

CORONARY ANGIOGRAPHY IN THE ANGIOPLASTY ERA: PROJECTIONS WITH A MEANING

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Many textbooks, atlases, and handbooks discuss the techniques for obtaining optimal views of all segments of the coronary arterial system. Most of these chapters, however, were written in an era when coronary surgery was the prevailing revascularisation treatment and little attention was paid to details of the lesion site and its relation with branches. Operators and surgeons were satisfied that the coronary angiogram provided sufficient information to judge whether lesions were “significant”—that is, deserving revascularisation, or “non-significant”, to be left alone and allowed visualisation of the likely site of coronary anastomosis of the bypass graft and its “run-off”. Percutaneous transluminal coronary angioplasty (PTCA) has now become the dominant method for coronary revascularisation, with a ratio of PTCA: coronary artery bypass graft surgery (CABG) of between 4–8:1 in most European countries and 2.1:1 in the UK in 2003.¹ With the exception of the UK, where we are still seeing new catheter laboratories being opened for purely diagnostic purposes, in the worldwide setting coronary angioplasty is carried out immediately after diagnostic angiography. Besides cost and organisational benefits, this approach offers advantages in terms of morbidity and mortality in unstable patients when rapid treatment reduces the incidence of ischaemic events.² Under this pressure, diagnostic angiography has evolved from a standard series of 8–9 views for the left coronary artery and 2–3 views for the right coronary artery to a more focused imaging modality. Nowadays, a limited number of projections are used to provide an overview of the status of the coronary arterial tree and to identify the ideal projections to be used as working views for coronary angioplasty.

CATHETER SELECTION AND MANIPULATION: WHICH SIZE AND TECHNIQUE

With improvements in catheter technology, 6 French thin walled catheters provide equivalent or better flow rates compared with old 7 and 8 French diagnostic catheters (table 1). Satisfactory coronary opacification can now be achieved with 5 French and sometimes 4 French diagnostic catheters.

In order to increase flow, the majority of modern diagnostic catheters no longer have a tapered tip, yet they remain safer for ostial cannulation by virtue of their softer tip construction and smaller size. Further downscaling of catheter size is limited by the need to apply considerable force during injection to obtain optimal opacification, especially of the left coronary artery. Even with a short length and large inner diameter of the connecting tubes it is not always possible to manually generate the required force, and additionally this force may disengage the catheter from the coronary ostium. Newly developed automatic injectors with adjustable rise in injection pressure (Acist, Bracco Diagnostics) have partially solved this problem and allow the routine use of 4 or 5 French diagnostic catheters with obvious advantages in terms of reduced vascular damage at the catheter entry site. A small catheter size is particularly helpful when a radial approach is used in small patients and especially Asian female patients, because this will minimise the risk of occlusion of the radial artery and prevent arterial spasm.³ A possible disadvantage of the disappearance of the 7 and 8 French catheters is the poor torquability of modern thin walled diagnostic catheters. This has resulted in the routine use of pre-shaped catheters (Judkins, Amplatz, etc) and the disappearance of techniques using a single straight catheter (Multipurpose, Castillo, etc) which had been used in the past particularly for the brachial approach. Interestingly, the catheter selection and technique described below can be used not only for the femoral and left radial or brachial approach but also for the right radial/brachial approach providing that the guide wire is advanced just above the aortic valve and withdrawn with the catheter tip pointing towards the desired coronary ostium. Specially designed catheters for radial angiography, however, are occasionally helpful in simplifying cannulation.⁴

LEFT CORONARY ARTERY

The standard catheter for imaging the left coronary artery is the 4.0 Judkins catheter in the majority of cases. Occasionally, for small females a 3.5 mm left Judkins catheter can be the first choice. If previous investigations have demonstrated an enlarged ascending aorta, a 4.5 mm or

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Table 1 Inner lumen diameter of commonly used diagnostic catheters (measurements provided by the manufacturers)

	8 French	7 French	6 French	5 French	4 French
Cordis	0.067 inch body 0.047 inch tip	0.057 inch body 0.047 inch tip	0.051 inch body* 0.042 inch tip* 0.057 inch body† 0.057 inch tip†	0.044 inch body* 0.042 inch tip*	0.042 inch body† 0.042 inch tip†
Boston Scientific Medtronic		0.064 inch‡	0.056 inch‡ 0.055 inch§	0.045 inch‡ 0.045 inch§	0.042 inch§

*Supertorque; †Infiniti; ‡Expo; §Site Steer.

5.0 mm left Judkins catheter may be the preferred choice. The optimal projection for engaging both right and left coronary arteries is the left anterior oblique view because this ensures that the sinus of Valsalva and ascending aorta are not superimposed on either of the coronary ostia. In particular, for the left coronary artery the use of a standard antero-posterior (AP) view or right anterior oblique view should be discouraged because it is difficult to appreciate the take-off of the left coronary artery including the presence of significant lesions or calcification at the coronary ostium (fig 1). For intubation of the left coronary artery, the need for catheter manipulation is minimal. The J tipped 0.035 inch or 0.038 inch wire is advanced to the level of the aortic valve and the Judkins catheter tip is positioned as low as possible pointing towards the left coronary ostium. The guidewire is then withdrawn, a pressure line connected and a test injection performed which normally shows the catheter to be engaged at the ostium or located immediately below it. In the latter case, gentle withdrawal of the catheter will allow engagement of the tip. Asking the patient to take a deep breath will facilitate engagement of both coronary ostia by ensuring a more horizontal course to the left main and proximal right coronary arteries. If the catheter tip loops immediately in the ascending aorta, one should switch early to a larger catheter (for example, 5.0 mm). When an unusual size or position of the coronary ostia is anticipated (aortic valve disease, Marfan syndrome, or congenital heart disease) it is helpful to perform an aortic angiogram in the left anterior oblique view to guide catheter selection. This may include unusual shapes such as left Judkins 6.0 or left Amplatz 2.0 and 3.0.

