearing on procedural success: this against the background of there being little immediate prospect of a single wire, device or strategy likely to improve the success rate of treatment for these lesions.

Another difference is that you cannot expect anything near a 100% success rate with CTOs, and should always be prepared for the unexpected. For that reason, a clear strategy is vital, and merely leaving it to touch, or sticking rigidly to a specific approach leaves the physician trusting too much in and relying only on luck, and not basing strategy for a better and more certain acute result on the sophistication of the available technology. The main point is that the best way to increase your chances of success is to adapt your strategy to the conditions you are faced with.

2. Before the Guidewire goes in ~ key points to watch

a) Getting the best handling from your wire

Obviously, achieving good handling of your wire once it is inside a CTO, and using a balloon catheter and wire delivery catheter (such as Transit®, Interpass® or the Multifunction Probing Catheter®) that let the wire move freely along them are very important. You may find that that maneuverability of the wire is complicated by natural tortuosity in the shape of the artery at the access point (whether you are using the brachial of femoral approach), by tortuosity or the angle of bifurcation at the entry to the coronary artery or the shape of the coronary artery leading up to the lesion. Tortuosity in the iliac or abdominal arteries can also lead to reduced maneuverability (Fig. 1-1). In a tortuous iliac artery, a large caliber 10-12 Fr long sheath can be used to stretch and straighten the vessel, and maintain maneuverability. You can even double-up by placing an 8Fr long sheath inside the 10-12 Fr one (Fig. 1-2). Another option is to attempt an approach from the opposite side of the body, left or right. When using an approach from the right brachial or right radial arteries, even a tortuous minor artery may contribute to reduced maneuverability, and switching to the left side often solves the problem altogether. Always bear in mind that even in vessels that would present no problems for usual PTCA wires to cross, CTO wires face more obstacles on their way to the lesion, and when you have difficulty steering the wire through, you may need to check that the guide catheter itself is straight and not bent at some point.

Figure 1-1: Tortuous iliac artery

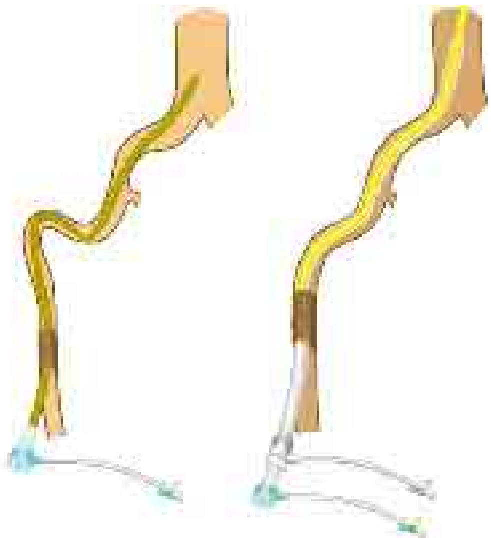


Figure 1-2: Straightening a tortuous iliac artery using a “parent” sheath.
The left figure shows an 8F long-sheath bent by a tortuous iliac artery. Placing the 8Fr sheath inside a 10Fr or 12 Fr stretches the tortuous artery and prevents the sheath being bent (see figure on right).

Another cause of poor guide wire maneuverability is when the right coronary artery bifurcates forward from the right Valsalva sinus and slants towards the atrioventricular sulcus at a very sharp angle, or when the LMT branches out from the aortic posterior wall, making it impossible to insert a guidewire along the vessel. When this happens, the wire is often severely bent at the ostium and maneuverability severely inhibited. To counter this, when the lesion is distal and there is no lesion in the proximal portion, insertion of a 5Fr or 6Fr guide catheter deep into the coronary artery can prevent any dangerous bending at the ostium (Fig. 1-3). When the lesion is proximal, or when for some reason the guide catheter cannot be inserted deep into the coronary artery, a support wire can be used in parallel (Fig. 1-4), inserted to the bifurcation immediately before the occluded portion, and the guide catheter brought properly into line. Alternatively, try the technique of inserting a 5Fr or 6Fr guide catheter through a 7Fr or 8Fr “parent” guide catheter (Fig. 1-5).

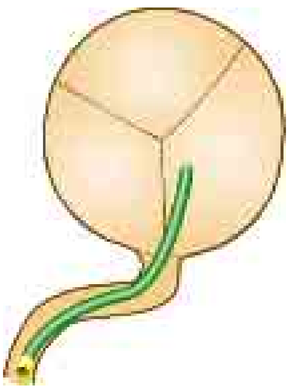


Figure 1-3: Straightening a bend at the ostium by deep engagement of small caliber guide catheter.

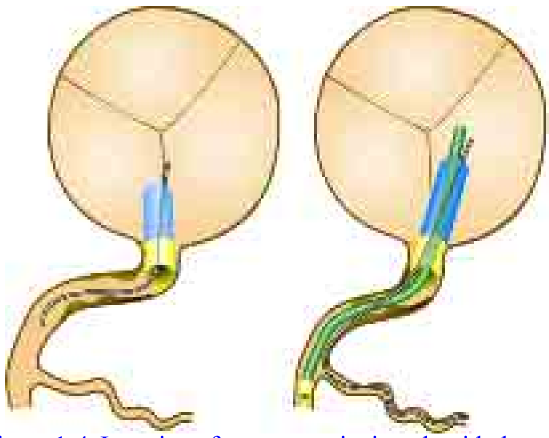


Figure 1-4: Insertion of a support wire into the side-branch proximal to a CTO as a parallel wire to improve poor guidewire maneuverability because of the bend at the ostium (figure on left), and then placing a support catheter (balloon or Transit) in the coronary artery can improve co-axiality of the guide catheter with the vessel. This will not work for a proximal ostial CTO.

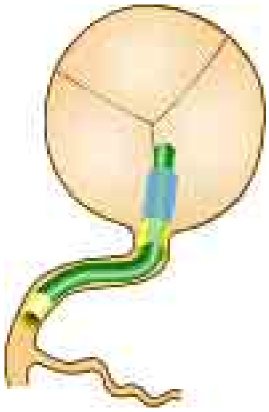


Figure 1-5: Inserting a 5Fr or 6Fr guide catheter into a 7Fr or 8Fr guide cath can straighten the proximal

For good stable wire-handling, the guide catheter needs to be stable, too. If you don't make sure of this, as can happen when you are using a Judkin's right (JR) in the RCA, or a JL in the LCA and you can't get the guide catheter very deep into the artery, the result may be that the guide catheter is not very stable, and keeps falling into the Valsalva sinus while you are maneuvering the wire. I advise changing to the other kind of guide catheter as soon as possible. For the RCA, the most common choices to change to are an Amplatz left 1 (AL1), or an AL1.5 (you must use a guide catheter with side-holes), a Hockey Stick cath, or when the lesion is ostial, a short tip AL2. One word of warning is that there is a higher risk of vessel injury at the ostium with an AL, as compared to a JR, and you have to be careful, especially with the recently developed 8F catheter. When using an AL, because of the bent shape of this catheter, it is not possible to avoid reduced wire maneuverability, but with the improved overall maneuverability that the stiff CTO wires offer, this is no longer a serious drawback. Bear in mind though that when you can't get your catheter co-axial to the RCA ostium, the shape of the AL will make it considerably less maneuverable than the JR. You will normally find that in most cases the RCA originates from the anterior upper portion of the right Valsalva Sinus, and torque-ing the AL catheter in a clockwise direction may enable you, to some extent, to get it co-axial. You also need to advance the balloon catheter or your Transit catheter along into the coronary artery. The important thing to look out for here is that when you get back-up force from the guide catheter acting against the balloon catheter, you would usually torque the JR catheter in a clockwise direction and at the same time change the shape of the catheter inside the Valsalva Sinus to secure it, but this does not work for securing the position of the guide cath for CTO wire-handling. You are better off exchanging the guide catheter or dilating a balloon (3.0~4.0mm) proximal to the CTO, and leaving the balloon catheter in the artery for back-up (Fig. 1-6). In the LCA, the most common choices to switch to are the Voda, or XB type, or AL1, AL1.5 or AL2.0 (especially in the LCX).

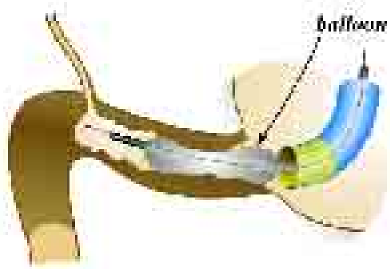


Figure 1-6: Fixing balloon catheter position during the wire-handling

Scenarios where the guide catheter causes problems for wire maneuverability are principally CTOs in the ostial LAD, and CTOs in LCXs with very sharp bifurcation angles. For CTOs in the ostial LAD, and when the bifurcation of the LAD from the LMT is at a wide angle, you can get away with a JL (short tip is best) or an AL, but when the LMT bifurcates posterially, an AL will usually be the best option.

When it is hard to get the wire into the CTO, even with back-up from the balloon catheter, this is probably because 1) the angle at which the entrance to the CTO bifurcates from the course of the artery is close to 90º and steering the wire towards the CTO and exerting sufficient steering force on the wire tip are difficult, or 2) the proximal fibrous cap of the CTO is too thick and too hard for the back-up force you have. If either of these is the case, the best strategy is to bring the tip of a short-tip JL right up to the mouth of the CTO (Fig. 1-7), where back-up and direction from the guide catheter can often be used to good effect, especially if you use a 7Fr catheter. Even when the LAD deviates sharply from the course of the LMT, a similar technique will usually work. When the LCX bifurcates at a very sharp angle, the best method is to use an AL1.5 or AL 2.0 (with side-holes), pull the catheter back slightly and try to direct the tip into the LCX. Whatever the situation, this is the way to get your guide catheter co-axial.

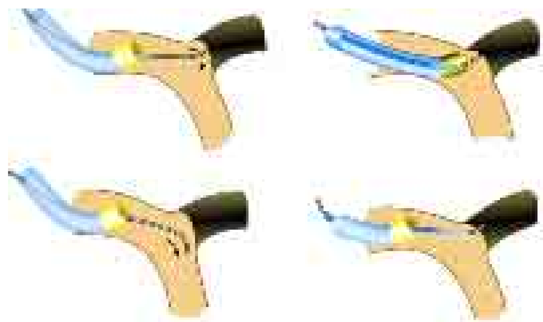


Figure 1-7: Setting wire and back-up direction for sharply angled LMT and CTO ostium.

One factor that affects maneuverability of the guide wire is bending or tortuosity in the vessel proximal to the CTO lesion. From my experience, this is especially true in CTOs in the RCA and LCX. One potential solution is to stretch and straighten the bends in the vessel, and you will usually find that just inserting a balloon catheter into the vessel will stretch it sufficiently to improve maneuverability of your wire. In some cases, though, where the bends are especially tortuous or heavy calcification means the elasticity of the vessel is reduced, this can cause the balloon catheter to be bent, and the wire lumen to be squashed, and in some instances, wire maneuverability is considerably diminished (Fig. 1-8). When this happens, either 1) change the

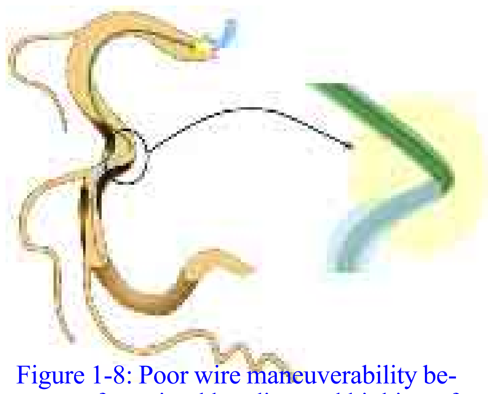


Figure 1-8: Poor wire maneuverability because of proximal bending and kinking of the balloon catheter in a tortuous vessel.

balloon catheter for a Transit, 2) use a wire with a hydrophilic-coating, 3) use a support wire in parallel to try to force the vessel to stretch and straighten, or try some other method (Fig. 1-9). In all these cases, correctly identifying the conditions by CAG beforehand is extremely important.

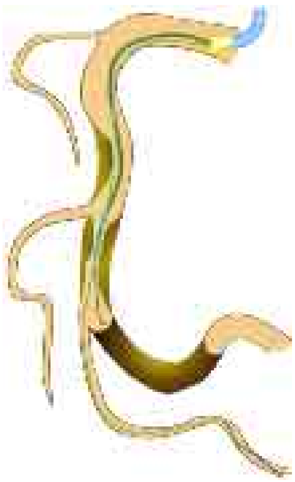


Figure 1-9: Straightening the vessel with a parallel wire.

b) Correctly Interpreting the lesion

Interpreting the lesion enables the physician to choose the optimal treatment modality, and gain an insight into potential problems before even starting the procedure, and is an essential part of strategy-design. It may be obvious at this stage already but even those doctors with plenty of experience with normal lesions, should realise the considerable difference in interpreting normal lesions and CTOs. Great care has to be paid to things which are don't come up with normal lesions.

i) **Occlusion Duration:** It is often difficult to measure exactly how long a vessel has been occluded, but even in the absence of a detailed history of myocardial infarction, you can get a good idea of the occlusion duration by obtaining a detailed medical history from the patient. Some CTOs presenting with bridging collaterals and which appear quite old, turn out to be relatively young. Be careful, as in these lesions, a stiff wire may easily and suddenly push through the occlusion and create a false lumen. As the occlusion duration has an important impact on wire-selection and handling-technique, finding out as much as you can about the patient's history is a great advantage.

ii) **Lesions Proximal to the CTO and Vessel Shape:** As I have outlined above, the location of the coronary artery ostium, the bifurcation direction and the shape of the vessel all have an impact on your choice of guide catheter, but when there is a lesion at the entry to the CTO or proximal to it, the guide catheter can cause ischemia or coronary artery dissection, so all the available CAG information must be carefully analyzed when choosing the correct guide catheter and identifying the best way to maneuver it. This is especially important in the RCA, as I have already said, and though it will depend on the individual circumstances, you may want to pre-dilate ostial or proximal lesions, and implant a stent. This often results in improved wire handling and can also reduce and prevent complications (Fig. 1-10).

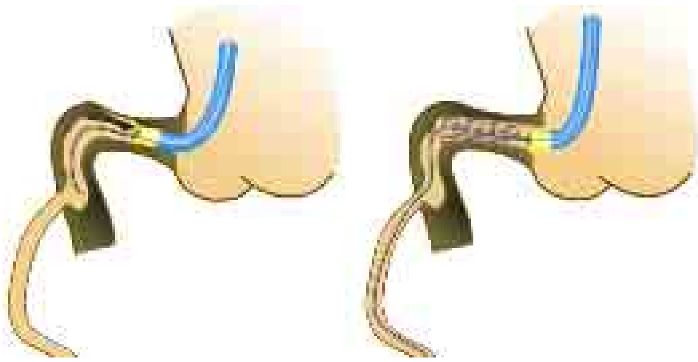


Figure 1-10: For ostial lesions, PCI for CTOs demands strong back-up, and the risk of ostial dissection is high. Operators should be aware of this, should proceed carefully and be ready to act quickly if required.

When there is tortuosity or bending of the vessel proximal to the CTO, this will have an effect not just on what wire you choose and how you handle it, but will also be an important factor in the positioning of the balloon catheter while maneuvering the wire. Thinking of ways to improve wire maneuverability before you begin the procedure, can not only reduce the procedure time and cut down on the amount of contrast medium you use, but it can reduce unnecessary wire-handling and limit injury to the vessel.

iii) **CTO Morphology:** It is well known that lesion morphology, (i.e. whether or not there is a dimple) inside the occlusion affects the success rate, and care must be taken not to overlook dimples when looking at the CAG pictures. For this reason you need to look at the images from a number of angles and frame by frame (Fig. 2), while at the same time, looking to see if there are any potential recanalization channels or existing lumina inside the CTO. Pursuing paths through the CTO along these channels doesn't guarantee that you won't create a false lumen, but they can often suggest a way through for the wire. It often happens that if you can accurately guide the wire through one of these, it makes it easier to get through to the distal true lumen. If the CTO is old and bridging collaterals have formed, however, you will still have to differentiate between the recanalization channels and any lumina with dilated vasa vasorum connected to the bridging collaterals. This is not an easy task, and if you get it wrong, you run the risk of causing a perforation.

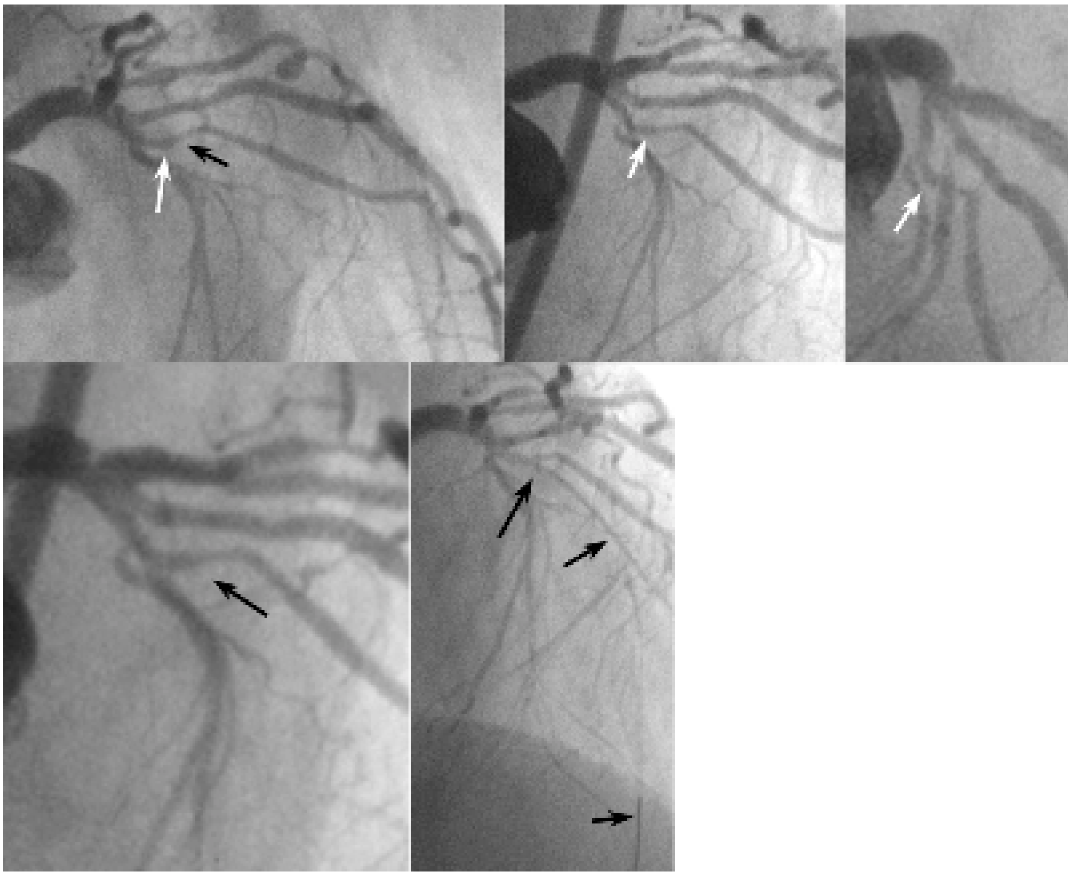


Figure 2: A CTO case in proximal LAD
A CTO just behind the bifurcation of LAD and diagonal branch. Occlusion duration is not clear but medical history suggests occlusion of several years. On CAG, the CTO ostium in the LAD is not clearly visible (white arrow shows what seemed to be the ostium but the black arrow turned out to be the true dimple). The dimple was only detectable from the AP cranial view, and even then only by frame-by-frame analysis. This would normally tend to be overlooked.

