4 Left Heart Catheterization

Satpal Arri and Brian Clapp

About Us The authors are based at St Thomas' Hospital in London. This is a busy tertiary surgical center providing a primary angioplasty service to its local residents in central and south east London. The unit has an interest in complex coronary intervention and a thriving structural heart disease program. The department also has an internationally recognized productive research team with a particular interest in coronary physiology.

Introduction

The selective injection of contrast media into the right coronary artery of a middle-aged male by Mason Sones on October 30, 1958, introduced a new era in cardiovascular medicine that was to revolutionize our understanding and management of coronary disease. Two radiologists, Judkins and Amplatz, later used the Seldinger technique to gain access to the femoral artery. Independently, they designed pre-formed catheters, allowing easier intubation of the left and right coronary arteries as well as facilitating access to the left ventricle. This subsequently enabled the widespread dispersion of angiography as a diagnostic technique throughout the cardiology and radiology communities.

Noninvasive Investigations Prior to Coronary Angiography

- In patients with stable symptoms, noninvasive testing can enhance the pretest probability of finding significant coronary stenosis at the time of angiography and also provides important functional information on the extent and anatomical location of myocardial ischemia, which may guide future revascularization strategies.
- These include exercise treadmill testing (ETT), stress echocardiography, nuclear perfusion imaging, cardiac MRI, and cardiac CT.

Indications for Coronary Angiography (See Tables 4.1, 4.2, and 4.3)

- Coronary angiography is a prerequisite for coronary revascularization, and assists in clarification of cases with diagnostic uncertainty following noninvasive testing and in the assessment of other forms of cardiac disease such as valve disease or cardiomyopathy.

S. Arri · B. Clapp (✉)
Cardiothoracic Centre, St Thomas' Hospital, Guy's and St Thomas' Hospitals NHS Foundation Trust, London, UK
e-mail: brian.clapp@gstt.nhs.uk

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Table 4.1 Indications for coronary angiography

°•°Canadian cardiovascular society class III or IV angina on medical therapy
°•°High-risk criteria on noninvasive assessment
°•°Return of spontaneous circulation following cardiac arrest/pulseless ventricular tachycardia
°•°Acute coronary syndrome
°•°ST-elevation myocardial infarction—primary percutaneous coronary intervention
°•°Cardiogenic shock patients who may be candidates for revascularization
°•°Persistent hemodynamic and/or electrical instability
°•°Prior to valve surgery
°•°Unexplained cardiac arrest
°•°Prior to surgical correction of congenital heart disease
°•°Prior to cardiac transplantation

Table 4.2 Relative contraindications to coronary angiography

°•°Coagulopathy or formal anticoagulation—consider radial approach
°•°Decompensated congestive heart failure
°•°Uncontrolled hypertension
°•°Pregnancy
°•°Inability for patient cooperation
°•°Active infection
°•°Renal failure
°•°Severe contrast allergy

Table 4.3 The coronary angiogram checklist

Has consent been obtained?	
Relevant comorbidities	°•°Diabetes mellitus—last BM? °•°Renal impairment—consider IV fluids °•°Peripheral vascular disease—consider radial approach °•°Previous stroke? °•°Previous CABG—graft details, previous operation note
Recent bloods	°•°Hemoglobin °•°Platelets °•°Clotting studies °•°Renal profile
Allergies?	Consider hydrocortisone ± antihistamine for previous contrast allergy
Medications	Current anti-anginal therapy?
Dual-antiplatelet therapy (DAPT)	°•°Any bleeding issues or coagulopathy? °•°Has the patient been loaded on DAPT? °•°Any contraindications to long-term DAPT?
Height and weight	Will influence catheter selection and heparin dose
Good pulse?	Radial/femoral/ulnar Allen's test for radial access
Previous study?	°•°Previous catheters used? °•°Previous problems encountered? °•°Previous access used? °•°Previous angioplasty details?
Previous echocardiogram?	°•°What is the LV systolic function? °•°Any regional wall motion abnormality? °•°Valvular disease? °•°Dilated aortic root—will influence catheter selection
Does the patient require sedation?	Consider for all radial procedures to minimize spasm
Timeout	°•°Ensure that all staff involved are aware of the patient history, indication of procedure, comorbidity, and planned strategy °•°World Health Organization checklist
Is the team present?	An operator—to perform the procedure A cath lab nurse—to administer drugs and collect/hand over equipment A scrubbed assistant to the operator A radiographer—responsible for fluoroscopic equipment A physiologist—responsible for monitoring the ECG and cardiac pressures

- Given the small, but significant, risks and radiation exposure of diagnostic angiography careful patient selection is essential.
- Formal clinical assessment is the first and most important step in assessing patients with suspected ischemic heart disease. This includes a detailed clinical history incorporating evaluation of risk factors, thorough examination and baseline investigations including relevant blood tests (full blood count, renal profile, fasting glucose, cholesterol, and HbA1c), and an ECG.
- The sensitivity and specificity of all subsequent investigations depend on the pretest probability of coronary disease established during this process. This assessment is also key in obtaining crucial data on relevant comorbidities that may alter the safety of subsequent coronary angiography.

The Coronary Angiography Checklist

There are a number of essential patient and procedural factors to consider prior to coronary angiography. **The most important is a relevant indication for the procedure to be performed.** The remainder of the checklist can be seen in Table 4.3.

Informed Consent and Complications

- Invasive coronary angiography is not without risk although with improving technique, experience, and equipment the risk of major complications is generally quoted as less than 1 in 1000.
- The most common complication is vascular injury and bleeding that occurs in 1–2% of cases and is more common with femoral angiography compared to radial.
- Important complications that should be covered during the consenting process include contrast allergy, arrhythmia, stroke, myocardial infarction, renal impairment, radiation injury, bleeding, vascular complication, pericardiocentesis, need for emergency coronary bypass surgery, and mortality.

Coronary Angiography via the Right Radial Artery

- The right radial artery is now the default for most contemporary operators.
- Radial coronary angiography is associated with fewer vascular and bleeding complications as well as being more comfortable for patients. Patients are able to mobilize much sooner and many units now have dedicated radial lounges.
- The left radial approach also allows easier intubation of the left internal mammary artery (LIMA) in patients with a history of previous coronary artery bypass graft (CABG) surgery.
- Access is achieved using the Seldinger technique. Following puncture with a cannula, a guide wire is passed into the artery and advanced smoothly with or without fluoroscopic guidance.
- The needle is then removed and an arterial sheath of appropriate caliber is passed over the guide wire into the arterial lumen. Finally the guide wire is withdrawn and the sheath left in position.
- For diagnostic coronary angiography, 4, 5, or 6 French diameter catheters are commonly used (1 French = 1/3 mm).
- More complex coronary intervention may require larger diameter catheters (and hence larger sheaths). Specialist hydrophilic sheaths are also now available specifically for radial access.
- Given its relatively smaller size the radial artery is susceptible to spasm. Measures to reduce the risk of spasm include adequate hydration with intravenous fluids, light sedation, and administration of intra-arterial nitrates and/or verapamil.
- When performing coronary angiography via the radial artery patients also require 2500–5000 units of heparin in order to prevent radial artery thrombosis. This can be administered

via the radial sheath or via a diagnostic catheter into the aortic root.