RIGHT CORONARY ARTERY

For intubation of the right coronary artery, the preferred strategy is the use of a 4.0 right Judkins diagnostic catheter in the left anterior oblique view. The catheter must be rotated to point to the right in this view and this is best achieved when rotation is combined with a slow pull-back motion of the catheter from the right coronary sinus. Breathholding in deep inspiration may facilitate this manoeuvre. In 10–15% of cases, a high origin of the right coronary artery complicates the search for the right coronary ostium. It is often possible to obtain a semi-selective injection with the Judkins catheter to guide catheter selection. If this is unsuccessful, an aortogram in the left anterior oblique view may be helpful (fig 2). A multi-purpose catheter should be used for a downward directed right coronary artery and Amplatz right 2 or Amplatz left 1 or 2 in patients with dilatation of the coronary sinus and ascending aorta.

Careful review of the images should be performed before completing the angiographic examination. This will avoid missing cases such as a separate origin from the aorta, a conus branch providing collaterals to occluded arteries, or an abnormal origin of the left circumflex artery from the

proximal right coronary artery—the most frequent coronary anomaly.⁵

PROBLEMS AND PITFALLS

In the approach to the left coronary artery, the main concern is the presence of ostial left main stem disease. A reduction in pressure with ventricularisation (low diastolic values) of the pressure wave form indicates that the catheter is obstructive. This may be caused by the presence of a true ostial stenosis or by a small coronary ostium occurring in a hypoplastic left coronary system or in a patient with small body weight such as Asian females. Additionally, it may result from deep engagement of the catheter tip beyond the left main into the ostium of the left anterior descending (LAD) coronary artery or left circumflex artery. This is more likely to occur when the left main stem is very short, or the two arteries originate directly from the aorta.

Coronary artery spasm can always be generated by catheter engagement. The problem of spasm is more frequent at the ostium of the right coronary artery where the catheter is almost always “damping” pressure if the artery is non-dominant. Pressure damping is also encountered in small patients despite having normal dominant arteries and using 5 French diagnostic catheters. Furthermore, a deep sudden engagement of the proximal coronary artery may elicit severe ostial spasm. The careful injection of a small amount of isosorbide dinitrate (100–150 µg) or glyceryl trinitrate (1–2 mg) helps in the differential diagnosis. Every case of pressure damping should be managed carefully, with prompt catheter withdrawal if needed. For example, it is imperative to avoid leaving contrast opacifying the conus branch of the right coronary artery because of the risk of triggering ventricular fibrillation.

ANGIOGRAPHIC VIEWS FOR THE LEFT CORONARY ARTERY

Table 2 lists the angiographic projections and optimal visualisation of the left and right coronary segments.

LEFT CAUDAL VIEW

The so-called “spider view” (fig 3B) has the main advantage of displaying the bifurcation of the left main stem into the LAD and left circumflex arteries (or trifurcation if an intermediate artery is present). For this reason, it seems sensible to use the left caudal view as the first projection to exclude the most fearsome of coronary lesions which still demand surgical intervention in most cases. A more horizontal or vertical axis of the heart will require steeper (increased caudal) or more lateral spider views, but in general the inclination varies between 25–40° caudal and 30–50° to the left. It should be noted that in the left caudal projection x ray penetration will be limited. This is a problem in obese patients where images are suboptimal and often

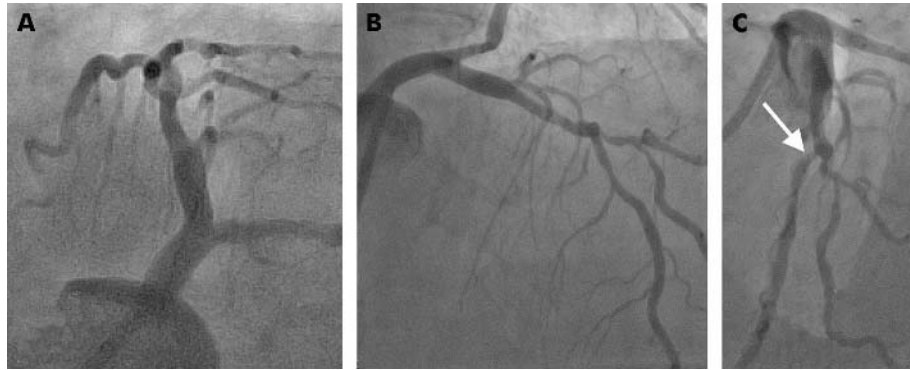


Figure 1 (A) Left anterior oblique, 30° caudal. The image is clearly inadequate for visualising the stenosis at the bifurcation of the mid left anterior descending coronary artery (LAD) and second diagonal branch. Note that the image optimally displays the bifurcation of the LAD and left circumflex, but the shaft of the left main stem is foreshortened and the left main ostium is partially hidden by the coronary sinus. (B) 10° right anterior, 42° cranial view. The image optimally elongates the proximal and mid segments of the LAD and offers the best working projection for treatment of the bifurcation lesion. Note the improved elongation of the left main shaft and optimal delineation of the left main ostium while at the left main bifurcation the two branches are completely superimposed. (C) 40° left anterior oblique, 35° cranial view. Despite the obvious foreshortening and superimposition of the sinus of Valsalva on the proximal LAD, this image offers the best view of the stenosis distal to the bifurcation of the mid LAD (arrow).