Bends in the vessel inside the CTO are also sometimes missed. These are especially difficult to anticipate accurately in long CTOs in the RCA and LCX. The only real way to get a feel of what path a vessel is going to take is to have as much experience as possible of vessel path patterns. During CAG, you should instinctively bear in mind the bends at distal RCA segment #1, and RCA #3, as well as at LCX #11, and the same is true for LAD #7. Even when you haven't been able to image them clearly, you should always know what to expect at these segments. Also, calcification configuration can often be a good indicator of vessel shape, so it can sometimes be useful to delay infusion of the contrast medium for 2-3 heart beats during fluoroscopy or CAG, to get a better image of the calcification. Another tip is that when the proximal and distal portions of the occlusion seem to slip out of alignment with each heartbeat, this is a sign of tortuosity inside the CTO.

As well as looking closely at morphology in the proximal part of the CTO, it is important to see what the situation is at the distal end. For this, making sure that you get a good image of the distal vasculature supplied by collateral flow is crucial. This is also important in gauging lesion length. You can sometimes mistake a short CTO for a long one, set the penetration point that you are aiming for as the true lumen too far down the CTO, and you don't realise that you are already making a false lumen. So you have to be very careful. When the distal end of the CTO is wider than the proximal part, there is a high probability that the lesion will be hard, and the distal fibrous cap thick and hard, unless you know from the medical history that the CTO is relatively recent. When you get a tapering distal portion and a chronic build up of jagged hard plaque around the true lumen, you can expect it to be extremely hard to get the wire through (Fig. 2-1). There needs to be only a single penetration point at the distal end of the CTO because once you make a false lumen anywhere in the vicinity of the fibrous cap, the true lumen becomes very difficult to locate (Fig. 3). So, for this reason, when the wire is near the distal end of the CTO, it vital that you steer the wire so as not to miss the distal cap and create a false lumen. This means that identifying the shape of the end of the occlusion is a valuable source of information for determining how to maneuver

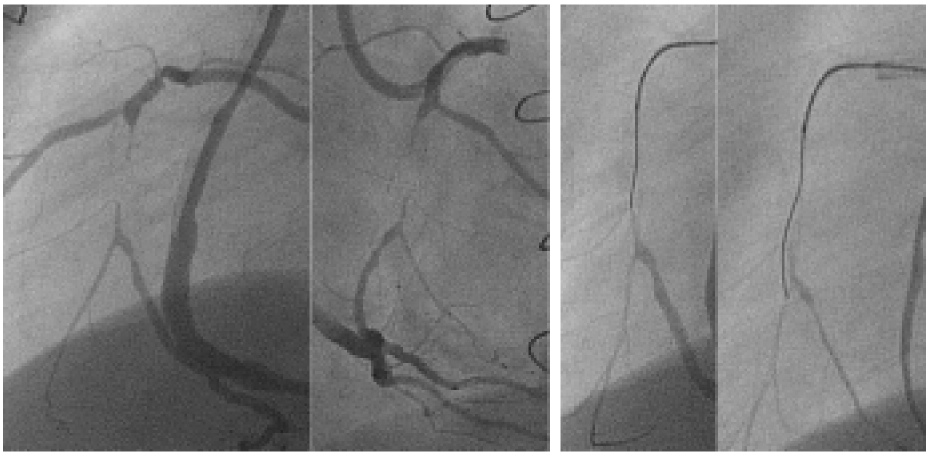


Figure 2-1: A case where crossing the wire through the lesion was difficult because of the tapering distal end of the CTO.
This CTO had been occluded for more than 10 years and there was hard tissue (fibrous cap) at the distal lumen, and it was hard to penetrate even the proximal portion, probably because of a problem with the course of the wire up to the proximal end.

your wire. It is hard to tell by CAG, but you will find that if the plaque at the distal end of the CTO is soft, in a tapering vessel the opposite will happen and the wire will cross quite easily. So, to sum up, you need to pay attention to lesion morphology at the distal end of the occlusion, as well as to any bends in the vessel. This is because if there is a major bend in the vessel, making sure you find the true lumen is crucial (Fig. 4).

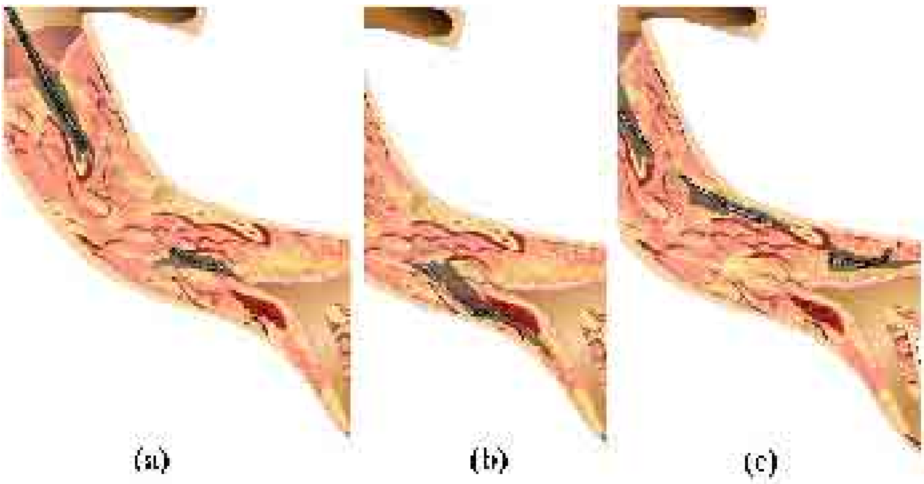


Figure 3: CTO morphology at the distal end (tapered type)
The morphology of old CTOs, as shown here, means the only potential access site for the wire is (a), and if you fail to find the true lumen, you not only risk creating false lumens easily as in (b) and (c), but also not being able to get create a different site in the distal cap.

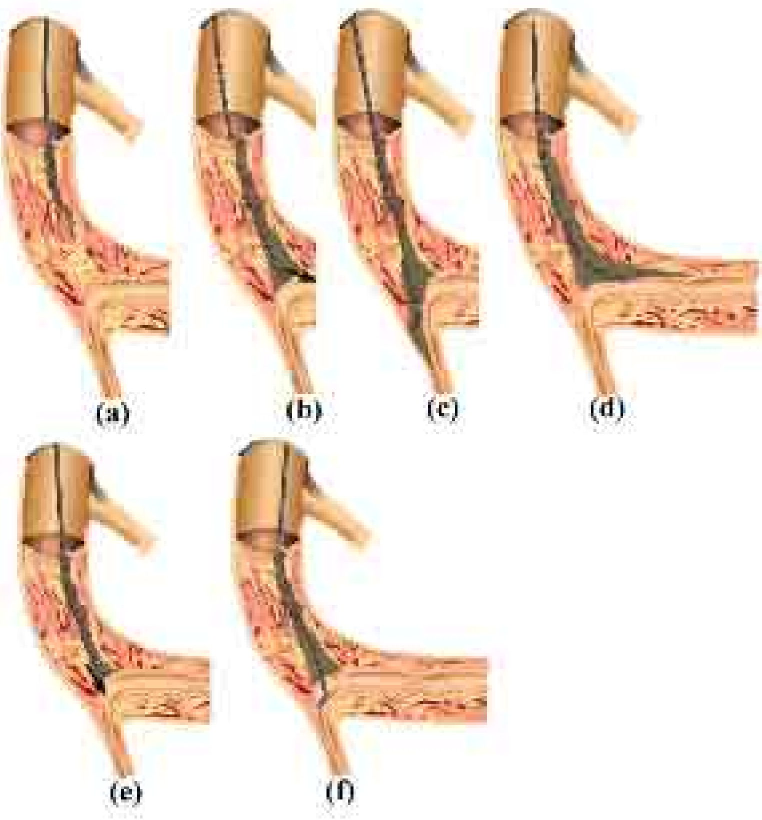


Figure 4: Bend at the distal end of the CTO
When there is a bend at the distal end of the CTO, trying to find the main branch directly like in (b) may lead you to create a false lumen like in (c) and (d). When the side branch bifurcates away from the direction you are trying to get your wire to go in, steer towards side branch as (c), as this will give you a good chance of breaking through the distal fibrous cap.

iv) Collateral Flow: Monitoring collateral flow when maneuvering your wire is also a very important part of the strategy. The longer the CTO has been there, the more influence age has on initial success. It is relatively straightforward to identify the channels supplying and receiving collateral blood flow, as well as the main collateral channels (sometimes because there are more than one of these, you have to identify all the main channels as they are competing for blood flow), but you have to be on the look-out for pitfalls. For instance, if one of the supply channels is an atrial branch or conus artery branch bifurcating from an RCA #1, the catheter tip can find itself down one of these branches and collateral flow will not show up on the angiogram. If you bear this possibility in mind, you should be able to prevent this happening. Also, if you make a point of checking to see that collateral flow is reaching as far as the cap at the distal end of the CTO, you sometimes notice collateral flow that is not showing up on CAG, because of competition for blood flow or a negative jet. Another hint is that it is not uncommon, in CTOs in LADs, for a separated conus branch to be the supply channel for collateral flow. In these cases, the distal cap of the CTO will be coming from the conus, and the image of the LAD trunk will be receiving collateral flow from the 4PD via the septal branch, or the right ventricular branch, and it is not uncommon for the operator to miss, on CAG, the collateral flow coming from the separated conus. Collateral flow from the conus, though, is extremely important in cases like this for wire-handling.

Also, when the CTO is in the RCA, you must check to make sure that collateral flow is being supplied to the 4PD and 4PL, and when the CTO is in the LCX, whether it is coming from the peripheral 14PL or the atrial circumflex branch. While you are maneuvering the wire, a poor image of the distal true lumen from collateral flow may be a sign that the blood-flow is being supplied from different collaterals. If that happens, you need to switch from the homo-collateral view to the opposite one. This can also be an important source of information for preventing ischemia.

There is also the possibility that during the procedure, the tip of the guide catheter will reduce collateral flow. Be especially careful that the tip doesn't block the collateral supply channel in the proximal portion of the ostial RCA.

Looking at collaterals is a useful and valuable way of gauging the distal true lumen. Knowing whether the vessel bifurcates towards the distal end of the CTO, knowing the angle of bifurcation, whether there is stenosis or plaque at the bifurcation ostium, are, as I will show later in the section on Side Branch Technique, extremely important. As I have already said, finding out whether there is diffuse distal plaque build up is also a vital part of pre-procedural strategy-formulation.

c) Contra-lateral Injection: Using contra-lateral injection is an indispensable part of strategy in Intervention for CTOs. It is no exaggeration, in fact, to say that all expertise as to how to maneuver your CTO wire comes from the use of this technique. It don't just tell you how to move the wire forward, but continually provides you with information during the procedure and while the wire is moving, into the distal course of the true lumen and any bifurcations. You really cannot tackle CTOs without contra-lateral injection, and all operators should understand that using it gives you your best possible map of the vasculature.

There are still a number of points to be careful of when using contra-lateral injection. i) the guide catheter and CAG catheter interfering with each other: this happens quite frequently, and you may find that it is very difficult or impossible to engage the guide catheter. Using the left radial artery approach for the CAG catheter is one way to solve this, but ideally, you should, wherever possible, avoid using ALs for both the guide catheter and the CAG catheter. If you have trouble getting the CAG catheter position stable, it may be easier to use either a soft 5Fr guide cath-

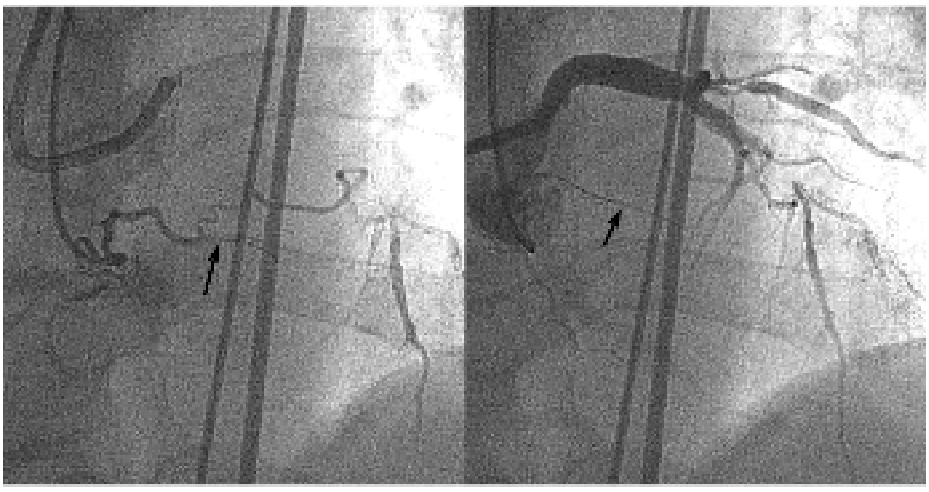
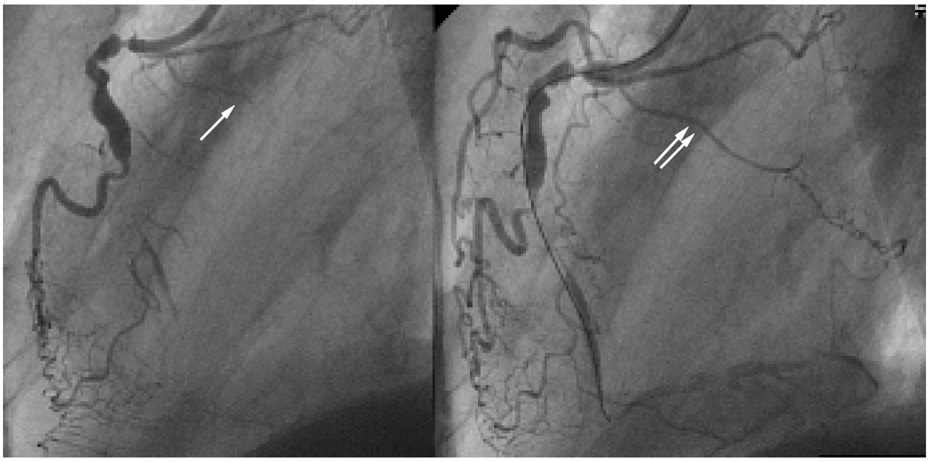


Figure 5: Fixing guiding cath position with an angiographic catheter designed for the conus branch.
Attempts to image the conus branch selectively on angiography came up against problems of fixing the catheter position and wedging, but this was solve by insertion of a guide wire into guide catheter.

eter + Transit® + guidewire, or a 4Fr or 5Fr CAG guide catheter + wire combination (Fig. 5). ii) ischemia: particularly when you are doing contra-lateral injection in the RCA, you have to be careful that the catheter doesn't find its way deeper into the vessel and cause ischemia. If the CAG catheter keeps getting wedged in the conus artery branch, passing a guidewire along the CAG catheter and forcing it back is a good way of preventing freeing it from the wedge. iii) the amount of contrast medium you use: you tend to use a lot of contrast medium during contra-lateral injection, but this depends on how you do it. You need a technique for infusing the contrast medium. I find that "super-selective" angiography (usually with the Transit®) is a good way to keep down the amount of contrast medium used, though you have to be careful not to cause ischemia. Parallel Wire Technique, described in its own section below, is another way of econo-



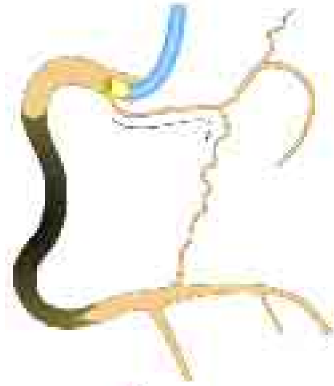


Figure 5-1: Occlusion of collateral flow by guide catheter tip
The ostium of the sinus node branch, a donor artery for collateral flow, is occluded by the tip of a JR guide catheter, with consequent loss of flow to the atrioventricular node branch.

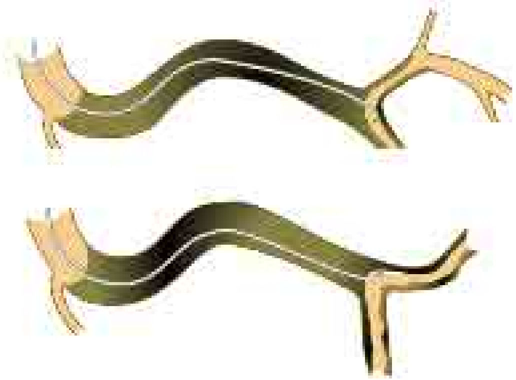


Figure 5-3: Deformation of the distal true lumen by the tip of the wire
This information is important when penetrating the proximal cap on your way to the distal true lumen.

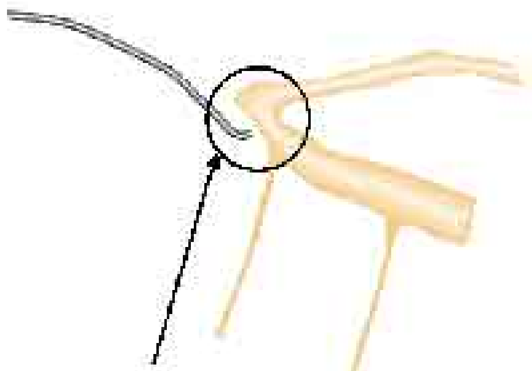


Figure 5-2: Your target depends on the bifurcation angle of the branches.

