PERCUTANEOUS CORONARY INTERVENTION ESSENTIALS

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Chapter 1

A PATIENT-CENTERED APPROACH

Deciding who should have PCI

Who should have percutaneous coronary intervention or PCI?

There are numerous detailed guidelines available to help assist us in this area, including those from the American College of Cardiology (ACC) and the European Society of Cardiology (ESC). ESC guidelines on myocardial revascularization provide a comprehensive overview.

Clinical Presentation

When deciding who should have PCI, the clinical presentation of the patient is one of the most important things to consider.

How is the patient presenting?

Acutely, with an acute coronary syndrome?

- ST elevation myocardial infarction (STEMI)
- Non-ST-elevation myocardial infarction (NSTEMI)
- Unstable angina

Electively, with chronic stable angina?

- Acute coronary syndrome (ACS) presentations are a spectrum of the same underlying pathophysiology (i.e., acute plaque rupture with subsequent thrombus formation and distal embolization).
- Remembering this fact helps you understand how and why they are treated predominantly with aggressive antiplatelet therapy.

The best evidence supporting PCI is in patients presenting with acute coronary syndrome.

PCI in acute coronary syndrome

- Significantly reduces mortality and morbidity
- Significantly reduces the need for future revascularization
- Significantly reduces length of stay in hospital
- Significantly minimizes the subsequent development of heart failure

Remember that other conditions can sometimes mimic ACS presentations with chest pain, ECG changes, and even an elevation in cardiac troponin. Therefore, a good clinical history and examination are essential!

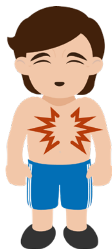
The following differential diagnoses should be excluded

- Acute pericarditis
- Perimyocarditis
- Aortic dissection

The benefit of PCI for stable angina is more contentious. It is certainly recognized as a good treatment for anginal symptoms. Symptoms are a crucially important factor to consider when recommending percutaneous coronary intervention as a treatment strategy.

Chronic stable angina

Does the patient have angina despite optimal medical therapy?



Have they had prior functional testing suggesting ischemia of > 10% of the myocardium?

If so, referral for coronary angiography and then PCI may be appropriate.

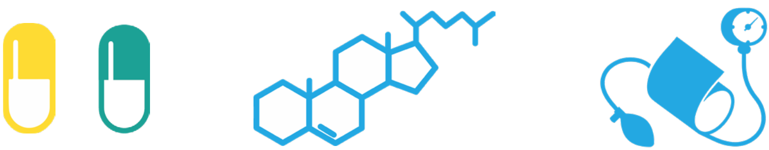
Another benefit of functional or ischemia testing is to target PCI to the appropriate vessel in patients with multivessel disease. This will help maximize the chances of rendering your patient symptom free.

Be wary of symptoms of exertional breathlessness, as the cause of this is often multifactorial.
It may be angina variant (i.e., an atypical clinical presentation of myocardial ischemia where the patient experiences breathlessness due to myocardial dysfunction with stress rather than chest pain). PCI guaranteeing improvement in symptoms for these patients is often difficult.

Optimal medical therapy

Most current guidelines recognize that optimal medical therapy or OMT is indicated in all patients prior to revascularization, including those undergoing percutaneous coronary intervention. But what is OMT?

- Antianginal medication
  - normally we only suggest PCI when angina is refractory to two antianginal drugs used in combination (at maximally tolerated doses)
- Optimal management of high cholesterol
- Optimal management of high blood pressure
- Optimal blood glucose control



These measures are vital for the long-term outcome of your patient, irrespective of whether or not they end up undergoing revascularization.

Antiplatelet therapy

The patient must be able to take a combination of antiplatelet agents, and may have to take these drugs for a minimum of 12 months, if not longer, depending on the clinical presentation and the complexity of the PCI procedure.

Remember we can't take a stent out once it's been implanted so we need to be able to appropriately prevent thrombosis medically.

Think about any planned surgery for other non-cardiac conditions and then assess bleeding risk on platelet therapy before you commence with percutaneous coronary intervention.

When deciding to proceed to PCI

- Consider frailty scoring (particularly in elderly patients)
- Think about quality-of-life issues
- Determine other comorbidities that may make one mode of revascularization potentially more attractive than another (including presence of the following)
  - left ventricular dysfunction
  - diabetes
  - co-existent valvular heart disease
  - co-existent pulmonary disease

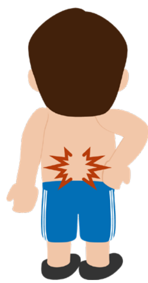
Tip: Consider discussion with your institution's heart team if things are not straightforward or there is more than one option for revascularization!

Finally, although this is a PCI course, remember revascularization can be performed by PCI, coronary artery bypass grafting (CABG) or medical therapy is always an option.

Considering patient-specific factors

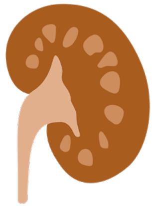
All patients are different! There is a vast spectrum of patient-specific factors present in any one individual. We need to think about a number of these patient-specific factors when recommending PCI for the management of coronary artery disease. I tend to ask myself and my patient a number of questions. This is by no means a comprehensive list but may help you think like an interventional cardiologist!

- What are the patient's wishes? Do they desire and agree to undergo the procedure you are recommending?
- Can they cooperate with the procedure? Can they lie flat? Do they have problems with their back? (Never underestimate how challenging and stressful a procedure can be if midway through a complex PCI the patient decides they cannot lie flat or still for one minute longer!)
- Does the patient have breathlessness or heart failure that would make lying flat for an hour or more difficult?



- Have we formally assessed frailty? (e.g., using the Edmonton score)
- Have they had previous severe bleeding? (e.g., GI or intracranial hemorrhage)
- Have they had a formal score to assess their bleeding risk?

- Is there a known allergy or previous intolerance to antiplatelet agents?
- Does the patient have normal renal function?
- Do they have any pre-existing hematological issues with their platelet count?
- What is the risk to this patient in not having a revascularization procedure? How does that compare to their bleeding risk if they do?



- Have we had a detailed discussion with the patient about the potential risk-benefit balance?
- Are there any other clinical requirements for additional formal anticoagulation (e.g., atrial fibrillation)?
- What is the thromboembolic risk prevention required for their atrial fibrillation, in addition to the antiplatelet therapy required for coronary revascularization with PCI and stents?

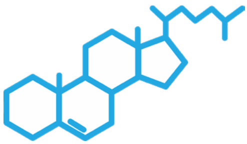
- Does the patient have a mechanical heart valve in situ requiring warfarin therapy?
- Is there any history of thromboembolic disease such as pulmonary embolus or deep vein thrombosis, which may mandate formal anticoagulant therapy with warfarin?
- Do they have other comorbidities (e.g., renal dysfunction, diabetes, valvular heart disease or left ventricular impairment)?
- Are they planning important non-cardiac surgery?
- How shall we decide the best mode of revascularization for patients with multivessel coronary artery disease? (e.g., SYNTAX score for PCI or EuroSCORE for surgery)
- Consider functional ischemia testing to decide which lesions may be causing ischemia in that particular patient. Target the strategy to get the greatest symptomatic benefit for the patient.
- Assess myocardial viability to determine if the coronary arteries are totally occluded? The patient won't benefit if the occluded artery supplies an area of full thickness myocardial infarction with no reversible ischemia but they will still be exposed to the risk of a PCI procedure.
- If required, has the case been discussed with the heart team?

Remember there is more than just the coronary anatomy and the technicalities of the procedure when we are considering percutaneous coronary intervention in any one patient.

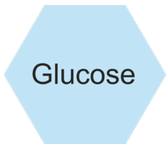
Administering periprocedural medications

It is essential to ensure the patient is on the correct medication before they undergo a PCI procedure.

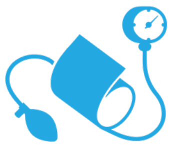
Antianginal therapy



lipid profile



blood glucose



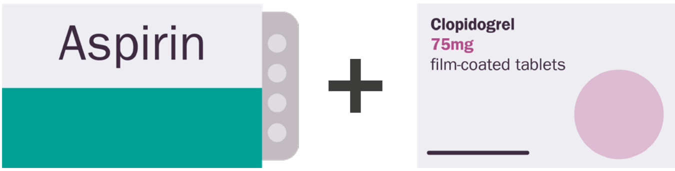
blood pressure

It is important to address the patient's lipid profile, blood glucose, and blood pressure to manage their current and also future cardiovascular risk. It will also have the additional benefit of reducing the risk of progressive coronary artery disease and need for future revascularization.

In addition, there is some evidence to suggest that high intensity statin therapy before PCI may reduce the complication rates of PCI related procedures, although the mechanism of this is poorly understood.

Antiplatelet therapy

This is crucial when considering PCI. For patients with chronic stable angina, undergoing elective PCI, most guidelines recommend the following therapy.



Aspirin and clopidogrel

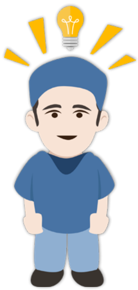
In patients with acute coronary syndromes, most guidelines recommend the following therapy.

Aspirin and ticagrelor (or prasugrel)

These agents also have a more rapid onset of action than clopidogrel, which is helpful in time-critical acute coronary syndrome presentations.

Heparin

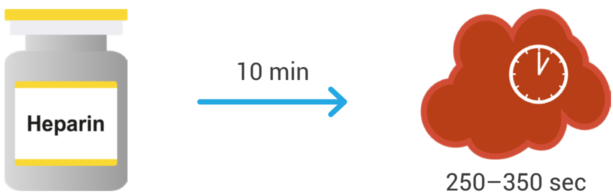
All patients undergoing a percutaneous coronary intervention procedure will require heparin.



A rough rule of thumb for dosing patients is 70–100 units per kilogram!

We determine whether the patient is adequately anticoagulated with heparin based on an activated clotting time (ACT) in the catheterization lab during PCI.

In particularly long or complex procedures, make sure to recheck ACT levels periodically to ensure that the levels remain therapeutic and to decide if another dose of heparin is indicated. Ask someone to set a timer after the initial dose of heparin and remind you at set intervals (e.g., every 30 minutes). Once you start concentrating on a complex case, it is all too easy to lose track of time and forget to check the clotting time!

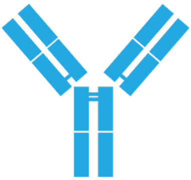


Aim for an ACT between 250–350 seconds when taken about ten minutes after heparin administration.

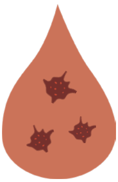
Intravenous antiplatelet agents

As oral antiplatelet therapy becomes more effective, there is a decreased need for supplemental intravenous agents.

The most commonly used intravenous antiplatelet agents in the catheterization lab are glycoprotein 2b/3a receptor antagonists.



Glycoprotein 2b/3a inhibitors can cause significant bleeding complications, particularly in the elderly and those with other comorbidities.



They can cause a significant drop in platelet count and consequent bleeding so check a platelet count shortly after initiation and regularly for the duration of the infusion to ensure that the patient is not becoming thrombocytopenic.

In contemporary clinical practice, glycoprotein 2b/3a receptor antagonists are now mainly reserved for high-risk patients with large amounts of visible thrombus on the angiogram and during the PCI procedure.

Commonly used available agents

- Abciximab (ReoPro)
- Eptifibatide (Integrilin)
- Tirofiban (Aggrastat)

The specific indications for using these agents, dosage, and side-effect profile are available for each on the respective drug information sheets.

Obtaining patient consent

Informed consent is mandatory before a patient undergoes any invasive procedure, including percutaneous coronary intervention.

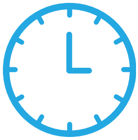
Check the national legal requirements in your country as these may be specific and you need to be fully aware of your responsibilities when obtaining consent.

Anyone obtaining informed consent for a specific procedure should have personal experience performing this procedure or be formally trained on the process in relation to this specific procedure.

The operator performing the interventional procedure should confirm appropriate consent has been taken, reconfirm consent with the patient, and ask if there are any further concerns or questions before proceeding.

- The most important thing is that consent is informed.
- The patient must have the capacity to make informed consent about their own care.

- They must have time to consider their options and time to ask any questions they may have about the procedure.



- They may wish to discuss their options with you as their doctor, another doctor, their relatives or whoever they feel comfortable discussing this with, as these are important healthcare decisions.
- They must be provided with sufficient information, generally in both written and verbal form before they sign and date the consent declaration.
- The patient should feel free to withdraw their consent at any point during the process.

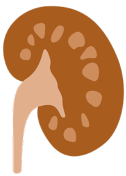
Obviously, in a time-critical procedure such as primary percutaneous coronary intervention (PPCI) for ST segment elevation myocardial infarction (STEMI), consent tends to be very limited due to the clinical situation or clinical condition of the patient.

The patient may be distressed or in pain, and may also often have received opiate analgesia. This may make more detailed discussion or consent difficult at that time. In these situations, verbal assent is often gained prior to the patient undergoing PCI.

Discuss the risks of PCI during consent

- Death
- Periprocedural myocardial infarction
- Bleeding
- Damage to the coronary or peripheral arteries
- Emergency cardiac surgery
- Contrast induced nephropathy (CIN)

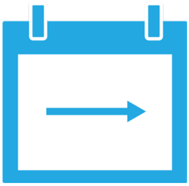
Remember, if the patient starts off with significant impairment of renal function, then the risks of complications from contrast nephropathy are higher. This risk also increases when the patient is taking certain nephrotoxic drugs or is volume depleted (for example when on diuretic therapy for co-existent heart failure).



The risk of contrast induced nephropathy (CIN) needs to be formally scored so that informed consent can be sought given the specific risk. Recognized scoring systems like the Mehran score can be useful in quantifying risk of CIN.

It is always my practice to ensure that patients are happy and are willing to consent freely before undertaking any PCI procedure. The patient should never be hurried into making consent decisions about their treatment.

If the patient has any reservations at any stage it is always best to defer, discuss, and document.



Defer

Discuss

Document

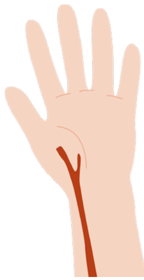
Considering vascular access sites

When deciding on an arterial access site for percutaneous coronary intervention (PCI), a number of factors need to be taken into consideration.

Radial versus femoral access

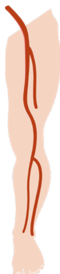
The two most common access sites used are the radial and femoral arteries.

Benefits of radial access



- Usually not affected by atheromatous disease
- Patient ambulation post-procedure
- Faster recovery time
- Radial lounges reduce hospital bed requirements
- Reduced bleeding post-PCI (especially in obese patients and acute coronary syndrome [ACS] presentations)

Benefits of femoral access



- Allows large caliber access for complex PCI
- Usually of large enough size even in patients of small stature / low body weight
- Allows insertion of left ventricular support devices (e.g., intraaortic balloon pump / Impella)
- Not subject to arterial spasm secondary to instrumentation

Right or left radial approach

Right radial artery

- Standard side for radial approach due to catheterization lab setup, operator familiarity, and comfort.
- Limitations in accessing a left internal mammary artery graft in patients who have had coronary artery bypass surgery. Left internal mammary arteries can be intubated via the right radial approach, although this requires a greater degree of operator experience and can be technically challenging.

Left radial artery

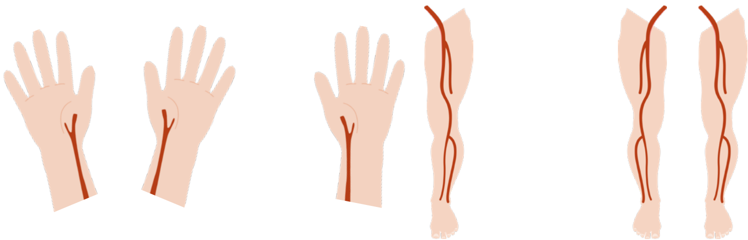
- Most often performed by leaning over the patient from the right side, often because the catheterization lab is setup to work in this way.
- Left arm can be positioned across the patient to allow easier access and supported in position by an arm board and extra pillows.
- Can lengthen the time of the procedure and increase the dose of radiation to the patient and the operator.
- Has been associated with possible increased risk of cerebrovascular embolic events, which may be due to instrumentation of the aortic arch across the head and neck vessels, so extra care and diligence is required.
- Challenging in certain patients, particularly those with significant central obesity, physically making reaching across the patient from the right side difficult.
- Can lead to discomfort for the operator in terms of shoulder and back pain if performing a prolonged or complex procedure or multiple procedures from this route.

Multisite access

Multisite access is occasionally used, usually in PCI of chronic total occlusions (CTO), to visualize retrograde filling of the CTO via one catheter, while a second guide catheter from a different access site is used to perform the procedure itself.

For multisite access (arterial sites utilized)

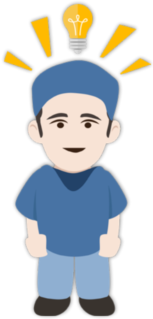
- One left and one right radial artery
- One radial and one femoral artery
- Bilateral femoral artery access



Multisite access is necessary if the patient requires left ventricular support during a PCI procedure with an intraaortic balloon pump (IABP) or left ventricular support device (e.g., Impella).

PCI operators must be able to really comfortably use both radial and femoral approaches.

Here is a brief discussion of other options for arterial access.



- Brachial arterial access is now used extremely infrequently given the advent of radial approach access. (I haven't seen it used for nearly two decades).
- Ulnar access (often straighter and less prone to spasm than the radial artery but higher risk of issues with median nerve damage and bleeding than radial access).
- Distal radial artery access can be used for PCI and is gaining popularity due to the following benefits.
  - even lower bleeding risks than radial access
  - greater patency post-PCI
  - greater patient comfort
  - easier left radial position for operator as the arm can usually be brought further across the patient
  - currently used less frequently than standard radial approach for PCI by most operators

Chapter 2

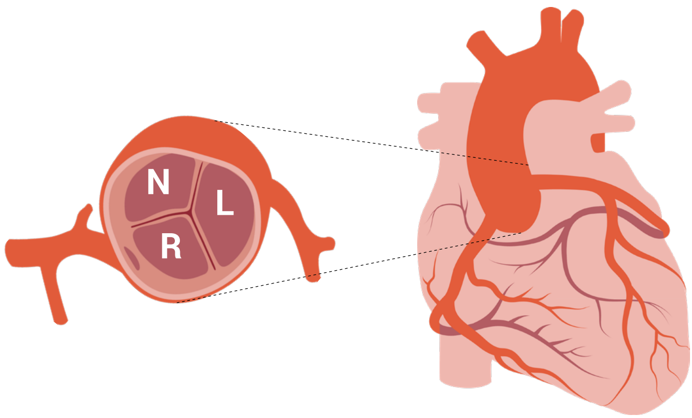
GETTING BACK TO BASICS

Reviewing coronary anatomy

I suggest you review the Coronary Angiography Essentials course before starting this one to refresh your memory on the anatomy of the coronary arteries.

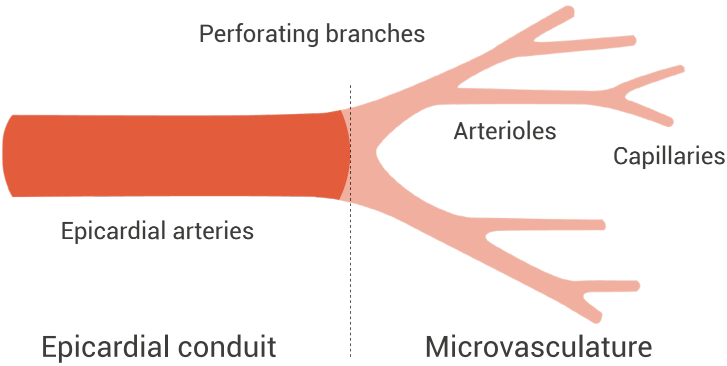
Coronary arteries originate from the aortic root, just above the aortic valve from the sinuses of Valsalva.

- The right coronary artery usually originates anteriorly from the right coronary cusp.
- The left coronary artery originates from the left coronary cusp.
- Remember, the third cusp is referred to as the noncoronary cusp as it is not associated with any coronary artery.



The coronary arteries are epicardial, which is important to be aware of if there are complications of percutaneous coronary intervention (PCI), such as perforation.

During coronary angiography and PCI we are mainly concerned with the epicardial arteries, which measure down to 0.5 mm. We cannot really see the microvasculature or perforating branches, which are comprised of arterioles (400–100 microns) and capillaries (less than 20 microns), as these are below the resolution of coronary angiography.

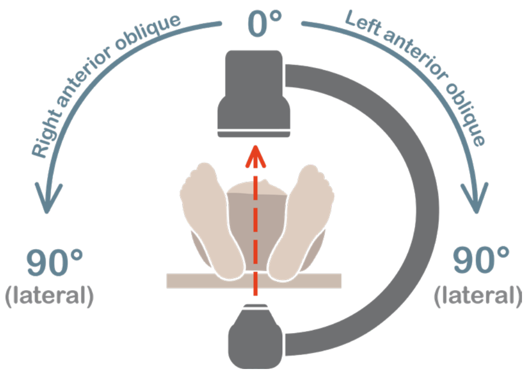


Although we can't stent the microvascular vessels, they are an incredibly important part of the functional assessment of coronary stenoses in the catheterization lab, and can be subject to the consequences of PCI performed in larger upstream vessels. Their role in physiologic assessment and complications of PCI (such as no-reflow) is also very important.

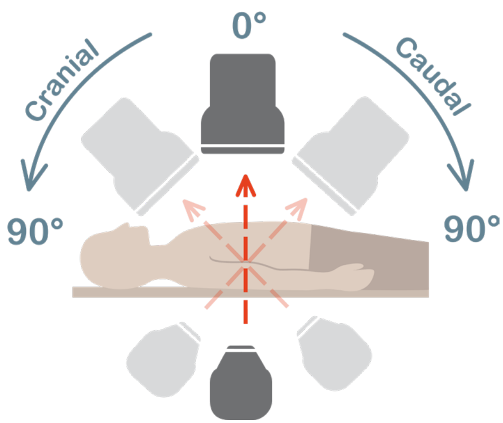
Image intensifier

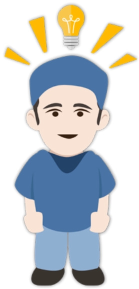
Image intensifier position is described in two planes.