have a grainy appearance, particularly with old angiographic equipment. It is rarely possible to use this view as a routine working projection for angioplasty, with the exception of wiring of the left circumflex and left anterior descending (LAD) coronary arteries if they lie partially superimposed in the right caudal views and, occasionally, during wiring of proximal diagonal branches. The LAD is greatly foreshortened in the mid segment in this view, but stenosis of the proximal segment or of the ostium of the first diagonal branch is often optimally visualised. The left circumflex artery, in contrast, is optimally displayed in its proximal and mid segments while cranial views are generally more helpful in elongating the more distal branches.

RIGHT CAUDAL VIEWS

The classical view uses a 30–40° angulation to the right. However, an easier working projection with less respiratory movement involves the use of reduced angulation to the right (10–20°) which provides an optimal image even with relatively skewed caudal angulation (30–40°) (fig 3A). The degree of caudal angulation is determined by the angle required to open the LAD and left circumflex artery and to

obtain an optimal image of the proximal and mid segments of the left circumflex artery and the bifurcation of its marginal branches. The right caudal view is of limited value for imaging the proximal and mid LAD because of the frequent superimposition of diagonal and septal branches, but remains the most important view for the distal LAD and should be used to measure the TIMI (thrombolysis in myocardial infarction) frame count when required. Occasionally, ostial lesions of the LAD or intermediate branch are better demonstrated in this view than in the spider view.

RIGHT CRANIAL AND ANTEROPOSTERIOR CRANIAL VIEWS

If the right caudal view is the usual working projection for the left circumflex and intermediate arteries, the AP cranial view is the ideal working projection for most lesions of the proximal and mid LAD. Although in the past the cranial view was obtained with a 30° angulation to the right, this has the disadvantage of greater superimposition of the diagonal branches and of an uneven background, with wide excursion of the diaphragm during respiration when used as working projection during angioplasty. It is therefore conventional to

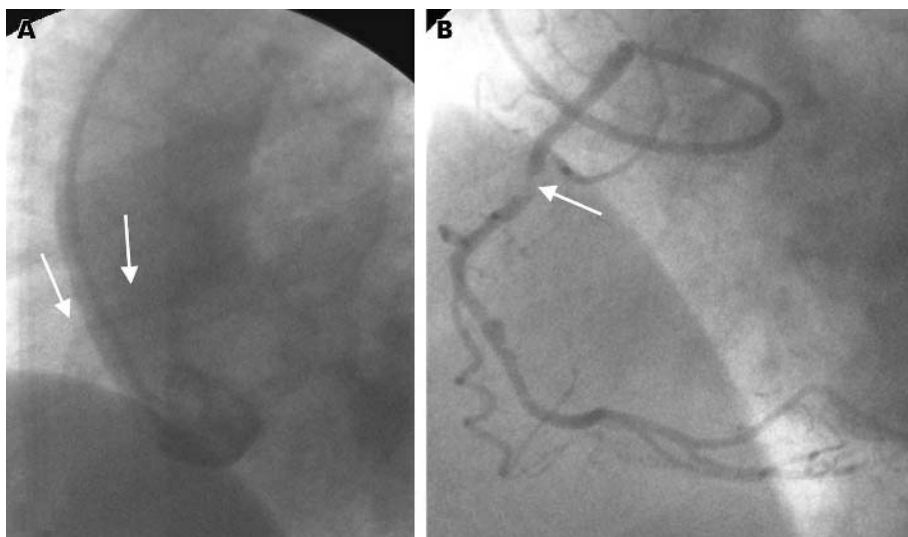


Figure 2 (A) Repeated attempts at cannulating the right coronary artery were unsuccessful and failed to visualise the ostium even with a large injection through the right Judkins catheter low in the right coronary sinus. An aortogram is performed in a 60° left anterior oblique view. The high posterior origin of the right coronary artery (arrows) is partially delineated facilitating the subsequent catheter selection. (B) A 5 French multipurpose catheter is used to cannulate selectively the right coronary artery in the same view, showing a severe stenosis of the mid segment (arrow).

Table 2 Angiographic projections and optimal visualisation of left and right coronary artery segments

Coronary artery segment	LAO 40–50°, caudal 25–40° (spider)	AP/RAO 5–15°, caudal 30°	RAO 30–45°, caudal 30–40°	AP/RAO 5–10°, cranial 35–45°	LAO 30–45°, cranial 25–35°	Lateral ± caudocranial 10–30°	LAO 45–60°	RAO 30–45°
LM ostium	++	+	+	+++	+++	-	-	-
LM bifurcation	+++	+++	++	-	-	-	-	-
LAD proximal	++	++	+++	++	++	+	-	-
LAD mid	-	+	+	+++	++	++	-	-
LAD distal	+	+	+++	+	-	+++	-	++
LAD/diagonal	++	+	-	++	+++	-	-	-
LCX proximal	+	+++	+++	-	-	-	-	-
LCX distal	+	+	++	+++	++	+	++	-
OM bifurcation	++	+++	++	-	-	-	+	-
RCA proximal	-	-	-	+	+++	-	++	-
RCA mid	-	-	-	-	+	+++	++	+++
RCA distal/crux	-	-	-	+++	+++	-	++	-
PDA	-	-	-	+++	++	-	+	++
PLV	+	-	-	+++	++	+	+	-
LIMA anastomosis	+	-	-	-	-	+++	-	-

- View not recommended; + occasionally useful; ++ very useful; +++ ideal view.