- Once access is gained a standard 0.38-in. 150 cm J-tipped guide wire is passed into the ascending aorta. The catheter is then passed onto the guide wire and both catheter and wire are advanced under fluoroscopic screening until the guide tip is positioned in the ascending aorta.
- The wire position is then fixed to prevent further movement and the catheter advanced over its tip. Once in the ascending aorta, the guide wire is removed and the catheter allowed to bleed back to remove any air, thrombus, or atherosclerotic debris.
- When approaching the aortic arch from the right radial artery the guide wire may select the descending aorta. In this situation using the curve of the diagnostic catheter to help direct the guide wire usually allows passage of the wire into the ascending aorta.
- Asking the patient to take a deep breath in and hold also helps in straightening the vasculature allowing the guide wire to pass down to the aortic root.
- Coronary angiography via the radial artery can be technically challenging due to the greater tortuosity that needs to be negotiated as the catheter is passed from the wrist to the aortic root.
- Significant vessel tortuosity can hinder advancement and this is usually detected by resistance to free guide wire manipulation. In this situation direct fluoroscopy is essential in identifying the position of the wire tip and excluding vessel dissection.
- Careful passage of the catheter to the point of resistance with subsequent contrast injection may allow visualization of the arterial lumen and identification of the cause of obstruction.
- Often but not always this can be overcome with the use of a hydrophilic wire such as the Terumo wire.
- It should be noted, however, that significant tortuosity can make manipulating and torqueing the catheter more difficult and sometimes transferring to femoral access is necessary.
- Following challenging guide wire passage into the aortic root, a longer (260 cm) "exchange" wire should be used during subsequent catheter exchanges.
- The extra length allows the tip of the wire to be fixed in the aortic root during catheter exchanges, thus preventing repeated guide wire passage and potential injury through difficult or diseased areas of the peripheral arterial system as well as reducing the risk of radial artery spasm.
- Once in the ascending aorta, the guide wire is removed and the catheter allowed to bleed back to remove any air, thrombus, or atherosclerotic debris.
- The catheter is then connected to the manifold assembly that is connected to a pressure transducer allowing continuous central pressure monitoring. Once connected a few milliliters of blood should be aspirated back into the manifold prior to flushing the catheter to ensure an air-free system (Fig. 4.1).
- The catheter should then be filled with 3–4 mL of contrast and advanced to intubate the coronary system.
- Many operators would advocate assessing the right coronary artery first when performing radial angiography. This is because right coronary catheters have less curve and so are less traumatic to the radial artery compared to left catheters, thus potentially reducing the risk of radial artery spam.

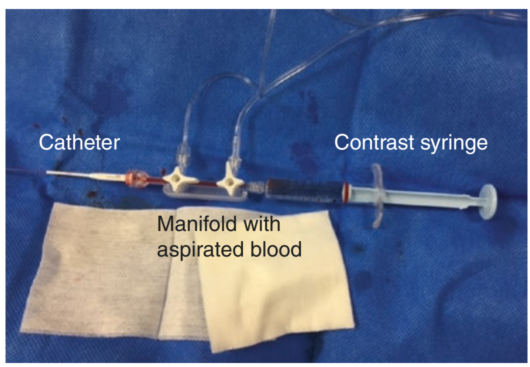


Fig. 4.1 Ensure that a few milliliters of blood are aspirated back from the catheter into the manifold prior to flushing to ensure an air-free system

- The right coronary artery should be engaged in the left anterior oblique (LAO) projection while the left coronary system should be engaged in the PA (posteroanterior) or LAO projection.
- Once at the coronary ostium operators must be diligent in ensuring that there is no ventricularization or damping of the pressure prior to a small contrast injection of 2–3 mL.
- Coronary angiography should be performed in standard views in orthogonal planes to appreciate the anatomy, visualize lesions, and serve as a road map for future revascularization or intervention.
- Non-standard views should be considered based on coronary anatomy, lesion location, and patient body habitus.
- At the end of the procedure the diagnostic catheter should be removed over the J-tipped guide wire to straighten out the curve on the catheter and thus minimize the risk of vascular injury.
- A number of devices including the TR band or Helix device can be used to achieve hemostasis once the radial sheath is removed.

Coronary Angiography via the Right Femoral Artery

- Technically easier as there are fewer bends to negotiate when advancing the catheter to the aortic root.
- Furthermore, the majority of diagnostic catheters were designed to intubate the coronary arteries from the femoral artery. In patients with a history of previous CABG, the left internal mammary artery can be intubated more easily from the femoral approach if the left radial is not directly accessed.
- The larger femoral artery is, however, associated with a greater risk of vascular injury and bleeding complications and the femoral artery should therefore be avoided in patients who are anticoagulated.
- Femoral access is achieved using the Seldinger technique as described above. Being a larger artery the femoral artery can accommodate larger 7F and 8F sheaths that may be required for complex coronary intervention.
- Vascular complications include hematoma, pseudoaneurysm, and retroperitoneal bleeding. The femoral puncture should ideally be at the mid point of the femoral head above the femoral artery bifurcation. Usually puncture should be made 1–2 cm above the inguinal crease although we would advocate screening the groin first using an overlying metallic object such as a blade, scalpel, or scissors (see also Chap. 5).
- One should also consider real-time ultrasound-guided vascular puncture especially when introducing larger sheaths for complex interventions.
- Following vascular access a femoral angiogram should be performed by injecting contrast directly into the side arm of the sheath. This not only confirms the position of the puncture and the appropriateness of vascular closure devices at the end of the procedure, but also excludes any significant vascular complication that may have arisen.
- If the patient then becomes hypotensive during the case, at least most femoral complications have already been excluded as a potential cause with the exception of a retroperitoneal bleed.
- Once access is gained and position of the puncture and sheath confirmed, a standard 0.38-in. 150 cm J-tipped guide wire is passed into the descending aorta.
- The catheter is then passed onto the guide wire and both catheter and wire are advanced under fluoroscopic screening until the guide tip is positioned in the ascending aorta. The wire position is then fixed to prevent further movement and the catheter advanced over its tip. Once in the ascending aorta, the guide wire is removed and the catheter allowed to bleed back to remove any air, thrombus, or atherosclerotic debris.
- Passage of the guide wire within the aorta may be difficult. From the femoral route, iliofemoral atheroma or tortuosity may hinder advance-

ment and this may be detected by resistance to free guide wire manipulation. In this situation direct fluoroscopy is essential in identifying the position of the wire tip. Careful passage of the catheter to the point of resistance with subsequent contrast injection may allow visualization of the arterial lumen and identification of the cause of obstruction.

- Switching to a hydrophilic (e.g., Terumo) wire may help. For atheroma or tortuosity within the iliac system, a long sheath may be useful in protecting and straightening the area and improving catheter torque.
- Following challenging guide wire passage into the aortic root, a longer (260 cm) "exchange" wire may be used during subsequent catheter exchanges. The extra length allows the tip of the wire to be fixed in the aortic root during catheter exchanges, thus preventing repeated guide wire passage and potential injury through difficult or diseased areas of the peripheral arterial system.
- Once in the ascending aorta, the guide wire is removed and the catheter allowed to bleed back to remove any air, thrombus, or atherosclerotic debris.
- The catheter is then connected to the manifold assembly that is connected to a pressure transducer allowing continuous central pressure monitoring. Once connected a few milliliters of blood should be aspirated back into the manifold prior to flushing the catheter to ensure an air-free system (Fig. 4.1). The catheter should then be filled with 3–4 mL of contrast and advanced to intubate the coronary system.
- In stable patients it is routine practice to visualize the left coronary system first when performing femoral angiography.
- The left coronary artery should be engaged in the PA or LAO projection while the right coronary system should be engaged in the LAO projection. Following intubation of the coronary ostium operators must be diligent in ensuring that there is no ventricularization or damping of pressure prior to a small contrast injection of 2–3 mL.
- Coronary angiography should be performed in standard views in orthogonal planes to appreciate the anatomy, visualize lesions, and serve as a road map for PCI. Nonstandard views should be considered based on coronary anatomy, lesion location, and patient body habitus.
- At the end of the procedure the diagnostic catheter should be removed over the J-tipped guide wire to straighten out the curve on the catheter and thus minimize the risk of vascular injury.
- Hemostasis can be achieved with a number of vascular closure devices such as the AngioSeal or Proglide. If these devices are contraindicated due to the position of the puncture then manual pressure is required.

Monitoring During Angiography

- During coronary angiography there should be continuous monitoring of the electrocardiogram, peripheral oxygen saturations, and invasive blood pressure—transduced from the fluid-filled catheter (Fig. 4.2).
- Full resuscitation facilities should be readily available, ideally with access to mechanical circulatory support devices if needed.

Fig. 4.2 Cardiorespiratory monitoring alongside radiographic images during coronary angiography

Catheter Selection

- Catheters usually have two curves: the primary distal curve and a secondary proximal curve. The distance between the two curves is the length of the catheter.
- Generally shorter curves are more ideal for superior takeoffs while longer curves are better for inferior takeoffs.
- Important considerations when selecting a catheter include the access site. For example a Judkins Left size 4 would be a standard choice for the left coronary system when approaching via the femoral artery whereas many operators would prefer a Judkins Left 3.5 if performing radial coronary angiography.
- The diameter of the aortic root may also influence the catheter selection—larger roots are likely to require a JL5 or larger.