- Lateral movement is described in degrees of angulation from 0 to 90 degrees, toward the right and left of the patient.



- Cranial-caudal motion, literally head to tail, is the other plane, described in degrees from the center point of 0 degrees. Remember cranial-caudal positioning of the image intensifier is limited physically by both the patient and the table.

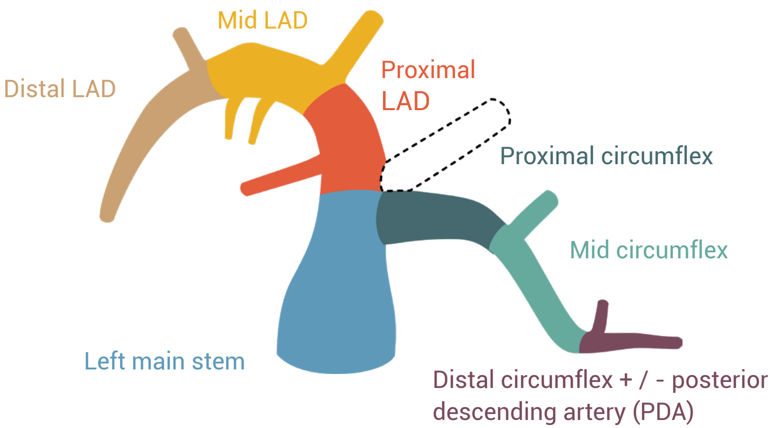




As noted previously, I would suggest reviewing the Coronary Angiography Essentials course before proceeding with this lesson if you are not familiar with basic coronary anatomy. It is imperative that clinicians know how to describe the segments of the coronary arteries so we can describe which segments are diseased, and as such, exactly where we are considering intervening.

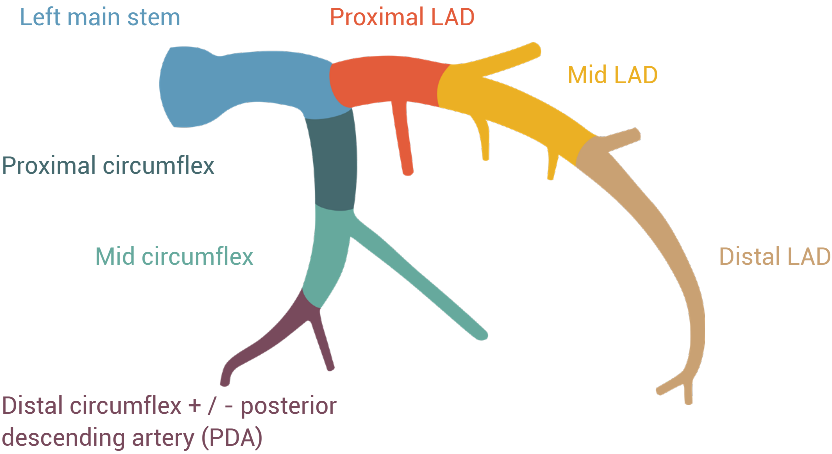
Left coronary artery—standard views

Left anterior oblique (LAO) caudal (spider) view

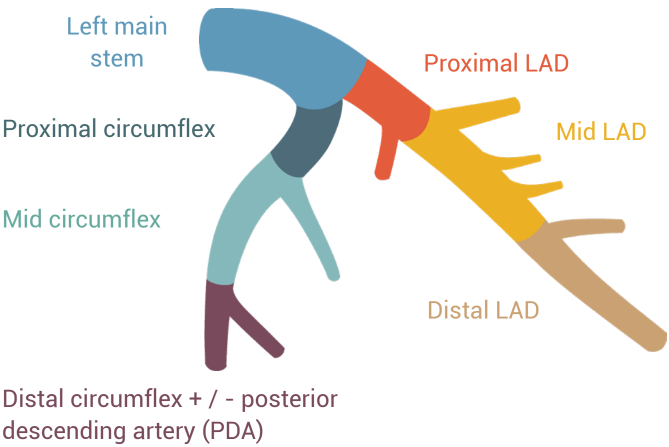


This is the left anterior oblique (LAO) caudal or spider view of the left coronary artery. It is good for the ostial and mid left coronary artery and also the proximal circumflex vessel, which is seen in profile in this view. The dotted structure is an intermediate artery or ramus intermedius.

Right anterior oblique (RAO) caudal view

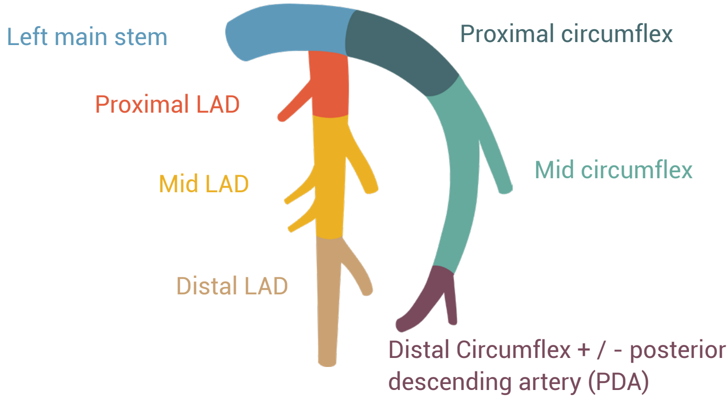


Right anterior oblique (RAO) cranial view



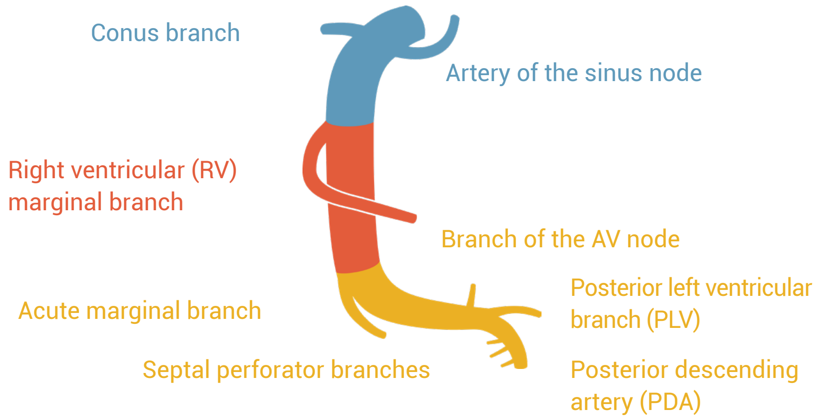
This is a right anterior oblique cranial view of the left coronary artery. It is a useful view for opening up or elongating the left anterior descending (LAD) artery to study disease in this vessel.

Left anterior oblique (LAO) cranial view

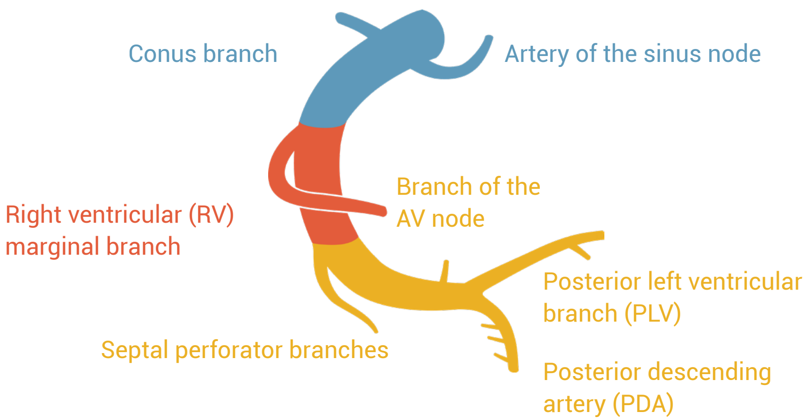


Right coronary artery—standard views

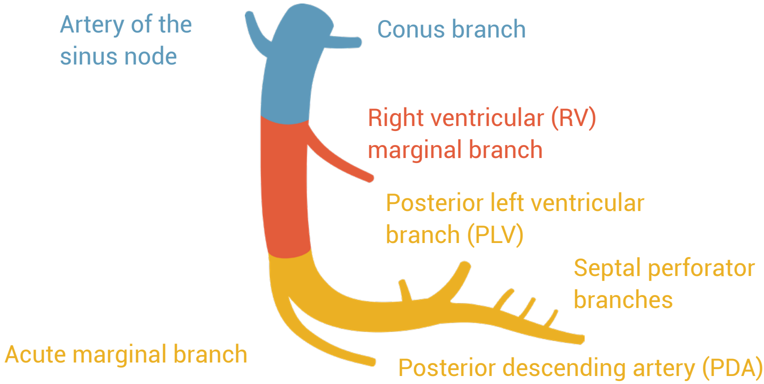
Left anterior oblique (LAO) 40°



Left anterior oblique (LAO) 40°, cranial 25°



Right anterior oblique (RAO) 30°



Blocking flow in the conus branch or directly injecting contrast into this branch can cause ventricular fibrillation. From a PCI perspective, the right ventricular marginal branch can often be small but occluding this branch with a stent may cause anterior ST elevation on the 12-lead ECG during the procedure, usually localized to V1 and V2, which is well worth knowing about in advance.

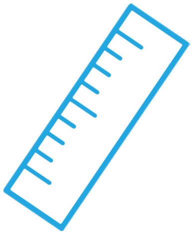
Modified Views

It is useful at this point to introduce the concept of modified views. Sometimes standard reference views do not allow us to make a detailed assessment of the diseased segment of vessel.

When considering percutaneous coronary intervention, one must assess the diseased segment carefully before deciding on a strategy. This often involves viewing the artery in nonstandard or modified views, which may require very steep cranial or caudal angles and sometimes will require a degree of trial and error.

Length of lesion

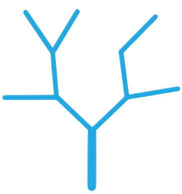
When reviewing a section of diseased vessel, one needs to determine the length of disease present in the vessel to decide upon a PCI strategy. In certain angiographic views, if the artery is moving away from or towards the plane of view, this may foreshorten the segment of vessel, underestimating the true length of disease.



The key message: take multiple and orthogonal views to appropriately assess the diseased component of the vessel and formulate a plan for percutaneous coronary intervention.

Branches

Before planning a PCI, we must ask ourselves—where is the lesion in relation to important branches?



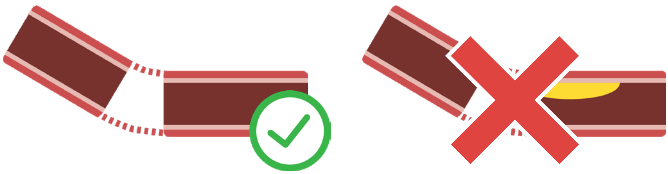
- Are the branches diseased and will they be involved in the PCI strategy?
- Could they be occluded (lost) if we stent the main diseased vessel?

Landing zones

When stenting a vessel, we often stent angiographically normal to normal vessel.

This minimizes the risk of

- Landing edges of stent into visually diseased vessel or plaque
- Causing small edge dissections
- Causing issues with either blood flow into the stent (inflow) or out of the stent (outflow)
- Poor angiographic results



In order to decide on the length of a lesion to stent, and to determine if there is sufficient landing zone for the stent edges, we must ensure adequate (and sometimes modified) views are taken.

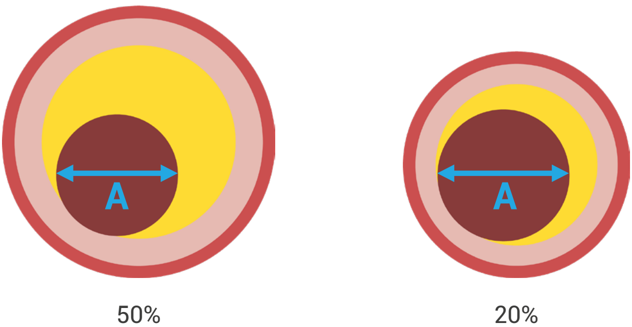
Ultimately, a strong understanding of the anatomy of the coronary vasculature, the standard views used to visualize them, and how to modify these to obtain all the required information are vitally important when performing PCI.

Identifying lesion severity

Assessment of lesion severity is often very subjective when evaluated by the clinician performing angiography. We often tend to eyeball the severity of the stenosis. This is usually reasonably accurate if the lesion is severe, but tends to get more subjective as the stenosis becomes less severe, especially in the mild to moderate range.

Remember that on an angiogram we are merely studying the lumen of the coronary artery!

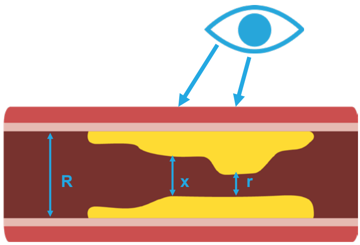
We are therefore only estimating the amount of disease in the coronary artery wall by how much it impinges on the lumen of the vessel.



In this diagram, we can see the lumen is the same size in both vessels (denoted by A), despite one having a 50% plaque burden and one having a 20% plaque burden.

In contrast, other modalities of imaging, such as cardiac CT, assess the proportional burden of disease within the vessel wall, in addition to the impact on the lumen.

When we assess disease based on an angiogram remember that we are also trying to assess the percentage stenosis in reference to the normal non-diseased vessel size.

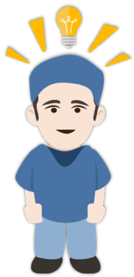


On this diagram, the diameter of the lumen *r* should be expressed as a percentage of the reference vessel diameter where it appears normal *R*, compared to the adjacent diseased segment ***x***. This can be difficult if the vessel is diffusely diseased throughout.

Lesions are usually determined according to the degree to which they reduce the lumen of the coronary artery, expressed as a percentage.

0%	no apparent stenosis
< 25%	minimal stenosis
25–49%	mild stenosis
40–69%	moderate stenosis
70–99%	severe stenosis
100%	complete occlusion

Plaque distribution is often not uniform, and can in some cases be very eccentric. This needs to be considered when determining percentage stenosis. Most lesions are not uniform in cross section. We don't have the luxury to look at them in cross section when performing an angiogram. When looking at them on an angiogram, lesions are always quantified by the most severe view of the stenosis.



Lesions are often underestimated but are never overestimated! This is due to failing to view a vessel in more than one view (or projection) to fully assess the degree of stenosis. Always take multiple orthogonal views when deciding on lesion severity!

Lesion length

We also need to assess the length of the diseased segment and this can be difficult, especially if the vessel is tortuous. As noted earlier, certain angiographic views will foreshorten certain segments of vessel, so choose the best view to assess the segment of disease you are interested in.

One way of doing this in practice is to either use a section of angioplasty guidewire, which is a defined length (on many wires the radio opaque section of the wire is 30 mm) or use a deflated balloon of known length, in the artery, for direct reference.

Lesion classification

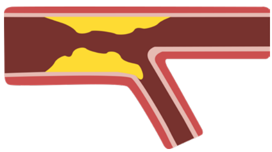
Both the American College of Cardiology and the American Heart Association classify lesions into three main types.

Type A

The diseased segment is usually discrete and less than 10 mm in length. It tends to be smooth and in a non-angulated vessel segment with little or no calcification, no major branching, and no associated thrombus. The lesion is usually easily accessible.

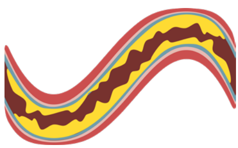
Type B

The diseased segment is usually 10–20 mm in length, moderate tortuosity, and moderately angulated. It may include ostial disease and major branches requiring two guidewires. It also includes lesions with moderate calcification or thrombus.

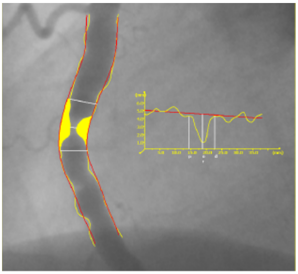


Type C

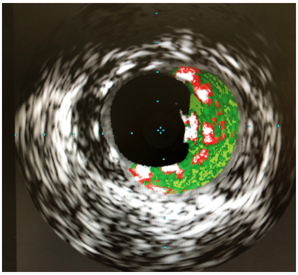
Often long, diffuse disease more than 2 cm long, very tortuous, with inability to protect major side branches. Degenerate vein grafts and chronic total occlusions are included here.



Using adjunct technology



Quantitative coronary analysis (QCA) is prone to artifact if there are branches, bends, overlapping vessels or poor opacification.



Intravascular ultrasound (IVUS) or optical coherence tomography (OCT) is costly but can also look at plaque characteristics.

Pressure wire studies add functional assessment as well as anatomical assessment.

Remember the limitations of angiography—it is just a luminogram! Use it to assess for percentage stenosis, lesion length, and other characteristics. If unsure, consider adding information from an additional in-lab modality, either by intracoronary imaging or functional assessment. Remember you can never have too much information!

Diagnosing special lesion types

Calcification

Calcification is the enemy of PCI!

- Makes it difficult to dilate a lesion with balloons and prevents stent delivery
- May require plaque modification to allow lesion to then be treated with balloon expansion and stents in usual way

Keep an eye out for calcification when performing an angiogram so you are prepared for it if you end up performing a PCI! Always wait a second when acquiring an image before injecting contrast to check for calcification.

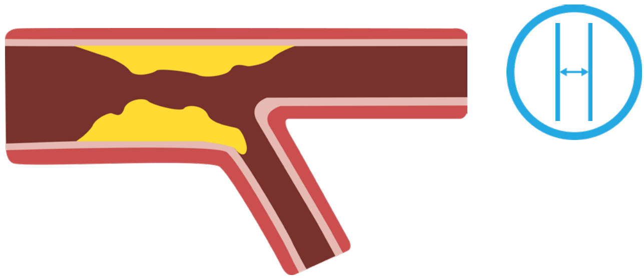
Thrombus

Can be due to

- Underlying disease process (such as acute coronary syndrome)
- Instrumentation
- Incorrect management of the patient's coagulable state (including heparin dosing, dual antiplatelet therapy, and use of Gp2b/3a drugs)

Size mismatch

It is important when assessing lesions to note differences in the size of the vessels, as this may affect therapeutic options. This may particularly be the case where a larger vessel divides or bifurcates into smaller branches, which would limit the use of larger stents during PCI.



In the example above, when considering stenting the main vessel across the branch, you can see there is a size mismatch between the proximal and distal vessel.

When deciding on which diameter stent to take, issues can arise if this size mismatch is large.

- Sizing the stent diameter to the proximal vessel may dissect or rupture the distal artery after the branch.
- Sizing it to the distal vessel would mean it may not be adequately apposed to the vessel wall proximally and be a risk for acute stent thrombosis.

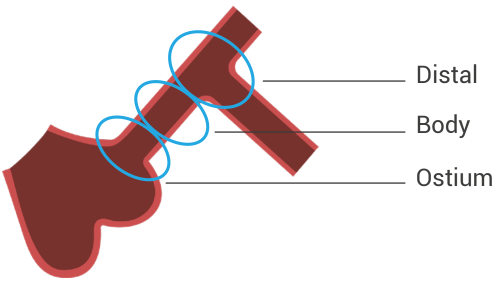
Bifurcations

Stenting a straight piece of artery is relatively easy but when it branches, the whole procedure changes, becoming more complicated. Of note, for PCI operators, coronary atheroma often seems to involve branches (we call them bifurcations), possibly due to shear stress at these points and so percutaneous coronary intervention often involves stenting for bifurcation disease.

Left main stem

Disease of the left main stem (LMS) segment of the left coronary artery can be broken down into three components, depending on location.

- Ostium
- Body
- Distal segment (often at the bifurcation)



Significant LMS disease is associated with increased mortality, improved by surgical revascularization (coronary artery bypass grafting [CABG]) in clinical trials. The left main stem usually provides blood to the largest proportion of the myocardium. Interruption of flow during PCI procedures may cause significant ischemia and consequent myocardial dysfunction.

It is helpful to use intravascular imaging in left main stem PCI to accurately measure the size of the vessel and to ensure optimal results when stenting.

Saphenous vein grafts

Saphenous vein grafts from the legs are frequently used by surgeons during CABG. Redo coronary artery bypass grafting may not be a desirable option if they fail, particularly if the left internal mammary artery (LIMA) is intact and functional, as redo sternotomy risks damaging the LIMA.

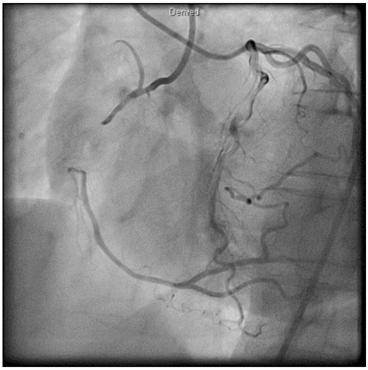
Issues during PCI to these conduits

- Often very large in diameter
- Often have a marked size mismatch between graft and native vessel
- Often filled with thrombotic and atheromatous material
- May be subject to distal embolization and abrupt occlusion (a complication during upstream balloon and stent deployment)

Chronic total occlusion (CTO)

- Total occlusion of the coronary artery
- Has been blocked for a minimum of three months (differentiating it from an acute occlusion)
- Challenging to open (often resulting in failure for PCI operators)
- Often requires specialized equipment and a specific operator skillset (has a higher rate of complications)

The Japanese registry CTO score (J-CTO) is a score given to the complexity of the occlusion and how likely, or unlikely, it is to be opened with PCI.



Depending on the lesion type, a specific approach to PCI may be required. Specialized equipment may be necessary to achieve a good result from PCI, depending on the lesion type. Use all available information, including adjunct imaging modalities to help in planning your PCI.