AP, anteroposterior; LAD, left anterior descending; LAO, left anterior oblique; LCX, left circumflex; LIMA, left internal mammary; OM, obtuse marginal; PDA, posterior descending artery; PLV, posterior left ventricular; RAO, right anterior oblique; RCA, right coronary artery.

work in a more skewed cranial view (40° or more). This manoeuvre separates the proximal and mid LAD from the diagonal branches which run to the right and septal branches which run to the left of the screen, while a possible superimposition remains only with the circumflex artery in the proximal segment. It is often necessary to incorporate a 5–10° tilt to the right to avoid superimposition of the catheter and the vertebral spine on to the LAD. The insertion of a filter wedge to cover the right upper field of the image is required to obtain better contrast definition. Although the ostia of the diagonal branches are often better delineated in left cranial or left caudal views, the AP cranial view is the most useful

working projection for angioplasty because treatment can continue in this view without breathholding, which is often required for the left cranial view in heavy patients and with suboptimal equipment. The segments which are foreshortened in the AP cranial view include the distal LAD and the proximal left circumflex artery. Interestingly, this view is also ideal for elongating the distal posterolateral branches of the left circumflex artery.

LEFT CRANIAL VIEW

This view is used to straighten the proximal and mid LAD and delineate its relation with septal branches which arise at

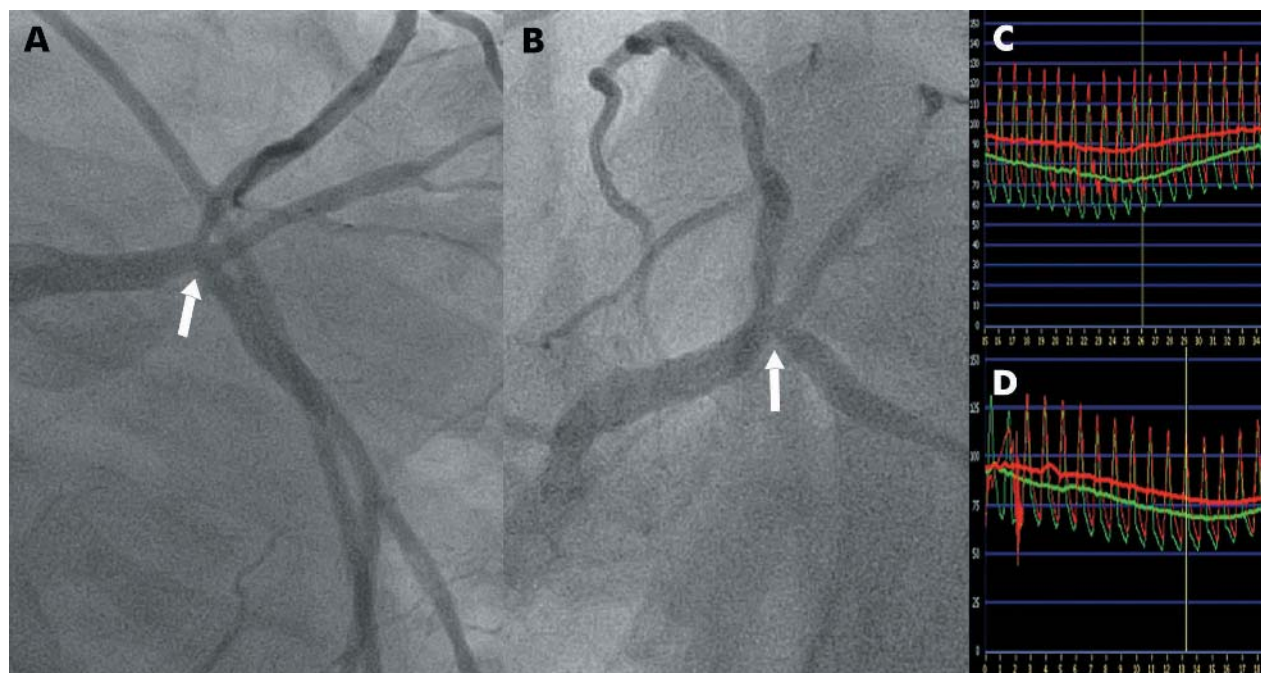


Figure 3 (A) 15° right anterior oblique, 30° caudal view. The improved fluoroscopic quality, smaller respiratory excursion, and reduced operator irradiation makes this view the preferred working projection for angioplasty of this lesion of intermediate severity of the distal left main/ostial LAD (arrow). (B) 45° left anterior oblique, 35° caudal view ("spider"). This view offers the greatest separation of LAD, intermediate, and left circumflex arteries. (C, D) As always, in the case of lesions of intermediate severity, a functional assessment is performed using a RADI pressure wire. After 86 µg of adenosine a fractional flow reserve of 0.89 is recorded in the left circumflex artery (C), reflecting the severity of the distal left main stenosis, and of 0.82 in the LAD (D), reflecting the severity of both the left main and ostial LAD stenosis. No intervention is required.

an acute angle to the left of the main vessel and diagonal branches running to the right. The LAD is further elongated by asking the patient to take a deep breath and maintain breath-holding during injection. This manoeuvre is also important for moving the diaphragm out of the field in this view. Visualisation may be suboptimal if the LAD lies on the spine so that, especially in obese patients, it may be necessary to increase the left angulation to 40–45° compared with the usual 30–35°. The cranial angulation varies according to the position of the heart in the chest and it is not unusual for vertical hearts to be optimally imaged with skewed views at 35–40° cranial. The cranial projection also offers optimal views of the mid and distal segments of the left circumflex artery, particularly in the presence of a dominant left circumflex system. If the previous views have optimally shown the distal LAD and circumflex, attention can be focused on the proximal segments using a 13–14 cm (5 inch) field of view. Obviously, “panning” will be required to follow the distal vessel. If the table movements during “panning” are smooth, the system can automatically adjust to the changes in background and maintain optimal quality.