Catheters for the Left Coronary System

- Engagement of the left coronary ostium is usually performed in the PA or LAO projection. The most common catheters used are the Judkins Left (usually JL4) catheters (Fig. 4.3). Larger aortic roots may require a broader hooked section at the catheter tip and alternatives include the Amplatz catheters.

Catheters for the Right Coronary System

- Engagement of the right coronary system is usually performed in the LAO projection. Once the catheter is located in the aortic root, gentle clockwise rotation is used to engage the ostium. The Judkins Right is a common first choice with the Williams (3DRC) catheter a popular alternative (Fig. 4.4).

Catheters for Saphenous Vein Grafts

- Location of vein graft ostia varies with surgical technique and aortic root anatomy.
- Right coronary vein grafts may be accessed with a Judkins Right 4, right coronary bypass (RCB), multipurpose, or Sones catheters.

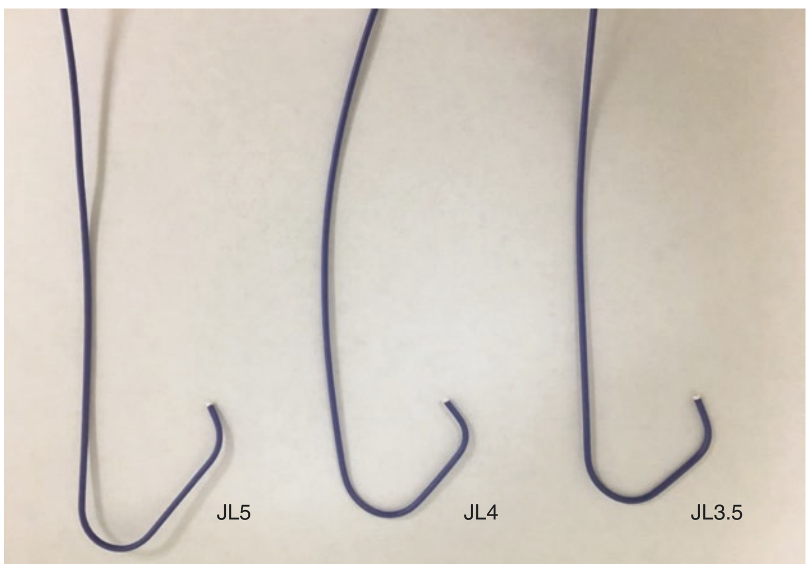


Fig. 4.3 Common diagnostic catheters to study the left coronary artery

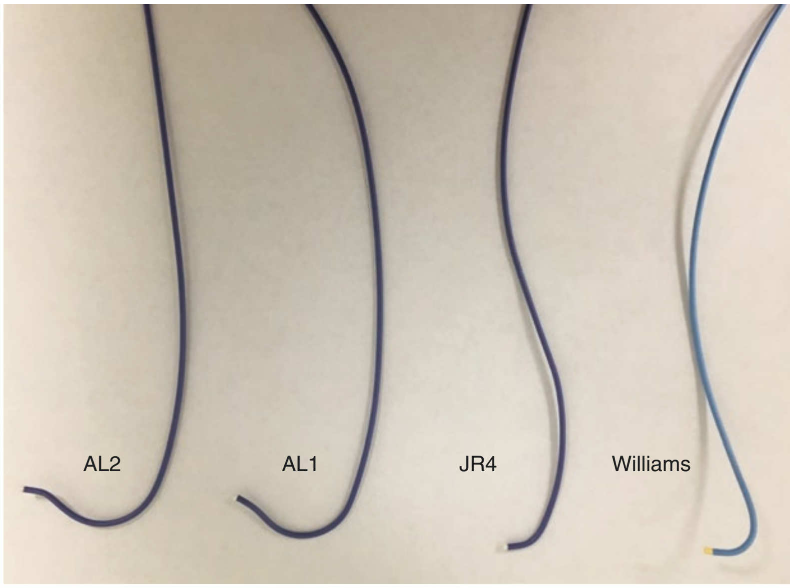


Fig. 4.4 Common diagnostic catheters to study the right coronary artery

- Left coronary vein grafts may be intubated successfully with a Judkins Right 4, left coronary bypass (LCB), or Amplatz catheters.
- Aortography can facilitate the location of vein graft ostia although patent grafts are not always identified, so this should not be first line when trying to locate vein grafts.
- Care must be taken to ensure coaxial intubation of a graft as otherwise lumen patency may be underestimated—this can typically occur with a right-sided graft and ma\y be avoided with a more gentle angle catheter such as a multipurpose.

Catheters for Internal Mammary Artery

- The left internal mammary artery (LIMA) is the most common arterial conduit used for surgical revascularization.
- The LIMA is usually accessed using a Judkins Right 4 or dedicated internal mammary artery (IMA) catheter from the aortic arch into the left subclavian artery (Fig. 4.5).
- Selective intubation does carry the risk of ostial dissection and often a nonselective injection is adequate to visualize the LIMA and the territory it supplies.
- Simultaneous inflation of a left-arm blood pressure cuff to supra-systolic pressure may improve LIMA visualization during nonselective contrast injection.
- LIMA grafts that are difficult to access may be more easily approached from the left radial artery.

Radial Catheters

- The standard catheters used in femoral angiography may also be used when performing radial angiography.
- However, most operators would start with a JL3.5 as opposed to a JL4.0 when initially attempting to intubate the left coronary system.
- Furthermore, many operators advocate imaging the right coronary artery first as the catheters used to intubate the right coronary artery have less curve and are thus less likely to induce radial artery spasm compared to standard left coronary catheters.
- Specific radial catheters now also exist that allow intubation of both left and right coronary ostia without catheter exchange. These include the Kimny (guide only) and Tiger and Ikari (guide only) catheters (Fig. 4.6).