Making a plan

Some take home points when planning a PCI

- Check indications for angiography and PCI determined by patient history
- Check for any patient specific factors
- Review the angiograms with a view of performing PCI (run through the sequence of performing a straightforward PCI in your head)
- Assess post-PCI for success and any complications

Chapter 3

BASIC TOOLS OF THE TRADE

Selecting a guide catheter

Guide catheters are probably the most important piece of equipment in percutaneous coronary intervention (PCI). Without a guide catheter you cannot take good angiographic images, and will not be able to deliver equipment into the coronary artery to treat the disease. They differ from diagnostic catheters and come in a variety of shapes, sizes, and designs.

All guide catheters have several standard features in common.

- Large internal lumen to allow the passage of equipment into coronary arteries
- Soft non-tapering tips
    - not as potentially traumatic to coronary artery as diagnostic catheters
    - less resistance to equipment passing out the end
- May have side holes to allow blood to enter the coronary artereries even if the guide catheter itself is physically obstructing coronary blood flow (prevents pressure damping)
- Kink resistant due to internal braiding (internal braiding helps maintain lumen patency when catheter passes around bends in systemic arterial circulation)

Shape

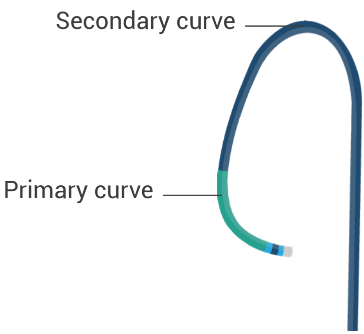
Many different varieties or shapes of guide catheters are commercially available. The shapes are distinguished by a primary and secondary curve. These allow both intubation of the coronary arteries and also provide back wall support.

Primary curve

This is nearest to the tip of the catheter and often is the angulation of the catheter, which allows it to enter the coronary ostium.

Secondary curve

This is further back along the shaft. It helps angulate the catheter from its point of contact with the back wall of the aorta and directs it toward the coronary artery.



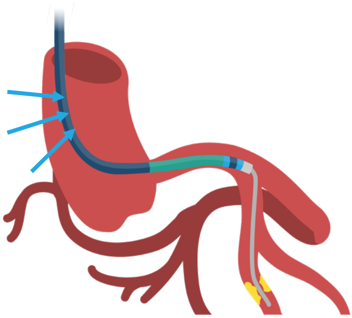
Some catheters, such as extra backup (EBU) or so called geometric guide catheters, have a long smooth curve, rather than two separate curves, to deliver the guide catheter into the coronary artery from the back wall of the aorta. Remember, they all heat up within the body and soften a little, losing some of their curves and support as the case progresses.

Get used to using a few guide catheters regularly, so that you know how they behave in your hands.

Back wall support

- Crucial for success of percutaneous coronary intervention
- Prevents guide from being pushed out of coronary artery when equipment passes out of guide
- More contact with back wall and a more fitted guide equals more support provided
- The primary curve should allow the guide catheter to reach the coronary ostium
- The secondary curve should sit against the aortic back wall opposite the coronary ostium

There are various methods of seating different shaped guides, which are best practiced in the catheter lab, to get a feel for how they behave inside a real patient.



Size

- Guide catheters are available in various external and internal luminal diameters
- Catheters are labeled according to French sizing

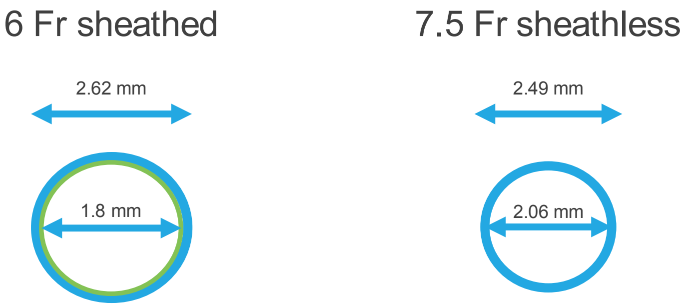
1 French (Fr) = 0.33 mm

- Larger French sizes are usually stiffer and provide more support
- Larger size is not an alternative to having the correct shape and back wall support
- Most PCI equipment will fit down a 6 Fr guide catheter (with the exception of large rota burrs)
- Often need several pieces of equipment down guide catheter at the same time for complex PCI cases and this may cause problems (may not fit or may interact with each other if fit is too tight)
- Peripheral arteries may only allow a maximal French size to pass (for example, an 8 Fr guide catheter may not fit down a small radial artery)—choose your arterial access site carefully if a large guide is needed
- Bigger is not always better
    - can increase complications and risk of guide catheter dissection of coronary artery or systemic arterial trauma
    - small catheters can be inserted deeply into coronary arteries more safely than larger catheters (may not have good back wall support but deeply intubated can provide very good overall backup)
    - deep insertion of small guide catheters requires an experienced operator due to risk of coronary artery dissection or reduction of coronary blood flow

Sheathless guide catheters

- Most guide catheters pass through an arterial sheath
- Guide catheter has to be smaller than sheath
- Usually external diameter of sheath is almost 2 Fr sizes larger than guide catheter

A sheathless guide is a guide catheter that can be inserted without a sheath.



A 7.5 Fr usable guide, therefore, paradoxically has an external or total diameter less than that of a standard 6 Fr guide (which would require almost an 8 Fr external diameter sheath).

Sheathless catheters

- Stiffer to use
- Can result in more guide catheter related dissections
- More challenging to exchange if incorrect in shape or size (as there is no sheath in place)

They are primarily designed for radial not femoral use, as the femoral artery can accommodate very large French size sheaths and guide catheters, due to its size.

Always handle guide catheters carefully!

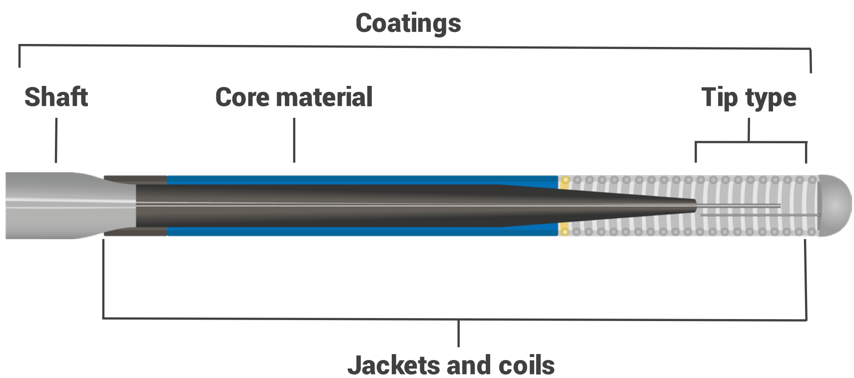
- They are kink resistant but that does not mean they cannot be kinked. If they kink they can be difficult to remove, especially from the radial artery.
- They can result in catastrophic coronary dissection if used too aggressively, which may prove fatal to the patient. Treat them with the greatest respect.

Selecting a guidewire

To deliver a balloon or a stent, apart from a guide catheter, a guidewire is the next essential piece of equipment required. Without being able to insert a guidewire across the lesion, the PCI procedure cannot progress. My advice is to try a few different types and get used to their behavior in your own hands. Every PCI operator has their favorite guidewires.

Guidewires

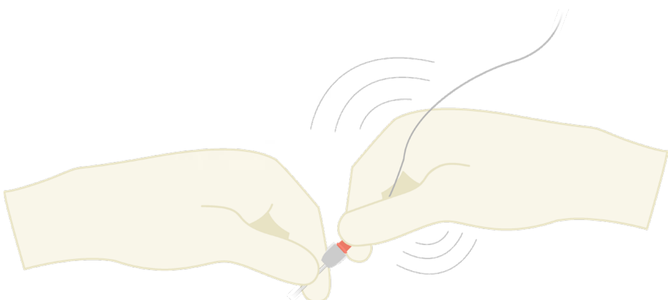
- Highly engineered devices
- Come in many different varieties (all having different properties)
- Can come with pre-shaped tip but most do not (requires operator to shape tip themselves to suit particular coronary anatomy)



To function successfully as a coronary guidewire, a wire must have several features.

- Radio opaque (so you can see it on fluoroscopy)
- Torqueable (i.e., when operator rotates external part of wire—outside of patient—tip will rotate in the same manner)
- Steerable (so you can direct it where you want it to go)
- Flexible (it can negotiate twists and turns within coronary artery)
- Stiff enough to allow guidewire to be pushed down coronary artery (i.e., it is not too floppy)
- Supportive enough for balloon and stent to be delivered along its length
- Provide feedback from the tip—the operator needs to appreciate how the guidewire is behaving inside the patient (i.e., if there is resistance felt it is sensible not to push—often better felt with a coil-tipped guidewire)

Torque devices are not part of the guidewire but are available with every wire. They allow the guidewire to be torqued, especially if slippery (i.e., wires with a hydrophilic coating) and can be useful. They can, however, reduce tactile feedback and some operators, myself included, don't especially like them.



Selecting a balloon

Balloons are a fundamental component of any angioplasty to dilate a stenosis.

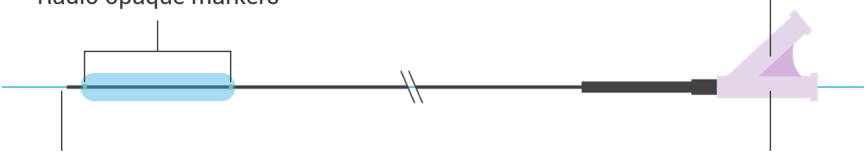
There are a huge variety of balloons from different manufacturers but they generally fall into two main types.

Rapid exchange or monorail balloon system

- One port to connect to the pressure generating device or indeflator
- Separate channel to slide balloon onto guidewire

Over-the-wire (OTW) balloon system

- One port to connect pressure generating device or indeflator
- One port to deliver balloon onto guidewire (guidewire comes out of balloon distal port)



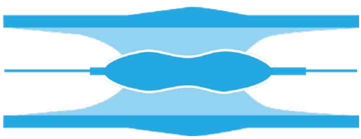
They both have radio opaque markers for better visualization on imaging.

Basic design (all balloons)

- Balloon is wrapped tightly during manufacturing process
- Plastic tip or nose to help balloon cross stenosis and be more deliverable
- Balloon is connected by a long tube (hypotube) to a port (which connects to a high-pressure inflation device known as an indeflator)

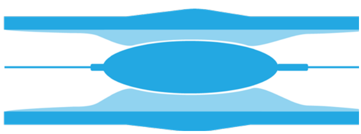
Semi-compliant balloons

- Workhorse balloons
- Relatively low profile to cross tight lesions
- Usually sufficient to pre-dilate a stenosis



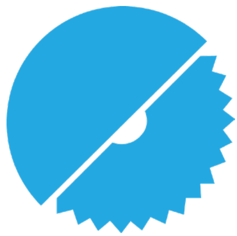
Non-compliant balloons

- Thicker and stronger material
- Useful in dilating a severe stenosis or calcified stenoses
- Used if the lesion will not dilate with a semi-compliant balloon
- Keep their shape relatively well on inflation (at high pressure will only be slightly more inflated than their reference diameter)
- Often used to post-dilate stents (to achieve adequate expansion and apposition against artery wall)
- Often quite bulky and inflexible (sometimes difficult to deliver)



Scoring or cutting balloons

- Specialized balloons
- Linear blades or wire on surface to deliver maximal pressure over very small area (to cut or score a tight or bulky lesion)
- Can be bulky and difficult to deliver as they are often inflexible
- Can sometimes tear or dissect the artery

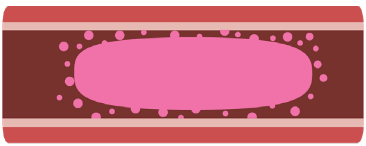


OPN balloons

- Specialized balloons
- Thick double skin allows inflation at very high pressure and to keep their shape
- Can be inflated to 30–40 atmospheres of pressure without rupture
- Very good at dilating difficult lesions or underexpanded stents
- Come with their own special indeflator
- Often bulky (makes delivery challenging)

Drug-eluting balloons (DEB)

- Specialized balloons
- Elute a drug into artery wall surrounding lesion (in attempt to reduce risks of restenosis)
- Can be used where it is not desirable to implant a stent (i.e., in small branch vessel or ostial disease in a branch already stented across)
- Can be used for treating in-stent restenosis
- Require low-pressure prolonged inflation (to give time to elute drug and need to be apposed to vessel wall and intima)
- Often bulky (making them harder to deliver than standard semi-compliant balloons)



Balloons come with a chart identifying two things.

Nominal pressure

The pressure required to inflate the balloon to its specified diameter.

Burst pressure

The pressure beyond which there is a risk the balloon may burst or rupture inside the coronary artery.

Choosing a coronary stent

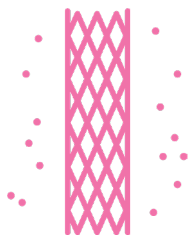
Plain old balloon angioplasty (POBA) can result in

- Abrupt vessel closure
- Restenosis or renarrowing at site of balloon injury

Original stents were bare metal (i.e., had no drug coating). These are still widely available for use. The Achilles heel of these stents was restenosis.

Drug-eluting or coated stents

Coating stents with a drug, which elutes into the artery wall helps prevent restenosis. Drug-eluting stents are commonly referred to as DES. A number of drugs and drug delivery systems are commercially available but conventionally the metal stent is coated with a polymer to which the drug is then attached.



Drug-eluting stent

Polymer coating

Drug coatings and delivery systems are all different and manufacturer specific. The drug used is an agent that interferes with cell cycle division and smooth muscle proliferation, which is fundamental in the mechanism underlying restenosis. Several common agents include paclitaxel, sirolimus, and everolimus.

Drug-coated stents, which are polymer free, have been developed because there is some evidence that it is the polymer itself, or the patient's reaction to it, which causes restenosis. In these drug-coated stents the drug is applied directly to the metal stent.

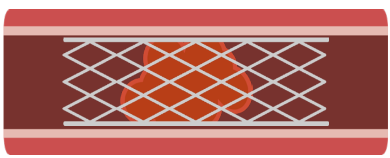
Bioabsorbable stents

There are a number of bioabsorbable stents on the market and currently in development.

Conceptual benefits

- Can scaffold the artery acutely after balloon dilatation
- Can be coated with drugs to stop restenosis
- Can be absorbed and leave nothing behind

These stents can be quite bulky and have to be implanted carefully. There have been some issues with higher than normal in-stent thrombosis rates with these devices, leading to withdrawal from the market. This is possibly due to malapposition of the stent to the artery wall, resulting in large amounts of pro-thrombotic material being left in the lumen during reabsorption and biodegradation. Initially these stents were largely polylactic acid based but others made from absorbable metals, such as magnesium, are in limited use and development.

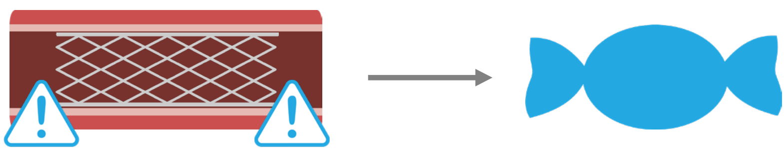


Specialized stents

There are numerous stents on the market designed to deal with bifurcations and are in limited use worldwide. There are also some balloon deliverable self-expanding stents in clinical use, such as the Stentys. While common in peripheral vascular intervention, these self-expanding stents are uncommon in coronary angioplasty. They are implanted differently than ordinary stents. This is purely to mention their existence.

Stent deployment

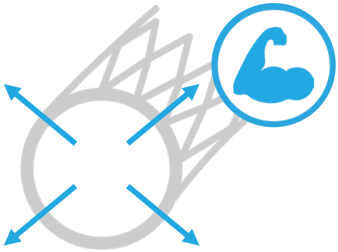
Remember when you deploy a stent, the edges of the balloon hang out of the edges of the stent. While the balloon is uniformly inflating at nominal pressures the edges of the balloon will probably not injure the vessel. If the stent is restricted in its expansion by the underlying lesion, especially if the balloon is overinflated because the stent is restricted, there is a risk of traumatizing the vessel at the stent edges. This results in a significantly increased risk of restenosis at these points, often giving rise to a candy wrapper appearance on subsequent angiography.



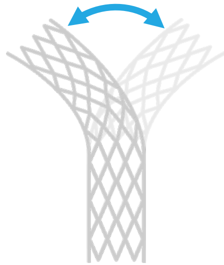
Stent delivery system

- Stents are loaded or crimped onto a semi-compliant balloon, which inflates and leaves the stent in the artery after the balloon is deflated and withdrawn.
- All stents have markers, which are radio opaque and allow the stent to be positioned in the correct place under fluoroscopic guidance.
- Stents tend to be more visible than balloons.
- They are usually made of relatively inert metal alloys, such as chromium but a platinum component can be used to improve visualization, as this is a very radio opaque metal.
- Like balloons, all stents have a chart to document nominal pressure (stent is fully expanded to the diameter stated on the box if not constrained) and a rated burst pressure of the stent balloon.
- There is a huge array of stent designs on the market.
- Stents can be laser cut from single tubes of metal.
- They can be made of wire rings or crowns welded together.
- Stent struts can be of differing thickness, depending on stent manufacturer and design.

Take care when implanting stents as they can be deformed in a longitudinal direction if, for instance, you were to inadvertently push the guiding catheter into a stent placed at the ostium of a vessel.



Radial strength



Longitudinal flexibility

- Design will dictate how large the stent cells are—the connectors and the thickness of the struts will also play a part.
- They are designed to have a strong radial strength (i.e., across their diameter).
- Stents are longitudinally flexible and longitudinally compressible from end to end.
- It will have a maximal diameter to which the stent can be overdilated with a bigger balloon and a point above which it will fracture.

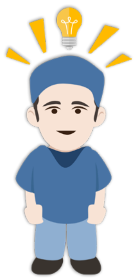
Using miscellaneous kit

We use a number of other pieces of equipment in percutaneous coronary intervention that are neither balloons nor stents.

Aspiration devices

Sometimes we need to remove large amounts of thrombus from the artery. The most basic tool is an aspiration catheter. Several are available on the market. Basically, they are small tubes with a tapered tip, which pass over the guidewire to the area of thrombus. They often have a metal stylet in situ, which helps deliver them to the region of thrombus. They can then be left in or removed while aspiration takes place.

Move slowly through the thrombus and then slowly back—do this gently as there is a risk of pushing the thrombus forward, into the coronary circulation or even losing it down a different vessel or branch, which can have disastrous consequences! If the suction from the syringe runs out and blood is being aspirated, the three-way tap can be closed to retain suction and a spare syringe should be attached on negative to continue aspirating while the three-way tap is open.

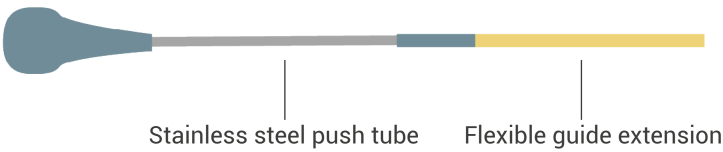


Watch when withdrawing the thrombectomy catheter, if crossing a major branch, that the thrombus does not dislodge and enter an unaffected branch. When withdrawing the aspiration device catheter into the guide, make sure the guide is well engaged in the coronary artery, to minimize the risk of losing the thrombus in the aorta and causing a stroke as it embolizes into the cerebral circulation.

Use caution after removing the aspiration catheter, as it can be bulky and can entrain air into the guide catheter if it is removed too quickly. Let the system bleed back once it has been removed (i.e., open the O-ring or equivalent device and let blood flow out onto a surgical pad outside the patient).

More complicated aspiration devices are available using jets of saline and / or mechanical thrombectomy to remove clots.

Guide catheter extensions

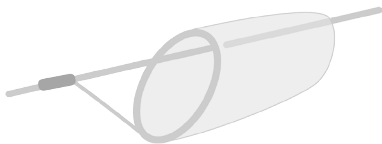


- A guide catheter extension is essentially just a soft extension tube.
- Similar results can be obtained by deeply intubating the guide catheter. Some operators use a smaller guide inside a larger one (i.e., a *mother and child* system).
- Guide extensions typically have a stiffer metal tube. This allows them to be pushed forward and delivered into the coronary artery over a wire, or even better over a balloon catheter system, to prevent trauma.
- If a balloon is inflated in the artery at the stenosis, the guide extension can often be pulled into the vessel using an anchored, inflated balloon to hold everything in place.
- Once in the coronary artery it essentially extends the guide catheter and allows delivery of other stents and balloons through it.
- It's best, if stenting a long segment of artery, to deliver the extension distally and then stent the vessel distal to proximal as it is withdrawn.
- Watch for the patient becoming ischemic if the guide extension is in for any length of time, as it may occlude flow.

Make sure you check an angiogram at the end of the case, to look at the proximal vessel, to ensure no damage to the vessel has occurred with use of the guide extension.

Distal protection devices

In cases subject to embolization of material distally during PCI (e.g., saphenous venous graft PCI), it is sometimes helpful to insert a distal protection device.



- Inserted distally using a guidewire, it requires a sufficiently sized landing zone so it can be opened fully.
- At the end of the PCI procedure a sheath is inserted over the wire and the basket is withdrawn into this sheath before the whole system is removed.
- It can be tricky to use if you are not familiar with them and are best demonstrated in practice.
- A separate guidewire is commonly used for the PCI procedure.

Beware of inadvertently stenting the guidewire of the distal protection device into the wall of the vessel, if you have two guidewires in place, as they can be very challenging to remove if this happens and may require surgical extraction.