LATERAL VIEW

This view is far from standard in modern coronary angiography. One practical reason is that the lateral view requires positioning of the hands above the head to avoid superimposition of the patient’s arms. This is a constrained position for the patient which cannot be comfortably maintained for long angioplasty procedures and often interferes with intravenous infusions. The main reason, however, is that the additional information gained from this view is minimal. The lateral view provides optimal visualisation only of the mid LAD and distal LAD around the apex—information which is at most complementary to the right caudal views. Occasionally, however, eccentric short lesions of the proximal and mid segment of the LAD might be obscured by septal or diagonal branches in all the conventional previously described views and can be better visualised in the lateral projection, often using variable cranial or caudal angulation to eliminate superimposition from the diagnostic catheter and side branches.

It should be noted that if the artery of interest is anterior in the chest (for example, the distal LAD territory), then there is no requirement for the patient to move to an uncomfortable

position with the hands beneath the head. This advice is particularly useful during visualisation of the distal anastomosis of the internal mammary artery where movement of the patient can dislodge the catheter from the mammary ostium or make selective cannulation more difficult. In cases where reduced contrast density in other views suggests the presence of an eccentric stenosis at the anastomosis of the left internal mammary artery, the lateral view should be performed with slight adjustment in the cranial-caudal angulation to optimise the visualisation of this critical segment and avoid any superimposition. Note that the lateral view is also ideal for excluding adhesion of the left internal mammary to the sternum, a condition which may increase the risk of re-intervention via a median sternotomy. Occasionally, the severity of an eccentric lesion of the left circumflex artery may be clarified in the lateral view.

RIGHT CORONARY ARTERY

The right coronary artery has fewer branches in the first, second, and third segment (from the ostium to the crux cordis) and often two views (left anterior and right anterior) are adequate to identify all stenoses, including eccentric lesions (fig 4, table 2). The lateral view may be ideal for assessment of the mid segment of the artery and is occasionally used as a working projection for occlusions in this segment or stent positioning. A problem with these standard views is the difficulty in interpretation of stenoses at the crux cordis or at the ostia of the posterior descending artery (PDA) and posterolateral branches, especially in the presence of a very well developed (hyperdominant) right coronary artery. Cranial angulation (30°) in the left anterior view usually solves these diagnostic questions. Many operators prefer to use a cranial (30°) AP projection as a routine view for the right coronary artery since this clearly delineates the region of the crux cordis and lesions of the posterior descending artery or posterolateral branches. Additionally, the AP cranial view is a more suitable working projection for angioplasty (fig 4C).

WHICH VIEWS SHOULD BE STANDARD?

The conventional approach to diagnostic angiography has been the use of a rigid sequence of multiple standard views. This often includes standard AP, right and left anterior oblique views without cranial or caudal angulation for the

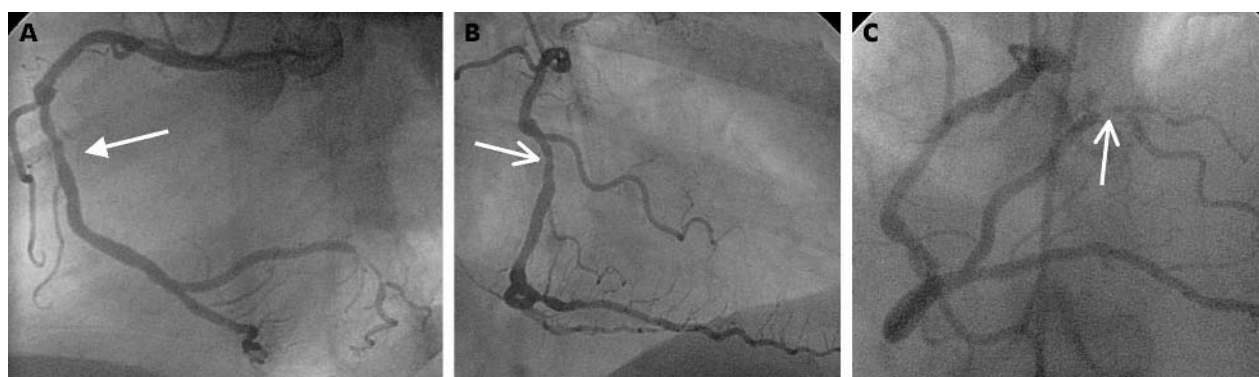


Figure 4 (A) 50° left anterior oblique view showing a 50% stenosis of the second segment of the right coronary artery (arrow). (B) 30° right anterior oblique view offering a complementary assessment of the severity of this eccentric lesion. Note that in this view the long posterior descending artery (PDA) is also well visualised at the bottom of the image with all septal branches pointing upwards. (C) 30° cranial anteroposterior view. Although this view conceals the stenosis of the mid segment of the right coronary artery, it offers excellent visualisation of the ostium of the right coronary, of the bifurcation of the PDA, and of the posterior left ventricular branch which, in this case, has a subocclusive stenosis (arrow).