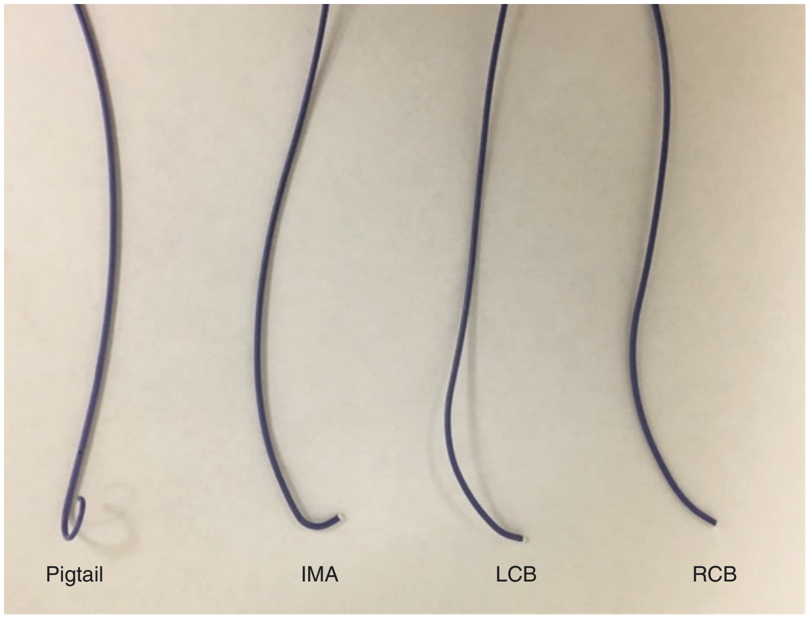


Fig. 4.5 Common diagnostic catheters used for graft studies

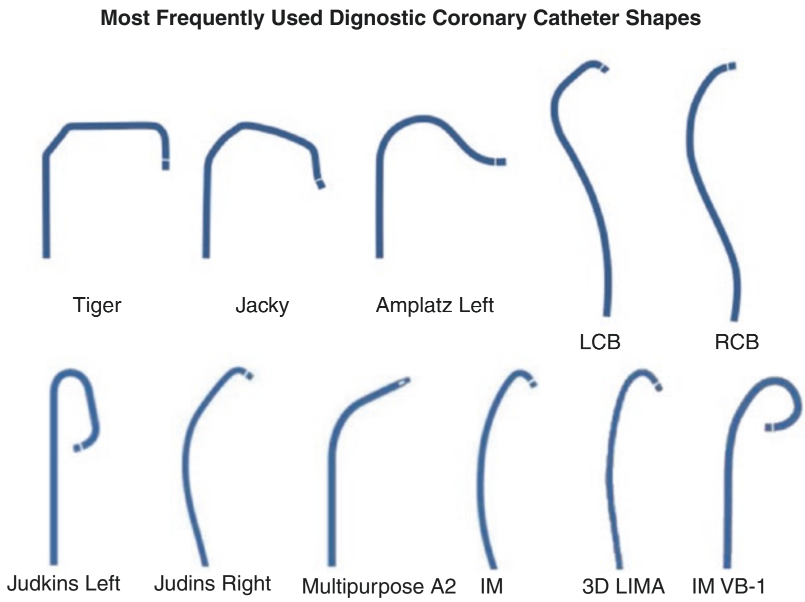


Fig. 4.6 Other commonly used diagnostic catheters

Complications That May Arise During Catheter Engagement

- **Coronary dissection**—This potentially life-threatening complication is more likely if there is ostial disease and may result from poorly controlled intubation, especially with a catheter tip that is not coaxial to the vessel. Subsequent high-pressure contrast injection can be potentially catastrophic.
- **Pressure damping**—This usually occurs in the presence of significant ostial disease although it can also occur on intubation of small-caliber vessels. Contrast injection reveals the extent of the disease usually with little back flow into the aortic root. Prolonged

intubation can lead to obstruction of coronary flow, ischemia, and arrhythmia.

- **Conal injection and arrhythmia—**Care must be taken when intubating the right coronary artery as the catheter tip may selectively intubate the conus branch. Subsequent contrast injection can result in ventricular arrhythmia. Thus injection of a small test shot of contrast is recommended following intubation and exclusion of pressure damping.
- **Coronary spasm—**Catheter intubation can promote coronary spasm and areas of spasm can appear angiographically similar to stenotic atheromatous lesions. Spasm, however, usually resolves with intracoronary nitrates.
- **Injection of air—**Operators should be meticulous in ensuring that there is no air in the manifold system and that all catheters are flushed prior to use. Despite these measures, in the event of injecting air ensure close monitoring of the ECG and hemodynamics as the patient can deteriorate quickly. In the majority of cases there is usually only transient ECG changes and/or hemodynamic instability.

Standard Angiographic Views (Figs. 4.7a–g and 4.8a–c)

Imaging Coronary Bypass Grafts

- Saphenous vein grafts are generally intubated in the LAO and RAO projections.
- In the LAO projection right-sided grafts are found on the left side whiles in the RAO projection left-sided grafts are found on the right side.
- The left internal mammary pedicle is accessed via the left subclavian artery in the PA projection.
- Two orthogonal views are required and may include the RAO caudal and LAO cranial projections although the projection angles may vary depending on each patient's anatomy (Fig. 4.9a–c).

Coronary Aneurysm

Coronary aneurysm is seen when the vessel diameter of a coronary segment is greater than 1.5 times that of a neighboring segment. The incidence is 0.15–4.9%. It is usually associated with atherosclerotic disease although other causes include Kawasaki, previous angioplasty, inflammatory disease, trauma, and association with connective tissue disease. Treatments include observation, surgery, covered stents, and therapeutic coiling (Fig. 4.10).

Common Coronary Anomalies

- Left main coronary artery originating from right sinus of Valsalva: This may run an interarterial course where there is an increased risk of sudden death, or a retroaortic course, which has a favorable benign prognosis.
- Right coronary artery originating from the left sinus of Valsalva.
- Right coronary artery originating above the sinus of Valsalva or from the anterior aortic wall.
- Left anterior descending artery originating from the right sinus of Valsalva.
- Left anterior descending artery and left circumflex artery originating from separate ostia.

Left Ventriculography

Although echocardiography has largely superseded left ventriculography it can still be useful in certain settings. The image is achieved by passing a pigtail catheter over a standard J-tipped guide wire into the left ventricle. Once in the left ventricle injection of a 30–40 mL