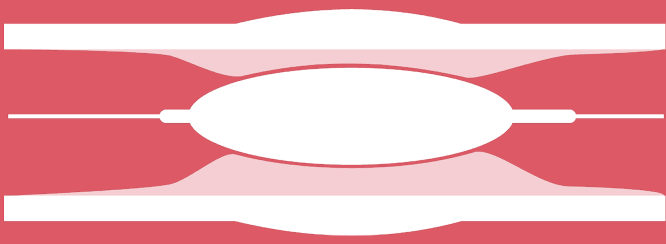
Beware of lots of embolic material blocking the basket, as this may also block flow in the vessel. You may need to act quickly and complete the PCI so that you can then remove the device as soon as possible.

Microcatheters

- Very small caliber catheters
- Can be delivered very distally in coronary artery without causing trauma (leave a channel from the outside of patient to distal coronary circulation)
- Can be used to inject medication distally or exchange out for different guidewires
- Can be useful in getting equipment through very tight stenoses or finding small channels
- Can be used to direct stiffer / sharper wires directly to coronary occlusion without first having to pass through normal vessel (which could cause trauma)

Chapter 4

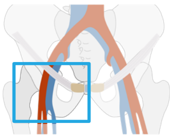
PERFORMING PERCUTANEOUS CORONARY INTERVENTION

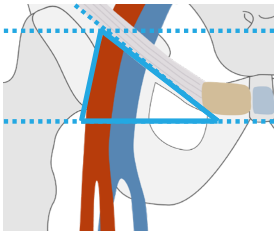


Obtaining femoral artery access

Borders of femoral triangle

- Superiorly by the inguinal ligament
- Laterally by the sartorius muscle
- Medially by the adductor longus muscle





Arteries in this region

- External iliac artery becomes common femoral artery as it passes under inguinal ligament (just distal to inferior epigastric branch) and enters femoral triangle
- Bifurcates into the superficial and deep (or profunda) femoral arteries

Pros and cons of femoral access

Pros

- Usually easy to puncture
- Not associated with spasm
- Usually of good caliber and can ordinarily accommodate size of equipment used for PCI and for other adjunct technology (i.e., intraaortic balloon pumps [IABP] and Impella devices)

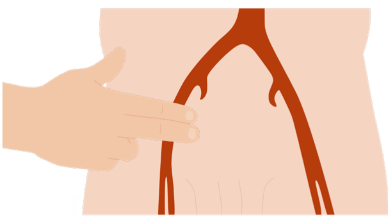
Cons

- Often subject to significant atheromatous disease in patients with cardiovascular (CV) risk factors and associated coronary artery disease (CAD)
- Often deep within the groin depending on the patient's size and build
- Depending on location of puncture may or may not be easily compressible (an artery needs to have tissue behind it—ideally bone to compress against to stop bleeding—unless you plan to use a closure device)
- Can be tortuous or calcified or in association with an abdominal aortic aneurysm (AAA)

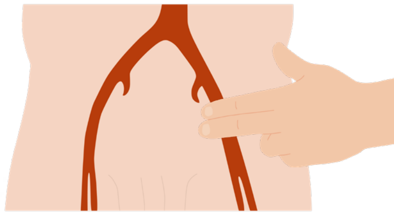
Puncturing the femoral artery

Ideally you should puncture the common femoral artery above the bifurcation and over the medial head of the femur to allow it to be compressed or closed as required.

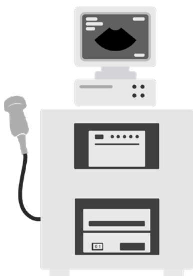
- Maximal pulsation is normally felt where the common femoral artery is compressible against medial head of femur
- Understand limitations of surface anatomy on the skin
- Use radiographical landmarks to help determine the best place to puncture



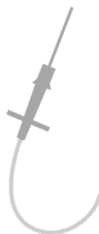
Remember to check the pulse in the other leg (the left common femoral artery) as this may be better. Disease can sometimes be unilateral.



Tip: consider the use of ultrasound and a micropuncture set if the artery is deep or difficult to feel.



Ultrasound



Micropuncture set

Accessing the radial artery

Pros

- Easier mobilization and ambulation post-procedure
- Decreases the requirement for patient beds (due to radial lounges)
- Fewer bleeding complications
- Radial arteries are less likely to be affected by atheromatous disease than femoral arteries

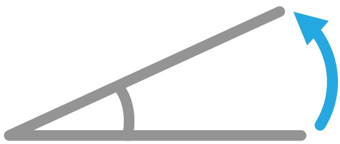
Cons

- Limited size (especially in smaller and female patients)
- Subject to spasm
- May have radial loops to negotiate
- Angulation into aortic root can make coronary intubation difficult
- Left internal mammary artery (LIMA) access difficult from standard right radial artery approach
- Cannot place intraaortic balloon pump and Impella devices

Troubleshooting radial access

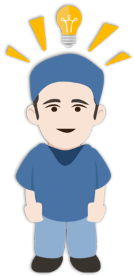
Tips for successful puncture

- Puncture just proximal to the flexor retinaculum, with the needle at about 45 degrees to the skin. Aim to puncture at not too steep an angle, as this can make advancing the guidewire difficult and more likely to enter the intima of the vessel.
- If there is any resistance as the wire exits the needle, the needle should be gently withdrawn and the guidewire advanced again (you may be advancing the wire into the back wall of the vessel).
- If this fails and blood is still coming out of the needle, gently alter the angulation of the tip (e.g., needle bevel) slightly and try again with the guidewire.
- If this fails, vary the angle of the needle in two planes, if it still won't go you may not have punctured the vessel centrally.



- Turn the wire slightly if it advances easily at first then stops—it may be that it has entered a small branch.

Remember the angle of approach affects the chance of successful puncture in the radial artery much more than the femoral artery, as it's a much small diameter vessel.



Never force the wire against resistance—it is not in the correct place if it doesn't go easily.

- Fix the sheath down with a dressing, which should ideally incorporate the side arm of the sheath, to prevent it inadvertently being pulled out.
- It is not necessary to take radial angiograms, unless there is difficultly advancing the wire, as contrast in the radial artery is quite an irritant and can cause the patient some discomfort.
- If the vessel is very tortuous you may need to use a Terumo-coated J-wire, rather than a standard one, to minimize the risk of spasm while negotiating the bends.
- If there are radial loops, a coronary angioplasty wire may be used to steer the wire around these and enter the brachial artery. The wire then should enable the loop to be gently straightened out to allow subsequent passage of the catheter up the arm.

Radial artery spasm

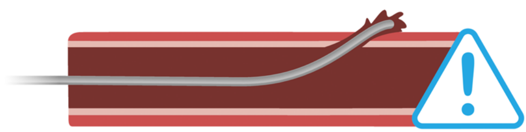
- Common (especially with inexperienced operators)
- Can cause issues with PCI and even angiography
- Provoked by excessive catheter movement or manipulation
- More common in small arteries and in patients who smoke
- Reduced by using an intraarterial anti-spasm cocktail
- Can be reduced by using long sheaths

I use concentrated drugs (nitrate and verapamil) and dilute them in the patient's blood, aspirated into the syringe from the sheath, as this is less of an irritant to the radial artery and also causes less discomfort to the patient.

Balloon tracking

If you cannot advance the guide catheter and you are in the main artery, one way of improving passage is to make the leading edge of the guide catheter smoother. This can be achieved by passing an angioplasty wire through the catheter up the artery and inflating a small angioplasty balloon, just out of the catheter, to essentially produce a smooth structure, to allow the catheter to track up the artery—known as balloon tracking. The distal balloon is positioned just outside the catheter before it is inflated, which then allows the catheter to pass easily up the artery.

Sometimes the J-wire and catheter go from the arm straight into the descending aorta rather than the aortic root (ascending aorta). If this happens, it is best to change to a left anterior oblique (LAO) view and to pull back the wire and catheter, using the catheter to redirect the wire into the root. Sometimes it helps to get the patient to take a deep breath in during this maneuver to straighten out the vessels and facilitate the correct position.



Remember, if you have caused an issue when accessing the radial artery, the patient may only bleed into the arm after the procedure, once the guide catheter is removed. This is due to the relatively smaller diameter of the radial artery, meaning that the large guide catheter may have been covering or sealing the perforation or dissection while in place. The patient is then anticaogulated for the PCI and when the sealing action of the guiding catheter is taken away, at the end of the case, the bleeding may be prompt.

If bleeding occurs, apply firm pressure to tamponade the leak at the puncture site. Fortunately, this is usually very easy to achieve for the radial artery in contrast to the femoral artery. If bleeding continues apply a manual sphygmomanometer cuff proximally and inflate higher than the last recorded systolic blood pressure. This will prevent blood flow into the arm and allow repositioning of pressure hemostasis devices distally. If there has been bleeding or a hematoma has developed, it is useful to elevate the arm in a Bradford sling above the level of the heart.

Following PCI, it is important to check distal pulses, evaluate capillary refill and general perfusion of the tissues, and to monitor arterial waveform noninvasively, using pulse oximetry to confirm good collateral circulation to the hand, while the hemostasis device is in place.

If there is bleeding or hematoma, watch for any signs of compartment syndrome, including pain and skin changes. This is a serious but rare complication following radial arterial access post-PCI. With appropriate and careful monitoring, it can usually be caught and managed early.

Seating the guide catheter

This is the most important part of performing percutaneous coronary intervention.

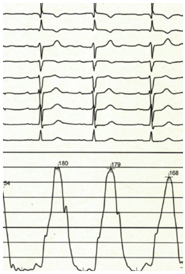
Ask the following questions

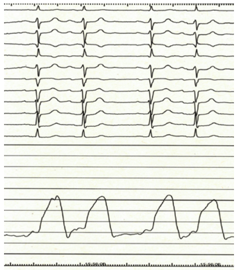
- Is the aortic root normal size, dilated, unfolded or tortuous? (can affect how a certain shaped guide catheter sits)
- Is the guide the correct size for the procedure? (i.e., for straight-forward PCI a 5 Fr guide catheter is fine but not for rotablation and two-stent strategy bifurcation of the left main stem [LMS])
- Is the catheter the correct shape to reach the origin of the artery, while touching the back wall of the aorta?
- Does it sit coaxially in the vessel? Be very careful about the guide catheter digging into the artery and dissecting it, especially before you have had a chance to wire the vessel.

Aim for the best back wall support you can.

Increase support by

- Increasing the size of the guide
- Using a stiffer guide
- Using a smaller guide with deeper engagement





Remember to **always** check the pressure trace **before** you inject contrast to ensure the pressure is not dampened or ventricularized, which may suggest the guide catheter is against the wall or deeply engaged in the vessel.

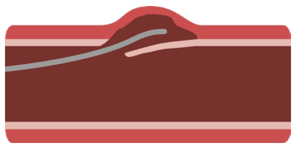
Do not inject contrast if the trace is dampened—you may dissect the vessel! Avoiding this at all costs is always the best policy. Reposition or change the guide catheter carefully until the trace normalizes.

Wiring the lesion

We tend to freeze an angiogram where the lesion is best visualized. This still image is projected onto a second screen next to the live image, as a reference or roadmap for us to follow so we don't need to keep injecting contrast when wiring the vessel.

Wiring a lesion

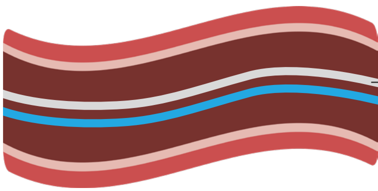
- Apply a primary and secondary curve of varying sizes to enable the guidewire to be steered.
- Make sure the tip of the wire is always free, and travels smoothly, especially when moving through a diseased segment of vessel, to ensure it does not dig into the intima and dissect the vessel, which we also call lifting a flap.



- Position the wire as distally, as is safely possible, in the artery being treated, to provide optimal support for balloons and stents to travel (depending on the complexity of the disease).
- Make sure you watch the distal wire position throughout the case, especially when loading and advancing balloons and stents, as the wire can migrate forward and if it's in a small branch vessel or very distal it may perforate the distal vessel with resultant cardiac tamponade (this may only present once the patient has left the catheterization lab if the perforation is small).

Dealing with tortuous arteries

- Watch for pseudolesions in tortuous vessels straightened out by stiff wires, which can make it difficult to decide what to stent if you are not expecting this or inexperienced.
- Recognize wire bias when traveling around bends, which may cause problems with friction when delivering stents or concerns debulking the vessel (like during rotational atherectomy, as it may direct the atherectomy device preferentially against one side or another, resulting in perforation).
- Consider a second or buddy wire alongside the first guidewire. This can provide significantly more wire straightening and support to enable us to deliver equipment.
- Buddy wires are physically in close relationship to each other and can interact, especially when equipment is being loaded onto the wire and delivered into the artery.



- Stents and balloons can then be delivered on either wire and don't always pass more easily on the stiffer of the two wires, if you have chosen a stiffer second wire, due to the wire bias phenomenon.

- Wires can wrap around each other (wire wrap) or can push one forward when advancing equipment on the other. You must be vigilant and take good care of your wire at all times when performing PCI. When you have two or three wires in place at any one time this can be a real challenge for the inexperienced.
- Try to mark or label your wires so you know which is which and try to keep them separate, when externalized, to avoid them getting twisted together (consider using a spare torque device for this purpose).

Remember to remove the wire or wires that don't have the stent on them before you ultimately deploy your stent. If it was really difficult to deliver the stent, such that you had to use buddy wires, a buddy wire stented into the artery may prove difficult to remove from behind the expanded stent. This is particularly the case in calcified vessels!

Loading a balloon and pre-dilatation

- We usually pre-dilate a lesion or stenosis with a balloon before stenting.
- When we don't pre-dilate but go directly with a stent we call this direct stenting.
- Try to choose a balloon that is the correct size for the vessel. Don't oversize—remember you can always go bigger.
- The idea is to check that the lesion will yield when pre-dilated so it will accept a stent. Conversely, don't use a tiny balloon that won't help you determine if the lesion will yield or not.
- For speed, most operators usually use a monorail rapid exchange balloon, unless you want to swap a wire or inject distally, then an over-the-wire (OTW) balloon may be useful.

Ensure that you receive the balloon size you asked for. Check the packaging and also the size on the balloon hub. Remember you are the one responsible for putting it into the patient. Never assume you have been given the correct size just because you asked for it. Mistakes happen and you must stay vigilant.

Tip: make sure it's the correct wire you are loading onto if using more than one guidewire. Make sure the wire is fixed with one hand while you slide the balloon along so it does not move inside the patient—forward may cause distal vessel wire perforation, backward may pull it completely out of your recently wired vessel.

Ensure good communication with assistants and catheterization lab team. Use clear statements like "I have the wire" or questions like "Do you have the wire?" before you move anything or let go of any equipment.

Wire husbandry is a term often used to describe looking after your wire once it is in the correct place.

Guidewires can be slippery and easily move. Wipe the wire to keep it clean and free of blood and contrast, which may impede the balloon or stent but watch when wiping the wire that you don't pull it out!

Procedural steps

1. Open the hemostatic device or O-ring enough to allow the balloon to be passed easily, then close it quickly to prevent blood loss and to record the pressure trace from the catheter.
   - It is useful to tell lab staff, monitoring pressure traces, when the O-ring is open. I say, "O-ring is open wide". I have to remember they can't see what is going on in the procedure from where they are sitting behind the screens and may wonder why the pressure trace has suddenly disappeared or the pressure has dropped.
   - Several hemostatic devices are commercially available, traditional O-ring, Super ketch, Ketch, and the OK device, to name a few. Get familiar with the one you use regularly.
2. When ready to inflate, hold the indeflator, screw the plunger down or release it to come off negative pressure back to neutral.

3. Inflate in a controlled manner reading off inflation pressures as you go, while simultaneously checking the balloon is expanding on the x-ray image, ensuring that it is still over the lesion and hasn't ruptured.
4. If the balloon inflates too quickly and the lesion does not yield or is rubbery (for example with in-stent restenosis), then as it inflates it may jump forward in the artery—pipping, soaping, or melon seeding.
5. Use your pre-dilatation balloon, when inflated, to a given nominal pressure to gauge the size of the vessel you are treating.
6. Make sure it is inflated uniformly and not restricted by the lesion or vessel. Use this to compare with your reference angiogram to determine the diameter of the vessel in question.
7. Use the deflated balloon to assess the length of a lesion.The balloon has two radio opaque markers at each end. These are obviously at a specified length, depending on the length of the balloon you have chosen. This can act as a ruler for deciding on length of lesion and subsequent choice of stent length.
8. Remember when deflating the balloon normally, pull the indeflator handle back to full negative and watch for air bubbles to come back from the balloon—the bigger the balloon the longer this takes. Watch for a sudden rush of bubbles toward the end of deflation to signify the balloon is fully deflated.
9. The balloon can then be safely removed from the artery, back into the guide catheter.

If the pressure in the balloon suddenly drops or you cannot maintain a constant pressure or you see the balloon deflate or contrast enter the coronary artery on fluoroscopy then it is likely the balloon has ruptured. If this occurs, the sudden bursting (especially if it was at high pressure) can cause vessel perforation and dissection.

- If you suspect balloon rupture, go immediately to full negative with the indeflator and remove the balloon from the artery, checking with an angiogram for any damage caused. Sometimes you will see blood enter the hub of the balloon or the indeflator as you go negative, which confirms the balloon has ruptured.
- If you remain unconvinced, reinflating it on the trolley out of the patient will often confirm the leak.

Selecting a stent

When choosing the correct stent consider

- Diameter
- Length
- Design
- Drug-eluting properties

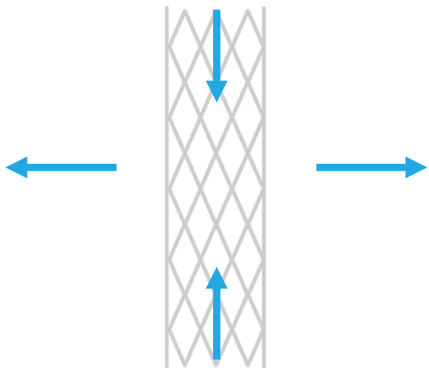
Diameter

- Stent diameter is partly determined by the size of the balloon it is preloaded onto for deployment. Some stents of different diameters are actually just the same metal stent scaffold but preloaded onto different size balloons.
- All stents can be overexpanded once implanted, by taking a larger (usually non-compliant) balloon within them and inflating this to high pressure.
- The amount of overexpansion of any one stent depends on the individual stent and the specific design of the stent. As stents get more and more overexpanded, the scaffolding effect becomes less, the amount of drug eluted into the artery is less, in proportion to the surface area, and the radial strength weakens slightly.
- Eventually the stent will fracture if over expanded too aggressively. Most manufacturers will provide data for their individual stents regarding the maximal size they can be expanded to, depending on the stent platform and design.
- It is very important to make sure that you never insert a stent which is too small for the vessel or leave it grossly under expanded.
- If the stent is too small, or not in contact with the artery wall it can

be very thrombogenic and result in problems with flow, acute stent thrombosis, and subsequently a myocardial infarction or death. Poorly deployed stents of the correct size may also lead to in-stent restenosis.

Length

- Make sure you check your landing zones carefully and try to stent from angiographically normal to normal, if practical. Remember you are trying to ensure complete coverage of the diseased segment and ideally not land the stent in any area of significant plaque burden.
- As stents expand above their nominal stent diameter, they do shorten slightly and the more you keep expanding them, the greater the shortening will be. Take this into account with your choice of length.



- Beware of tortuous vessels, as you may need a much longer stent than you think, to account for the bends.

Design

- Certain stents have particular designs that may be useful depending on the coronary anatomy or lesions you are planning to treat.
- Some have large stent cells, which may be useful if you are stenting across a bifurcation or branch and may need to re-enter the branch through the stent cells.
- Some stents can be more overexpanded than others.
- Some are available in larger sizes, which may be useful if the vessel you are stenting is large (i.e., the left main stem).
- Certain stents are thought to be more deliverable than others. This is a complex interplay between the stent design itself and the delivery system (stent balloon, nose cone, etc.). They may have thinner stent struts and differing joints between rings and as such may be more flexible for use in tortuous vessels or small caliber vessels, where they will take up less physical space in the artery.
- Some stents will come in longer options than others for stenting long segments of disease.
- Some are more visible on x-ray than others due to stent composition of the metal alloy, which may be useful in obese patients where fluoroscopy is limited.
- Some stents may have better clinical trial and registry data than others in the subset of patients that you are treating.

Drug-eluting properties

- The decision to implant a drug-eluting stent over a bare metal stent is also important. Drug-eluting stents reduce risk of in-stent restenosis and are recommended where the rates of restenosis are high (i.e., long lesions over 15 mm and smaller caliber / diameter vessels less than 3 mm).
- Drug-eluting stents were originally much more expensive than bare metal stents and required longer duration of antiplatelet therapy than bare metal stents.
- In reality, drug-eluting stents are now much cheaper than in previous years and most new generation drug-eluting stents (DES) are gaining licenses for short-term dual antiplatelet therapy (DAPT)—down to around a month. Currently, more patients are being treated with drug-eluting stents (DES) than ever before.
- Newer polymer-free drug-coated stents are an alternative and perhaps the best of both worlds, providing a drug for elution to prevent in-stent restenosis (ISR) but often requiring a duration of dual antiplatelet therapy (DAPT) similar to bare metal stents.

Positioning a stent

Check the stent visually yourself before you load it onto the wire.

- Where are the markers in relation to the stent?
- Is there any obvious physical damage to the stent, either due to manufacturing issues or rough handling when removing it from the packaging?

When passing a stent through an O-ring or similar device, make sure it is sufficiently open to allow passage, so no damage occurs to the stent itself, which may then prevent it passing into the vessel or traveling smoothly. Rough or damaged stents may cause significant trauma to the vessel.

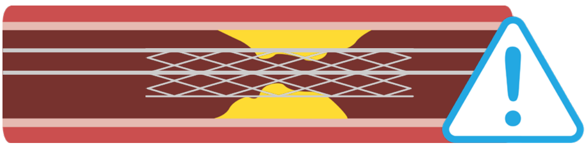
Positioning a stent is not as easy as positioning a balloon. Stents are metal, rough, and bulkier than balloons and there is much more friction when they are advanced.