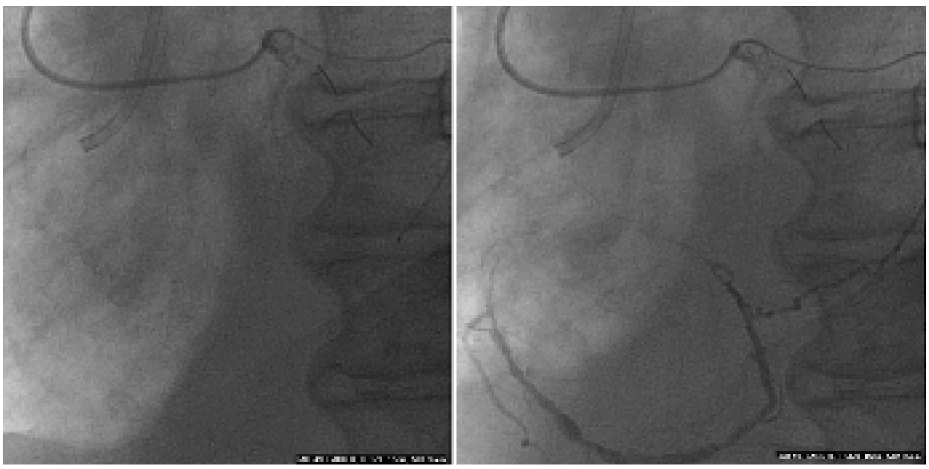


Figure 5-4: Placing a Transit catheter into the donor artery of collateral flow (as on left), and contra-lateral injection for selective angiography. This technique can restrict the amount of contrast used to less than 1cc.

mizing on the amount of contrast medium used, as that technique requires fewer contra-lateral injections.

d) Imaging View: It may be obvious that it is a good idea to do CAG from as many views as possible before you begin the procedure, but it really is imperative that you assess the relation of the guidewire tip to the distal cap of the CTO from a number of angles, both during fluoroscopy and CAG, once you have begun the procedure, too. Some operators do work from only one angle but their success rates suffer as a result. Even experienced operators should remember that they can get carried away during a procedure and forget to look at the vessel from multiple directions. Be careful.

It goes without saying that CAG is the best way to monitor the relative positions of the distal cap of the CTO, but even though this gives a 3D image of the relative positions, it can sometimes be useful, during CAG, to use an intensifier. Similarly, a biplane device is a good way to cut down on how much contrast medium you use, but in order not to limit yourself to just two angles, you will need to put in a bit of footwork.

3. Steering your Wire

a) Wire characteristics ~ which one to choose?

i) Basic characteristics of the different wires: Looking at those wires that are either already on the market or soon to come out, and leaving the Magnum Wire aside as a special case, wires designed for treating CTOs largely divide into two main groups, polymer coated wires and coil wires, as shown in Table 1. The polymer coated wires have a hydrophilic coating, which means they attract very little resistance when they come into contact with the tissue in the lumen, and move quite easy through soft tissue, a feature of these wires being that the operator feels little resistance. These wires do however offer good maneuverability in tortuous vessels, and compared to the coil wires, can be steered more easily to the true lumen immediately after a sharp bend. On the other hand, you do have to be careful as they can easily find their way down false lumina, and as these wires do not have the greatest torquability, as a rule, they are generally harder to steer than coil wires, and may not respond as well to your attempts to get them to follow the precise path you have in mind. In contrast, the coil wires tend to encounter more resistance inside the lumen than polymer coated wires, but as these wires have been developed to have good torquability even inside a hard tight CTO, they do respond well to the minutest commands. They also tend not to slip very easily into the softer tissue of false lumina, and the operator can usually learn the feel of the guidewire tip. The harder the wire tip, however, the higher the torquability of the wire, but the less resistance at the tip is felt by the operator and the easier it is to find yourself in a false lumen. To give an example, the tip of the Miracle 3g wire is not quite as hard as that of the ACS STD wire, and resistance will be harder to detect if by mistake it ends up in a false lumen. Once again, the harder the tip of the wire, the more careful you have to be about false lumina when advancing it round a sharp bend. Another thing to bear in mind is that, as the tip of the coil wires attracts a lot of resistance, it is more difficult for it to end up in or select very small channels, which means that it is more likely than the polymer coated wires to end up creating a false lumen. We've recently also seen the introduction of tapered wires (Conquest 0.014-0.009 in; Crossit 0.014-0.010 in), and notwithstanding the fact that these wires tend to slip into or select very narrow channels more easily than normal coil wires, these wires are very useful for making your penetration point in the fibrous cap. With the Conquest and the Crossit XT 300-400 wires, though, the hard tip means that they do tend to end up in false lumina just after tight bends, and it is hard to feel the resistance if they do so, both of which mean they require the close attention of the operator. Bear in mind, too, that they can easily cause perforations in the actual vessel wall.

ii) Which wire to choose?: When tackling CTOs, wire selection must be tailored to the specific characteristics of the lesion, and exchanged for more suitable wires during the procedure if circumstances demand it. This is because, and as I have already said, different wires offer different advantages. There is no one wire that fits all eventualities.

When the occlusion is no older than 6 months, and the CTO is relatively soft still, an intermediate wire will usually be your first choice. When you use a wire with a hard tip in this kind of softer tissue, it is quite difficult to feel subtle changes in resistance and easy therefore to end up creating a false lumen. The Miracle3g with its superior torquability may sometimes be a good choice here, but again you have to be careful not to open up a false lumen. For a relatively hard CTO of between 6 months to a year, if it is tapered, I tend to start off with the ACS STD or Miracle 3g or 4.5g. When there is a recanalization channel or some other kind of channel there, and you spot some kind of light bend in the channel, a polymer coated wire such as the Choice Wire will probably be a good one to go with, but change to a coil wire if you get any indication that you have started along a false lumen. When you are dealing with a convex-type lesion with no dimpling, go for a hard wire like the Miracle 12g, or a tapered wire, such as the Conquest, the Cross It XT300-400). If you go for a less hard wire, I think you run the risk of creating a false lumen. In a really hard convex-type lesion, you need a heavy-duty wire like a Miracle 12g or up, or a Cross Wire 80g or up. In CTOs that are fairly short, or where you can predict the course of the lumen relatively easily, it should be possible to use a single hard-tipped wire all the way through, from penetrating the proximal fibrous cap, passing through the CTO and getting through the distal fibrous cap, too. In longer CTOs, however, especially if the course of the lumen is not obvious, if you try to avoid making a false lumen by judging from the feel of the resistance at the wire-tip, you may end up pushing the wire into the media, and if you carry on using the same hard wire you chose to penetrate the CTO's proximal fibrous cap, you run a higher risk of causing a perforation or making a false lumen. It is normally better, after the initial breakthrough into the CTO, to switch to a Miracle 4.5g or less, or on a case-by-case basis, to an intermediate wire. For similar reasons, a polymer coated wire is less than ideal in these kind of lesions. Once you have made a false lumen and are looking for another channel, or broken through the hard tissue in the middle of the CTO, there will be times when you want to switch back to a harder wire, or a tapered wire. If because of tortuosity or tight bends, resistance is strong and handling difficult, the best thing might be to switch to a polymer coated wire when trying to find a channel through relatively soft CTO tissue.

Once you penetrate the distal fibrous cap, you then go back to a hard (Miracle 6g or 12g) or tapered wire. Going back to a hard wire when you need to penetrate the distal fibrous cap can help to minimize the risk of false lumina. As I state below, handling the wire is a delicate and painstaking task. You will also often find that the distal fibrous cap is thinner than the occlusion's proximal fibrous cap, so it helps to be able to feel a channel that actually connects to the distal true lumen. A tapered wire may be useful for this. Once again though, once the wire goes along a false lumen in the distal fibrous cap, you will often have no choice but to use that penetration point.

b) Wire tip shapes

There are four different shapes for CTO wires, as is shown in Fig. 6, and the most common, or basic shape has a 2-3mm 45° curve as in (a). When you are selecting a branch with the wire and then planning to cross it forward to the CTO, use a (d) type wire. Wire type (b) with its large curve is a good wire to use when you have created a large false lumen and need to pull out of that and locate the true lumen. One thing to bear in mind however is that big-curved tips have a tendency to find their way through the intima and as these can make existing false lumina even larger, you should try to use one with as small a curve as possible. With the (c) type wire, the core wire can get bent as the wire is bent meaning this wire can quickly get worn out inside highly-resistant hard CTOs. This kind of curve though is sensitive to resistance, and is a good one when you need very delicate and precise control of the wire tip, but as it doesn't withstand torque so well, it tends to make false lumina and any other channels you make even larger.

The new tapered wires have quite different properties from their conventional counterparts. Their tip shapes are also designed for different uses than those of normal wires. When you are trying to get through a hard proximal fibrous cap, the slightly curved tip of (e) is probably best, but only if you are certain that your wire is co-axial with the direction of the CTO. If you are not sure what direction the vessel takes, you have to proceed extremely carefully because the wire can easily perforate the intima once it has passed the fibrous cap. The tiny curve of the (f) type wire was until now too difficult, technically, to incorporate into wire manufacture. The enhanced sensitivity for wire-tip control that this small curves

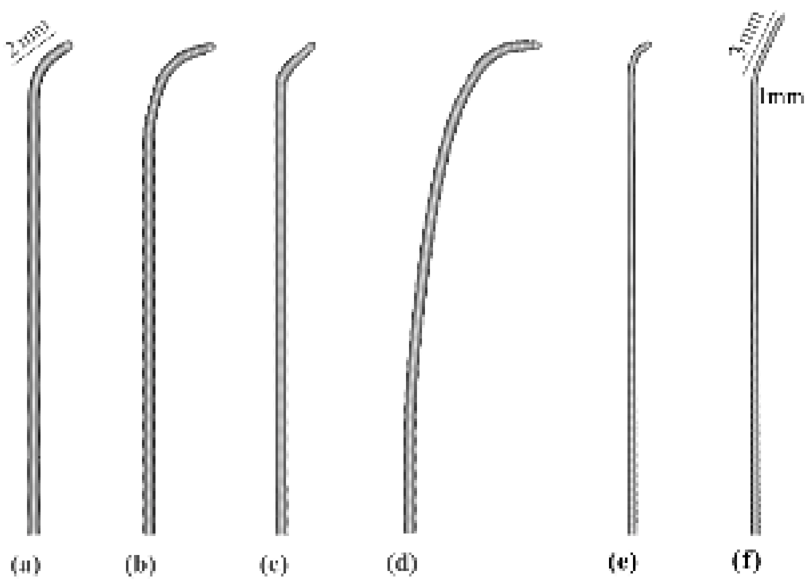
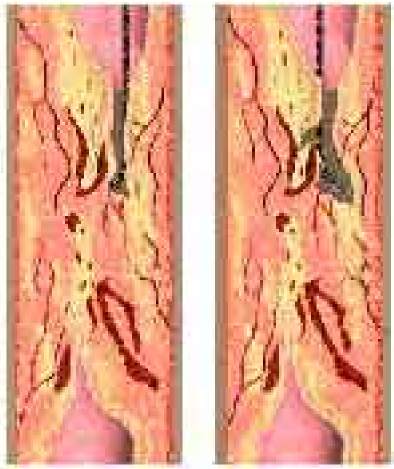


Figure 6: Wire tip shapes

offers is of great use when you are creating a new channel or looking for an existing one. The fact that tapered wires have enabled the development of these small curve-type wires is one of their most valuable contributions.

c) Basics of wire-handling ~ when to do what

i) Basic wire-handling technique: Needless to say the two fundamental elements of wire handling are rotating and "pushing" or feeding the wire forward. However, as it is also important to feel the resistance at the wire tip, when maneuvering the wire, you should use your left hand to feed the wire, back and forward, and your right to rotate the wire. It is possible to maneuver the wire using just your right hand, but using the same hand to rotate the wire, feed it back and forward and feel resistance is unrealistic. Rotating the wire is important because it enables you to minimize the resistance at the tip, as the wire advances, and it also makes it easier to achieve the all-important penetration once you have your wire in place in the hard tissue inside the CTO, or at the fibrous cap. A very skilled operator will also be able to get a feel of the resistance from the whole field of rotation of the wire tip, as it goes forward. One thing to be careful of though, is minimizing wire rotation so that you don't miss you're the point you are aiming at when making the penetration, or that the wire rotation doesn't make the channels too big (Fig. 7).


(a) (b)
Figure 7: Channels made by wire
Rotating a wire with a wider curved tip (b) creates a larger channel

Another technique is to feed the wire little by little towards the target without rotating it at all. This has the advantage over the rotational approach of minimizing the size of any channels you make with the wire, and ensuring the wire goes straight forward. On the other hand, this makes it harder accurately to select the direction you want to go in once inside the CTO, and you have to push forward without getting a feel of resistance in the surrounding tissue. Also, as the wire is deflected by hard tissue, it can easily end up only going through softer tissue. Either method has advantages and disadvantages, and the key is differentiating which method best suits your specific needs. To sum up, when you are advancing the wire along the vessel, you continually check for resistance at the tip, and you need to rotate as you go, but when you are trying to get through the fibrous tip, you need to push it in the direction you want to go in. When trying to decide on the correct path inside a CTO, will a route that meets very little resistance be the right one? The answer is usually yes, if the proximal portion of the CTO is tapered. When the CTO ends abruptly, or is very long, though, it is very easy to end up in a false lumen (between the intima and the media), and in these cases, not uncommon for the wire to meet very little or no resistance even while heading down that wrong path. Unfortunately, there is no way of knowing in advance whether you are heading into a false lumen. Realizing that you have gotten through to the medium though is just about the only thing you can do to when this happens, to prevent your wire-handling making the false lumen even bigger. The only thing to do when you find there is no resistance is withdraw the wire 1-2mm. If the tip is in a false lumen, you will feel an unusual and unmistakable sense of it being stuck, resisting withdrawal. The only problem is that if you have gone too far down the false lumen and made it quite large, you won't get this feeling of it being stuck. The trick is to realise as soon as possible that you are in a false lumen, which you can do not just by rotating the wire or feeding it along, but by repeated withdrawal. And one rule of thumb is that if you feel any kind of crunching sensation from hard tissue at the wire tip, you can be pretty sure that you are in the intima.

The key rules for basic wire handling then are to get as accurate a picture as possible of the path of the wire from as many angiographic angles as possible, to realise as soon as possible if you go down a false lumen, and to make sure if you do end up in a false lumen, you bring the wire back and look for a new channel to continue down.

ii) Getting the wire to go where you want it to

(1) Penetrating the proximal fibrous cap: The real problem scenario for penetrating the proximal fibrous cap is when the occlusion is several years old, there is no dimpling at the CTO's proximal end and the CTO is an abrupt-type one. Reasons can be that you can't get a normal CTO wire into the lesion, the wire slips and you can't get a fix on the point you want to pierce, or you just don't know where the ideal spot for the penetration point is. For the first two of these, you will need a Miracle 12g or a Conquest, and when you are able to get the wire co-axial with the course of the vessel you will probably need to put a light curve into the wire tip. Once you've made your break-through though, bring the wire out and change the shape, and very probably change to a different softer wire altogether (Fig. 7-1). When you can not get the wire and vessel co-axial, putting a loose curve in the wire tip, or adjusting the size and angle of the curve may often solve the problem (Fig. 6(d)). Again, with the latter, once you have made the penetration point, you have to remove the wire and change the angle and size of the curve (Fig. 7-2). As I have mentioned already, there are certain times (i.e. ostial LAD CTOs) when it is useful to insert the guide catheter very deep (Fig. 8).

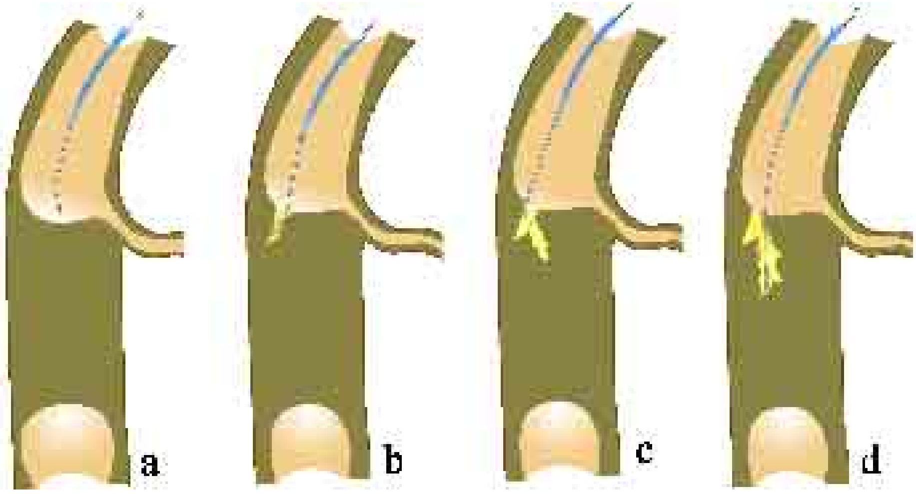


Figure 7-1: For cases with hard-to-penetrate CTOs, a shallow curved tip on your stiff or tapered wire may be a good idea, but changing the tip curve after you get through may make it easier to control direction, and safer.

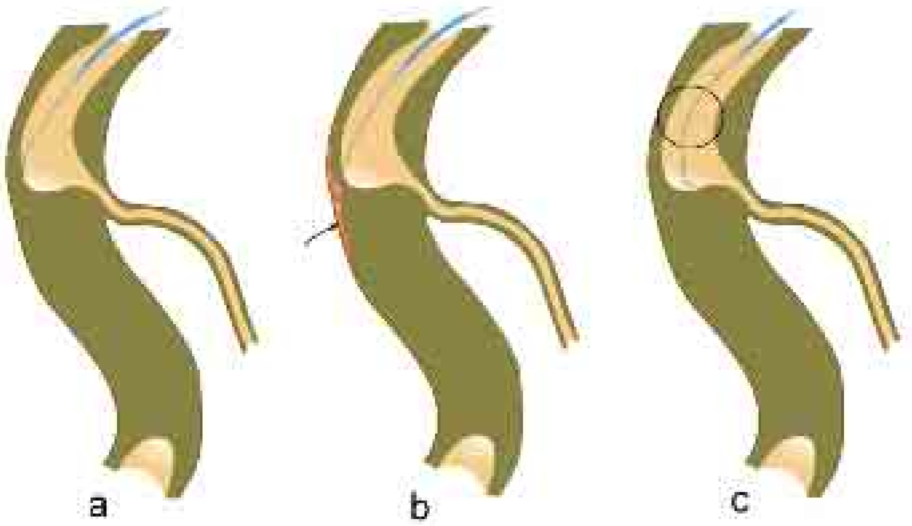


Figure 7-2: Curve in wire when wire and vessel will not align co-axially
When the wire is straight as a or b, it can easily wander into sub-intimal space. Adjust the shape as in c.


Figure 8: Back-up from a guide catheter for an old CTO at LAD ostium without dimpling
For ostial LAD CTOs with no dimpling, where you find it hard to fix a puncture site due to the wire tip slipping or cannot penetrate the fibrous cap due to poor back-up, you may be able to get through by getting the lesion and the guide catheter co-axial, with guide catheter back-up from deep engagement of a JL short tip.