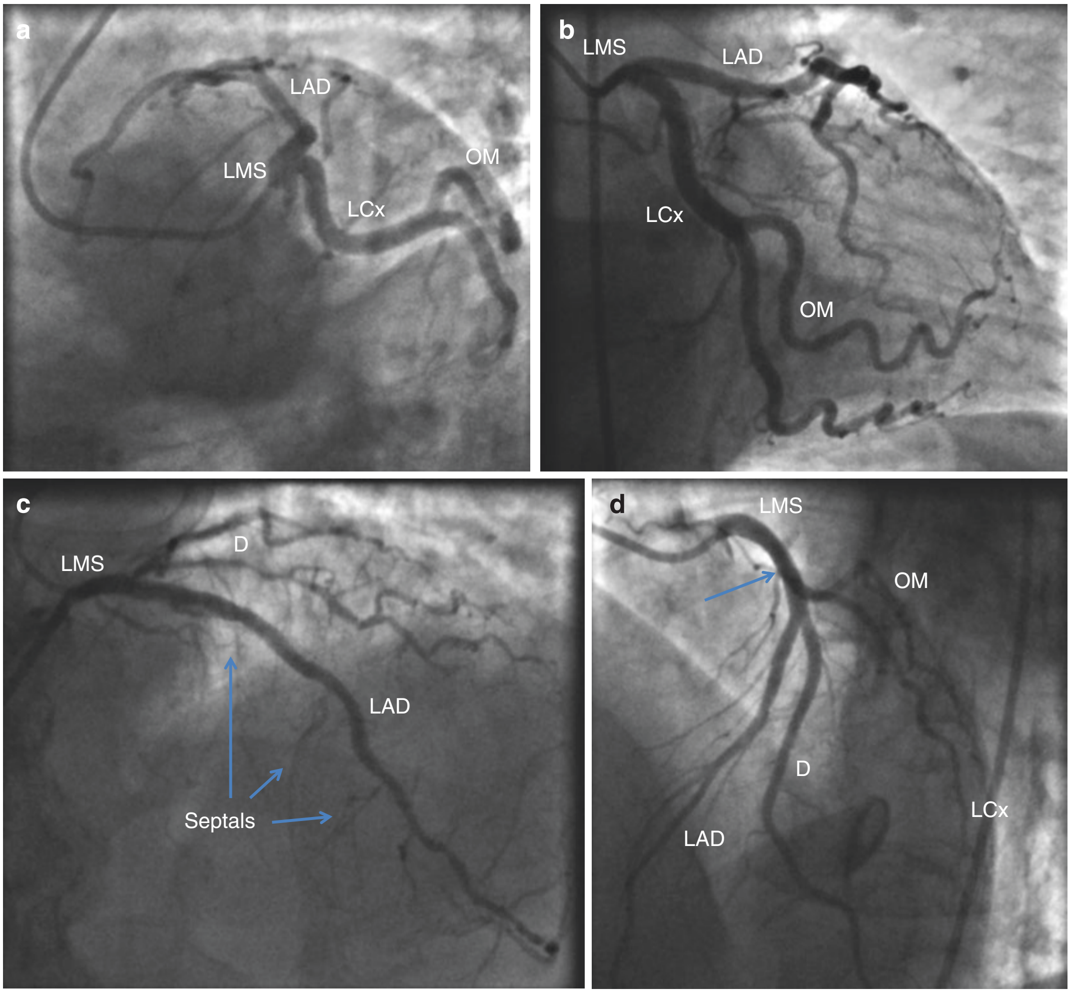


Fig. 4.7 Standard angiographic views—left coronary system. (**a**) *LAO caudal projection: 40–60° LAO and 10–30° caudal.* Commonly referred to as the "spider" view. This projection is best for visualizing the left main stem and proximal LAD/LCx bifurcation. Key: *LMS* left main stem, *LAD* left anterior descending, *LCx* left circumflex, *OM* obtuse marginal. (**b**) *RAO caudal projection: 10–20° RAO and 15–20° caudal.* Best for visualizing left main bifurcation, proximal LAD, and proximal to mid LCx. The greater separation of the LAD and LCx in this projection allows for better visualization of the OM branches of the LCx. Key: *LMS* left main stem, *LAD* left anterior descending, *LCx* left circumflex, *OM* obtuse marginal. (**c**) *RAO cranial projection: 0–10° RAO and 25–40° cranial*. Best for visualizing the proximal LAD and its diagonal branches. This view separates out the septals from the diagonals. The LCx is poorly seen in this projection. Key: *LMS* left main stem, *LAD* left anterior descending, *D* diagonal branch. (**d**) *LAO cranial projection: 30–60° LAO and 15–30° cranial.* This view is best for visualizing mid and distal LAD and the distal LCx in a left dominant system. This view also separates out the septals from the diagonals. The proximal LAD may be foreshortened in this view and overlapped by the LCx (arrow). Key: *LMS* left main stem, *LAD* left anterior descending, *LCx* left circumflex, *OM* obtuse marginal, *D* diagonal. (**e**) *PA projection: 0° lateral and 0° craniocaudal.* Many operators take their first image in a straight PA projection. This provides visualization of the left main stem ostium, proximal LAD, and Cx arteries. Key: *LMS* left main stem, *LAD* left anterior descending, *LCx* left circumflex, *PA* posteroanterior. (**f**) *PA caudal projection: O° lateral and 20–30° caudal.* This is an alternative view for assessing the proximal LAD/LCx bifurcation, especially if the other caudal views are affected by foreshortening or overlapping vessels. Key: *LMS* left main stem, *LAD* left anterior descending, *LCx* left circumflex, *OM* obtuse marginal branch. (**g**) *PA cranial projection: 0° lateral and 30° cranial.* This is an alternative to the RAO cranial projection and is best for visualizing the proximal and mid LAD and its branches. Key: *LMS* left main stem, *LAD* left anterior descending, *D1* first diagonal branch, *RAO* right anterior oblique

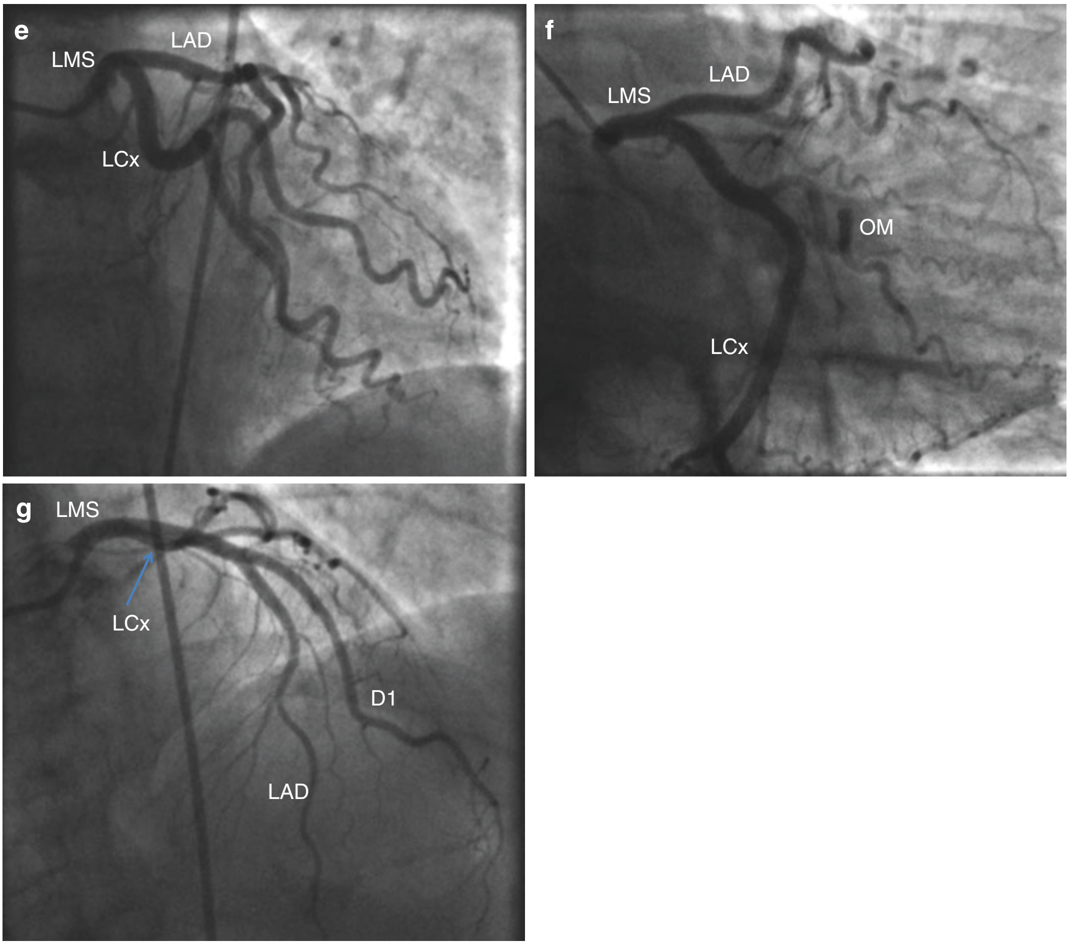


Fig. 4.7 (continued)

bolus of contrast via a mechanical pump at 10–15 mL/s allows assessment of left ventricular function and identification of any regional wall motion abnormalities. Left ventricular angiography is usually performed in the right anterior oblique projection, which also allows assessment of the degree of mitral regurgitation and demonstration of the aortic root. Crossing the aortic valve also provides key information on any gradient across the valve as is seen with aortic stenosis, although in cases of severe AS this is often avoided due to concerns of embolic stroke associated with trauma to a heavily calcified valve (Figs. 4.11 and 4.12).