- Always check the guide catheter is well engaged and supportive.
- Make sure that the guidewire is deployed far enough distally in the artery to offer enough support.
- Position the stent then inject contrast to confirm the appropriate position.
- If the disease is severe and / or the vessel is small, the stent may occlude the vessel. This may prevent any contrast being injected into the vessel to aid positioning.

If this occurs, withdraw the stent until contrast will pass, then inject a small amount of contrast just as you advance the stent to determine position or use a visible proximal branch you can see to help as a landmark.

What if the stent will not pass into the lesion? Stop and re-evaluate!

- Where is the stent getting stuck? It may be that bends in the proximal vessel are hard to negotiate or the significance of more proximal disease has been underestimated.
- If the stent will not cross the lesion itself it is likely that you have not prepared it sufficiently.
- If more support is required to deliver a stent, then consider another option. Adding an additional wire to help deliver the stent may help by providing more support.



Remember to remove the buddy wire from the vessel before you deploy the stent, so as not to trap it in the artery—very important if this is a tortuous or calcified artery.

- If removing a buddy wire, remove the correct wire. Don't remove the guidewire on which the stent is travelling. This is when good wire husbandry and marking is essential so you know which wire is which if you have more than one.

Additional support to deliver stents can also be obtained by use of guide catheter extensions (e.g., GuideLiner and a number of others are commercially available). These can be inserted deeply into the coronary arteries, sometimes even all the way down to the lesion to allow stent delivery, particularly if the proximal vessel is causing a lot of problems due to friction or resistance. Take care as they can cause dissection of the vessel.

Good stent position is the key to delivering good PCI results. Deploying a stent is a permanent decision and once the balloon starts to inflate you are essentially committed to that position.

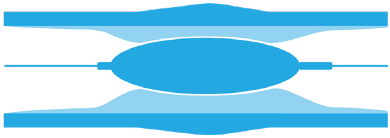
Try to make sure the guide catheter and guidewire are relatively stable and the patient is breathing normally and not taking large variable breaths. We are often talking about disease length in a matter of millimeters and stent movement caused by these factors may result in not covering the lesion fully. We refer to this as a geographical miss.

Deploying a stent and post-dilatation

1. Acquire an image to confirm the stent position for future reference.
2. Go negative on the indeflator (if not already).
3. Deploy under fluoroscopic guidance (counting out the atmospheres of pressure as you inflate to the desired final pressure).
4. Watch the inflation directly for uniformity of stent deployment and for any wasting, where the stent does not expand properly, due to being constricted or restrained by the lesion.

Never attempt to deploy a stent if the lesion seems underprepared. It may be tempting but it is usually the beginning of a nightmare. Once the stent is in place but is underdeployed, the options are limited, with the exception of post-dilatation with a non-compliant balloon. Before the stent is deployed there is the option for further balloon pre-dilatation, cutting balloons, rotational atherectomy or even terminating the procedure and rethinking the options before the point of no return.

The best way to ensure adequate stent expansion and apposition to the vessel wall, is to deploy the stent at a modest pressure and then use a non-compliant balloon of either the same or greater diameter (depending on the desired final size) but of a slightly shorter length than the stent in question.



Non-compliant balloons (NCBs) are thicker skinned and stay the same shape when constrained compared with semi-compliant balloons. Therefore, they can deliver more controlled and evenly distributed pressure to further expand the stent.

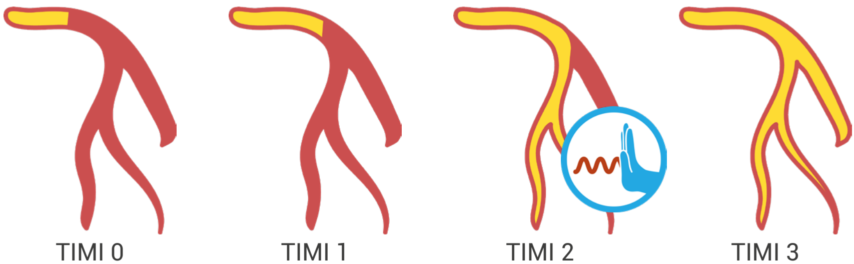
When post-dilating stents, ensure the balloon is visually within the stent before inflating so as not to damage the vessel at the stent edges. This can be confirmed by either taking an enhanced image of the stent (available from most manufacturers on catheterization lab systems) or by acquiring an image of the balloon in the stent, often without contrast.

Assessing success

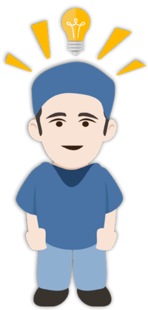
How do you know that you have done a good job?

- How is your patient? It is common to get some mild chest discomfort during PCI. The procedure temporarily occludes flow down the coronary artery, for a period, while the balloon or stent is inflated and induces myocardial ischemia. It stretches the vessel wall and can lead to coronary spasm. There may be distal embolization of thrombotic material from the culprit lesion or occlusion of side branches. Normally, these things will settle quickly as the procedure is completed, however, the patient may require some analgesia and reassurance.
- Worsening chest pain or chest pain that fails to settle, persistent ECG changes, malignant arrhythmia, especially ventricular tachycardia (VT) or ventricular fibrillation (VF) or hemodynamic instability, are indicators that your procedure has been unsuccessful or complications have occurred.
- Check arterial access sites and for occult bleeding, if there is unexplained hemodynamic instability, also check for iatrogenic pericardial effusion due to missed vessel perforation (usually very distal and wire-related). An on-table echo will help exclude pericardial tamponade, assess left ventricular function, and exclude valvular or structural issues simultaneously.

- Check the angiogram in at least two orthogonal views. Assess the flow down the artery and ensure it is the same or better than before the PCI. Use the thrombolysis in myocardial infarction or **TIMI flow score** to determine success, especially in acute lesions.
  This looks at flow down the coronary artery.
  - TIMI 0 is no flow past the lesion
  - TIMI 1 is passing the lesion but not reaching the distal vessel
  - TIMI 2 is delayed flow but reaching the distal vessels
  - TIMI 3 is prompt or normal flow to the distal vessel
- Check expansion of the stent—does it need further post-dilatation?



Have you covered the whole lesion? Has there been prolapse of plaque outside the stented segment? Are there any edge dissections or distal dissections? Are there any filling defects to suggest thrombus?



Use a wide angle lens. Don't just look at the stented part of the artery. Check the guide catheter and ostium of the vessel to ensure there is no guide catheter related trauma. Also, check the distal wire position for migration forward and any evidence of distal vessel wire perforation you may have missed.

If everything looks good angiographically but flow is compromised or you are unsure, consider assessment with intravascular ultrasound (IVUS) or optical coherence tomography (OCT).

- Maybe the stent is not fully expanded but due to eccentricity of the plaque this is difficult to visualize on angiography?
- Maybe the vessel was much bigger than you thought and the stent is undersized for the vessel?
- Maybe there is a dissection at the stent outflow / inflow or disease you have not appreciated?

Imaging resolution is now so advanced that with imaging modalities, such as optical coherence tomography, it is common to see small microdissections at stent edges. It is difficult to know whether these have any clinical relevance or significance for the patient or are just a consequence of improvement in technology (visualizing what normally happens when we deploy a metal scaffold in an artery). If they are small and flow is good we tend to ignore them.

In summary, take a holistic view when assessing the success of your PCI. Check the patient. Check your angiogram. Consider advanced intracoronary imaging if you are still unsure.

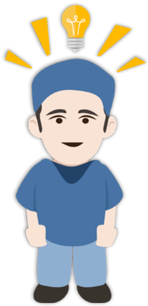
Removing arterial sheaths safely

Radial sheath removal

There are a number of commercially available devices to facilitate this. Usually, they all use a type of band, which compresses the radial artery but does not prevent flow down the ulnar artery; therefore, blood flow to the hand is maintained.

For radial procedures, even when fully anticoagulated the size of the vessel, proximity to the skin, ease of compressibility, and ease of visualizing any bleeding usually means the sheath is removed immediately and manual compression is applied.

Depending on the procedure and size of sheath, the band will normally stay on for a couple of hours before gradually being released, with a confirmation of hemostasis for at least one hour after removal, before the patient is allowed to return home.



Applying compression too distally will not stop bleeding as the arterial puncture site will not be compressed sufficiently. Adequate space to allow ulnar artery flow is confirmed by the person positioning the band.

The sheath is removed and air inflated up to the maximum advised by the manufacturer. Hemostasis is confirmed by no visible bleeding from the puncture site. Gently remove air from the cushion, until it is possible to just feel the return of a pulse, distal to the device. We then check hemostasis again. This method usually allows hemostasis without over aggressively compressing the radial artery, improves radial patency post-procedure, and prevents late radial artery occlusion.

Tip: if using the left radial artery, the compression device usually needs to be put on upside down (if it is a single cushion of air), as they are usually designed for the right radial artery approach.

Femoral sheath removal

If the femoral site is used, there are a number of options available to deal with access closure.

Suture the sheath in situ

This prevents it from falling out or being accidentally pulled out.

- The activated clotting time (ACT) can then be measured and once acceptable the sheath can be removed and manual pressure applied proximally to the puncture site.
- ACT values of less than 175 seconds are conventionally used as a cutoff for sheath removal.
- Manual pressure is usually achieved either by a person physically compressing with their fingers or by the use of a proprietary device, such as a FemoStop, which applies pressure using an air-filled device attached to the patient via a band or strap around their body. The device pressure is slowly reduced over time until hemostasis is obtained. This method is quite time consuming and not good for early mobilization and day case procedures.

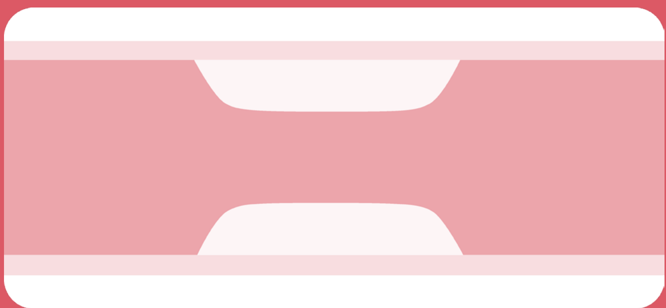
Close the arterial puncture

- This can be done by a wide variety of closure devices on the market, that largely work by either implanting a collagen plug (e.g., Angio-Seal) onto the arterial puncture site or by delivering a suture to close the artery (e.g., Perclose).

These closure techniques require specific training for each method, initially on a model and then under direct supervision in the catheterization lab, before an operator is deemed competent in their use.

Chapter 5

ASSESSING INTERMEDIATE LESIONS



Defining an intermediate lesion

Epicardial coronary arteries largely serve as conduits to deliver blood to the microcirculation. The microcirculation subsequently regulates most of the flow to the myocardial tissue.

Any angiographic or visual estimation of whether a stenosis is significant or **not**, is therefore based on anatomical appearance alone.

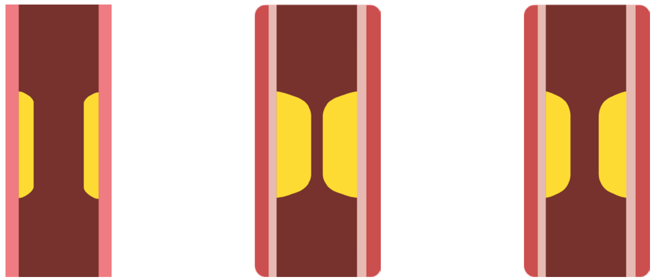
Although a stenosis may be intermediate in terms of visual assessment in an epicardial conduit, the effects on the myocardium via the micro-vascular circulation may still be profound.

Therefore, it is important that we evaluate the physiological significance of any intermediate stenosis (i.e., how much does a stenosis impact the amount of blood flow to the area of myocardium, which that blood vessel supplies?).

Ask yourself
Is the stenosis important and is it causing the patients symptoms?

- If yes, the patient may benefit from intervention on an intermediate lesion.
- If no, then they may potentially suffer harm, for example due to complications of the procedure or inappropriate long-term exposure to medication such as antiplatelet agents.

This is the concept of anatomy versus physiology. How does one determine the physiological rather than anatomical severity?



- An angiographically mild stenosis is unlikely to impact on the flow of blood to the myocardium.
- An angiographically severe stenosis will most likely reduce blood flow to the myocardium.
- An angiographically intermediate lesion is the grey area in the middle, where it is difficult to predict the impact on the myocardium. This is where physiological assessment comes in.

Using a pressure wire

We assess physiological importance of a stenosis in the catheterization lab by using a pressure wire.

A pressure wire, very simply, is a pressure transducer on a wire, that enables it to be delivered down a coronary artery and positioned across a stenosis.

These wires have a pressure transducer, therefore, they are often not as deliverable as conventional angioplasty wires. The operator needs to take great care and remember this is still a diagnostic procedure. The patient does not want to end up with a dissected coronary artery for a stenosis that turns out to be physiologically insignificant! Pressure wires are now available from a number of manufacturers and are constantly improving in terms of how deliverable and steerable they are.

How does a pressure wire measurement work?

- We know the pressure in the aorta Pa (being measured from the guide catheter).
- We know the pressure in the coronary artery after the stenosis Pd (measured from the pressure wire transducer).
- We can determine the difference between these two values and therefore, the pressure gradient across the stenosis or the Pd / Pa.
- We can express Pd / Pa as a ratio, which equates to flow, called the fractional flow reserve (FFR).

Pd / Pa should be 1 if there is no stenosis and no difference in the two recorded values.

- We then dilate the microcirculation.
- We conventionally use adenosine, which can be given intravenously or intracoronary.
- Adenosine causes maximal blood flow or hyperemia very quickly.
- This increases any gradient across a stenosis as the myocardial blood flow increases, mimicking exercise.
- This generates a new Pd / Pa or fractional flow reserve (FFR), which we then use to determine if a stenosis is physiologically important.

As mentioned earlier, if there was no stenosis then the fractional flow reserve (FFR) would be 1 and blood flow in the artery would be normal with stress or hyperemia.

FAME trial

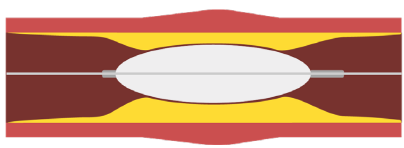
Any stenosis or narrowing in the coronary artery will reduce the FFR—when does this become significant for the patient?

The FAME 1 and FAME 2 trials provided recommendations for revascularization strategies based on FFR values.

Medical management of those with FFR > 0.8

Intervention for vessels with FFR < 0.8

FFR > 0.80



FFR < 0.80

The trial concluded these recommendations were both safe and improved long-term outcomes for patients with stable coronary artery disease.

Instantaneous free ratio

Groups have now looked at using different parts of the pressure wave to assess flow, which does not require the patient to be hyperemic and therefore, eliminates the need for adenosine. These measurements have been termed wave free ratios and can be used to generate measurements such as an instantaneous free ratio (iFR).

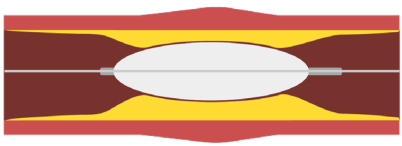
Wave free ratios have potential benefits by removing added time and cost to procedures (in terms of adenosine use) but generates slightly different numbers.

They are not yet as well established globally as FFR but are rapidly becoming more widely adopted due to ease of use.

Medical therapy is recommended for an iFR > 0.94

Revascularization is recommended for an iFR < 0.86

iFR > 0.94



iFR < 0.86

Grey areas (where we are unsure what to recommend) are outside the scope of this basic overview. For iFR, this grey zone is values of 0.86–0.94.

Performing a pressure wire study

Prior to performing a pressure wire study, it is important to ensure that you have the proper setup.

- Check the guide catheter position and aortic pressure tracings, and make sure there is no damping of the pressure traces.
- Ensure that heparin has been administered before any instrumentation of the coronary arteries.
- Give intracoronary nitrate to vasodilate the epicardial vessels and ensure no coronary artery spasm secondary to guide catheter intubation or guidewire insertion.
- Watch out for ostial or very proximal left main stem or right coronary disease, as your guide catheter may already be in or across part of the lesion, which will render the results of your pressure wire assessment inaccurate.
- Setup is similar for most commercially available pressure wires but check with the manufacturer for any specific recommendations or requirements.

1. All wires need to be flushed with heparinized saline and laid flat on the table and then connected to the system. Wait for your system to connect then confirm the wire is calibrated.
2. Once calibrated the wire can be inserted into the patient and the sensor part of the wire placed into the very proximal part of the coronary artery, just out of the guide catheter.

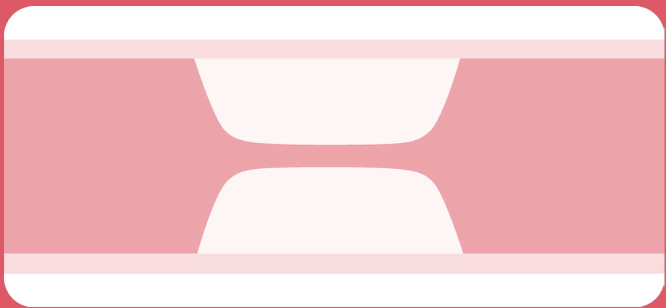
3. Remove the introducer tool, close the O-ring, and flush the system free of any contrast.
4. It is important at this point to equalize the pressures between guide catheters, in other words at the aorta and at the transducer, so that the starting Pd / Pa equals 1 (pressure traces should essentially be superimposed on each other with no difference in aortic and sensor pressures).
5. The pressure sensor can then be advanced distal to the stenosis. Remember the sensor is located between the floppy and stiffer parts of the wire, where there is a change in radio opacity on fluoroscopy.
6. Acquire an image to document sensor position.
7. Remove the introducer tool and check O-ring tightness.
8. Flush the system to remove any contrast and allow things to stabilize.
9. If using adenosine, ensure that you warn the patient about the effects of this in advance so that they do not panic. Adenosine side effects can include chest pain, breathlessness, dizziness, and rather alarmingly what is reported as feeling a sense of impending doom. Thankfully, most side effects are very short lived and usually resolve in just seconds, when the drug is stopped.
10. Commence the adenosine infusion if using it intravenously or give a bolus followed by a flush if giving it directly into the coronary artery.
11. Monitor the patient's ECG. Watch for any signs of atrioventricular (AV) block.
12. Record a continuous FFR to determine lowest value at steady state.
13. After obtaining the measurement, stop the adenosine.
14. Check that Pd / Pa is back to 1, at the ostium of the coronary vessel, before pulling it into the guide (to ensure no drift in the system).

15. Repeat an angiogram to check that no wire trauma has occurred.

- The pressure wire can be used for performing the actual PCI if the lesion is significant and for rechecking FFR post-PCI.
- Some operators prefer using their workhorse wires and reinsert the pressure wire for a measurement at the end of the case.
- If you leave the pressure wire in situ and use a second workhorse wire—don't stent the pressure wire into the patient. The pressure wire component on the wire can be difficult to remove and may break off if trapped behind a stent.
- If using the wire for PCI remember to wipe contact at the end of the wire with a damp swab. Carefully dry before reconnecting the electrical connector prior to using it to record measurements again.

Chapter 6

COMPLEX LESIONS

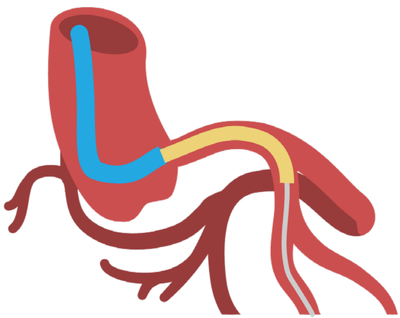


Dealing with branches and bends

Tortuous vessels

Addressing intervention in tortuous vessels

- Change the shape of the guide catheter, creating a greater curve that allows for better back wall support in the aorta.
- Increase the size of the catheter because this will increase the stiffness and decrease the likelihood of it being pushed out of the coronary artery.
- Add a second, or buddy wire, that lies alongside the original guidewire and assists in deploying stents and other devices by potentially straightening the artery to a small degree.
- Use a guide catheter extension, something that goes down the guide catheter and protrudes further into the coronary artery. When the operator pushes, this provides more extension of the guide into the artery, to counteract the guide catheter being forced back out of the artery.



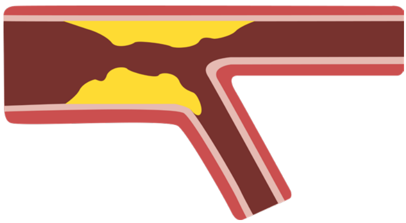
Guide catheter extension

Bifurcations

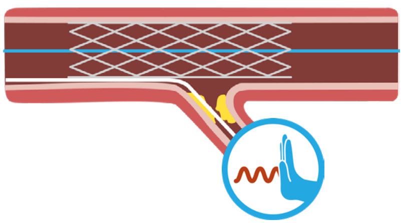
A bifurcation is the term we use for vessel branching. Atherosclerosis seems to like branches or bifurcation points, probably due to sheer stress and unique local blood flow patterns in these areas of the vessel. Twenty percent of all percutaneous coronary interventions will involve a bifurcation.

Bifurcation disease (as defined by the European Bifurcation Club)

Disease where a coronary artery narrowing is adjacent to or involving the origin of a significant side branch, that you don't want to lose!



Deciding on a strategy to deal with disease, when it involves a branch, is challenging. It depends on a number of factors, which try to determine the importance of the side branch, more specifically what the consequences of losing the branch would be if we stented across it and flow was lost.