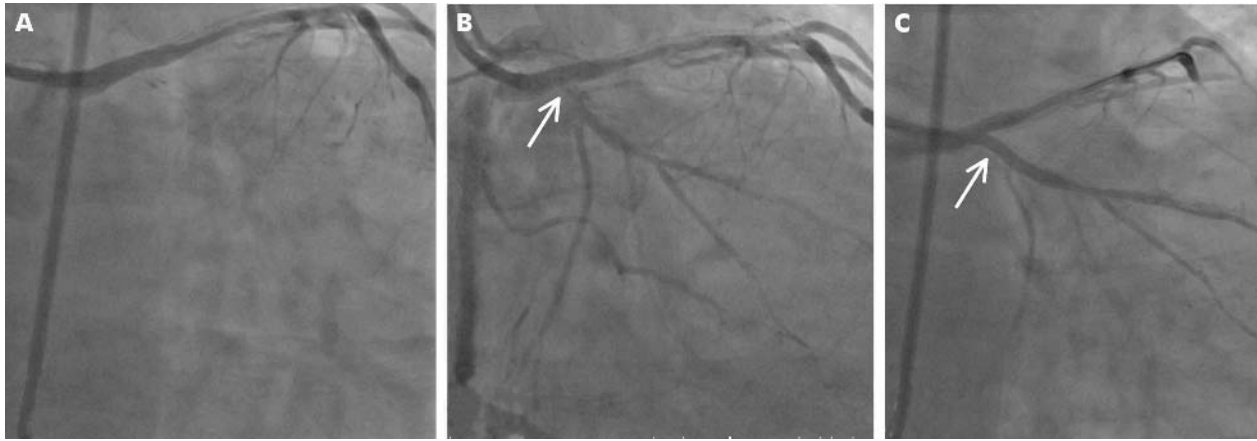


Figure 5 (A) 10° right anterior 30° caudal view. Injection of the left coronary artery shows a long left main stem with no visible circumflex and a moderate restenosis of the mid segment of the LAD. (B) In the same view contrast is injected simultaneously through the right and the left coronary arteries showing well developed collaterals from the right coronary to the mid distal left circumflex, identifying the site of origin of the circumflex and allowing measurement of the short segment of occlusion. (C) Final result after angioplasty in the same view showing complete recanalisation of the circumflex artery using a 3.5 mm drug eluting stent.

left and right coronary arteries. The modern approach requires immediate interpretation of the first angiographic images and interactive decision making guided by the question: did I see enough—that is, have I confirmed or ruled out the severity of all the individual lesions visualised and their relationship with side branches? The mature operator should be aware of the angioplasty possibilities and techniques and visualise the lesion in the most appropriate working projections for angioplasty. New projections should be used only when they are likely to offer additional important information, bearing in mind the radiation dose and contrast volume. In practice, this means that only three to four angiographic skewed views will be sufficient for the left coronary system in most cases and two to three views (or sometimes one if non-dominant) for the right coronary artery.

Rotational x ray coronary angiography is a promising new development which may completely change our technique of image acquisition. This method has been shown to reduce exposure to radiation and contrast and to offer comparable diagnostic accuracy.⁶ The currently available systems, however, can rotate only in a single plane (either transverse or sagittal). Rotational angiography will possibly replace the use of single plane acquisitions when the combined rotation in two planes will allow inclusion of most of the skewed caudocranial views described above.

HOW LONG SHOULD THE INJECTION BE?

It is very important that the injection of contrast is delayed until fluoroscopy commences in order to identify calcification or staining of contrast. The acquisition should continue until the contrast has cleared from the arterial tree. Slightly longer acquisition times are needed for TIMI frame count before and after treatment in primary angioplasty or for thrombus containing lesions. An important determinant of the length of injection is the need to visualise collaterals for occluded vessels. This also requires adjustment of the view to include the recipient vessel in the image—for example, showing the anterior wall and the mid distal LAD in the right anterior oblique view during injection of the right coronary artery. It is often valuable to image the occluded artery through both anterograde injection and retrograde injection of collaterals

in exactly the same view and in the same phase of respiration. For example, in the circumstance of an occluded right coronary artery, injection of the left coronary artery in the LAO view during deep inspiration opacifies the distal right coronary artery. A prolonged acquisition can allow an assessment of the length of the occluded segment by comparing this image with the image obtained after injection at the right coronary artery in the same view. Obviously, the ideal way to study occlusions in the presence of well developed collaterals from the contralateral artery is to perform a bilateral injection (fig 5). However, a double arterial puncture limits this approach which most operators would reserve to the time of angioplasty.

VENOUS BYPASS GRAFTS AND LEFT INTERNAL MAMMARY ARTERY

The optimal study of patients who have undergone coronary bypass surgery begins with a careful review of the operative and prior catheterisation records. The number of aortic anastomoses, the presence of sequential grafts, and a description of the quality of the arteries downstream must be carefully considered at the time of angiography to avoid wasting time searching for non-existent grafts. One possible approach can be to drag the right Judkins catheter along the right profile of the ascending aorta in the left anterior oblique view from the right coronary ostium. Aortic anastomoses of radial arteries or venous grafts, even if not indicated by radio-opaque markers at the time of the operation, can often be visualised in this view a few centimetres above the ostium of the right coronary artery. Although the position and direction of the aortic anastomoses is influenced by the surgical technique, in general the anastomosis for the right coronary artery tends to be the lowest and has a more vertical origin from the aorta.