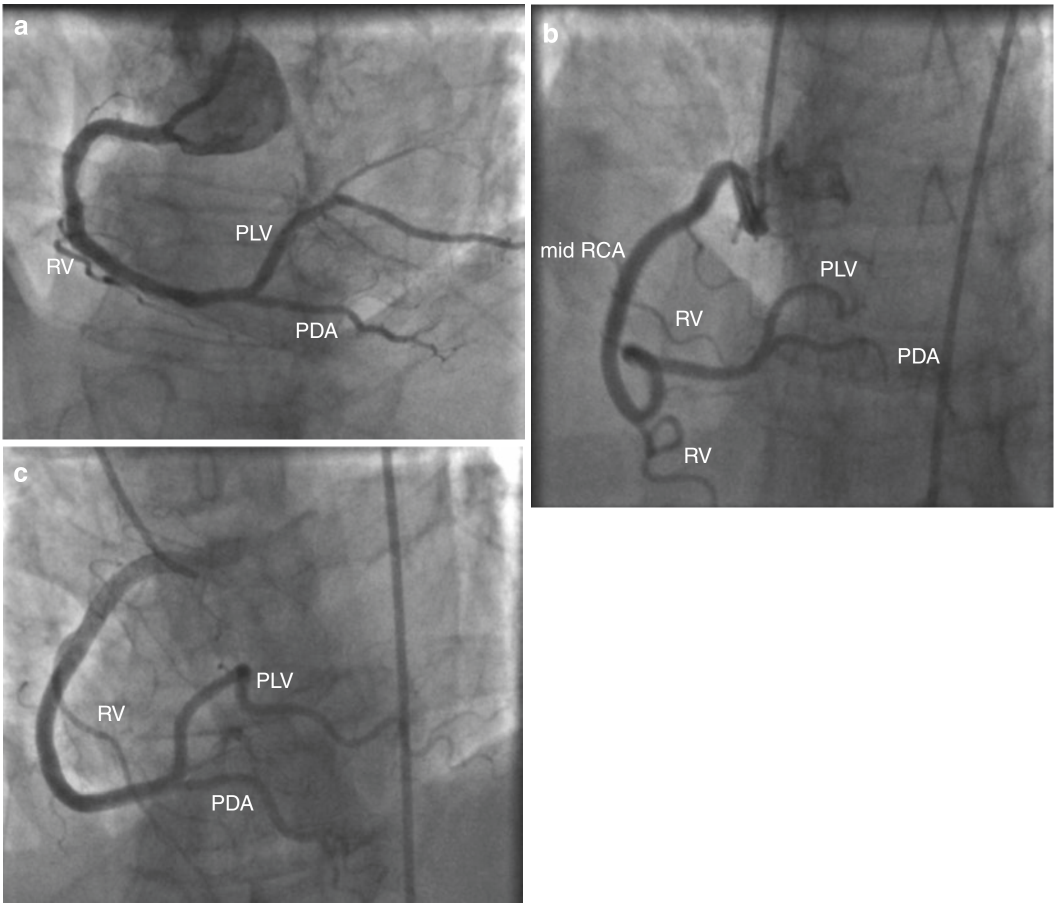


Fig. 4.8 Standard angiographic views for the right coronary system. (**a**) *LAO 30: 30° LAO*. This view is best for visualizing the ostial, proximal, and mid RCA. There is often some overlap of the distal branches. Key: *LAO* left anterior oblique, *PDA* posterior descending artery, *PLV* posterolateral ventricular branch, *RCA* right coronary artery, *RV* right ventricular branch. (**b**) *RAO 30: 30° RAO.* This projection is best for visualizing the mid RCA and PDA. The ostium and proximal RCA is often foreshortened in this view. Key: *RAO* right anterior oblique, *PDA* posterior descending artery, *PLV* posterolateral ventricular branch, *RCA* right coronary artery, *RV* right ventricular branch, (**c**) *PA cranial: PA and 30° cranial.* This view is best for visualizing the distal RCA bifurcation and the PDA. Key: *PA* posteroanterior, *PDA* posterior descending artery, *PL* posterolateral ventricular branch, *RCA* right coronary artery, *RV* right ventricular branch

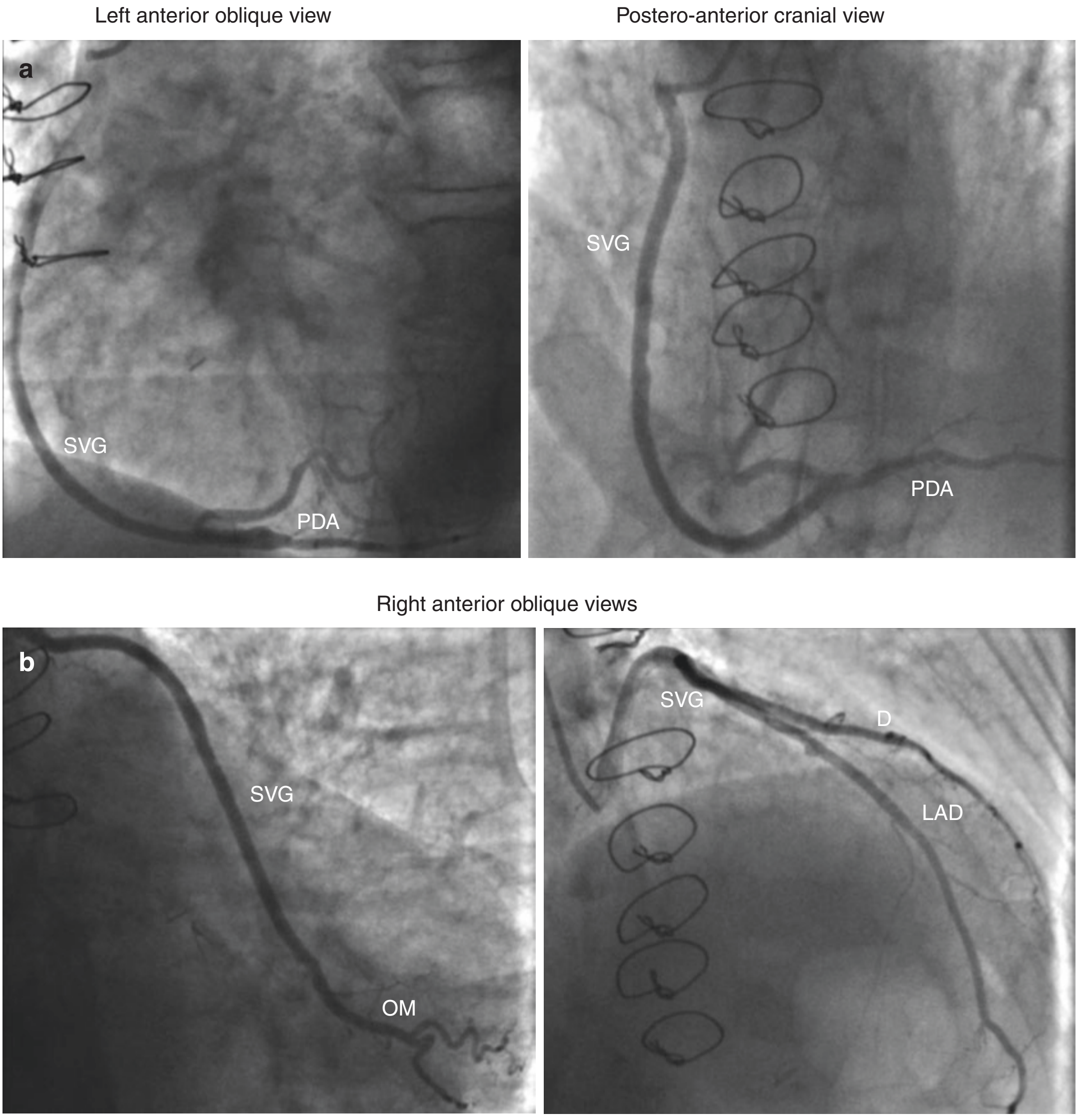
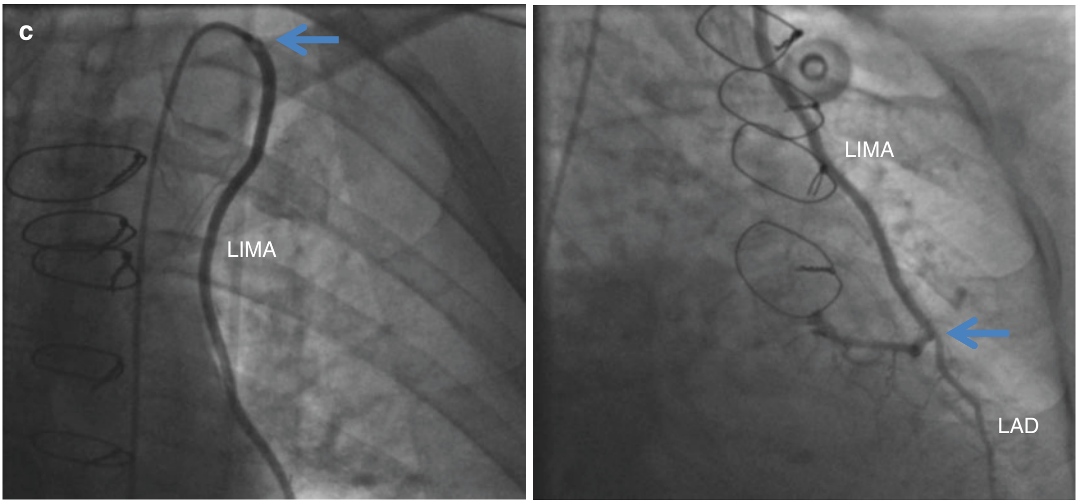


Fig. 4.9 (**a**) Standard graft study projections: saphenous vein graft (SVG) to posterior descending artery (PDA). (**b**) Standard graft study projections: saphenous vein graft (SVG) to obtuse marginal and SVG to left anterior descending (LAD) artery. (**c**) Standard graft study projections: left internal mammary artery (LIMA) graft origin (left, arrow) and anastomosis (right, arrow) with left anterior descending (LAD) artery