What we need to know

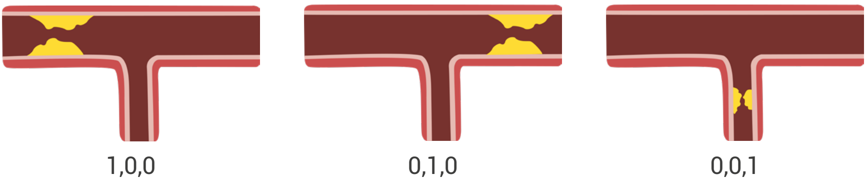
- The size of the side branch.
- The distribution of myocardium it supplies.
- Is the branch supplying collaterals to another territory or does it have a collateral supply itself?
- What is the overall left ventricular function? Specifically, what will be the impact of a periprocedural myocardial infarction causing loss of the branch on the overall left ventricular function?
- The angle of the side branch to the main branch—the more acute this angle the greater the chance it will lose flow after stenting the main branch.
- If the side branch is diseased at the origin or ostium it is more likely that stenting across it will compromise flow.

The medina classification is a three-digit system used to describe the pattern of disease at a bifurcation.

A score of 1 denotes presence of significant disease (i.e., > 50% stenosis) and 0 denotes lack of significant disease (i.e., < 50% stenosis).

- The first number in the sequence denotes disease in the main branch proximally.
- The second number denotes whether there is significant disease in the main branch, distal to the bifurcation of the side branch.
- And the third number denotes the presence of significant disease in the side branch itself.

Here are a couple examples of the medina classification in use.



The medina classification is easy to use and helps describe bifurcation disease but doesn't include anything about lesion length, side branch angle or size, and the presence or absence of calcification.

We can use the medina classification to help orient ourselves regarding the pattern of disease at the bifurcation but we must consider other factors when assessing lesion disease, in order to add detail and better inform our final percutaneous coronary intervention strategy.

Performing provisional stenting and T and protrusion

All of the evidence from registry data and clinical trials suggests that PCI for bifurcation disease, with complex multi-stent related procedures, ends up with a higher incidence of complications and with a higher rate of in-stent restenosis.

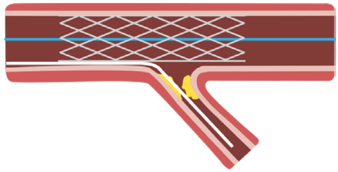
Always try to keep it simple!

Aim for provisional stenting. In other words, just stent the main branch across the side branch and only consider treating the side branch if the flow is compromised or the patient has symptoms, something we call bailing out the side branch.

Even if we don't intend to treat the side branch, I recommend wiring the side branch from the outset if it's not a branch you are happy to lose.

Wiring the side branch

- Marks side branch ostium
- Modifies angle of main branch to side branch
- Helps locate side branch if flow disappears and is no longer visible (allowing it to be rescued if needed)

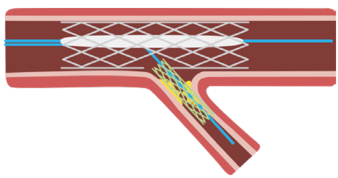


What do you do if you stent the main branch and the flow goes down in the side branch?

1. Rewire branch through stent cells
2. Remove jailed branch wire
3. Open some of main branch stent cells to help restore flow
4. Place removed jailed wire or a new wire down main branch

If we need to put a stent in the side branch this is usually done using a T and protrusion or **TAP technique**.

1. Insert an uninflated balloon in position in main branch stent opposite bifurcation
2. Insert a stent into side branch and pull back so it protrudes into main branch stent and covers ostium of side branch—where it can then be deployed



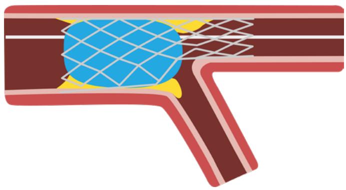
3. The side branch stent balloon is then pulled back partially and both balloons inflated simultaneously—known as kissing balloon inflation or kissing balloons

Utilizing the proximal optimization technique and kissing balloons

Proximal optimization technique (POT)

This is a very important step in PCI procedures involving bifurcation disease.

- Bifurcations usually result in the main branch becoming smaller after the bifurcation or side branch.
- Often the stent is sized to the distal vessel.
- Once the stent is deployed, it is really important to ensure that it is well apposed to the artery walls in the proximal vessel.
- We do this by taking a slightly larger, shorter balloon inside the stent and inflating it before the branch origin.

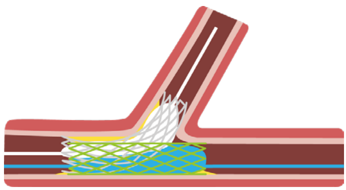


- This can also further open up the stent cells and can actually improve flow into the side branch or make accessing the side branch easier than before it was post-dilated.

Kissing balloons

Most bifurcation strategies, especially those involving two stents will require kissing balloon inflations.

- Two balloons are simultaneously inflated so that we essentially create a new carina or bifurcation point within two arteries.
- If we were to inflate balloons individually or sequentially we would just move the flexible metal carina, we have created, to one position and then back again with subsequent sequential inflations.



Employing dedicated bifurcation techniques

Sometimes the pattern of disease in the arteries is such that we have to decide to stent both the main branch and the side branch as part of the upfront strategy.

Reasons

- A large side branch
- Severe disease at the ostium of a side branch extending beyond the ostium
- A narrow or unfavorable angle for rewiring or provisional stenting between main branch and side branch

There are a number of options for which technique to use and all have their limitations and issues. These techniques are a little difficult to visualize conceptually. You may have to run through these steps a few times until they become clear. For these techniques you will be handling multiple wires and balloons, in quick succession, so you need to be methodical about managing your wires.

You will also need

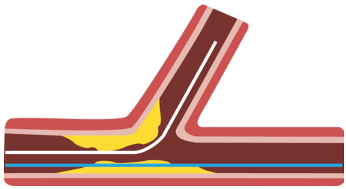
- An assistant
  - kissing balloon inflations and simultaneous stent deployment needs two separate indeflators and two separate operators to inflate and deflate at exactly the same time

The culotte technique

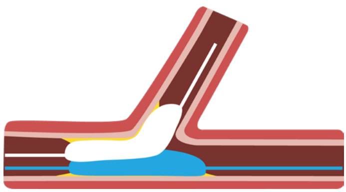
- Named after the final stented result, which looks like trousers or culottes.
- This is useful if the side branch and the main branch are similar sizes.

A step-wise list for this technique is outlined here—please use this in reference to the video animation provided in this chapter.

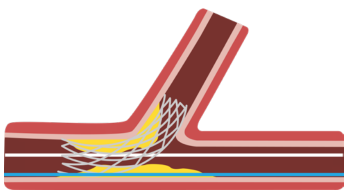
1. Insert a wire in both branches.



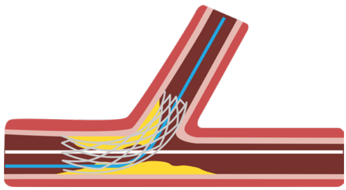
2. Now perform a pre-dilatation in both branches to allow easier stent access.



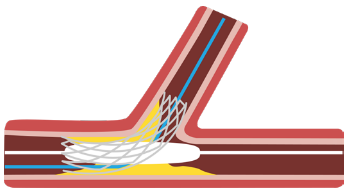
3. Insert a stent in the side branch back into the main branch.



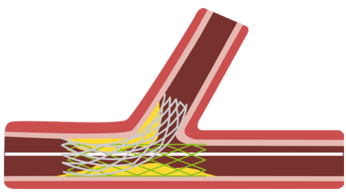
4. Perform a wire swap. The white wire is removed from the side branch and passed through the white stent cells into the main vessel branch.
5. The blue wire in the main branch, which is jailed by the white stent, is then removed and repositioned down the white stent into the side branch.



6. Use a balloon to open up the cells in the side of the white stent.

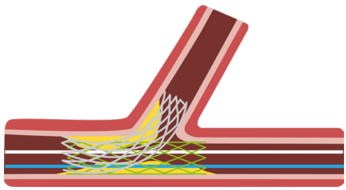


7. This allows a stent (green) to be positioned in the main branch through the side of the white stent.
8. The blue wire is then removed from the side branch stent so it doesn't get trapped between layers of metal.

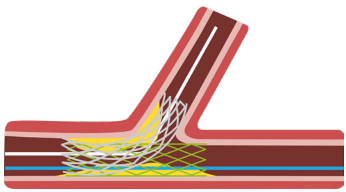


9. The green stent positioned in the main branch is then deployed.

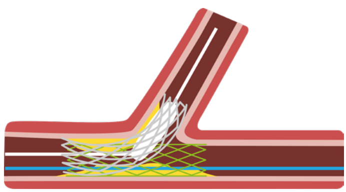
10. We can then insert a new wire (blue) through the recently deployed green stent, down the main branch.



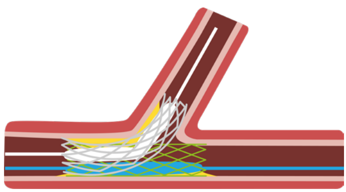
11. The white wire can then be withdrawn into the green stent and directed across the green stent cells, into the side branch.



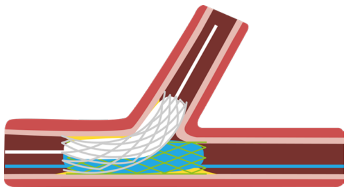
12. A small balloon is often required at this point on the white wire to open up some cells in the green stent.



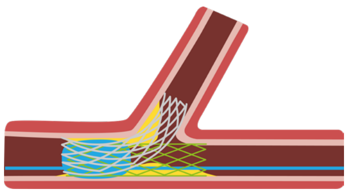
13. Then two balloons are taken side by side, one on each wire.

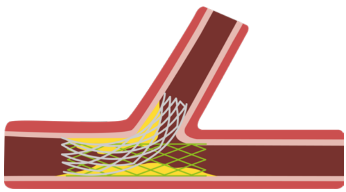


14. The balloons are inflated simultaneously as kissing balloons to refashion a new carina in the new bifurcation produced by the stents.



15. We then perform a final POT by inflating a larger, short balloon in the proximal part of both stents, before the branch, to ensure these stents are well apposed to the vessel.



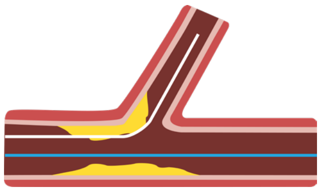


The crush technique

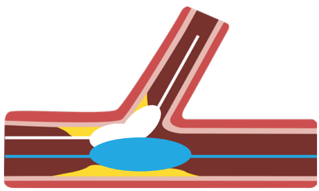
- This is useful if the side branch and main branch are different sizes.
- It protects the small branch from the outset.

A step-wise list for this technique is outlined here, but please use this in reference to the video animation provided in this chapter.

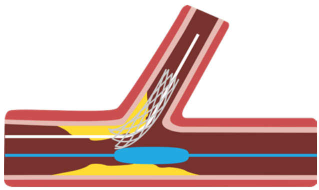
1. Insert a wire into both branches.



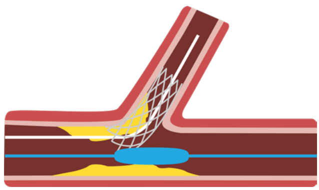
2. Perform a pre-dilatation in both branches to allow easier stent access (This can be done with a kissing balloon inflation at this point, in which case the technique is known as double kiss, or DK crush, as you will also perform kissing balloon inflations again at the end of the stent deployment).



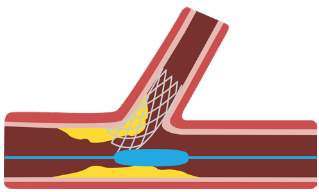
3. Position a stent in the side branch (pictured in white along the white wire), leaving an uninflated balloon in the main branch (pictured in blue) opposite the side branch being treated. This balloon will be used to crush the stent, which gives the technique its name. It needs to be sufficiently inserted down the main branch vessel, as should our white stent come too far back into the main branch, we may not be able to subsequently pass this balloon past it.



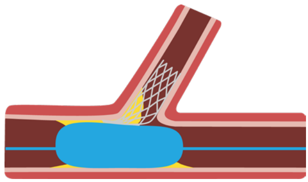
4. The white stent is then deployed or expanded.



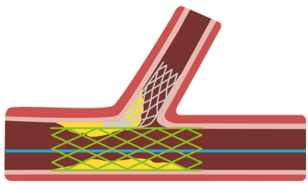
5. Then the white wire in the side branch is removed, as we don't want to trap it within the crushed metal stent.



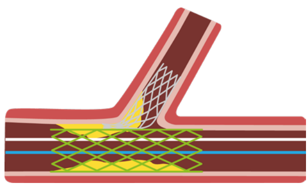
6. The balloon on the blue wire is inflated, crushing the stent in the side branch against the wall.



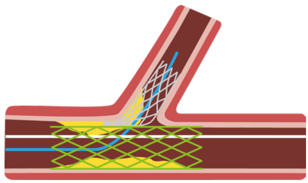
7. A second stent is then deployed into the main vessel, pictured in green.



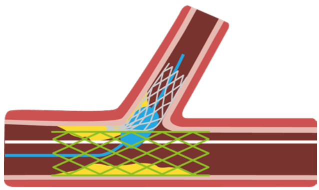
8. A new wire is inserted into the main branch through this stent, shown in white.



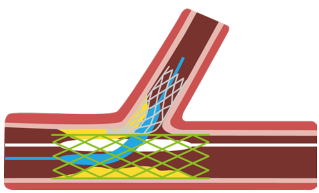
9. The blue wire from the main branch is pulled back and inserted into the side branch through the green stent cells and the crushed white stent cells. This is often the most difficult part of this procedure, as sometimes it can be impossible to perform this wiring step.

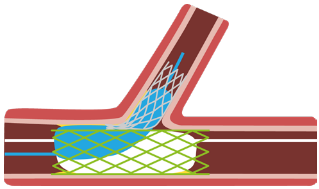


10. A balloon is then fed over the blue wire and inflated to open a path into the side branch through the layers of both stents.

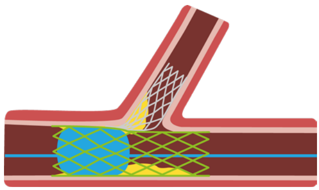


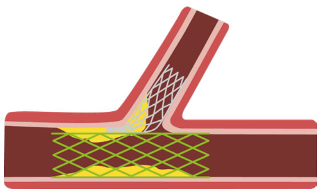
11. Finally, the kissing balloon inflations are performed, as in the previous culotte technique, to open up both vessels fully and again create a new carina.





12. We then perform a final POT by inflating a larger, short balloon in the proximal part of both stents, before the branch, to ensure these stents are well apposed to the vessel.





The V stent technique

- This is useful if the branches are of similar size and there is no disease in the proximal main branch.
- Only really useful for 0,1,1 lesions, which are not very common in clinical practice.

A step-wise list for this technique is outlined here—please use this in reference to the video animation provided in this chapter.

1. Wire both legs or branches of the V bifurcation.
2. Pre-dilate both lesions.
3. Deploy a stent on each wire and inflate at the ostia of both branches without coming back into the main vessel.

Note: no POT is required as we don't have one common stented segment in the main vessel.

Simultaneous kissing stents (SKS) or the shotgun technique

- Sometimes called the shotgun technique because if you look down the artery, from the proximal end, both stents would be side by side and it would appear like looking down a double-barreled shotgun.
- This is useful in large caliber vessels, that can accommodate two stents side by side (essentially only in the left main coronary artery), to establish a new central carina fashioned in metal.

- The main advantage is that it is quick and straightforward.
- It requires a large caliber guide catheter for this technique.
- It's very fast and has no difficult recrossing with multiple steps.
- It can cause problems for future PCI. It is hard to know which stent your wire is entering or if it's even crossing over between stents (i.e., in and out of stent cells).

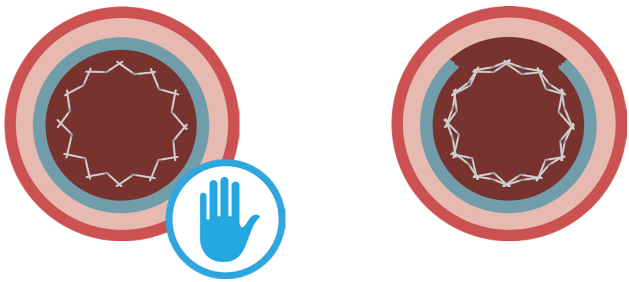
A step-wise list for this technique is outlined here—please use this in reference to the video animation provided in this chapter.

1. Wire both vessels.
2. Pre-dilate the lesions.
3. Load both stents onto the wires simultaneously then pull them both back together into the main diseased branch.
4. They can then be inflated simultaneously, exactly the same way as performing kissing balloons, this time using stents—hence the name simultaneous kissing stents (SKS).
5. Deflate the balloons leaving the stents in place. Reposition two new larger, non-compliant balloons and perform a final kissing balloon inflation.

Remember, no POT is required as you have no common main branch stent—you now have two side by side.

Managing calcified vessels

- Calcification is the enemy of percutaneous coronary intervention.
- Calcification is particularly seen in the elderly (as the population ages, it is more commonly encountered during PCI procedures).
- It is also more common in patients with diabetes and with chronic kidney disease.
- Sometimes calcification within the wall of the artery goes completely around the artery, known as circumferential calcification (napkin ring calcification).
- You cannot deploy a stent unless you can crack open this ring of calcification.



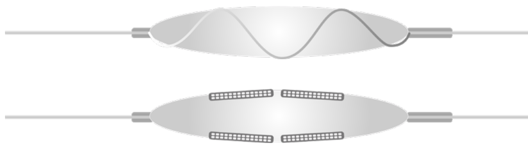
- If you try to deploy a stent without first preparing the vessel, the stent won't be able to fully expand and appose to the wall. This can lead to problems with flow down the vessel, risks subsequent in-stent thrombosis and myocardial infarction, and in-stent restenosis.

If you are unable to dilate a stenosis with a balloon then it is impossible to treat the patient with stents.

Techniques to deal with calcification

Scoring or cutting balloons

- Use a scoring or cutting balloon to modify the ring of calcification.
- These deliver focused pressure, which leads to a linear tear or crack in the calcification.
- Note that they can be hard to deliver in tight spaces because of the bulkiness of the balloon, due to the metal component.
- A number of scoring or cutting balloons are commercially available.

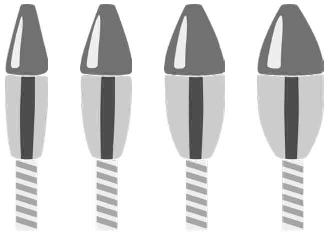


What if we can't insert a balloon because the lesion is too tight or it still won't expand?

Rotational atherectomy

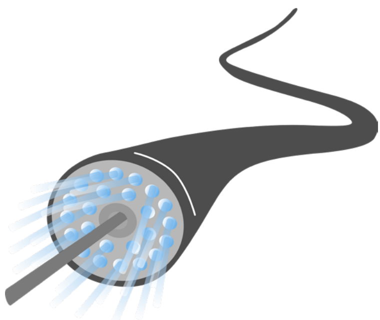
- This is commonly referred to as rotablation.
- Uses a rotating burr that is tipped with crushed industrial diamond and rotates very quickly, around 160 000 rpm.
- Fragments the calcium into microscopic particles that are absorbed into the distal coronary circulation.
- This is a complex procedure that requires considerable operator experience and training.
- Necessitates the use of a larger size guide catheter.
- Increases complication of dissection or no flow in the artery.
- Requires a dedicated, lubricated stainless steel rota wire, due to the heat generated by the rotating burr.

- Rotablation, or rota wires, can be difficult to use and are not as easy to insert into a coronary artery when compared with normal angioplasty wires.
- If you can't insert a rota wire through a lesion, you can't rotablate, which is one of the limitations of this technology.



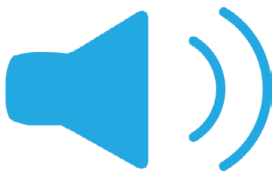
Laser atherectomy

- It can't deal with calcium on its own.
- It can be effective in complex calcified lesions, where we cannot pass a rota wire but can pass a normal wire.
- Laser catheters can travel over any normal workhorse wire and create enough space to then allow the passage of a rota wire.
- A combination of laser followed by rotational atherectomy is called Raser.



Shock wave / lithotripsy

- Newer technologies use sound or shock waves to disrupt deep calcium, in much the same way that lithotripsy is used for renal stones.
- Sound waves are delivered via a balloon inserted over a standard wire.
- Limitations of this technology include the bulkiness of the balloon, which may not pass in severe or tight lesions or where calcium is projecting significantly into the vessel lumen.



Evaluating left main stem disease

- Disease of the left main stem has conventionally been treated with coronary artery bypass grafts (CABG).
- Current outcomes for PCI versus CABG in contemporary treatment are similar in terms of subsequent myocardial infarction or mortality, depending on the complexity of the disease. However, there are increased revascularization rates with use of percutaneous coronary intervention.
- The left main stem (LMS) supplies a large amount of myocardium, so myocardial jeopardy is large when it is significantly diseased or obstructed with PCI equipment.
- It usually bifurcates but may sometimes trifurcate if a ramus intermedius branch is present.
- Navigating angles from the left main stem into the left anterior descending or more commonly the left circumflex, can sometimes be challenging.
- PCI often requires bifurcation stenting strategies, multiple wires, imaging assessment or rotablation and requires a certain level of skill or competence by the operator.
- A large amount of myocardium is supplied by the left main stem, so patients may present acutely in cardiogenic shock when flow in this vessel is reduced.
- Left main stem disease is more common in the elderly; therefore, there may be more issues with calcification or bulky disease.

Terminology

- An unprotected left main stem (LMS) is one which has not been previously grafted, usually with a left internal mammary artery (LIMA) graft, during coronary artery bypass grafting (CABG).
- A protected left main stem is when the left anterior descending has been previously grafted and the graft is patent.

Left main stem PCI may be required if the patient has comorbidities, such as left ventricular impairment, pulmonary disease, renal impairment or a previous cerebrovascular accident (CVA)—they are not good candidates for CABG.