Selective cannulation of the right coronary graft may require a multipurpose catheter, forming a hook against the aortic valve and then withdrawing and rotating the catheter to cannulate the graft selectively. Grafts for the marginal or diagonal branches are more difficult to visualise and often require rotation with the catheter pointing in an anterior or posterior direction to engage the ostium. A longer catheter tip (for example, Amplatz right 1, or left 1 and 2) can often be

useful for difficult grafts. Rather than using large quantities of contrast for location of the ostia, it can be cost effective to perform an aortogram with the catheter slightly above the usual position against the valve—that is, immediately above the level of the right coronary artery. The aortogram will clarify at least the number of open grafts with the possible exception of grafts with extremely slow flow. These grafts, however, are often identified by the presence of contrast staining in cases of recent occlusion. Please note that the injection of small vein grafts (for example, diagonal or marginal branches) should be performed cautiously. If the assistant continues injecting for a prolonged period while following the graft from the ostium to the distal end, especially in the presence of flow limitation due to the catheter at the ostium, malignant arrhythmias may develop.

INTERNAL MAMMARY ARTERY

The use of the left internal mammary artery (LIMA) has been standard practice for the last 10–15 years, so that most patients after bypass surgery require the evaluation of these grafts, by far the most important in terms of prognosis. The origin of the subclavian artery can be most easily engaged in a left anterior oblique view (40–60°) and the use of a gentle 5 French diagnostic catheter is unlikely to damage even a calcified aorta or ostia of the cranial vessels. Occasionally, a non-selective injection at the ostium of the left subclavian or innominate artery can be useful when important tortuosity or narrowing of these vessels are expected. Once the right coronary artery or LIMA catheter are positioned at the ostium of the left subclavian artery, it is worthwhile rotating the x ray gantry to an AP or a slightly right anterior oblique angulation to define the origin of the internal mammary from the subclavian artery. In older patients with calcification and tortuosity, a 0.035 inch J tipped guide wire should be used to lead the diagnostic catheter in order to minimise trauma. It is not sufficient merely to confirm patency. The injection should offer complete visualisation because the presence of distal stenoses (anastomotic or in the distal native vessels) needs to be excluded and collaterals for other occluded vessels must be visualised.

The selective visualisation of the mammary artery is more easily achieved with a specially designed LIMA catheter which has a longer tip than the classical right Judkins catheter. However, the presence of severe tortuosity of the proximal subclavian can make manipulation of the LIMA catheter very difficult. Occasionally, other types of LIMA catheter with a “hook like” shape (Bartorelli, etc) can be helpful, especially if the LIMA catheter tends to have an excessive horizontal orientation when withdrawn around the curve of the subclavian artery. The alternative approach of injection through slightly larger catheters (6 French large lumen diagnostic) or with the use of power injectors, possibly combined with occlusion of the brachial artery with a pressure cuff, can occasionally avoid the risks of a true superselective injection of the LIMA in very tortuous and frail subclavian vessels. Please note the importance of checking carefully for a normal pressure trace to exclude wedging of the catheter against the vessel wall before any injection, including test injections.

In the most complex cases steerable wires (Whooley) can be used to engage the ostium of the LIMA, with the catheter subsequently advanced over the wire. This manoeuvre, however, has an inherent risk of ostial damage. A left radial approach is occasionally the only and often the safest

solution if multiple attempts from the groin remain unsuccessful. The problems become more difficult to overcome for the right internal mammary artery because of the more tortuous course from the ascending aorta. Since in most cases a LIMA will also be present, the right radial approach unfortunately cannot be used for visualisation of both mammarys, although some operators report high success with techniques for visualisation of the LIMA from the right radial approach.⁷ In the case of the right internal mammary, the same principles of cannulation of the left subclavian artery are applied with greater care to avoid trauma to the right common carotid artery.

Regarding coronary views, for both grafts and mammary arteries the optimal projections are similar to the projections recommended for the native arteries to which the grafts are anastomosed. We will therefore require an AP cranial view or right cranial view for the mid LAD, a right caudal view to visualise the distal LAD, a lateral view or a spider view for better visualisation of the distal anastomosis and to exclude adhesion of the left internal mammary to the sternum. For anastomosis to posterolateral or diagonal branches, right cranial views offer an optimal elongation of the vessel and visualisation of the distal branches. For right coronary artery grafts often anastomosed to the PDA or posterolateral branches of the right coronary artery, or both, it is necessary to open the distal right coronary artery bifurcation using AP cranial or left cranial views.

The right gastroepiploic artery (GEA) has been used as a conduit for bypass surgery, usually when mammary and saphenous vein grafts are unavailable. Angiography of this vessel is performed by first entering the common hepatic artery using a cobra catheter. The operator then advances a torquable hydrophilic guidewire to the gastroduodenal artery and then to the right GEA. Exchanging the cobra catheter for a multipurpose or right Judkins will permit selective angiography of the right GEA.