And if the wire keeps going down a side branch, it can also sometimes be a good idea to use a balloon to block the side branch to prevent that from happening (Fig. 8-1).

In a proximal CTO, when you have no idea where you are aiming for for your perforation, IVUS can often be invaluable in locating the entry point. I will go into this in more detail below.

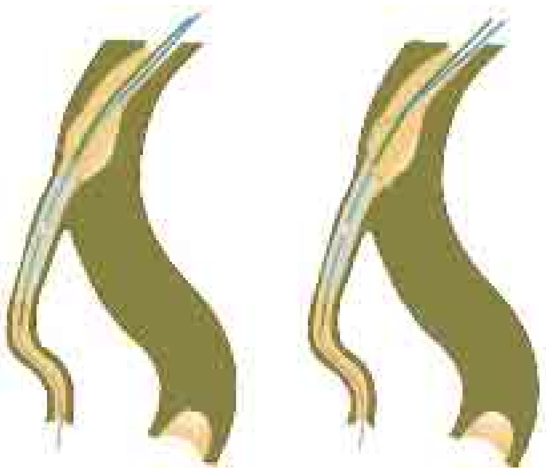


Figure 8-1: Balloon dilation to preventing wire slipping into side branch by.

(2)Getting the wire to the distal end of the CTO: As there is no easy way to master this technique of getting your wire to the distal end of the CTO, it really is a question of trial and error and learning from your mistakes. If inside the CTO there is a portion of surviving lumen, or you find a recanalization channel, these can serve as a guide, but equally, if you go down one of the bridging collaterals, or new vessels in the media or adventitia by mistake, you run a high risk of perforating the vessel itself, and so great care has to be taken. Calcification can also be a good guide to vessel course. Whether the path is signposted or not, sensitivity to resistance at the tip of the wire is crucial. What tells you that your wire tip is in the lumen, is a gravely sensation caused by contact with the relatively harder tissue there. As I have mentioned above, it is sometimes hard to sense this feeling with anything heavier than a Miracle 6g. Also, even if the vessel is dead straight, proceed with caution as is there is no guarantee that the channel you are navigating will be as straight (Fig. 8-2). Care is required in the RCA especially, and even a very small deviation can send you burrowing down a false lumen. Remember as I mentioned above, when this happens, the only thing to do is pull back and try to tell from the feel of things where the right path is.

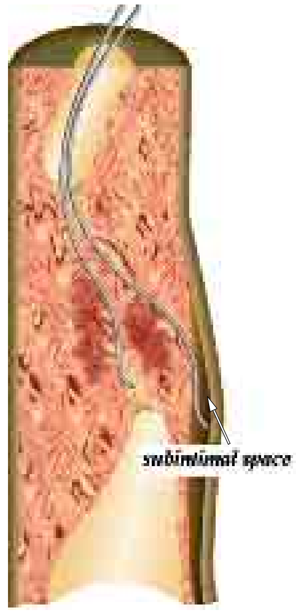


Figure 8-2: Tortuous of channel inside CTO due to lack of co-axiality of proximal and the distal true lumens and distribution of hard tissue inside the lesion.

If the wire tip repeatedly creates a false lumen, you are unlikely to get a better result with the same or an identical wire. Before you make the false lumen even bigger, it is best to change the shape of the curve or change to another wire altogether. Changing wires in this situation can be difficult but, as is further set out below, this is an indispensable part of basic CTO wire-handling technique. You will also find that once a channel has been forged by a wire, you will usually be able to pass another different wire along it, but you need to be 100% confident that you will be able to locate the channel with the new wire. If you find that wire handling is very tricky, which is often the case when you've made a false channel, or when the vessel shape is not conducive, and you are not sure you can find the channel, the parallel wire technique can come in very useful, as I set out below. There are also times when you can get the balloon catheter and transit wire inside the CTO but you still have to be very careful that the tip doesn't pass into a false lumen. When proximal bends in the vessel obstruct wire maneuverability, one option is to inflate the balloon at the proximal point, while you are passing it along to the CTO, but if you do this, make sure you don't dilate a false lumen (Fig. 8-3).

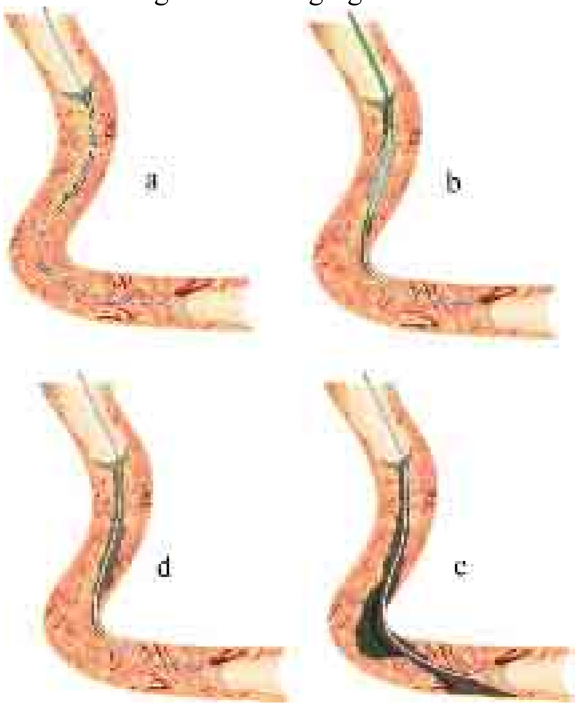


Figure 8-3: Extremely inhibited wire maneuverability due to tortuosity inside the CTO (a), may be improved by dilatation of a 1.5mm balloon in the lesion (b), reducing channel tortuosity (d). Balloon inflation can widen subintimal space, and complicate wire-handling.

In the event that a vessel bend causes you to make a false lumen, generally speaking, it is best to avoid switching to a stiff wire or a stiff tapered wire because that increases the risk of perforating the vessel itself, and reduces your chances of finding another channel through the lumen. In many cases, to stop yourself making the false lumen even bigger, it is a good idea, once you have opened a route into a new channel using a stiff wire, to switch to a softer one instead. If you still find it hard to locate another channel, you may well find that changing to a tapered wire with a small-curved tip helps. Bear in mind, however, as I explain below, that using the parallel wire technique with a tapered wire is a key component of successful strategy for this kind of case (Fig. 8-4). And, as positioning the wire at the outer part of the curve of the tip at the bend can often cause the tip to enter the intima (Fig. 9), it is a good idea to position the curve at the inner part of the vessel bend.

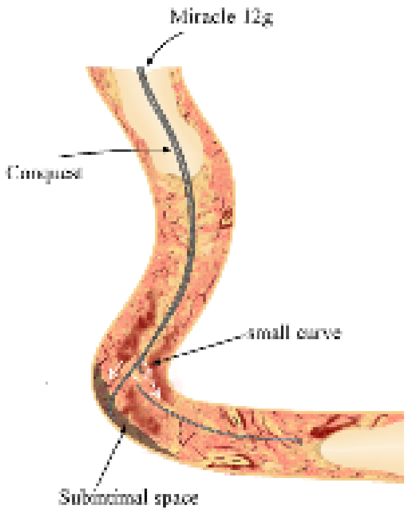


Figure 8-4: A Conquest wire used in the parallel wire technique can help you locate a channel, but it you must use the parallel wire technique.

If the cause of the false lumen is not connected with a bend in the vessel, it will often be the case that the wire's path has been obstructed by hard tissue, and passed into the sub-intima instead. The best thing to do in that case is pull back proximal to the point where you made the false lumen, and switch to a stiff wire (Miracle 6g or up) or a stiff tapered wire. A Conquest wire will normally be your best bet, as you can get a good feel of the way to go from resistance at the wire tip. The important thing is not to go any further forward as soon as you realise that you have made a false lumen. You must pull back and try your best to find a new channel. If this is your last available option, you may have to attempt it but carrying down a false lumen and then trying to force a way into the true lumen from the false lumen (i.e. from the sub-intima) is an extremely difficult technical undertaking, and should be avoided wherever possible.

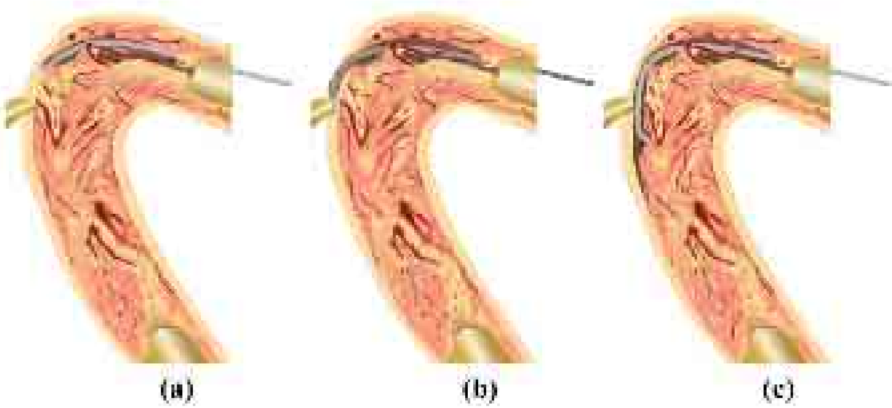


Figure 9: Wire-handling in tortuous CTOs
If you steer the wire to the outer part of the curve, the wire easily can easily end up going through the intima, especially with these stiff wires. This can create a large false lumen, is the wire advances further into the sub-intima.

Fig. 10 illustrates how to pull back and look for a new channel. This involves rotation as well as careful forward and backwards maneuvers, and with the trick being not to over-rotate. While it should be relatively easy to find and advance along a different channel with a stiff wire or a tapered wire, you have to be careful not to over-rotate as that can easily take you down a new false lumen or widen an existing one. The curve of the tip should also be kept as small as possible, except when the false lumen has already been enlarged.

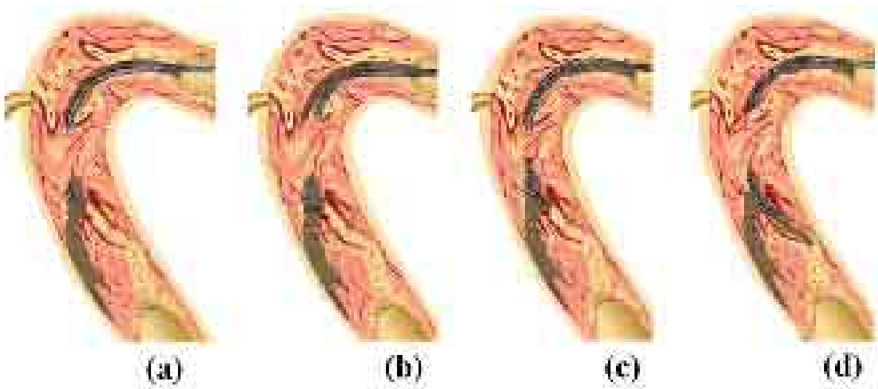


Figure 10: How to make a new channel in the CTO
(a) Look for a site where the wire is touching hard tissue. (b) Push so the wire tip bends slightly (but remember that stiffer wires, ACS standard and above, do not bend like in the figure). (c) Pull back slightly and rotate the wire (<180º‹clockwise), and when the wire straightens, push it by rotating (d).

When making a new channel, you should as a matter of course be clear of its position relative to existing channels, and you may find the parallel wire method, which I outline below, is a useful technique.

(3)Changing wires inside the CTO: As I have already said, there are times when you need to change wires during the procedure. When this happens, it is technically demanding to feed the new wire through the channels you have already made inside the CTO and all the way to the right place inside the channel. I have set out below the various available methods for exchanging wires.

a) *Bare Wire-Exchange*: This technique involves simply removing the first wire and inserting a new one in the same channel, and is easier if the CTO is relatively hard and not peppered with too many false lumina. Disadvantages with this technique, though, are that it adds to your overall procedural time and uses more contrast medium. Also, as it is technically challenging, the chances of an operator inexperienced in handling fairly stiff wires accurately locating the same channel are fairly low, and by extension, his or her chances of creating a new false lumen relatively high. Be especially careful if you end up creating false lumina in a CTO with a bend: better to try a different technique before you cause too much damage.

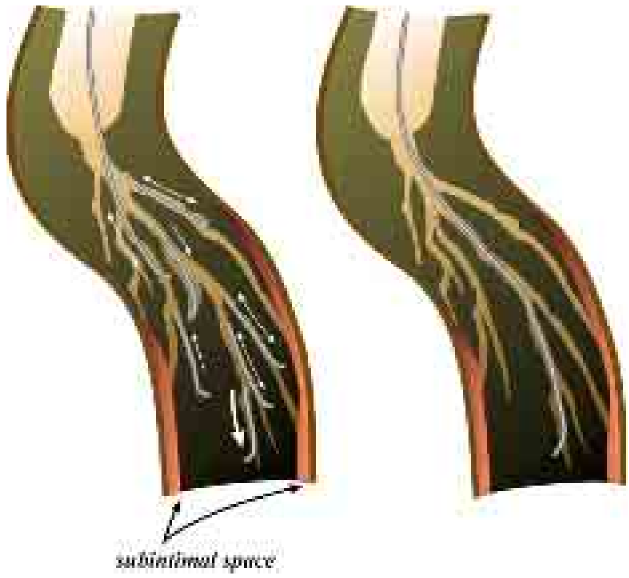


Figure 10-1: Exchanging wires by the bare wire technique When you have already made several channels, changing wires is difficult.

b) *Catheter-based Wire-Exchange*: If you are able to get a 1.5mm over-the-wire balloon catheter inside the CTO, or if the wire has advanced to a bifurcation inside the CTO, you will be able to exchange wires while keeping the tip of the balloon catheter inside the CTO, or in the bifurcated branch (if you are using side-branch technique). A note of warning is that this method carries a risk of causing a dissection inside the CTO as the balloon catheter is inserted, especially if the wire penetrates the intima. Also, a wire that has not passed completely through the CTO, will not provide any back-up, and will often mean that you won't be able to get the balloon catheter itself into the CTO. You are unlikely to use this method when attempting side-branch technique, or if the CTO tissue is anything other than relatively soft. In fact, taking into account the risk of dissection, it is probably best to opt for the parallel wire method.

c) *Parallel Wire Method*: The parallel wire method is used more and more for exchanging wires, and the two other methods described are in fact rarely used these days. The parallel wire method also calls on the skills required for mastering the broader parallel wire technique, which forms the basis of the concept behind this method for exchanging wires. As is Fig. 10-2, this method essentially involves feeding the second wire along the same path as the first wire, in parallel, using the first wire as your guide or marker to make the whole process fairly straight-forward. The trick is to advance the tip of the second wire right along the shaft of the first wire so that it looks as though one is on top of the other from the various angiographic views. The experienced operator can feel the contact between the two wires as the second slides along the first. Also, to make sure that the wires do not get wound around each other, it is a good idea to bring the support cath for the balloon catheter right up to just proximal to the lesion. At first glance, you would think this was a difficult technique to perfect, but it can be quite easy, with practice, and is a sure way to avoid causing dissections or perforations. You can also expect close to 100% success rate exchanging wires with this method. Advantages of exchanging with this method are that you minimize the risk of creating new false lumina in the process, and if you are changing a Miracle 12g or Conquest for a tapered wire, you can also keep perforations to a minimum. Remember too that the second wire should be harder (a Miracle 6g, 12g, Conquest) than the first wire.

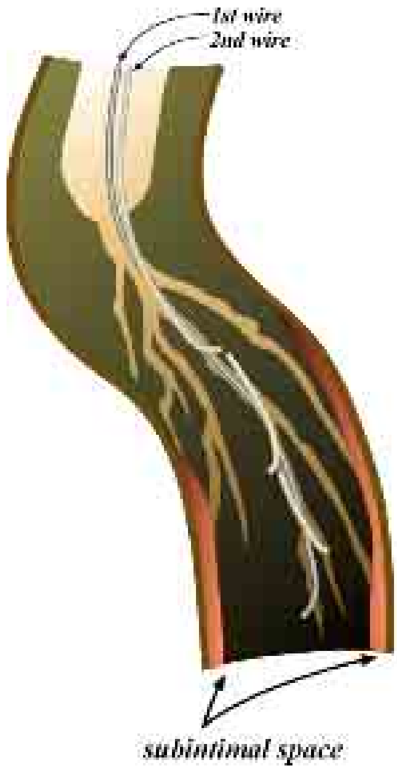


Figure 10-2: Wire exchange using parallel wire technique

(4)Penetrating the distal fibrous cap: Before you get to the question of how exactly to make your penetration point with the wire, the first requirement is getting the wire tip to the point you want to target. Choosing the optimal point for the penetration is a skill best learned from experience. There are some kinds of distal fibrous caps however where experience isn't a great help, such as tapering CTOs, or diffuse occlusions, and with these, there is no correct way to get through the distal fibrous cap. In other words, there are some CTOs whose shape will decide whether or not you are going to be able to get through to the distal fibrous cap, before the wire tip is even in position. As there will be some channel that you should be able to get through, if you are not in this channel (and most probably you will be in the sub-intima, if you are not in this channel), and are trying to reach the distal true lumen at the distal fibrous cap, your chances of success are low. It is important to understand that this is true even today, with the emergence of the various kinds of stiff wire. So once again, if you are not in the right channel, pull back and try to find the right one before you make the false lumen any larger.

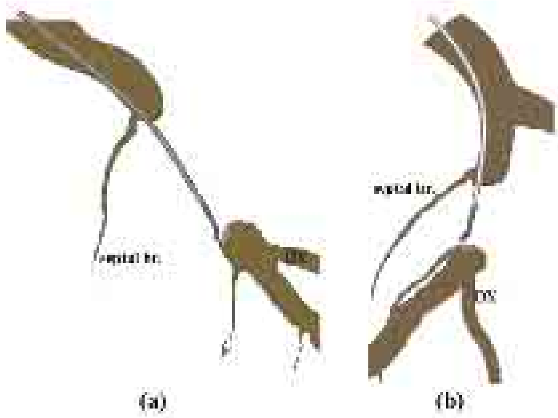


Figure 11: Optimal entry point (in pink) in LAD; (a) RAO cranial view, (b) LAO cranial view

Figs. 11~13 show the optimal point to attempt a perforation when the CTO is one of those that ends abruptly. This will usually be on the myocardial mural side. This is important to remember. One thing to be aware of is that the end of the CTO occupies the inner part of the lumen more than the outer part, and is a 3-D dome-like shape, which doesn't come out very clearly on a 2-D image such as fluoroscopy gives. So, when the wire is touching the distal fibrous cap at the optimal perforation point, be careful because in 2-D the wire can look as if it is already in the distal true lumen (Fig. 13-1). This isn't necessarily true though, and the wire tip may not have lodged in the fibrous cap at all. In cases like these, experience may not be enough and extreme vigilance is the only way to be sure. In order to make the penetration at the point where you want it, you have to carefully advance the wire from the central portion of the cap towards the point you are aiming for, and make sure that you are not forcing the wire along an unnatural path, otherwise the chances are that your perforation will not be at the target site.