- If the right coronary artery (RCA) is blocked, there is a higher chance of hemodynamic instability and intolerance of a PCI procedure.
- In the presence of severely impaired left ventricular function, the patient may need an intraaortic balloon pump or Impella, to provide periprocedural left ventricular support.
- Decision making regarding mode of revascularization depends on clinical presentation (emergency versus elective).
- Elective or stable presentations—recommendations are to discuss the case with a multidisciplinary heart team; a cardiac surgeon, a non-interventional cardiologist, an interventional cardiologist, and ideally a geriatrician.
- Emergency presentations—the patient needs treatment in the most expeditious way possible (in most cases via PCI).
- Consideration of the patient's risk for surgery, such as by EuroScore or STS and also the complexity of the coronary disease by Syntax score, should be considered, in addition to determining options for more complete revascularization via either strategy.

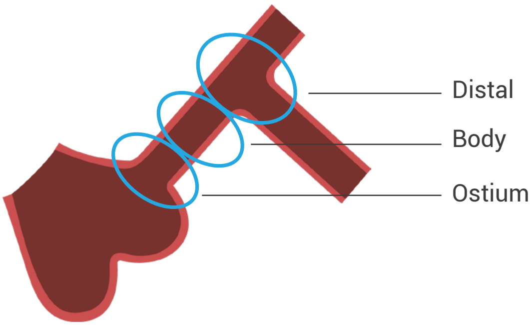
- Is there concurrent valvular disease, more common in elderly patients, that may require surgical intervention in the near future and which would support surgery rather than PCI?

Treatment

It is best to subdivide the left main stem of the left coronary artery into three component parts when considering revascularization options.

1. The ostium
   - Disease here is often aorto-ostial and can cause problems with intubation, with immediate guide or pressure damping.
   - Assessment of functional significance is difficult using pressure wire assessment and may require withdrawal of the guide catheter for accurate measurements.
   - May require debulking with either a cutting balloon or rotablation.
2. The body
   - Disease here is usually the most straightforward and most like any other section of coronary artery.
   - The body is often much larger in diameter and sometimes even bigger than the maximal size available for stents.
3. The distal left main or bifurcation
   - This is the most challenging region.
   - Greatest risk of complications, restenosis or reintervention.
   - Two thirds of left main stem cases involve bifurcation.
   - Issues with size mismatch and angles between the left main stem and the left anterior descending (LAD) or circumflex vessels.
   - Keep it simple—perform provisional stenting using one stent, if at all possible.
   - No one bifurcation strategy is better than another here.

- Good technique is imperative for the best results angiographically, to secure the best long-term outcome for the patient.
- Be aware that you may lose one of the three branches if it is a trifurcation—usually this is the ramus intermedius, which tends to be the least important of the three, but not always. This can occasionally be a large vessel if the circumflex artery is small (i.e., in a right dominant system).



High quality intervention on the left main stem invariably requires the use of intravascular imaging. The greatest experience worldwide is probably with intravascular ultrasound (IVUS)

Optical coherence technology (OCT) imaging requires blood in the coronary vessel to be replaced with contrast, which requires good guide catheter engagement into the vessel for this to be achieved. This can be very difficult if there is very proximal or ostial left main stem disease, which prevents such guide engagement or intubation.

Imaging modalities

Intravascular ultrasound (IVUS)

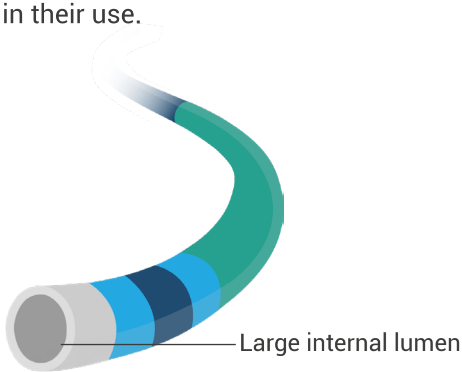
- Checks for any significant calcification, which may cause issues with adequate stent delivery or deployment. You don't want a stent sticking or inadequately deploying in the left main stem position and impeding flow—it may be disastrous.
- Helps to ensure appropriate stent sizing and to confirm optimal stent deployment, expansion, and apposition against the wall.
- Helps determine minimum stent size and alerts you to the fact that you may not have a stent stocked or be able to get a stent to expand sufficiently to reach the minimum required diameter. If a stent won't reach the sides it will cause obstruction to flow and be a nidus for acute thrombus formation, which may prove fatal for the patient.
- Assists with determination of disease in the origin of the left anterior descending and circumflex branches, which may help guide your stenting strategy from the outset.
- Can directly measure cross-sectional area.

For reference, significant disease in the left main stem (LMS) usually correlates to a cross-sectional area of < 6 mm²

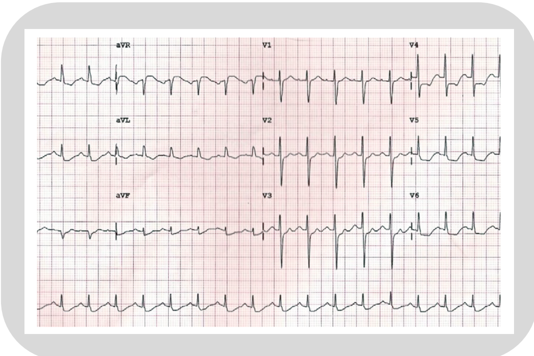
Pressure wire studies can be performed to assess functional significance of left main stem (LMS) disease but can be challenging depending on the location of disease. You often need to sit the guide catheter out in the aorta so it doesn't damp pressures or interact with the diseased segment being assessed.

For elective cases, the most important thing is to have a plan.

- Do you know what the blood supply from collaterals is like? Is the right coronary artery diseased or occluded so that it won't offer much support when you lose flow during balloon inflations in the left main stem?
- What is the left ventricular function? Do you need left ventricular support, such as an intraaortic balloon pump (IABP) or at least consider obtaining additional arterial access, at the start of the case, if you then need to insert a left ventricular support device in a rush?
- Take the correct guide. You don't want to dig into an ostial lesion or dissect the LMS. You don't want the guide to intubate too deeply past the disease if it is very proximal. You want to be able to remove the guide quickly (back out) if there are problems with flow or pressure damping. Sometimes simpler guides like Judkins may be easier than geometric guides like an extra backup (EBU).
- Radial or femoral access are both acceptable but you may need to check sizes depending on left main stem size and stenting strategy (8 Fr for SKS shotgun or large rota burr). Radial sheathless guides with large internal lumens may offer a suitable alternative if used with care; they can be aggressive and cause dissections if you are not well versed in their use.



- It might help to have a guidewire and balloon preloaded in your system and be ready to pre-dilate very severe ostial disease as soon as the guide catheter is engaged or adjacent to the lesion.
- What is your debulking strategy? Are you all set to rotablate? Don't start the case without having all of the equipment you require checked and on hand, as once you start compromising flow the patient will become ischemic very quickly.
- Remember to use all of the available information you have. In an acute presentation, an ECG showing widespread ST depression and ST elevation in aVR should be a red flag.



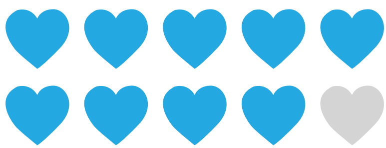
This is often seen in left main stem (LMS) disease. The ST elevation in aVR is pretty diagnostic. If you recognize the ECG you should be prepared to watch the pressures very carefully when delivering your catheter into the LMS, and already be thinking of a plan if your first angiogram shows severe disease in the body of the left main stem.

Defining and treating a coronary chronic total occlusion

Chronic total occlusion (CTO)

- This is chronic total occlusion of the coronary artery.
- Usually estimated to have been blocked for a minimum of three months (i.e., not an acute occlusion).
- This remains the most difficult category of coronary artery lesions to treat—they pose one of the greatest technical challenges to interventional cardiologists.
- PCI is more time consuming, with dynamic and relatively steep learning curves for the operator.

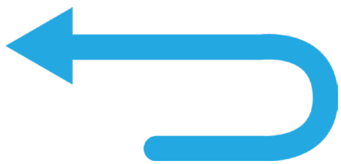
There is a contemporary approach developed by dedicated experts in Japan, Europe, and the USA for standardized modern chronic total occlusion (CTO) recanalization techniques, which provide focused training and proctorship worldwide, increasing success rates currently to > 90%. It combines all available crossing techniques to optimize procedural efficacy, efficiency, and safety.



Two main approaches

- Antegrade (i.e., forward through the occlusion in the same direction as blood flow)

- Retrograde (i.e., coming from the occlusion at the distal end or the end furthest away from the origin of the artery)

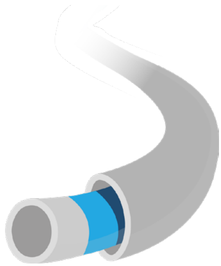


Subgroups

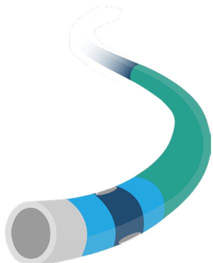
- Antegrade wire escalation (AWE)—this means pushing your way through the occlusion by using stiffer and stiffer wires (wire escalation).
- Antegrade dissection / fenestration re-entry—pushing through the occlusion into the wall of the vessel, then the intima, and tunneling the wire past the occlusion, then re-entering the true lumen (distal to the occlusion) with a sharp wire.
- Retrograde wire escalation (RWE)—essentially the same as antegrade wire escalation but coming at the occlusion distally (by passing the wire down another open artery and connecting through to the blocked vessel via collaterals). The distal cap often may be easier to puncture than the proximal cap.
- Retrograde dissection re-entry (reverse CART)—as with antegrade dissection re-entry but approaching distally.

There is special equipment that operators need to be particularly trained to use when addressing CTO.

- We often have to use much longer sheaths, up to 45 cm, for improved guide catheter support and control.



- Guide catheters are also important when treating chronic total occlusions, like in any PCI. We often take larger French sizes due to the complexity of the procedure and amount of equipment we need to pass it through the vessel.



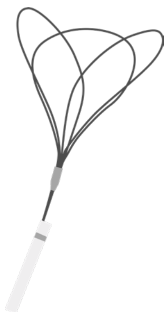
- We need dual arterial access so one catheter can image the collaterals and one facilitate the PCI. Approach can be biradial, bifemoral or radio femoral. We sometimes use a shorter length guide catheter for retrograde approach PCI, when we have to eternalize a wire and a shorter guide helps.

- Dedicated guidewires are produced for CTOs. These can be very soft-tipped, tapered, and coated with a polymer to try to find and enter a tiny microchannel through a CTO (e.g., Fielder XT). The problem is they are not very supportive once they have crossed and you often have to exchange for a stiffer wire via a microcatheter.
  - soft tip, polymer-jacketed, tapered guidewire (Fielder XT)
  - stiff, polymer-jacketed wire (Pilot 200)
  - stiff, tapered wire (Confianza Pro 12, Hornet)
  - composite core stiff guidewires—good torque control but also require different manipulation (Gaia first, second, and third)

- R350 for externalization
- Long wires are needed for retrograde approach techniques, as the wire has to travel down the collateralizing coronary artery and then back up the occluded vessel retrogradely, then be externalized (i.e., R350, which is 350 cm long as the name suggests and around double the length of a standard PCI wire)
  - some wires are stiff to help puncture the cap (i.e., Confienza Pro 12) and some require training in specific manipulation and direction for use but have extremely good torque control (i.e., Gaia wires)
- Imaging is very helpful in CTO procedures to confirm position within the vessel architecture and measure true vessel size.

- Microcatheters are an essential kit for PCI (Finecross and Corsair).

- Dual-lumen catheters can also be of use in certain situations, such as twin pass.
- Dissection / re-entry equipment is required to both work your way through a CTO (i.e., the Crossboss) and to facilitate puncture and re-entry into the true lumen distally (Stingray).
- Snares are needed to capture the retrograde guidewire into the antegrade guide catheter (i.e., EN Snare and the Atrieve).



- Uncrossable or undilatable lesions can be crossed by increasing guide catheter support, for example using guide catheter extensions (i.e., a GuideLiner), by various anchor balloon techniques or by modifying the lesion using the Tornus catheter, rotational atherectomy or even laser.

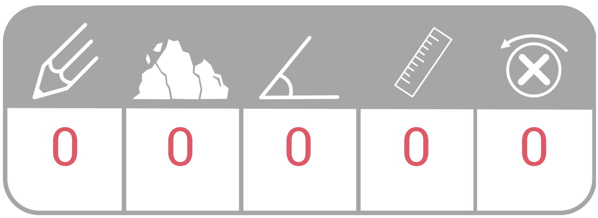
Japanese CTO

The Japanese registry CTO score (J-CTO) is a score given to describe the complexity of the occlusion and how likely, or unlikely we are to open it with PCI. The score is made up of five variables.

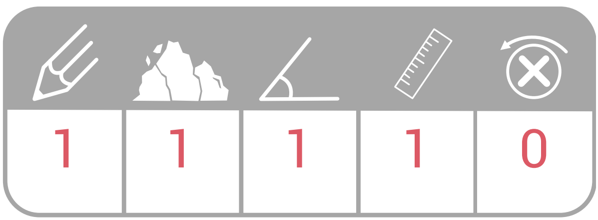
1. Is the stump of the occlusion tapered (versus blunt)?
2. Is the segment calcified?
3. Is the vessel tortuous (more than 45-degree bends)?
4. How long is the occlusion (is it more than 20 mm)?
5. Has it already been attempted and failed previously?

One point is awarded for each *Yes* above—providing a total score.

0 means a CTO should be relatively easy to open



> 3 means a CTO will be very difficult to open



J-CTO score helps

- Predict complexity of CTO recanalization
- Aid with case selection
- Help decide how to plan approach to treatment

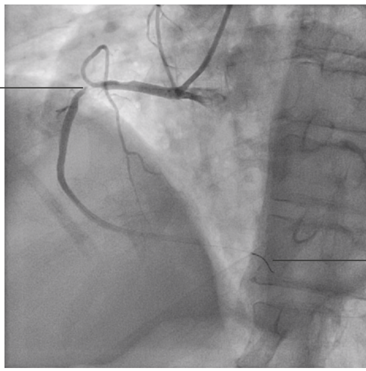
Successful CTO PCI can be achieved using a combination of equipment and crossing strategies with acceptable complication rates. Successful revascularization correlates strongly with operator experience. Developing highly skilled operators and catheterization lab teams and establishing proctoring and referral centers, all help build successful CTO programs. Education of the catheterization lab team, a dedicated CTO trolley, minimizing radiation and contrast, and monitoring anticoagulation are all important to the success of CTO. In addition, denoting specific CTO days in which chronic total occlusions will be tackled by the catheterization team seems to work best.

Chapter 7

COMMON PROCEDURAL COMPLICATIONS

Recognizing and treating acute no-reflow

- Acute no-reflow is when the epicardial vessel appears open but there doesn't appear to be any distal runoff of contrast into the microcirculation.
- It is a very complex phenomenon thought to occur through a combination of thrombus embolization, from the culprit proximal lesion, which transiently blocks up some of the smaller vessels in the microcirculation.
- It is exacerbated by spasm of the microcirculation, which is thought to be secondary to prostaglandin and prostacyclin release from proximal balloon injury.



What do we do about this phenomenon?

- First, is to be aware that acute no-reflow exists so you are not perplexed when it happens.
  - often associated with ST elevation on ECG and acute onset chest pain

- Second, is to recognize which cases are most common and likely to result in acute no-reflow.
    - acute coronary syndrome (ACS) presentations (with visible thrombus) and those requiring significant over dilatation of stents and lesions
- Third, is to have a management plan so you can act quickly.

Treating acute no-reflow

The treatment of no-reflow is to deliver a pharmacological agent using a small microcatheter, placed as distally as we can get it in the affected artery, to help reverse microvascular spasm. There is little point in delivering drugs to the proximal coronary artery—in the absence of flow, they are not going to reach their target in the microcirculation.

Commonly used agents for reversal of spasm

- Adenosine
- Verapamil
- Sodium nitroprusside

In acute syndrome cases with high thrombus burden, the chance of thrombus formation and distal propagation or embolization may be reduced with the use of upstream oral antiplatelet agents.

- Aspirin
- Clopidogrel
- Prasugrel
- Ticagrelor
- Tirofiban
- Abciximab
- Eptifibatide

In cases with higher thrombus burden, such as in the context of ST-elevation myocardial infarction, acute no-reflow phenomena can be profound and can be very difficult to manage, even with modern adjunct pharmacotherapeutic therapy. It is often seen if the artery is over dilated or repeatedly dilated. This should be avoided if at all possible in patients presenting with acute coronary syndromes.

Managing acute side branch occlusion

Side branch loss

- We sometimes have to treat the main segment of artery by stenting across a side branch.
- This may result in abrupt loss of flow into the side branch.
- When we occlude a side branch, the patient will usually become quickly symptomatic, assuming the myocardium supplied by the vessel is viable.
- Symptoms will ordinarily depend on the size and distribution of the vessel and the amount of myocardium subtended by the occluded vessel.

Consequences of side branch loss

- Chest pain is the most common symptom.
- ST segment elevation on the surface ECG recording.
- Sudden onset ventricular fibrillation (VF) or ventricular tachycardia (VT).
- Hemodynamic compromise instead of or as well as chest pain (e.g., if left ventricular (LV) function is already severely impaired).

Management of acute side branch loss

- IV opiate analgesics for symptomatic relief.
- Closely monitor the heart rhythm and hemodynamic parameters.
- If possible, restore flow to the side branch as quickly as possible.
- Usually requires rewiring of the vessel through the implanted stent and balloon inflation in the ostium of the branch vessel, either with or without subsequent stent implantation.

Classifying and managing coronary dissection

Abrupt vessel occlusion

- Can occur at any time so be vigilant.
- Usually iatrogenic, mainly secondary to coronary artery dissection and the creation of an intimal flap.
- Luminal obstruction abruptly occurs, mainly due to blood entering the false lumen and an extending intramural hematoma compressing the true lumen.
- Coronary dissection can be due to guide catheter or wire trauma, trauma due to balloon inflation or due to stent deployment.
- Occlusion may be secondary to acute thrombotic occlusion so remember to recheck anticoagulation, by performing an activated clotting time (ACT), if you suspect thrombosis.
- Coronary artery obstruction may also appear due to acute no re-flow, as seen in the previous lesson, this is treated in a very specific way so it is important to recognize this cause from the outset.

What about when things don't go as planned?

- It is important to always have a strategy prepared for complications.

Complications—ask yourself

- Expected? (e.g., localized dissections around the area of pre-dilatation, especially in complex disease requiring cutting balloons)
- Unexpected? (e.g., despite taking precautions we may still experience guide catheter induced dissection either of the coronary artery or aortic root or dissection related to the wire tip or stent edges)

NHLBI classification system

The national heart, lung, and blood institute (NHLBI) classification system describes dissections, which are essentially tears in the intima of the vessel. These were largely used in the pre-stent era to determine how likely it would be that the vessel would close abruptly, a recognized complication of plain old balloon angioplasty (POBA).

- **Type A**—minor radiolucent areas within the coronary lumen during contrast injection with little or no persistence of contrast after dye has cleared.

- **Type B**—parallel tracts or a double lumen separated by a radiolucent area during contrast injection, with minimal or no persistence after dye clearance.

- **Type C**—contrast outside the coronary lumen (extraluminal cap) with persistence of contrast after dye has cleared from the lumen.

- **Type D**—spiral (barber shop pole) luminal filling defects, frequently with excessive contrast staining of the dissected false lumen.

- **Type E**—appear as new, persistent filling defects within the coronary lumen.

- **Type F**—lead to total occlusion of the coronary lumen, without distal anterograde flow.

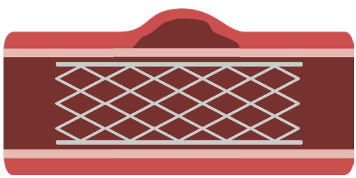
Management of dissections

Immediate management of coronary artery dissection

- Balloon inflation at the dissection point.
    - relatively low pressure and prolonged inflation time (when compared to usual balloon inflation to dilate lesions)
    - aim is to tack up intimal flap that has been created and prevent any further blood flowing into false lumen or subintimal space (extending dissection)

Do not lose position of the wire at this stage of the procedure. This is extremely important. While the wire remains down the artery you have some control of what happens next. If you lose wire position and the wire comes back proximally to the dissection, the vessel may then close completely. Reintroducing a wire may alter the false lumen and again close the vessel. It may not be possible to enter the true lumen again with the wire, in which case the vessel may remain occluded and the patient suffer a periprocedural myocardial infarction or require transfer for emergency bypass surgery.

Once the dissection flap has been tacked up, additional stents may be required to scaffold the vessel and seal the dissection flap closed.



Dissection involving the ostium of the vessel

- It may extend back into the aortic root.
- Stents implanted to manage this should extend back across the ostium to ensure the dissection flap is adequately sealed.
- Likely to heal if treated with PCI and stenting.
- Further imaging such as CT aorta may be required to document the extent of the aortic root dissection.
- Echo is particularly useful to evaluate the patient during an ostial dissection to exclude significant associated pericardial effusion.
- As noted earlier, the patient may also need emergency surgical repair if the complication cannot be managed by PCI. The operator may need to call a colleague or other team members for assistance to help manage this complication.

Classifying and managing coronary perforation

Perforation is never planned! We need to recognize it quickly and act fast if it does occur. Things can deteriorate in a matter of just a few minutes. It is also important to watch the patient carefully for signs of hemodynamic compromise, suggestive of cardiac tamponade.

The Ellis classification system

The Ellis classification system helps delineate the different types of coronary perforations.