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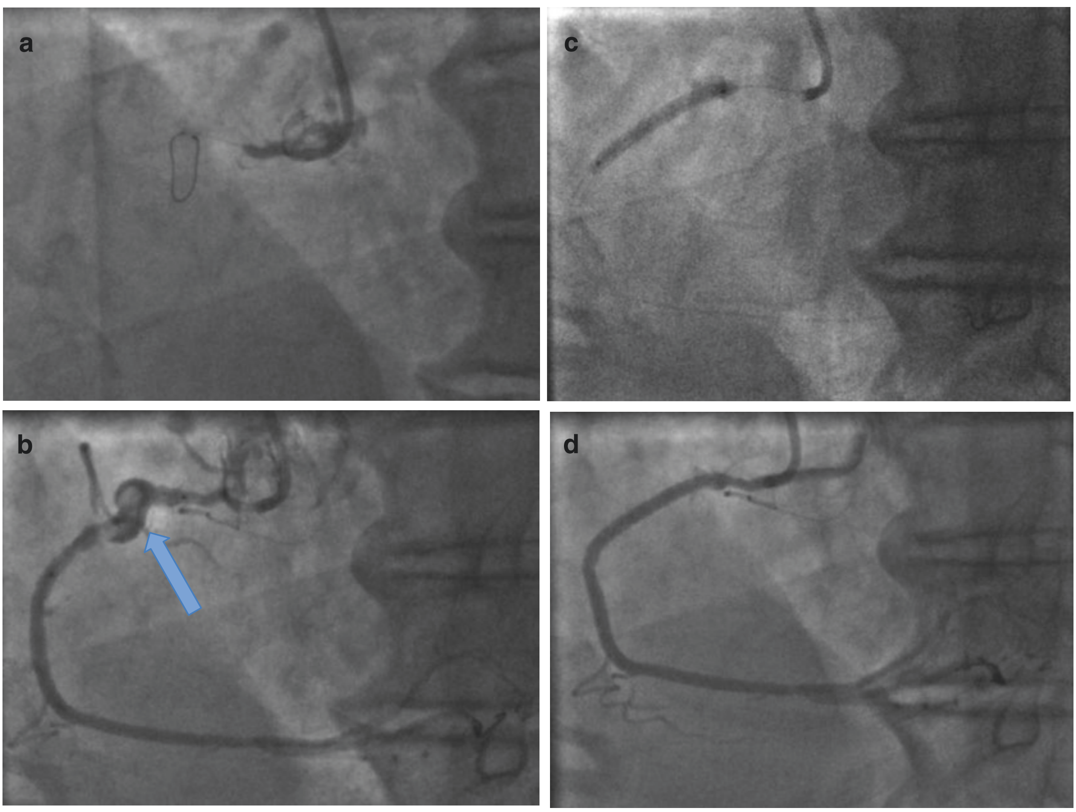

Fig. 4.10 Acute occlusion of right coronary artery (RCA) aneurysm treated by deployment of covered stent. (**a**) Acutely occluded proximal RCA with coronary wire looping around aneurysm; (**b**) restoration of coronary flow followed by positioning of covered stent across aneurysm (arrow); (**c**) inflation of covered stent balloon; (**d**) deployment of covered stent with restoration of normal coronary flow

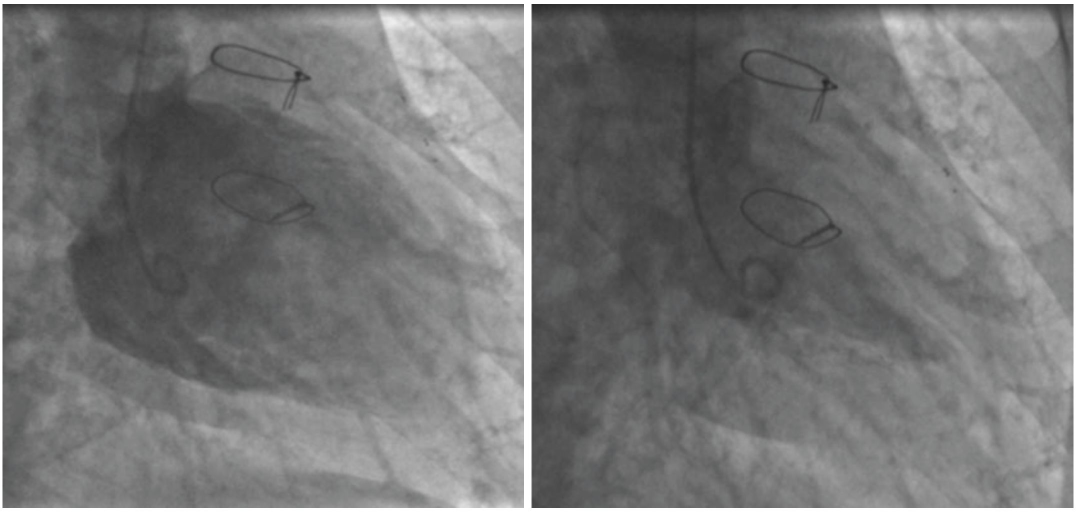

Fig. 4.11 Left ventriculography revealing overall preserved systolic function

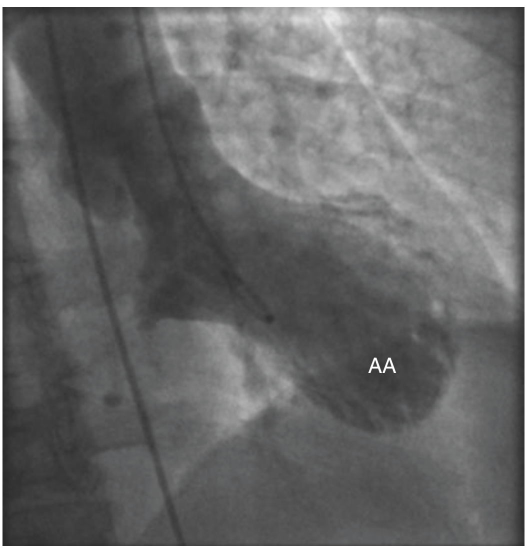

Fig. 4.12 Left ventriculography revealing an apical aneurysm (AA) consistent with Takotsubo cardiomyopathy

Aortogram

This is usually performed in the left anterior oblique projection and involves injection of 30–40 mL of contrast via a mechanical pump at 15–20 mL/s and pigtail catheter positioned in the aortic root. This allows assessment of the aortic root, ascending aorta, and arch and is particularly important in the workup of patients with significant aortic valve disease. An aortogram may also be performed when trying to locate the origins of bypass grafts (Fig. 4.13).

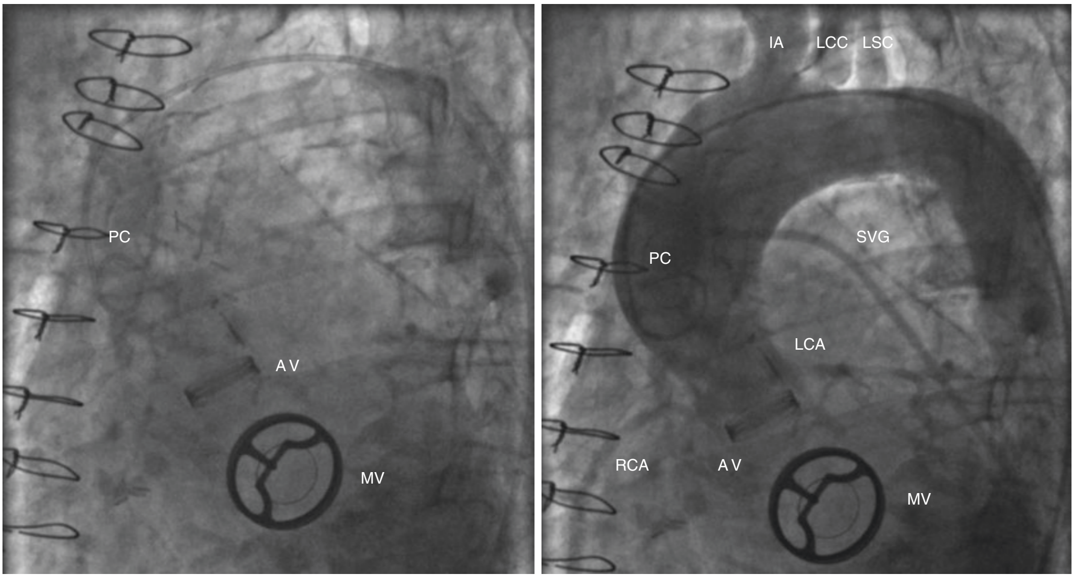

Fig. 4.13 A standard aortogram, before and after contrast injection, which allows for visualization of the aortic root, coronary ostia, aortic arch and great vessels, and origin of cardiac bypass grafts. Key: *PC* pigtail catheter, *AV* aortic valve (prosthesis), *MV* mitral valve (prosthesis), *RCA* right coronary artery, *LCA* left coronary artery, *SVG* saphenous vein graft, *IA* innominate artery (brachiocephalic trunk), *LCC* left common carotid artery, *LSC* left subclavian artery