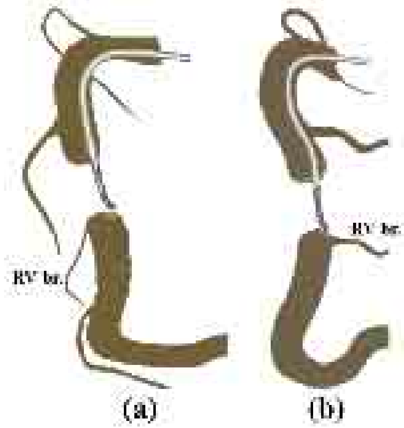


Figure 12: Optimal entry point (in pink) in RCA; (a) LAO view, (b) RAO view

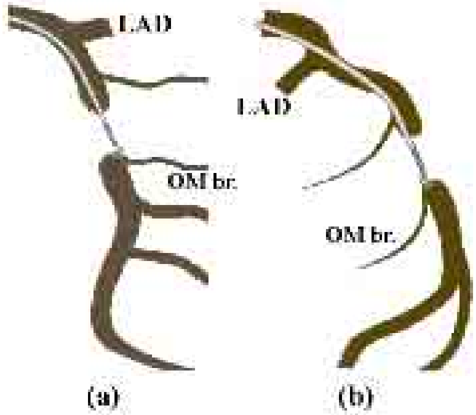


Figure 13: Optimal entry point (in pink) in LCX; (a) RAO view, (b) LAO

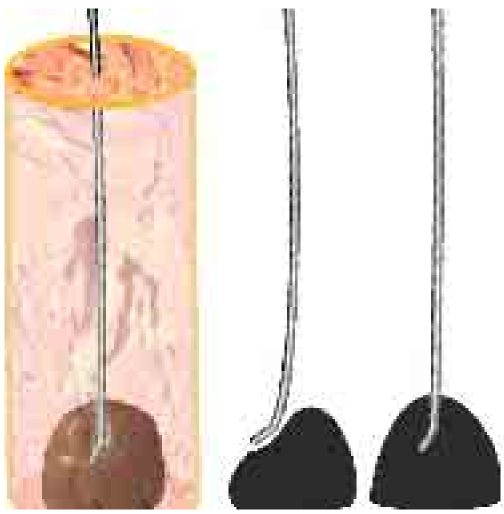


Figure 13-1: Wire tip position in distal fibrous cap (3-D view)

The most important thing of all, even after repeated attempts to make a penetration in the distal cap and even if the wire has been deflected by the fibrous cap, is to bring the wire tip back, try a different approach route to the distal cap and try to locate a new channel. If you fail, pull back before you make the false lumen even bigger and switch to a stiff or tapered wire. And so that you don't lose your position in the CTO at the distal fibrous cap, when you are changing wires, it can often be useful to leave the first wire in, and feed the second wire along parallel to it, checking the relative positions of the wires all the time as you go. Watch out though that the because of a bend in the vessel, the position of the first wire doesn't block the way to the distal true lumen, and obstruct your ability to maneuver the second wire.

If IVUS or the pathology leads you to think that the distal fibrous cap is softer than the hard tissue at the proximal fibrous cap, you may think that that will make it easier to make the distal penetration (Fig. 13-3). In practice, you will find that it is still far from easy. Reasons for this could be that (1) the wire has

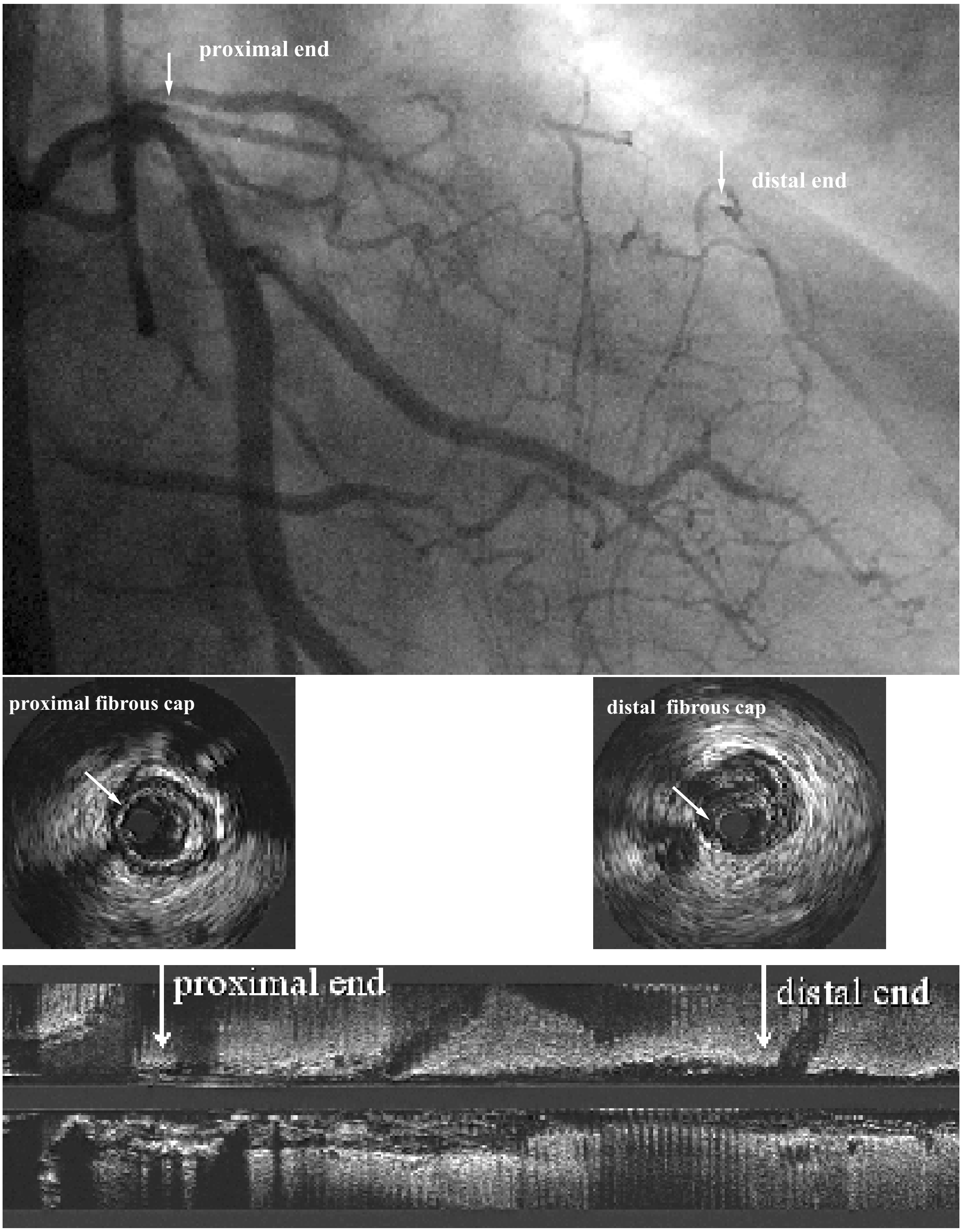


Figure 13-3: Difference between proximal and distal fibrous caps
3-D IVUS image of a CTO (>15 years old) at the LAD ostium after post-dilation with a 1.5mm balloon; the difference in thickness between proximal and distal fibrous caps is striking.

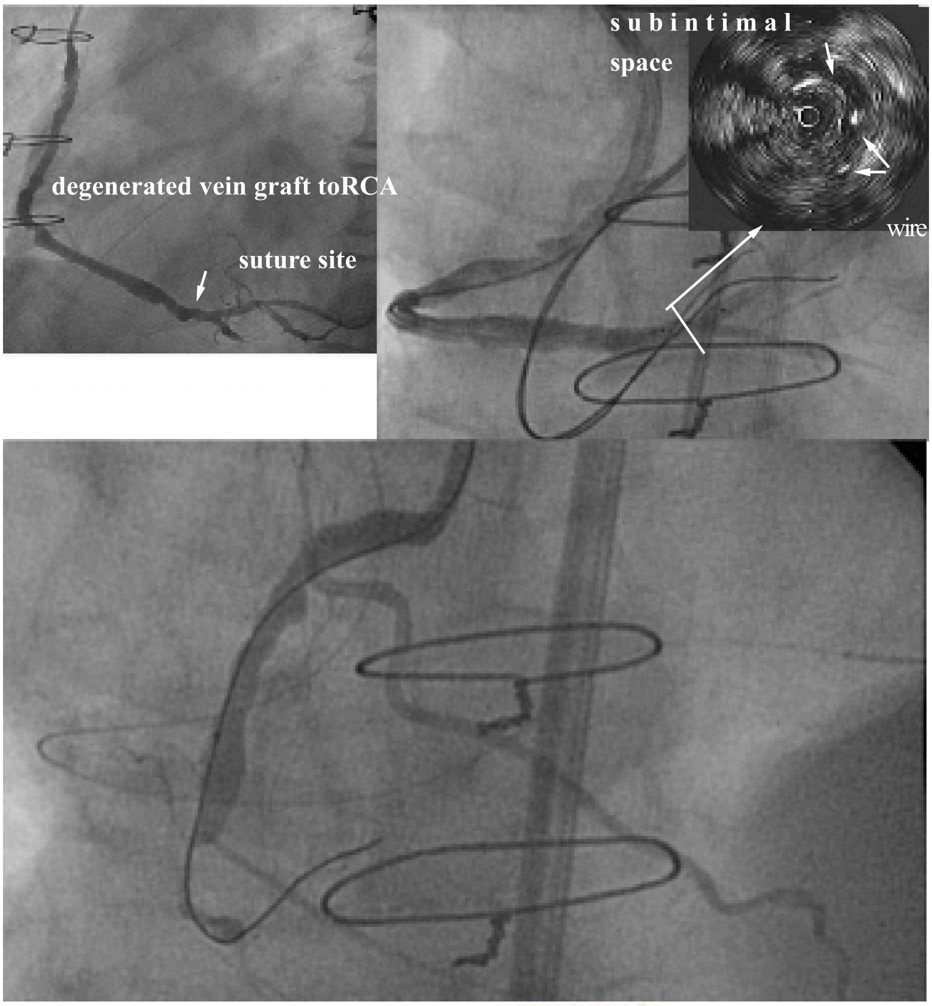


Figure 13-4: CTO in a native RCA treated by PCI due to the reoccurrence of stenosis in post-CABG SVG. Since the vessel wall distal to the suture site in the RCA was covered by a hard fibrous cap, the wire ended up in the sub-intimal space and could not be rectified even by parallel wire technique. IVUS of the SVG obtained imaging of wire movement in the native RCA. An access point was finally created with a Cutting Balloon, and the wire passed successfully (see text for details).

already strayed into the sub-intima at the distal end, and it is hard penetrate through to the distal true lumen because the tissue there is thicker (Fig. 13-4), or (2) that maneuverability at the distal end of the CTO is poor and that the distal fibrous cap moves as the wire tip does and you can't actually pin down a spot to make the penetration point (Fig. 13-5). For (1), all you can do is pull back and change your access route, while for (2) you have to pin the fibrous cap down so that you can get through. To do this, maneuver your wire as you would when trying to pierce through hard tissue at the proximal end of the CTO, only use a wire with a sharp stiff tip, and keep rotation to a minimum to position it securely at the perforation point.

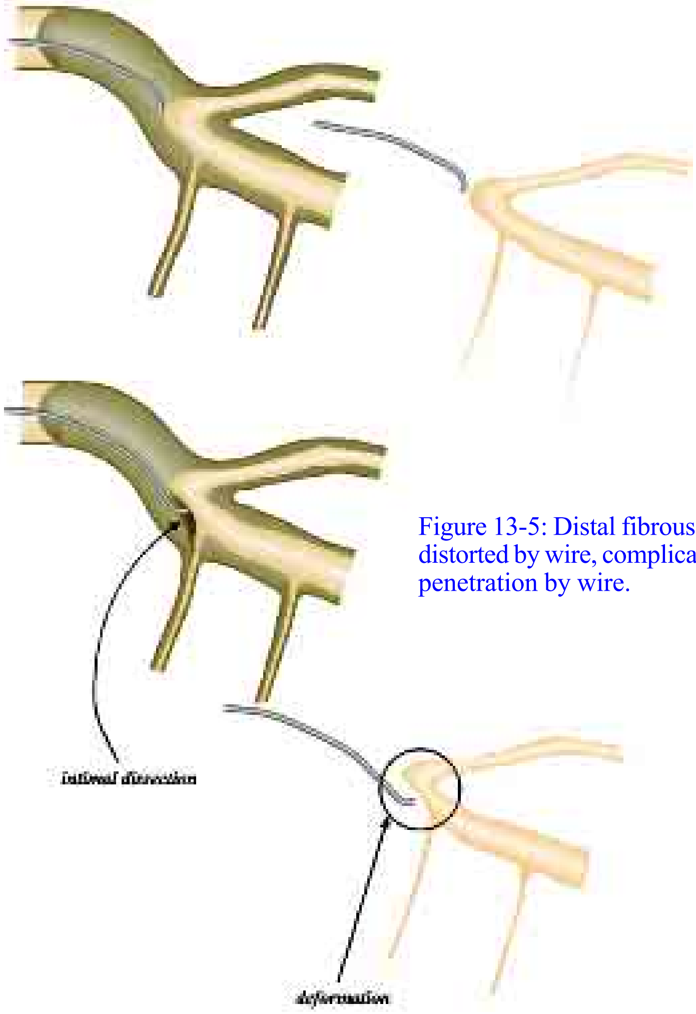


Figure 13-5: Distal fibrous cap distorted by wire, complicating penetration by wire.

4. Parallel Wire Technique

As I have already said, I believe that the parallel wire technique will come to be the principal wire-handling technique for CTOs. It has the advantage, over the other techniques in use until now, that it can be applied to all CTOs, irrespective of individual lesion characteristics. It is a technique that anyone can perfect as long as they follow the guidelines on wire-handling. In that sense, it can be said to constitute the first revolution in the development of PCI for CTOs. The parallel wire technique requires the insertion of a second wire into the CTO while the first one is still in place there, and I have set out below the 6 main points that must be observed for successful execution of the technique.

a) Basic Parallel Wire Technique

(1)Pre-conditions for the technique: one absolute condition is that the distal end of the CTO in the distal true lumen must be clearly visible on angiogram from the vessel's own collateral flow ("homocollaterals") or from that of a sister vessel. Though not strictly necessary for changing wires, but very important for ensuring the efficacy of the parallel wire technique, make absolutely sure that you can see under fluoroscopy the site you are aiming for, i.e. the distal true lumen, and that you know specifically what the relative positions of the distal true lumen and first wire are, using the full range of available angiographic views (Fig. 14). As application of this technique requires that you be able to view not just collateral flow, but also the distal true lumen, you will need to do super-selective angiography of specific collateral flow (cf. the section on contra-lateral injection).

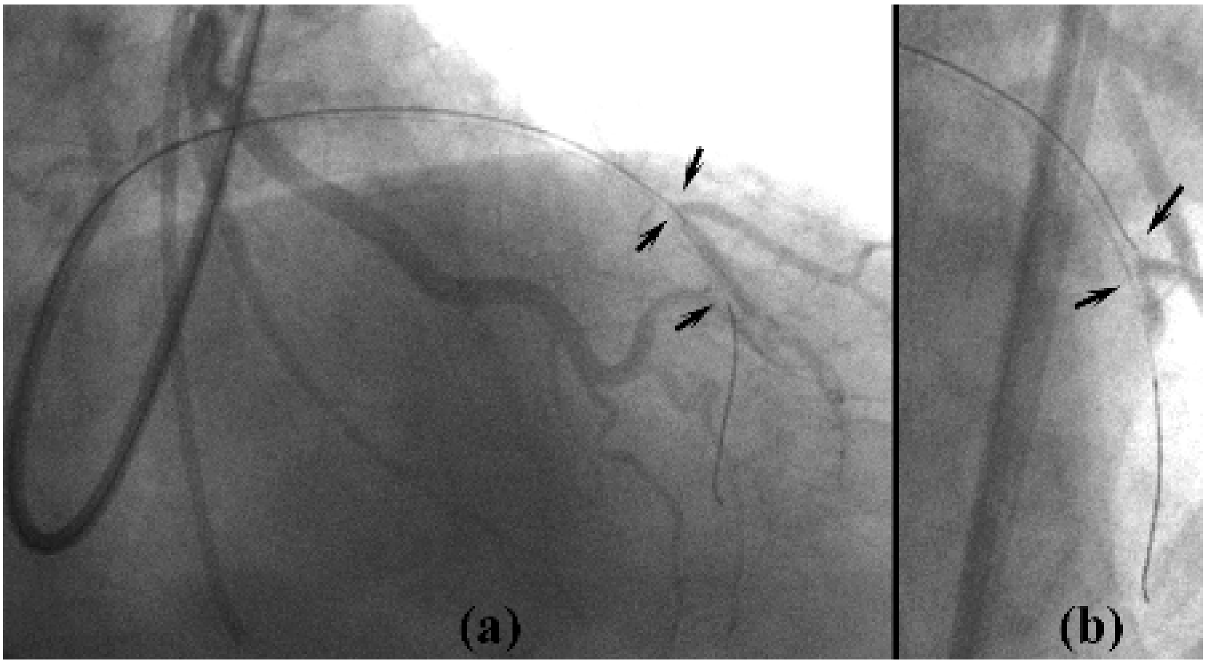


Figure 14: Penetrating the distal fibrous cap using parallel wire technique; the first wire entered a false lumen, and on to the septal branch bifurcating from the distal true lumen. An attempt was made with the second wire to penetration to the distal fibrous cap. Collateral angiogram showed a clear distal true lumen, here the position of the second wire is crucial for finding the relative position of the first wire and the distal true lumen. By RAO cranial view (a), note that the second wire tip seems to occupy a position in the true lumen. The AP cranial view (b) shows the first wire has stretched and enlarged the true lumen.

(2)The importance of a support catheter: When inserting the second wire, you really must use a 1.5mm balloon, or a Transit or even an Interpass catheter, and not just a bare wire. This is to avoid twisting the wire, and even more importantly, to maintain maneuverability of the second wire, and as such is a key factor in the simplification or successful execution of the technique.