- **Ellis Class 1**—a crater extending outside the lumen only in the absence of linear staining angiographically suggestive of a dissection.
- **Ellis Class 2**—involves pericardial or myocardial blushing through a less than 1 mm exit hole.
- **Ellis Class 3**—includes frank streaming of contrast through a greater than 1 mm exit hole.

Perforation requires immediate recognition and management

- Perforation is a complication of PCI that requires swift action on the part of the operator to monitor the patient's hemodynamic status and look out for further complications such as pericardial tamponade.
- IV fluids should be administered to maintain right ventricle filling pressures.
- Balloon inflation (balloon tamponade) across the perforation is required to prevent further extravasation of blood into the pericardial space.
- If this fails to stop the leak, the perforation may need to be sealed by implanting a specially designed covered stent. This is normally two stents with a layer of bovine pericardium sandwiched between them or a single stent covered with a polyurethane membrane.
- Occasionally, if the perforation is very distal in the vessel, as may be seen when the angioplasty wire perforates a very small distal branch, the vessel may need to be purposefully blocked by insertion of coils or by fat embolization (where a small amount of subcutaneous fat taken from the patient is injected very distally into the vessel using a microcatheter).
- Often an emergency pericardial drain is required.
- Anticoagulants may need to be reversed if you cannot control the situation and the perforation is severe.
- Very occasionally it may necessitate emergency cardiac surgical repair as a lifesaving procedure.

Ping-pong guide technique

- Second arterial access puncture allows a second guide to be delivered to the coronary artery.
- Enables your balloon to remain inflated, to tamponade the artery, while a second wire is passed with very transient deflation of the balloon to allow passage, then immediate reinflation.
- A covered stent is then loaded on the second new wire and introduced into the artery.
- It is advanced and when ready to go into final position, the balloon performing tamponade is deflated and withdrawn quickly and the covered stent positioned and immediately inflated. This minimizes the amount of time the artery continues to leak blood into the pericardial space and is a useful technique for severe coronary perforation with large leaks.

Recognition of the type of perforation determines the speed of action required and the likelihood of requiring more definitive action such as covered stents, pericardial drains, and emergency cardiac surgical intervention, all quite likely with an Ellis 3 perforation compared with an Ellis 1 perforation—where no serious sequelae may occur.

Dealing with stent loss

Stent loss

- Uncommon
- A dreaded complication for most PCI operators
- Requires strategies for management

The most common cause of stent loss is inadequate lesion preparation.

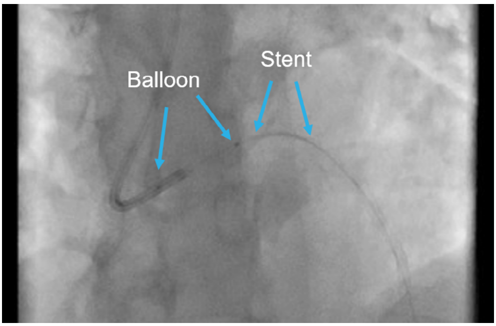
- A stent balloon pulled out of an undeployed stent will expand slightly and usually not go back into the stent.
- Often due to the force being applied by the operator when pushing on the stent delivery system, the guiding catheter position is lost and everything flies out of the vessel.
- The undeployed stent will either be left stuck in the vessel where it was or will come back when the wire and guide come out under tension. The stent may be free and then lost or embolize into the systemic circulation.
- The stent may then lodge in one of the arterial branches to the head and neck, or fortunately and more commonly, in the femoral vessels.
- The main way of avoiding stent loss is to minimize friction on the stent by preparing the lesion adequately with balloon pre-dilatation or rotational atherectomy if calcified.

Never force the stent if it will not go!
Remove it carefully before it gets stuck and prepare the lesion some more.

If you are unable to position a stent successfully, remove the stent from the patient carefully, ensure you still have possession of the stent (when it is removed from the patient), and it has not been damaged. Be careful when withdrawing a stent that it comes coaxially into the guiding catheter and not at an angle, which may catch the stent and strip it from the balloon.

Solutions for when stent comes off balloon

What options do you have when the stent comes off the balloon?



1. Crush it where it is.
    - Take another wire and pass it down the side of the undeployed stent.
    - Pass a large balloon next to it and inflate at high pressure to crush the stent into the wall of the artery.
    - Once the stent has been crushed by the balloon it will need to have a stent deployed across the vessel, at this point, to seal the crushed undeployed stent in the wall.

2. Deploy it where it is.
    - If still on the wire, you can try to pass a very small diameter balloon into the stent to deploy it where it is, if you are satisfied that the position is acceptable even if it's not the position you were aiming for.
    - For this option, the stent would have to be of sufficient size to cope with over dilatation. You wouldn't be able to deploy a 2.5 mm stent if the reference vessel size, where it was lost was 4.5 mm, as it would fracture before it reached the required size.
    - Once it starts to deploy it will be easier to get sequentially larger balloons inside the stent until it gets to the desired size.
3. Try to remove it—using a balloon.
    - If the undeployed stent is still on the wire and is not suitable due to the size of the reference vessel and stent, to try to deploy where it is, if possible, pass a small balloon through the stent.
    - This can be inflated distally to the stent and pulled back in an attempt to drag the stent back into the guide.
    - Sometimes it will not enter the guide and the whole system of wire, balloon, and undeployed stent may have to be removed together, taking care not to lose the stent during this withdrawal.
    - Check to ensure you have the stent when everything is out of the patient. This technique may traumatize the coronary artery as the stent is dragged out. Check carefully after this maneuver, as evidence of intimal disruption may require cover with another stent.

4. Try to remove it—using a snare.
    - An attempt can be made to retrieve the stent using snares to grab it. This is very challenging and in my personal experience is rarely successful unless the stent is hanging out of the ostium of a vessel.
5. Try to remove it—using the wire wrap technique.
    - Multiple wires are passed down the artery past the stent.
    - These can then be twisted repeatedly around each other to trap the stent and then the whole system can be withdrawn as above (use care not to lose the stent on withdrawal).

Embolization into circulation

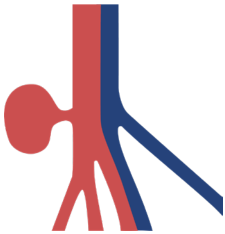
- If this happens it can be hard to find.
- You may have to fluoroscopy the patient, usually starting with the aortic root, then down to the legs to see if you can locate the stent. Then try to retrieve it using a snare device, usually from a femoral access site.

Very occasionally the patient has to go to surgery to deal with a lost stent—either to retrieve it from a position that is difficult to access percutaneously or to deal with a coronary complication of stent loss, maldeployment or failed attempted retrieval. Also, to simultaneously treat the underlying coronary disease, which was potentially not treatable with PCI.

Managing arterial access complications

Pseudoaneurysms

Pseudoaneurysms can form in any part of the arterial circulation, as a result of iatrogenic trauma weakening the wall.



Signs of pseudoaneurysms

- Swelling
- Pulsation
- Pain
- Bruit on auscultation

An urgent ultrasound should be requested to confirm the presence of a pseudoaneurysm.

Inital managent of pseudoaneurysms

- Symptomatically treat with analgesia
- Manually compress—preferably under ultrasound guidance
- Inject with thrombin if patient has a narrow neck
- Treat surgically (avoid if possible as ordinarily the patient will be on dual antiplatelet therapy in the presence of a recently implanted coronary stent)

Hematomas

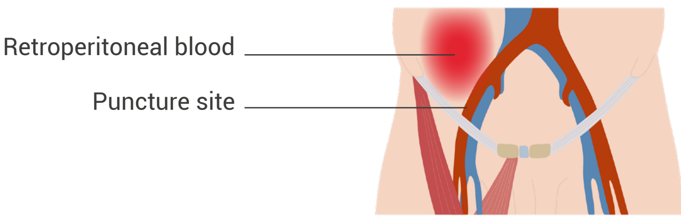
- A common complication associated with arterial access, as well as with the use of anticoagulant and antiplatelet agents—all utilized in PCI.
- Usually mild and self-limiting but can look fairly alarming to the patient.
- Very rarely, if extensive in the arm, they can result in compartment syndrome requiring surgical decompression.

Management for hematomas

- Analgesia
- Compression if acute and evolving
- Rest
- Elevation of the limb (if it is an arm that is affected)
- If severe and tender consider ultrasound to exclude additional underlying pseudoaneurysm

Retroperitoneal hemorrhage

- A dangerous complication associated with femoral PCI.
- Can sometimes be difficult to recognize, as bleeding occurs into the retroperitoneal space and cannot be seen externally.



- Clinicians should suspect a retroperitoneal hemorrhage if the hemoglobin value falls, especially in the context of a post-procedural fall in blood pressure.

- Abdominal pain on a straight leg raise exam.
- Cullen and Grey Turner signs usually occur late in the presentation as discoloration or bruising around the umbilicus and abdominal flanks.

Management of retroperitoneal hemorrhage

- Early diagnosis of retroperitoneal hemorrhage is imperative
- Fluid resuscitation should be initiated as soon as possible for circulatory support
- Emergency CT abdomen should be obtained to confirm diagnosis
- Manual compression of bleeding site may help if femoral vessels are easily compressible
- May require emergency blood transfusion
- May require reversal of anticoagulation
- May require interventional radiology stenting or open vascular surgical repair

Distal embolization

- May occur as a consequence of instrumentation of the aorta.
- Introduction of instruments to the aorta may cause cholesterol embolization from existing plaques.
- Embolization can involve peripheries and also renal or other end organs, which may present with organ specific findings, such as renal impairment.

After performing PCI, it is important to monitor patients for clinical and vital signs that indicate bleeding due to arterial access complications. You have to think about retroperitoneal hemorrhage if the patient is in shock with no obvious external bleeding, since it can often be occult.

Air embolus

- Almost always results from poor preparation of the system or lack of care by the operator and is occasionally a fault within the system due to a poor connection, allowing air to be entrained.
- Beware of too rapid withdrawal of a balloon, stents or equipment from the guide, this can create a vacuum as they are withdrawn and suck air from the outside. This is more common in smaller caliber guide catheters than larger ones.
- Air can also enter the system if the guide catheter is aspirated when the O-ring or hemostatic device is not properly closed. Make sure the O-ring is opened sufficiently and withdraw equipment in a controlled manner and not too quickly.
- Once removed it is good practice, if the equipment was bulky, to let blood bleed back from the O-ring before it is tightened up again.

Managing consequences of air emboli—such as ventricular fibrillation

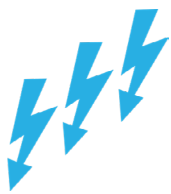
- Prepare for prolonged CPR
- Often things will get better as air is slowly absorbed from the distal coronary circulation
- Operator can try injecting contrast or saline into coronary vessels to push any air more distally
- Some advocate injection of patient's blood down coronary vessels (usually taken from a separate venous site)—there is little evidence of a different outcome compared to saline or contrast (probably just time and supportive therapy that works)

Arrhythmias

Arrythmias are common during percutaneous coronary intervention.

Management

- Clinicians should be trained in advanced cardiac life support. Always be ready to deal with arrhythmias with a team approach, utilizing all catheterization lab staff, including cardiac physiologists and nursing staff.
- Often in a monitored environment, clinicians can recognize arrhythmias and shock before the need to deliver cardiopulmonary resuscitation (CPR).
- Remember to try to wait a few seconds for the patient to lose consciousness.
- Stacked shocks—in the UK at least, the Resuscitation Council guidelines ordinarily advocate two minutes of CPR between each shock as part of the conventional cardiac arrest resuscitation algorithm for management of ventricular fibrillation (VF) or pulseless ventricular tachycardia (VT). We can shock straight away before a significant fall in coronary perfusion pressure occurs because the cause of the arrhythmia is often iatrogenic and can be quickly corrected; we sometimes just deliver stacked shocks (i.e., one immediately after another, up to three shocks of escalating energy).



- Continuing to manage the PCI procedure while safely defibrillating is sometimes very challenging. Remember to work as a team.
- Be aware as patients go into cardiac arrest and lose consciousness, they often move or sit up and therefore you can lose equipment balancing on the patient, lose the position of guide catheters, guidewires, inserted stents or lose sterility as the patient pulls off drapes or vomits, which can create further problems or complications for the PCI operator.
- Correct the issue causing arrhythmia if there is something readily correctable.
- Check for guide catheter dampening due to over engagement that you may not have noticed. You should have already been alerted to this by watching the pressure trace. Is the flow in the artery okay? Is the balloon or stent obstructing the vessel or is there acute no-reflow?
- Try not to keep injecting contrast if it is not clearing quickly—if it accumulates this may cause ventricular fibrillation (VF). Also, you may not have noticed a complication, such as dissection and you could be increasing intramural hematoma by forcing contrast into the false lumen.

These problems may also result in profound bradycardia, which may require atropine or the use of temporary cardiac pacing to achieve sufficient stability of the patient, in order to continue the PCI procedure.

Guide catheter kinking

- The guide catheter can become kinked or knotted due to operator manipulation.
- The operator should avoid over torqueing of the guide catheter, especially smaller diameter catheters, which can kink or twist more easily.
- For difficult manipulations try to leave the guide wire in situ while torqueing, to avoid kinking.

Management

- Try gentle counter torqueing.
- Try to reintroduce the guide wire or a very slippery wire, such as a Terumo wire, to pass through the kinked segment so it can be safely removed.
- Try to gently withdraw the guide catheter through the sheath. If this is impossible the guide can be snared from a larger access sheath (usually femoral) to enable it to be withdrawn.
- If the kink or knot does not allow removal through the sheath consider removal of sheath and knotted guide as one unit. This will then require hemostasis and alternate arterial access to complete the procedure.

With any complication, operators should always consider *phoning a friend*—a colleague with more experience can assist with complications or at least offer support in stressful situations. There is no shame—remember the most important thing is the best outcome for your patient.

Chapter 8

POST-PROCEDURE MONITORING

Caring for patients post-intervention

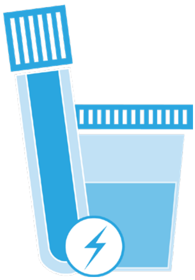
Following percutaneous coronary internvention, it is imperative that we ensure the patient is appropriately monitored throughout recovery.

We want to ensure that the patient has an optimal recovery and recognize any potential complications early. We do this by carefully monitoring the patient's vital signs following our intervention.

- Heart rate
- Blood pressure
- Continuous ECG monitoring
- Oxygen saturation
- Consciousness level
- Symptoms
- Cardiac enzymes
- Urine output (if hemodynamic compromise occurred or there is a history of pre-existing renal dysfunction)

Remember that a fall in blood pressure and / or an increase in heart rate could indicate early decompensation for possible blood loss and this should be evaluated urgently.

- Check that hemostasis has been achieved at the arterial access sites.
- The patient should also be assessed.
    - symptoms (e.g., chest pain or breathlessness)
    - consciousness level if sedation was administered
    - adequate tissue perfusion and renal status by observing urine output
    - obtain a blood sample for urea and electrolytes and a complete blood count
    - 12-lead ECG and cardiac enzymes evaluated post-procedure (if there were complications to suggest periprocedural MI)



CBC and electrolytes

Cardiac enzymes

Treating post-PCI hypotension

What if blood pressure is low post percutaneous coronary intervention?

There are a number of factors that can cause hypotension post-PCI. Some are benign, others concerning.

Benign causes of hypotension

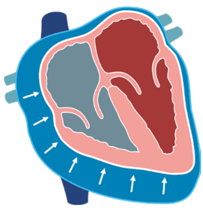
Benign causes include

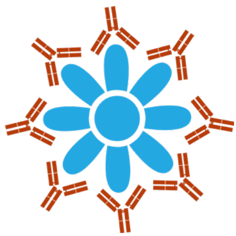
- Sedation
- Analgesics
- Use of intracoronary nitrates
- Use of a radial artery anti-spasm cocktail (usually verapamil and isosorbide dinitrate)

Serious causes of hypotension

Serious causes include

- Cardiac tamponade
- Coronary perforation
- Anaphylaxis
- Myocardial infarction
- Arterial hemorrhage

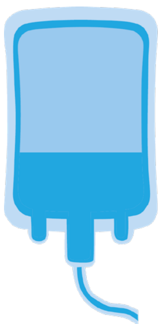




Management of hypotension

Management steps should include

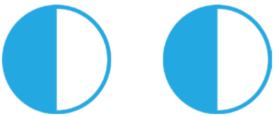
1. Address and manage post-PCI hypotension by rechecking observations, including arterial access sites, the abdomen, and the skin.
2. Secure adequate IV access and administer fluids.
3. Vasopressors, such as phenylephrine or metaraminol, may be warranted, if major hemorrhage is suspected.
4. Urgent blood products or transfusion may be considered.
5. Consider reversal of any sedation the patient received.
6. Look to find and correct the underlying cause of the hypotension.
7. An ECG should be obtained.
8. Urgently repeat angiogram or echocardiogram to help identify the cause (e.g., missed coronary perforation, pericardial tamponade).
9. Suspected retroperitoneal hemorrhage may require an urgent CT scan.



Evaluating for visual or neurologic complications

Assess patient for any features clinically consistent with stroke (including the following)

- Homonymous hemianopia
- Facial droop
- Limb weakness
- Speech disturbance



If present request an urgent CT brain to determine if a stroke is hemorrhagic or embolic and determine subsequent emergency management.

Acute hemorrhagic stroke

- May need to reverse heparinization based on the measured activated clotting time (ACT)
- Stop administering antiplatelet agents
- Consider a platelet infusion if active or ongoing bleeding or if emergency neurosurgical intervention is required

Embolic stroke

- Emergent embolectomy or thrombolysis should be considered in coordination with a stroke team

Nonspecific neurological symptoms

What if there is no evidence of a cerebrovascular accident?

Patients undergoing any contrast related procedure can develop nonspecific neurological symptoms.

- Confusion
- Cerebellar dysfunction
- Ophthalmoplegia
- Cortical visual impairment
- Triggering of visual aura associated with migraine

The etiology of these is unclear but may be due to the direct neurotoxic effects of the contrast agent used, called contrast induced neurotoxicity. This is more frequently seen in patients undergoing cerebral angiography where large amounts of contrast are delivered more locally into the cerebral circulation.

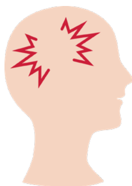
In coronary angiography and PCI, these symptoms seem to be more common in patients with hypertension or poorly controlled blood pressure, significant renal impariment, and patients undergoing angiography of the internal mammary arteries (probably due to more contrast entering the carotid and vertebral arteries during these procedures).

Most resolve spontaneous and completely with supportive management and the passage of time.

Visual changes

Minor visual symptoms are not unusual after contrast procedures including angiography or PCI. Transient visual disturbance seems particularly common post-angiography or post-PCI.

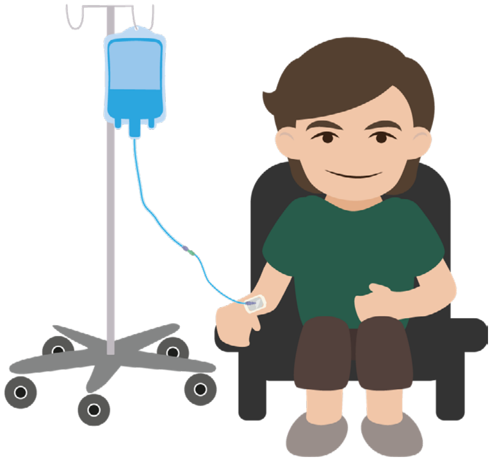
- It is often related to the volume of contrast used, being more prevalent when high volumes are used in complex PCI.
- It is thought to be related to the direct effects of contrast in the visual cortex, which may be exacerbated by lying for long periods in the supine position during complex PCI.
- Can rarely result in transient cortical blindness or visual disturbance.
- Can sometimes trigger visual aura in patients who are susceptible to migraine.



- It may also be related to the use of intracoronary nitrates, which act as potent systemic vasodilators throughout the body and the heart.
- The patient will often complain of transient blurring of vision or visual disturbance as flashing lights or lines across their vision, which quickly resolve.
- There are rarer causes of visual disturbance reported.
  - ophthalmoplegia
  - retinal cholesterol emboli
  - sub-clinical embolic or ischemic brain events following instrumentation of proximal aorta (may not show up on standard CT imaging but may be detected on subsequent brain MRI)

Management

1. The patient should sit up as soon as possible (a benefit of radial artery intervention)
2. Ensure adequate hydration (IV and oral)



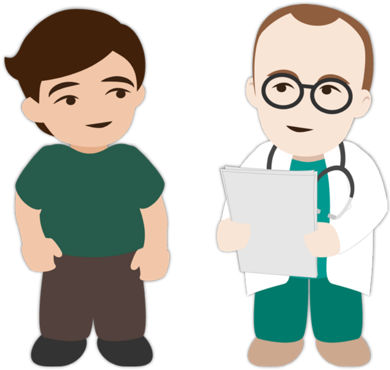
Discharging patients on the appropriate medical therapy

Ensuring that the patient understands their condition and can appropriately manage or seek follow-up care is an important part of post-procedure care.

Before a safe discharge

- Ensure the patient has been adequately monitored to assess for hemodynamic stability.
- The patient has been counseled on discharge instructions.
- The patient has been given verbal and written advice as to what they can and cannot do immediately post-PCI, how to manage bleeding complications, and who to contact should they have concerns.
- The patient has had their medications confirmed, especially any which have been newly commenced.
- The patient has been informed regarding any driving restrictions or recommendations, reviewed in line with the regulations and requirements applicable in your own country. (You need to ensure you are familiar with these, as patients often ask after the procedure when they are allowed to drive, in addition to when they can travel and go on vacation).
- The patient has had cardiovascular risk factors addressed and the importance of dual antiplatelet therapy post-PCI explained, reinforcing the need for good adherence to prescribed treatments to prevent acute stent thrombosis.

- The patient has a referral for cardiac rehabilitation.
- The patient has had future follow-up discussed and arranged if possible.



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