Limitations of Coronary Angiography (See Table 4.4)

- Coronary angiography provides a two-dimensional image of a three-dimensional structure. Therefore a series of images must be obtained to allow visualization of all segments of the coronary arteries in at least two orthogonal projections.
- This is particularly relevant when assessing eccentric plaque as this may only be seen in a single projection.
- Particular attention must also be taken when assessing overlapping vessel segments as disease may be concealed.
- Significant disease may also be underestimated if coronary segments are progressing towards or away from the imaging plane as opposed to perpendicular to it—so-called foreshortening of the coronary vessel. This may also lead to underestimation of lesion length, which is problematic when planning a PCI strategy.
- These issues of overlapping segments and foreshortening are particularly relevant at bifurcation points. Here angiographic images should be obtained where the vessels are maximally divergent to ensure adequate assessment.
- Modification of standard views may be required to achieve an optimal dataset. Further information on lesion severity may require invasive techniques such as fractional flow reserve or intravascular imaging.

Table 4.4 Tips and tricks

RAO vs. LAO	If the spine and the catheter are to the right of the image, it is LAO and vice versa. If central, it is likely PA view
Cranial vs. caudal	If the diaphragm shadow can be seen on the image, it is likely a cranial view; if not it is caudal
LAD or LCx?	The circumflex is seen closer to the spine in all projections
Minimizing radial spasm	°•°Sedation °•°IV fluids + adequate hydration °•°Intra-arterial nitrates °•°Verapamil °•°Right coronary acquisition before left coronary system (especially when using radial access)
Radial loops	Significant tortuosity can usually be negotiated using a hydrophilic wire (e.g., Terumo). Subsequent passage of the diagnostic catheter usually straightens up most loops
Femoral tortuosity	Exchanging for a long sheath can help straighten out any iliofemoral tortuosity to allow better control of the diagnostic catheter
Vascular tortuosity	°–°Hydrophilic wire °–°Stiff wire—with caution °–°Long sheath—femoral °–°Exchange length wire for subsequent catheter exchanges
Dedicated radial catheters	When using dedicated radial catheters such as the TIGA, engage the left coronary ostium as you would normally do. Following left coronary acquisition, disengage the catheter, advance, and rotate clockwise to engage the right coronary ostium
Grafts	°–°Know the anatomy of the grafts prior to starting the case °–°Walk the catheter up and down in the RAO and LAO projections. For right-sided grafts the catheter tip should be pointing left in the LAO projection. For left-sided grafts the catheter tip should be pointing right in the RAO projection °–°If known LIMA graft consider femoral or left radial approach
Catheter selection	°–°If the catheter is easily folding up—consider larger size °–°If the catheter is pointing down into the aortic root consider a smaller catheter
Aortic stenosis	In patients with severe aortic stenosis the aorta can be very tortuous and the ostium of the RCA is often very inferior; aortic flow in valve disease may require a larger French catheter to allow adequate coronary opacification
Coronary anomalies	Always check that you have seen enough coronary arteries to supply the entire myocardial bed—are you missing another coronary?
Valves	Practice caution and be careful not to cross the aortic valve if there is active infection or significant calcific disease or with prosthetic valves
Minimizing contrast	Limited views – Left coronary system—LAO caudal, RAO caudal, and PA cranial/RAO cranial – Right coronary system—LAO and RAO
Poor radial pulse	Consider the left radial, ulnar, or femoral artery instead

Angiogram Interpretation

- Evaluate extent and severity of coronary calcification—ideally just prior to or soon after contrast opacification.
- Lesion quantification in at least two orthogonal views:
  - Severity
  - Calcification
  - Presence of ulceration/thrombus
  - Degree of tortuosity and angulation
  - Lesion length
  - ACC/AHA lesion classification (Table 4.5)
  - Reference vessel size
- Grading thrombolysis in myocardial infarction (TIMI) flow (Table 4.6).
- Grading TIMI myocardial perfusion blush grade (Table 4.7).
- Identifying and quantifying coronary collaterals:
  - *Grade 0*—no collateral circulation

Table 4.5 ACC/AHA lesion classification [1]

Type A lesion	Minimally complex, discrete (length <10 mm), concentric, readily accessible, non-angulated segment (<45°), smooth contour, little or no calcification, less than totally occlusive, not ostial in location, no major side branch involvement, and absence of thrombus
Type B lesion	Moderately complex, tubular (length 10–20 mm), eccentric, moderate tortuosity of proximal segment, moderately angulated segment (>45°, <90°), irregular contour, moderate or heavy calcification, total occlusions <3 months old, ostial in location, bifurcation lesions requiring double-guide wires, and some thrombus present
Type C lesion	Severely complex, diffuse (length >2 cm), excessive tortuosity of proximal segment, extremely angulated segments >90°, total occlusions >3 months old and/or bridging collaterals, inability to protect major side branches, and degenerated vein grafts with friable lesions

Table 4.6 TIMI flow grades [2]

TIMI 0 flow	Absence of any antegrade flow beyond a coronary occlusion
TIMI 1 flow	Penetration without perfusion—faint antegrade coronary flow beyond the occlusion, with incomplete filling of the distal coronary bed
TIMI 2 flow	Partial reperfusion—delayed or sluggish antegrade flow with complete filling of the distal territory
TIMI 3 flow	Complete perfusion—normal flow, which fills the distal coronary, bed completely

Table 4.7 TIMI myocardial perfusion grades [3]

Grade 0	Either minimal or no ground-glass appearance (“blush”) of the myocardium in the distribution of the culprit artery
Grade 1	Dye slowly enters but fails to exit the microvasculature. Ground-glass appearance (“blush”) of the myocardium in the distribution of the culprit lesion that fails to clear from the microvasculature, and dye staining is present on the next injection (approximately 30 s between injections)
Grade 2	Delayed entry and exit of dye from the microvasculature. There is the ground-glass appearance (“blush”) of the myocardium that is strongly persistent at the end of the washout phase (i.e., dye is strongly persistent after three cardiac cycles of the washout phase and either does not or only minimally diminishes in intensity during washout)
Grade 3	Normal entry and exit of dye from the microvasculature. There is the ground-glass appearance (“blush”) of the myocardium that clears normally, and is either gone or only mildly/moderately persistent at the end of the washout phase (i.e., dye is gone or is mildly/moderately persistent after three cardiac cycles of the washout phase and noticeably diminishes in intensity during the washout phase), similar to that in an uninvolved artery

– *Grade 1*—very weak opacification
– *Grade 2*—re-opacified segment, less dense than the feeding vessel and filling slowly
– *Grade 3*—re-opacified segment as dense as the feeding vessel and filling rapidly

References

1. Scanlon PJ, Faxon DP, Audet AM, et al. ACC/AHA guidelines for coronary angiography: executive summary and recommendations. A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee on Coronary Angiography) developed in collaboration. Circulation. 1999;99(17):2345–57.
2. TIMI Study Group. The thrombolysis in myocardial infarction (TIMI) trial. Phase I findings. N Engl J Med. 1985;312(14):932–6. https://doi.org/10.1056/NEJM198504043121435.
3. van ‘t Hof AW, Liem A, Suryapranata H, Hoorntje JC, de Boer MJ, Zijlstra F. Angiographic assessment of myocardial reperfusion in patients treated with primary angioplasty for acute myocardial infarction: myocardial blush grade. Zwolle Myocardial Infarction Study Group. Circulation. 1998;97(23):2302–6.