(3)Positioning the support catheter: It is important to advance the tip of the catheter right up to the CTO. This also is designed to stop the wire twisting and ensure its maneuverability, and preferably it should be a Transit, for its very flexible tip. A balloon catheter would not be without its advantages but neither the tip or balloon portion can match that of a Transit for flexibility. Note however that when your CTO and vessel path are not co-axial, or when you have a proximal CTO before a bifurcation, bringing a balloon catheter right up to the CTO may actually have the opposite result of hampering wire-handling.

(4)Wire-handling in Theory: As you feed the second wire inside the CTO, do it so that the second wire closely follows the course of the first, "hugging" it as it goes. Once you have got the tip of the second wire right at where the tip of the first is, it is vital to use every available to confirm that the two wires occupy the exact same channel inside the CTO, under fluoroscopy. As with experience you get better at this you will need fewer views, and so use less and less contrast medium, but the important thing is knowing the exact relative positions of the two wire tips, as it is this that gives you the minute control you need. Be careful at the same time that the wires do not get too tangled up with each other inside the CTO, as this too will cause twisting. If that does happen, the best option is to pull them back to a point where you can untangle or untwist them and re-cross to the same point. With the parallel wire technique, there are no particular safety issues associated with moving wires forward or backward, which makes life a little easier.

(5) **Wire-handling in Practice:** Preferably, your second wire will be stiffer than the first, and will have superior torque transfer, because during these procedures the wires can tend to get twisted, and these features serve to preserve maneuverability of the second wire, while stiffer wires are less likely to get twisted in the first place. The most commonly used wires are the Miracle 12g or Conquest. I would say that the ideal wire combination is a Miracle 12g + Conquest (or another Miracle 12g), a Miracle 3g + a Miracle 12g (or a Conquest). The reasons for this, once again, are to do with preventing twisting, and because the job of the first wire is to secure the position inside the CTO, both wires should be stiff. Having the second wire stiffer and with better torque (and therefore better maneuverability) means that the first wire can be used more efficiently as a marker, and reduces the risk of you making new false lumens or perforating the vessel.

(6) **Timing and the Parallel Wire Technique:** You will usually find that whether you manage to get your first wire through to the distal true lumen at the first attempt depends on the tissue inside the CTO. If the first attempt does not prove successful, you need to try again, but be careful, as you run the risk of creating a false lumen, which will not only make subsequent wire maneuverability more difficult, but if you end up widening the false lumen it can lead to the compression of the true lumen and also to the collapse of the CTO proximal cap. Normally, if even repeated attempts do not enable you to get your first wire through, it will probably mean, as in the case in Fig. 13-4, that the sub-intimal space has been widened and that the wire cannot get out of that and back into the plaque. Under fluoroscopy, it may look as though the wire, as it advances with each of your repeated attempts, is advancing along a channel but in actual fact, it is probably simply moving along the sub-intimal space. If things go wrong and you end up making a big enough false lumen, you will find it very difficult to make any other channel even using the parallel wire technique. It follows that you should always switch to this parallel technique before you risk creating a large false lumen. Personally, if I am unsuccessful with my first wire, rather than blindly attempt time after time to get through, I switch straight to the parallel wire technique.

The above 6 sections represent the fundamental requisites of this technique, and I would like strongly to caution that neglecting any of these points will make wire-handling extremely difficult and most likely cause you to fail.

b) Perfecting the Parallel Wire Technique

Clearly this not the most straight-forward of techniques, and mastering it entails something of a learning curve. Personally, it took me about three years before I felt entirely comfortable with the technique, and there was a great deal of trial and error along the way. At first, the degree of difficulty involved meant that I used the technique as a last resort, which as I have already said, reduces its usefulness by half. In order to be entirely comfortable performing this technique, you need to get a feel for the interaction of the two wires. And I have said how long that took! In the early days, I also tended to mistakenly pull back the first wire a little while inserting and handling the second. With hindsight, I would say that it is very unlikely that an operator without some experience of the technique could perform it entirely free of stress. My own record is shown in Table 1, which demonstrates clearly that I used the technique more as my own experience of it grew. One simple and effective way to rehearse the kind of skills required for the technique is in PCI for non-totally occluded lesions. Try to cross a second wire, say a Miracle 3g, 6g, 12g or a Conquest up along in parallel with your first wire,

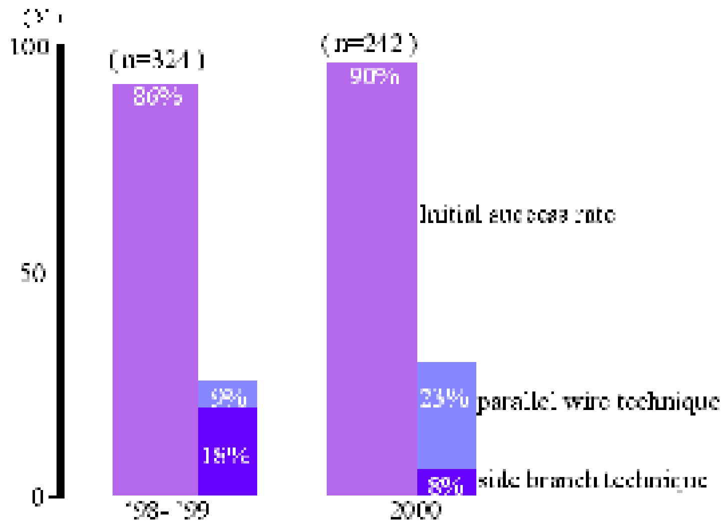


Table 1: Initial success rates for parallel wire technique since 1998 (i.e. post-technical advances) and frequency of use of parallel wire technique and side-branch technique. Since the superiority of the parallel wire technique was established in early 2000, the frequency of use of the technique has increased. The side-branch technique is normally used in combination with the parallel wire technique and its use has declined accordingly.

taking care to avoid twisting. This is especially good practice if the lesion has some degree of tortuosity. Similarly, for CTOs where the wire passes through relatively easily, before you dilate your balloon, try to cross a stiff wire through using the parallel technique as described above. With practice, you should be able to get the wire across close to 100% of the time. I estimate that if you keep to these guidelines, you will be doing stress-free parallel wire technique after about 20 cases. When this happens, you can consider yourself to have largely mastered the technique, and all that remains is to know when and how to use it. I would add that the easiest aspect to learn and the most useful in terms of versatility of this technique is the parallel wire technique for exchanging wires.[Cf. Section 3 c ii].

c) Applying the Parallel Wire Technique

The following are examples of when the parallel wire technique can be expected to be of use in the clinical setting of intervention for a CTO.

(1)*Exchanging wires*: as described above.

(2)*Finding or creating a new channel inside the CTO*: We now have wires that allow maneuvering of the tip even inside the CTO, which have made it possible to make a channel(s) inside the occlusion different from the one your wire has already made and currently occupies. This normally entails pulling back a little along the original channel, turning the wire slightly away from the existing direction channel and edging it along in that direction, making a new channel as you go. This will, naturally, feel different to the pre-existing one (Fig. 10). A lot will depend on the experience and instincts of the operator. The difficult thing about this is that knowing what direction to go in is also largely dependent on operator instinct ~ you do not have any visual markers to show you the correct direction to go in or the exact spot to rotate at ~ and it is all further complicated by the fact that heart is, of course, beating, meaning that every point in the vasculature and every potential direction are constantly "jumping" with each of the heart and correcting or "fixing" the images before is no easy matter. You will also find that once you have made a channel, the wire tip will tend naturally to slip back into that channel (Fig. 14-1), which complicates your efforts to turn it in other directions. You have to constantly battle the natural orientation of the wire, to get it to face the way you want it to. One advantage of the parallel wire technique is that as you have the first wire to act as a marker, which gives you a 3D view, and makes it easier to compensate for this jumping effect. Another merit of the technique is that you can use the first wire as an anchor, enabling you to guard against any slipping of the second wire when you are turning it. This should give you a better chance of getting your tip to turn to the point you want it to face.

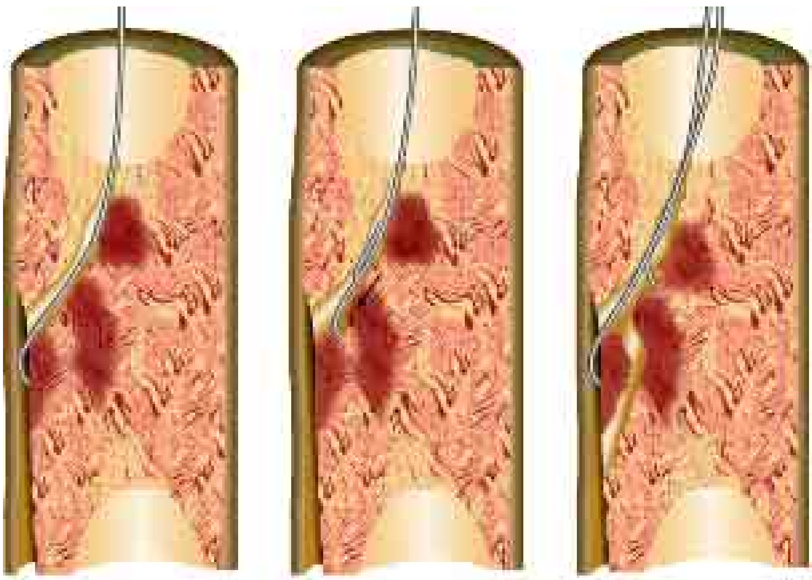


Figure 14-1: Once a wire enters the sub-intimal space (left), a new channel cannot easily be created. The wire repeatedly slips back into the space and changing its direction is very difficult (center). A new channel can be created relatively easily with the parallel wire technique (right).

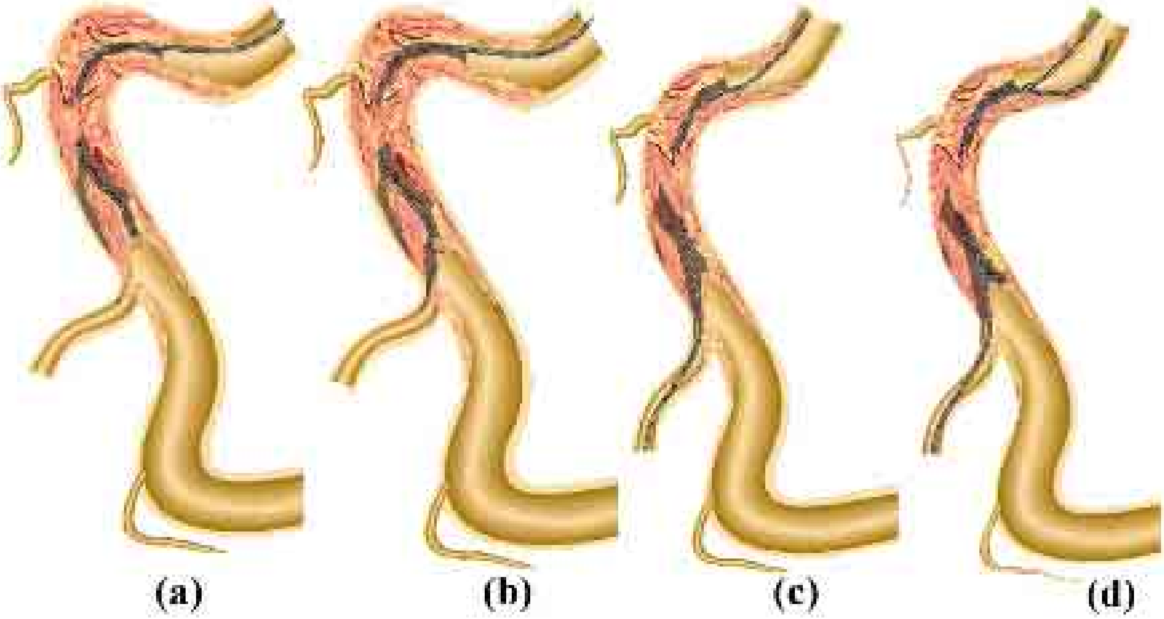


Figure 15: Stretching the vessel using parallel wire. When proximal bends in the CTO obstruct the wire penetrating to the true lumen (a), insert the wire as distally as possible into the distal side branch to stretch the curved vessel (b, c). Then access the true lumen through a new channel with the second wire (d).

(3) *Navigating a bend inside the CTO*: When there is a bend or curve in the vessel inside the CTO, a stiff wire will tend to pass around the outer (broader) edge of the curve, increasing the risk of the wire passing through the intima at the bend and ploughing a bigger and bigger dissection lumen under the intima as it goes forward. This is not an uncommon phenomenon. If you realise that your first wire has gone into the intima at a bend, leave the wire where it is, helping to straighten the bend, and use it as a marker to get the second wire around the smaller inner side of the bend (Fig. 15). When there is a tortuosity at the distal end of the CTO, it may well be difficult to find the distal true lumen with the first wire. It may be that you haven't put enough of a curve in the tip of your wire, or that the CTO anatomy it too tortuous. When this happens, position the first wire just proximal to the tortuous site, put a very sharp angle in the curve of the second wire's tip, advance that wire right up to the same site using the parallel wire technique, and you should be able to locate the point you need using the relative positions of the two wires (Fig. 15-1).

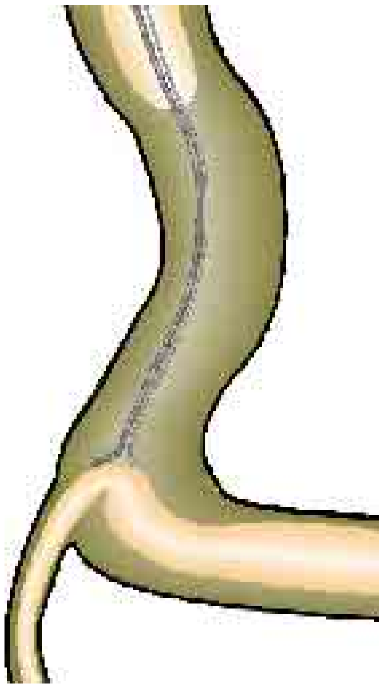


Figure 15-1: Technique for crossing from the point where the first wire is placed proximal to the distal fibrous cap as a marker. In this case, using a "tapered wire" with its tip slightly curved can be very effective.

(4)*Negotiating the tissue inside the CTO*: Once you have actually created a false lumen, it becomes harder to make any new channels or locate a new puncture site with the wire. The main reason for this is that when you try to push the wire through a new point, the existence of the false lumen means that the tissue shifts or "escapes" from the stiff wire tip, and actual penetration is difficult. Though no good if the false lumen is too big, if you switch fast enough to the parallel wires, you can use the first wire by leaving it in the false lumen where to some extent it steadies or pins down the tissue, and makes it easier for you to find a way through it. You may find this trick especially useful when you are trying to puncture the distal fibrous cap (Fig. 16, 17).

° Re-crossing via a different route: If you have successfully crossed a wire to the distal true lumen but it has then gone through the intima, or you feel that the wire's position in the distal true lumen, if used to dilate a balloon, would cause occlusion of a side-branch or sub-intimal dilatation with the risk of dissection, the best thing to do is leave the wire where it is and use the parallel wire method to try to get the second wire through a more central distal puncture site (Fig. 17-1).

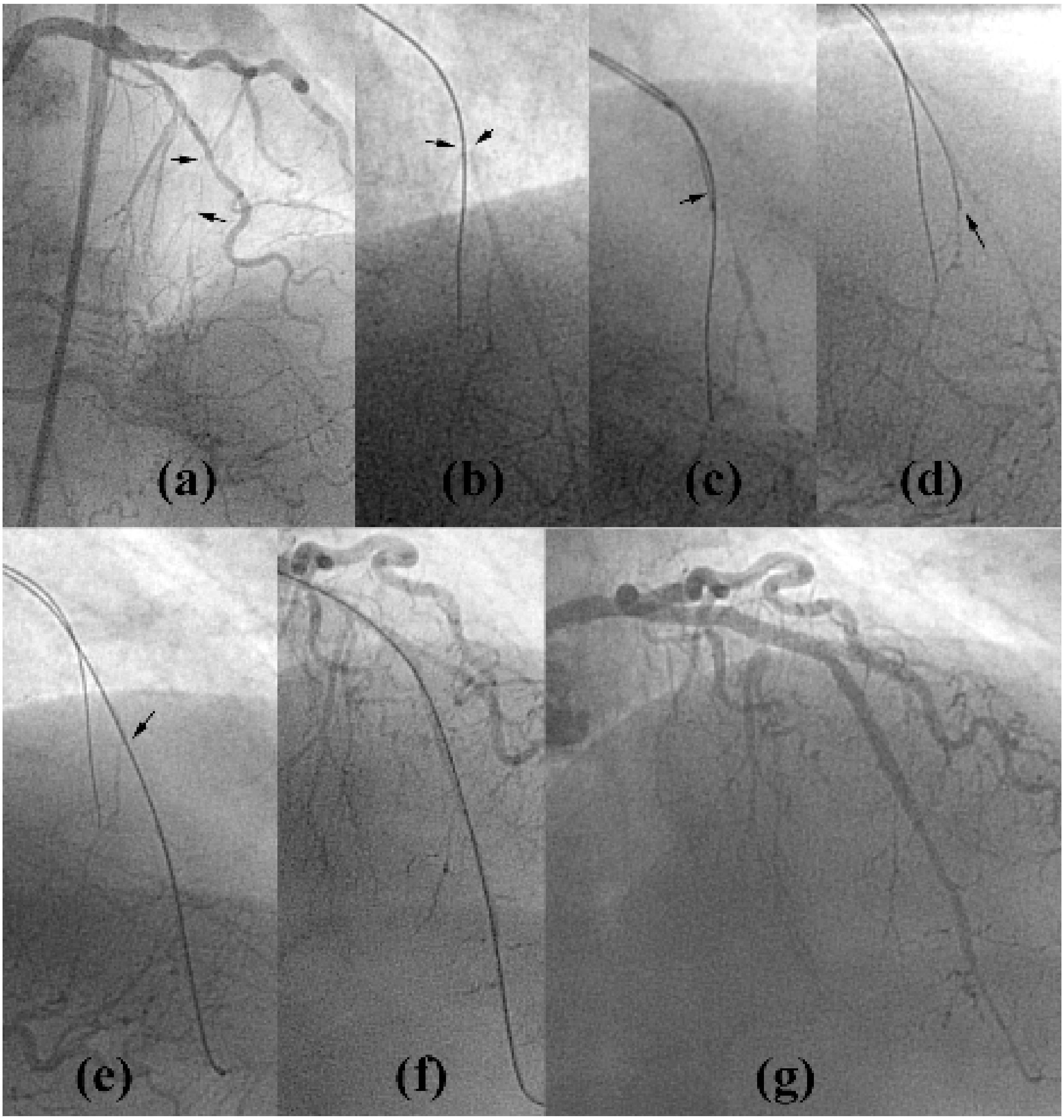


Figure 16: “Steadying” the vessel using parallel wire technique. In this case, getting the wire directly through the target vessel was difficult due to the fact that the distal lumen was very small (a). The wire was then inserted in the septal branch (b), and the target lumen “steadied” using second wire (c). The wire successfully penetrated to the true lumen.

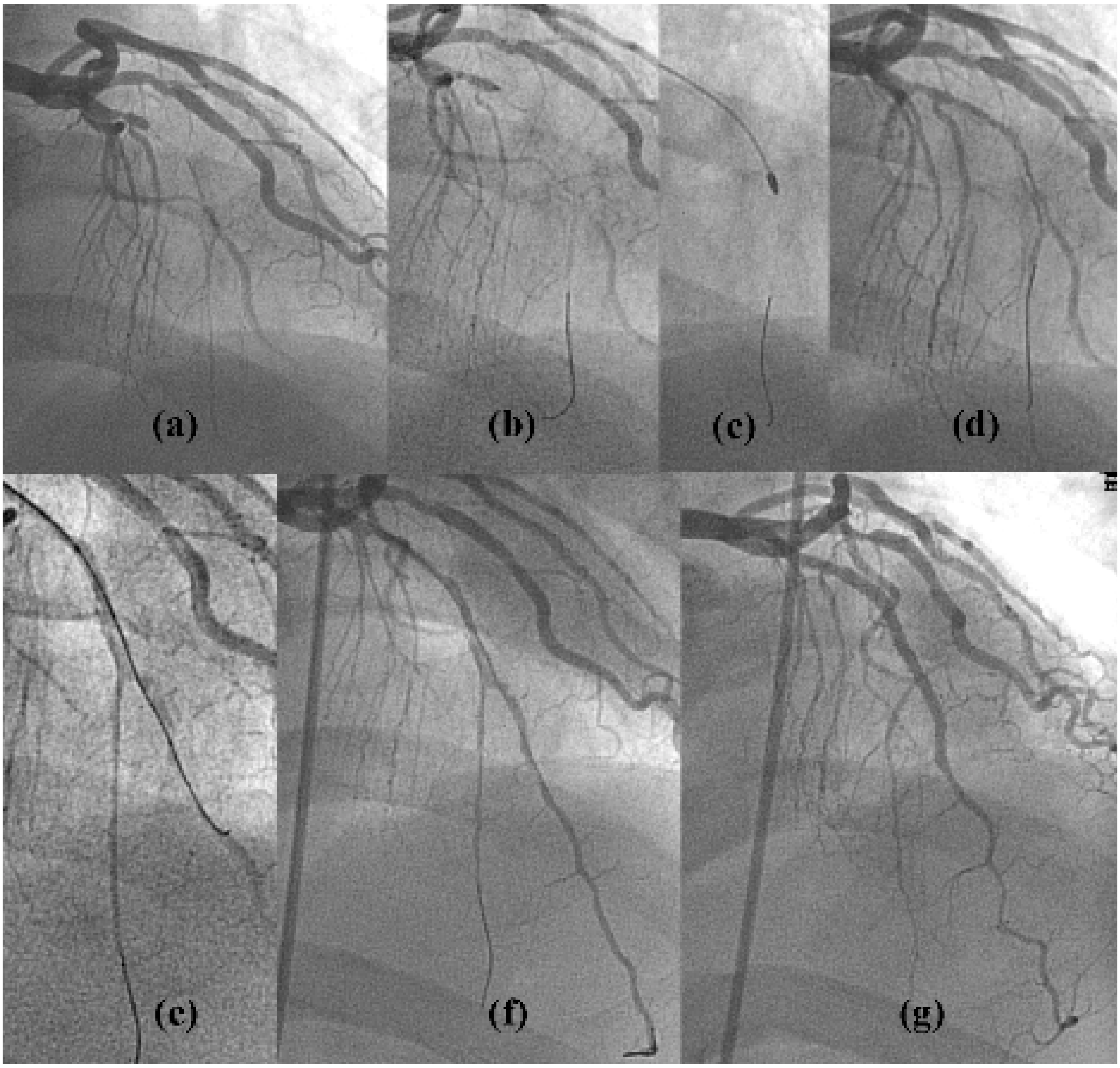
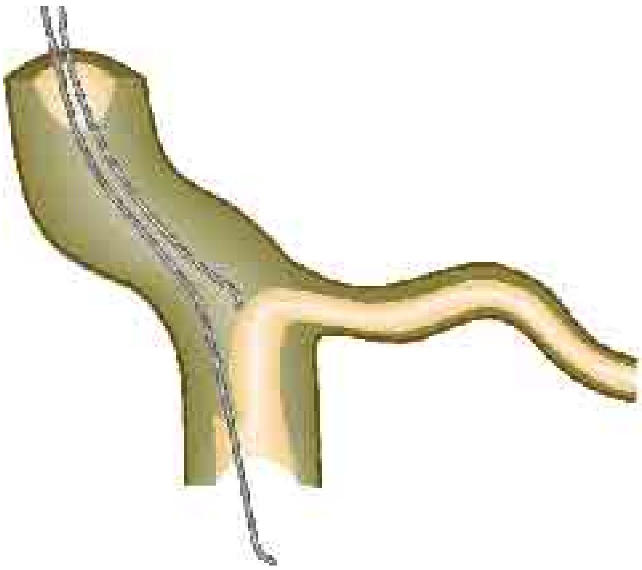


Figure 17: "Steadying" the vessel using parallel wire technique. As the proximal portion of the distal true lumen was too small, the wire created a false lumen through to the septal branch. Rotablation was performed, starting from the occlusion just in front of the septal branch (a-c). Reperfusion was successful (d), but reaching through to the true lumen was still difficult, so the wire was advanced into the septal branch to steady and straighten the vessel, and the distal true lumen successfully reached.

Figure 17-1: If there is a large bifurcating branch at the distal end, the wire may enter the true lumen more distally, as in the figure. In these cases, leave the wire there and using parallel wire technique, get another wire to enter at a more proximal point.



d) Reasons For Using the Parallel Wire Technique

What is this technique for? I have heard some people say that the whole point is to use the first wire to steady the vessel or block any false lumens you make, but that is not what the technique is for. As I have set out, there will be times when you can use the first wire to steady the vessel while you locate a new channel with the second, or to make it easier to get through one of the fibrous caps. That much is clear from the section on parallel wire technique above, [Cf. 3c (ii) (4), “Penetrating the distal fibrous cap”] where I describe advancing the first wire to a side-branch distal to the CTO, and leaving it there while you insert and advance your second wire to the same distal side-branch. What I would like to stress, though, once again, is that the most concrete and beneficial use for this technique is that by leaving the first wire in place as a marker, and then using that to advance a second wire along the same path to the distal true lumen, you can then use multiple angiographic views to confirm the relative positions of the two wires under fluoroscopy. This is what makes the technique so useful, as no other technique gives you such a wealth of information or this much clarity. This should be borne in mind by everyone using the technique.

(1) *Verifying the exact relative positions of the wire-tips*: As with the case shown in Fig. 14, in order to get the second wire through using the first as a marker, obviously, you first need to be able to see the relative positions of the wire tip and the distal true lumen under angiography. With the parallel wire technique, where you are not relying solely on angiography to see what is happening, confirming relative positions is usually easier, even while you are advancing the wire.

(2) *Saving contrast medium*: As you can confirm position without having to do angiography every time, you use less contrast medium.

(3) *Reduced fluoroscopy times*: As you spend less time exchanging wires and trying to cross, fluoroscopy time is reduced.

(4) *Spotting false lumens and avoiding making them any bigger*: Just because you are using the technique does not mean that you will be able to spot false lumens or avoid making them bigger, but at least if you are sure your first wire is still inside the lumen, feeding the second one along the same route should make it less likely that that wire ends up going through the intima.

(5) *Avoiding coronary perforation*: For exactly the same reasons, there is less risk of the second perforating the vessel.

(6) *Higher procedural success rates*: The above points can all be expected to contribute to improved procedural and initial success rates.

e) Using the Parallel Wire Technique at the Distal Fibrous Cap

As I have said, one of the most common reasons why you might find it hard to get through the distal fibrous cap is that the wire may have entered the sub-intima at the distal end of the CTO (Fig. 13-4). Unfortunately, there is no sure way to guarantee that your wire doesn’t end up by mistake in this sub-intimal space. Your chances of successfully finding a path through the distal fibrous cap, once you have wandered into the sub-intimal space, will largely depend on how quickly you can realise what you have done and find a different channel.

There follow some tips for getting through specific types of distal fibrous caps:

(1) *Dome-shaped or convex distal fibrous caps*: Wire position is everything when you are trying to penetrate the distal fibrous cap. If you cannot get through with the first wire, switch to parallel wire technique before you make the false lumen any bigger. The technique is at its most effective with dome-shaped or convex distal caps.

(2) *Tapered or very old occlusions*: Older CTOs are often tapered at the distal end and are very difficult to penetrate, even using the parallel wire technique. If you can get a wire through to the distal end though without going through the intima, using the technique to locate an access point into the distal lumen through the distal cap will be your easiest option.

(3) *Tortuosity at the distal cap*: The section below on side-branch technique deals with this question. These kinds of lesions call for an aggressive strategy combining both parallel wire technique and side-branch technique.

(4) *Reduced sub-intimal dilation*: Without the benefit of IVUS it is very difficult to be absolutely sure but in my experience, judging from angiography done after pre-dilatation with a 1.5mm balloon, use of the parallel wire technique may reduce the incidence of sub-intimal dilation.

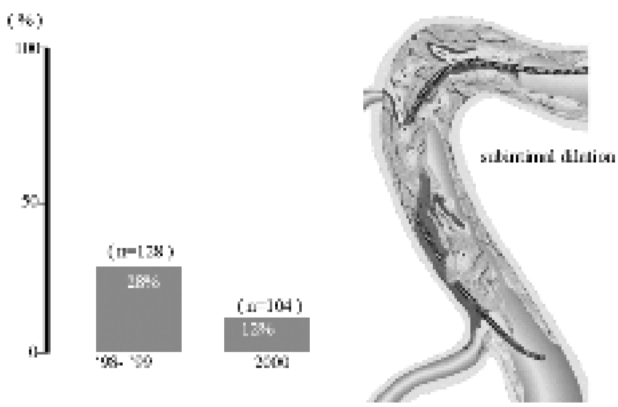


Figure 17-2: Frequency of incidence of sub-intimal dilation, before and after 2000, the year when the aggressive use of the parallel wire technique began.

f) Potential Pitfalls

There are some pitfalls associated with the technique, as will be apparent from what I have already said. I want to emphasize again that mastering the basic skills requires something of a learning curve.

(1) *The learning curve*: I think that practice exchanging wires using the basic parallel wire techniques, outlined here, in 20~30 cases will be sufficient for an experienced interventional cardiologist to master the basic demands of the technique.

(2) *Twisted wires*: From the point of view of safety, you might be tempted to use a softer wire as your second wire, but in actual fact, you will struggle to pull the technique off with a Miracle 3g or intermediate wire. If the wire gets twisted, handling becomes extremely difficult, and even more so with the softer wires. As finding channels is also easier with the stiffer wires, the enhanced safety of the parallel wire technique even with the stiff Conquest or Miracle 12g wires means that aggressive wire selection is both feasible and desirable.

(3) *Technical complexity*: It may also take a bit of time to get used to having two wires in play at the same time.

5. Special Wire Operations

1)Side-branch Technique: this technique has two broad applications

(1) If at the end portion of the CTO, there is more than a certain angle between the way the wire is going and the true lumen, you will often find that it is very hard to get the wire along the true lumen. It will also be quite easy to create a false lumen around the true lumen and generally make things more difficult for yourself. In these cases, if there is a side-branch forking out from the CTO's distal portion, try from the beginning to feed the wire into the side-branch through its ostium. This is actually the ideal scenario for side-branch technique. You pass the wire into the side-branch, restore blood flow in the parent artery by dilating at the side-branch ostium with a 1.5mm balloon, and after changing to a softer wire, pull back out from the side-branch and return to the parent artery. If the wire penetrates too far down the side-branch ostium, even if you manage to restore blood flow by dilating a balloon, you will often find it impossible to get the wire out of the side-branch into the parent artery. For this reason you have to be very careful where the wire goes. If the wire goes just slightly past the side-branch ostium, and if the side-branch is relatively big, using a 1.25mm rotablator burr at the ostium to ablate the obstruction can enable you to get through to the main trunk (Fig. 18). Bear in mind though that rotablator carries a high risk of perforating the vessel, and you should only really attempt it when you can be sure it will be safe. Generally speaking, you should use the parallel wire technique to get your wire into the true lumen in the parent vessel. You also have to be extremely careful that the curvature of the vessel doesn't lead to you compressing the true lumen.

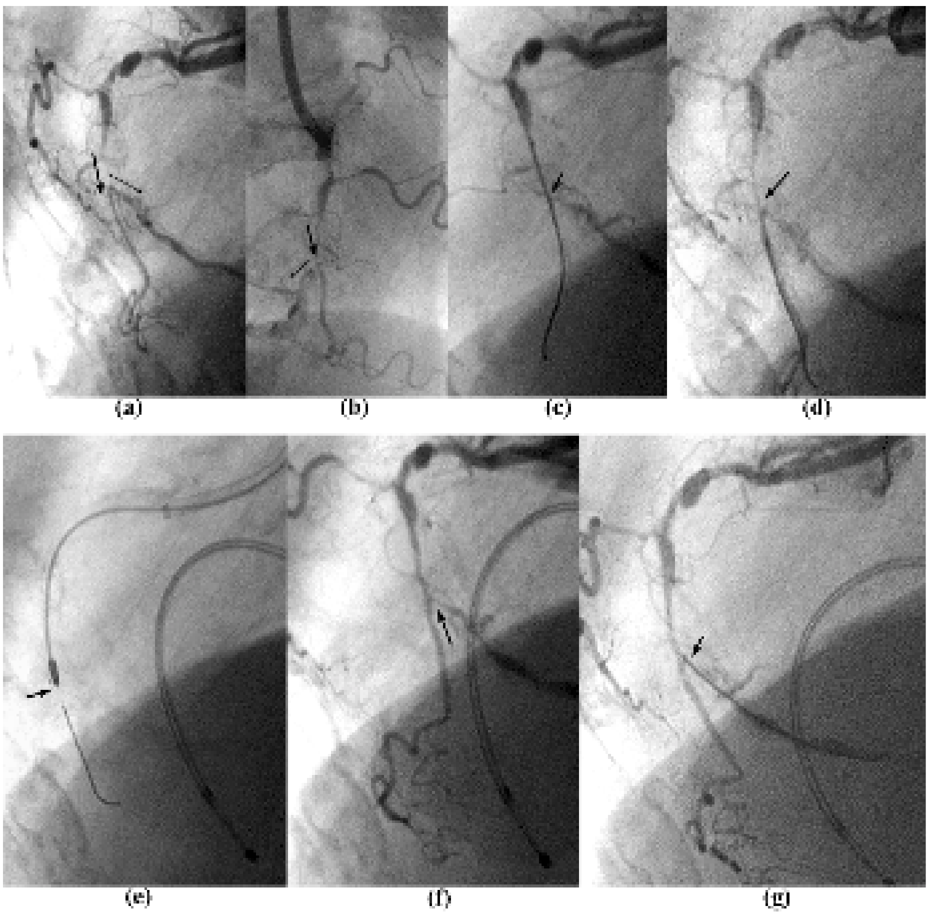


Figure 18: Penetrating the distal fibrous cap using side-branch technique. In this case, wire movement was obstructed by severe calcification in the entire RCA and at the proximal bends. Another bend was also located at the distal end of the CTO with diffuse plaque inside the distal true lumen. Strategy of penetrating via the AM branch ostium was attempted (a, b), but the angiogram (c) revealed that the wire entered from slightly distal to the AM branch ostium. The wire was then switched to a rota-wire (d) and rotablation performed with a 1.25mm burr. We stopped the burr at the ostium of the AM branch to prevent distal vessel perforation (e). After ablating the plaque in the AM branch (f), the wire easily advanced to the main lumen (g).

(2) In cases where you find it very hard to get through the distal fibrous cap, you can pass the wire through to the ostium of any side branch towards the distal portion of the CTO, dilate a 1.5mm balloon there at the ostium and make cracks in the fibrous cap, making it easier for the wire to get through (Figs. 19-21). This strategy does entail the risk of causing dissection around the true lumen, and should only be attempted under the following conditions. Generally, in the LAD, you will have a high chance of success if the septal branch is small and the angle of bifurcation not too high. Success will usually depend on the following conditions; (1) the angle between the direction the wire is lying in and the bifurcating side-branch being less than 90° (Fig. 22); (2) the diameter of the side-branch being small, under 1mm; (3) there being no diffuse plaque build-up about the true lumen in the distal portion of the CTO; (4) from the true lumen to the ostium of the side-branch, the wire must be just to the side of the true lumen in the distal part of the CTO. A situation like that in Fig. 19 should be avoided at all costs; if you realise that the wire is not running very close to the true lumen, you should forget about using a balloon, but opt instead for the parallel wire technique to find a channel right next to the true lumen.

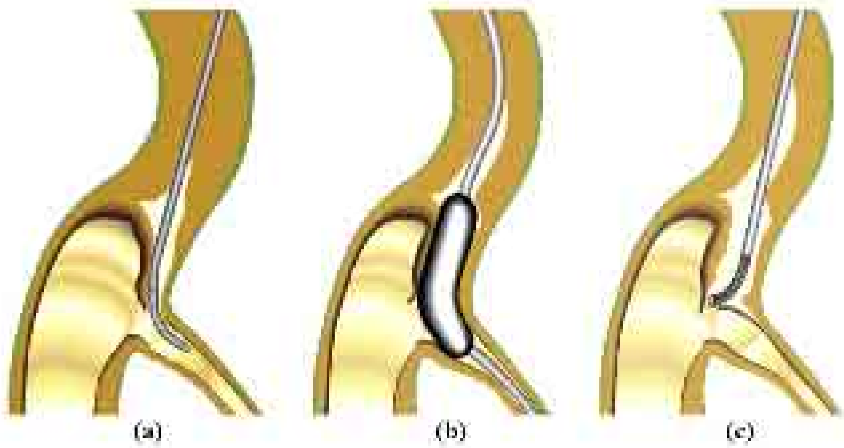


Figure 19: Just like with side-branch technique, pass a wire through the side branch, following closely in the direction of its ostium (a). Reaching the side branch with a stiff wire is quite easy, but make sure you confirm carefully, using multiple angiographic view angles, that the puncture site is not be distal to the ostium. Create a crack at the branch's ostium with a 1.5mm balloon (b). After successful reperfusion, exchange the wire for a softer one and pass it through to the main lumen (c).

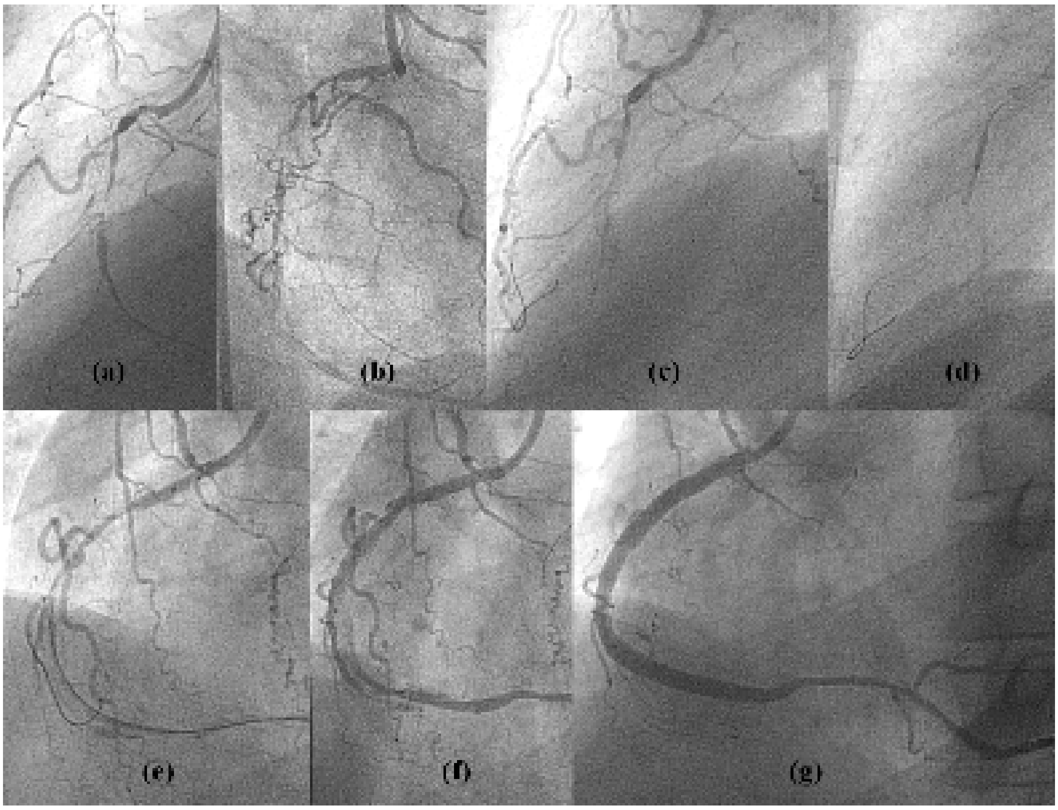


Figure 20: Use of side-branch technique at an RV branch bifurcating from the proximal end of the distal true lumen: A small RV branch bifurcates from the proximal end of the distal true lumen (a). We tried to get the wire to pass to the true lumen, but failed, creating a false lumen, with the wire ending up in the RV branch (c). After dilating the RV branch with 1.5mm balloon, distal blood flow improved slightly and the wire successfully penetrated to the true lumen (e).

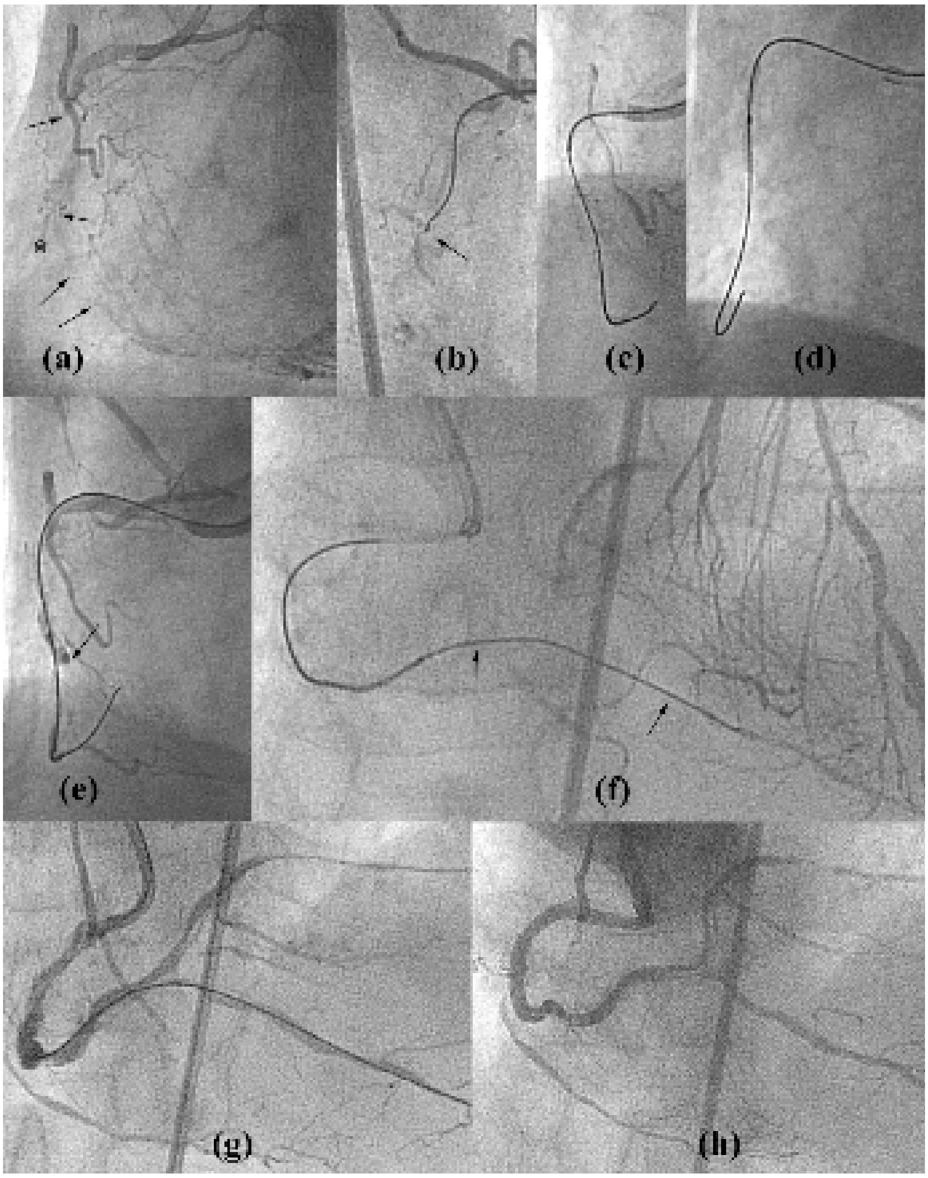


Figure 21: For these tandem CTOs, side-branch technique was used effectively to obtain initial blood flow. The tandem CTO lesions are shown by the three arrows shown in (a). In order to restore blood flow to the proximal CTO, the wire was crossed to the RV branch (marked * in (c)). The proximal CTO was successfully reperfused (e), which enabled the wire to cross through the distal CTO (f).

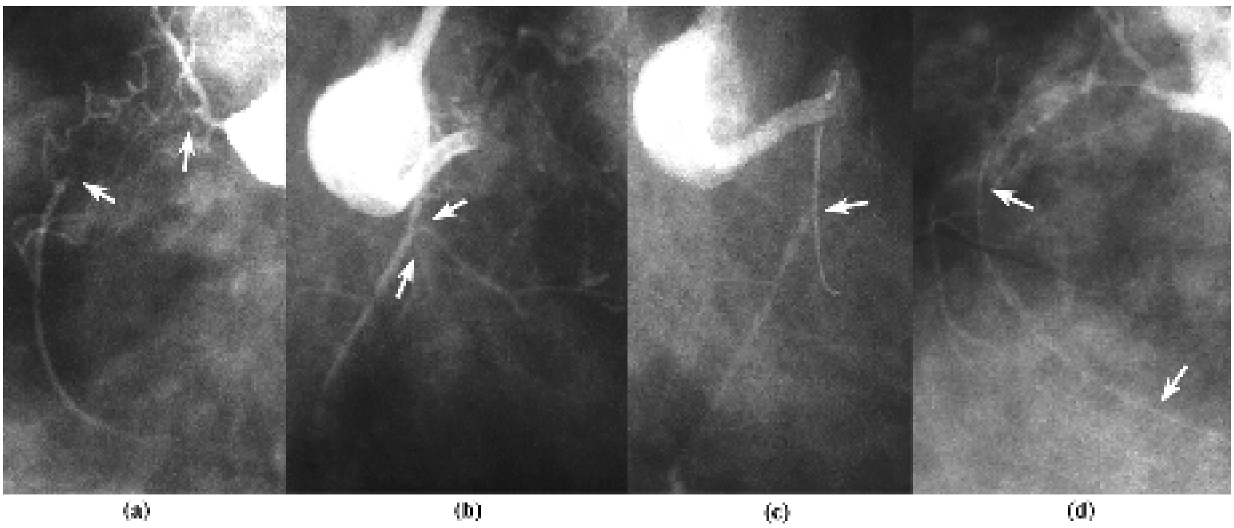


Figure 22: Cases using side-branch technique: The RAO view (b) showed that the right ventricular branch, which was relatively large, bifurcated upwards (b). This branch was not suitable for side-branch technique, but the smaller right ventricular branch bifurcating at the same site was indicated (c). Although a big dissection was detected at the CTO, dilation with 1.5mm balloon achieved successful reperfusion and the wire pen

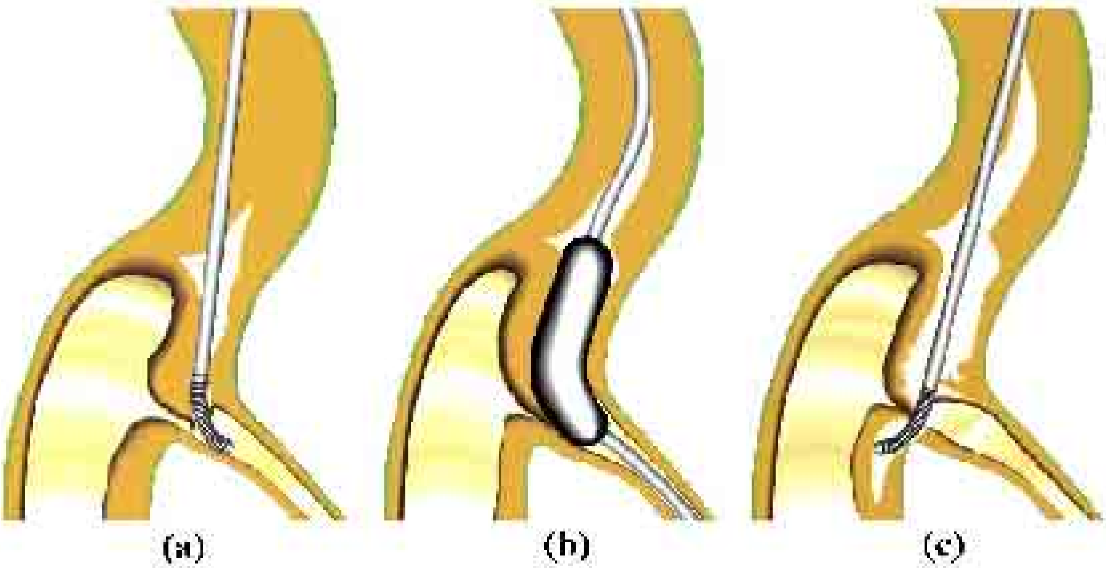


Figure 23: Reasons for failed side-branch technique: If there is thick plaque in the distal true lumen, and a wire strays a long way from the true lumen, the result will often be that it goes through the distal site to the ostium of the side branch and enters the true lumen. If this site is then dilated, reperfusion may be fail, or a distal false lumen may be created by the wire.

2)Kissing Wire Technique: This method is possible when the wire is able to approach from the opposite (downstream) direction (for instance in the presence of large collateral channels without serious tortuosity ~ this will often be a septal branch or some channel connecting with the atrial branch, or an approach from a graft), and involves advancing this wire up to the distal fibrous cap of the CTO and using it as a marker when you pierce the distal cap with the other wire coming from the proximal direction in the conventional way.

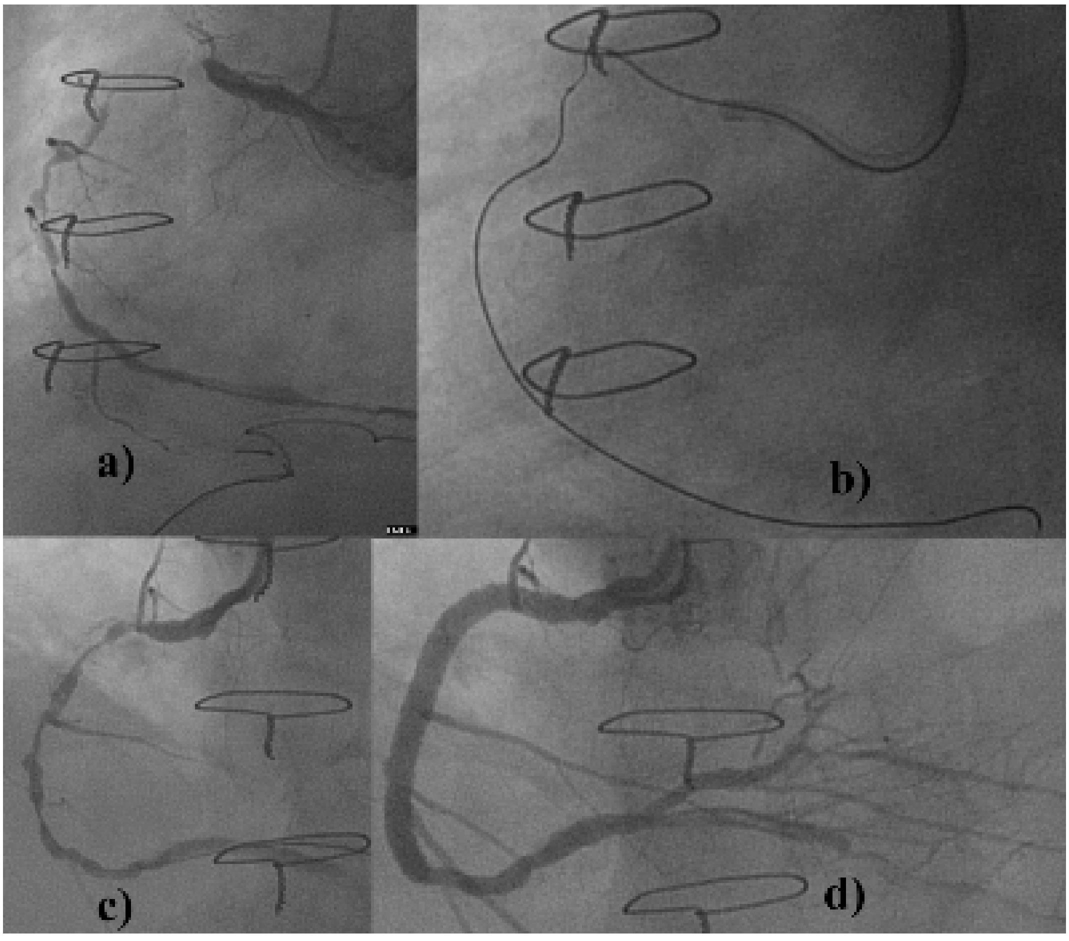


Figure 24: Kissing wire technique in a CTO in an RCA post-CABG: Due to the large vessel diameter and a bend inside the CTO, the wire quickly strayed into the sub-intima, coming from the reverse direction. So we advanced the second wire to the proximal end of the CTO, lined it up with the first wire (b), and were able to cross it (c). The lesion was successfully dilated and stented.

6. **Using IVUS**

It is sometimes hard to get a clear idea from CAG about the tissue at the entry to the proximal edge of a CTO. CTOs are especially hard to assess in the ostial LAD, when the LAD is totally occluded immediately after the bifurcation of a large diagonal branch or septal branch; in the RCA, when the occlusion occurs just after the bifurcation of the right ventricular branch, or ostially at the 4PD or 4PL; or in the LCX straight after the obtuse marginal. In cases like these, you can often confirm the location of the occlusion by inserting an IVUS catheter into a side-branch. IVUS will be no use however when you cannot get the catheter very far into the side-branch, or when there is heavy calcification on the vessel wall at the CTO ostium or side-branch.

One use for IVUS is first to use it to check the CTO ostium, and take a look at the transducer position where you can get a good look at the CTO ostium using CAG. You can then use the transducer position to check on the position of the CTO ostium (Fig. 20). You might find that you can confirm the position of the CTO ostium from longitudinal positions, but that it will be often hard to see very clearly on the axial view. This will not usually be a problem if you use CAG.

Other uses for IVUS include when the wire has re-entered the true lumen from a false lumen, and you want to see where the wire entered, or where exactly where the false lumen was made (especially whether it went through the sub-intima or not). You will need IVUS for this. Similarly, when the wire is in a side-branch, it is very important to establish the location of any plaque build-up at the bifurcation of side-branch and parent vessel, and to know whether rotablator or DCA are needed to pass the wire through, and whether that is safe or not. IVUS is the best way to get this information.

7. **In Closing**

It is important to bear in mind, while you develop your wire handling skills for CTOs, that acquiring the ability to tackle these lesions is a gradual process. To put it another way, the chances of an operator with experience of intervention in less than 100 CTO patients, suddenly being able successfully to tackle a several year-old CTO are rather remote. Of course, the low initial success rate will put some operators off doing CTOs altogether, and the high incidence of complications is another disincentive. In this text, I have not dealt with how to reduce and prevent complications associated with these CTO lesions. CTOs are different from normal lesions in the sense that there is a very low risk of dangerous coronary occlusion, but conversely, there are other complications peculiar to CTOs. A good grounding in normal interventional procedures is a good starting point for getting to grips with these CTO-specific complications.

As you experience of CTOs expands to include more indications, it should first be possible to achieve a success rate of 90% for CTOs three months old or less. For CTOs older than three months, the operator should expect gradually to work up from tapered occlusions to abruptly closing CTOs, from CTOs with no tight bends to moderately tortuous ones, from CTOs less than 20mm long to longer CTOs, and from occlusions up to a year to ones even older than that. And as I said at the beginning, making sure you have a solid grasp of how to read the lesions and a good understanding of all the pitfalls and important details is crucially important before you begin to tackle CTOs.

Finally, I have, in this text, concentrated entirely on wire handling and not the handling of the other devices used in intervention for CTOs. It goes without saying that good CTO technique also requires the operator to possess an greater degree of skill and ability, than even is required for normal intervention, for backing-up the guide catheter, crossing the balloons, implanting stents, and using the rotablator and DCA. All would-be operators would do well to bear this in mind.