LEFT VENTRICULOGRAPHY

The injection of the left ventricle during coronary angiography has been considered an integral part of the examination. Many non-invasive techniques can provide similar or superior definition of the left ventricular cavity volume and global and regional wall motion, with the advantage that most of them can also dynamically study wall thickness and tissue characteristics (echocardiography, magnetic resonance imaging). In my experience, however, few patients will arrive at the catheter laboratory with a full recent report of one of such non-invasive techniques, despite their wide availability. Although this obviously demands better organisation of activities and a more logical sequence of non-invasive and invasive tests, a practical approach is to perform left ventriculography in these circumstances unless it is felt that the excess contrast load could jeopardise renal function, especially if angioplasty has to follow.

This pragmatic approach also includes a decision regarding the number of views of the left ventricle to be acquired. When biplane systems were a standard in catheterisation laboratories, this was obviously not relevant and a right anterior oblique and left anterior oblique view were routinely obtained. Nowadays, biplane systems are rarely used. They offer limited advantages for coronary angiography and angioplasty since a much smaller number of views is required, and preference is given to very skewed views which are difficult to obtain with a biplane system. The right



Figure 6 Angiographic result following an injection of 25 ml of contrast, injected at 18 ml/s, with a pigtail catheter positioned immediately above the renal artery origin in an 8° left anterior oblique view. This identified a severe ostial stenosis of the right renal artery (arrow). This additional information allowed a more complete treatment of this 76 year old patient undergoing coronary angiography because of unstable angina but with a history of hypertension refractory to treatment, raised creatinine, and recurrent episodes of pulmonary oedema.

anterior oblique view should be considered the standard for left ventriculography. Incorporation of a left anterior oblique view can be considered in those cases where elucidation of the function of the posterolateral wall, most often supplied by the left circumflex artery, is of paramount importance for clinical decision making. Note that moderate cranial angulation can facilitate better detection of mitral regurgitation and regional wall motion.

EXTRACARDIAC ANGIOGRAPHY DURING CORONARY ARTERIOGRAPHY

While we recommend focusing on limited views of the coronary arteries for deciding the need and type of treatment, it seems contradictory to discuss prolongation of the angiographic examination and the use of increased contrast and radiation doses for extracardiac imaging. Unfortunately, patients with coronary artery disease often have atherosclerosis affecting other large vessels which greatly influences their long term prognosis and may modify the therapeutic approach for treatment of their coronary artery disease. For example, the presence of severe carotid stenosis, especially if bilateral, may constitute a contraindication to on-pump bypass surgery and require a staged approach with carotid stenting or endarterectomy followed by coronary surgery. The presence of a subclavian stenosis is an obvious contraindication to the use of the LIMA as a pedicle graft and should be excluded before the intervention.

The presence of a severe stenosis of a renal artery may be responsible for hypertensive attacks with pulmonary oedema and resistance to multi-drug treatment. The use of drugs widely recommended for coronary artery disease such as angiotensin converting enzyme (ACE) inhibitors might be contraindicated in the presence of bilateral renal artery stenosis. When clinical history or previous non-invasive tests

clearly suggest that one of these important vascular territories are involved it may be wise to complete the diagnostic angiogram with a selective injection or an aortogram.

A small movement of the table in a caudal direction is often sufficient during injection in the ascending aorta to visualise the ostia of the head vessels without the need for additional contrast. A selective injection of the left subclavian artery with the catheter advanced to the ostium is normally sufficient to rule out the presence of significant subclavian stenoses. If a moderate narrowing is detected, advancing the catheter over the wire to inject the mammary artery selectively will confirm the presence of a significant stenosis by measuring the trans-stenotic pressure gradient. For carotid angiography, the 23 inch or 25 inch field of view (the largest normally available on a coronary angiographic system) is more than adequate for visualisation of the carotid artery from the ostium to the bifurcation.

In the absence of digital subtraction angiography, best results are obtained with the diagnostic catheter selectively advanced to the ostium of the right common carotid artery or the left common carotid artery. In general, the very gentle 5 French diagnostic catheters used nowadays (right Judkins or right Amplatz) are very unlikely to induce damage to the vessel ostium if care is taken to avoid advancing against resistance and by ensuring pressure damping is absent before injection, including hand tests. Separating the carotid bifurcation requires that the patient's neck is kept extended, removing the pillows under the head, and possibly placing a small pillow under the patient's neck with the patient looking straight up at the ceiling. The x ray tube is moved to an oblique left or right anterior view to obtain optimal opening of the carotid bifurcation, checked with small test injections. The use of truly iso-osmolar contrast agents, such as the dimer iodixanol, reduces patient discomfort during all peripheral injections.

For renal artery stenoses, it is often sufficient to perform an aortogram of the descending aorta with the pigtail catheter

Coronary angiography in the angioplasty era: key points

- ▶ Early and correct selection of catheter size and shape is important for patient safety and to minimise procedure time, radiation exposure, and contrast load
- ▶ Modern diagnostic coronary angiography should be focused on providing optimal information for clinical decision making and planning coronary angioplasty
- ▶ The diagnostic coronary angiogram should incorporate a limited number of carefully selected views. This demands a full understanding of the advantages and limitations of different projections for each specific coronary segment
- ▶ Image acquisition by standard left anterior oblique and right anterior oblique projections is useless for routine imaging of the left coronary artery and should be substituted by steep cranial or caudal angulations
- ▶ Left ventriculography provides additional, not indispensable, but often valuable information concerning left ventricular function, regional wall motion, and mitral regurgitation
- ▶ Diagnostic angiography provides an opportunity to investigate widespread arterial disease including the diseases of the aorta, carotids, subclavian, and renal arteries

positioned at the level of the first lumbar spine, clearly above the position of the contrast inside the kidneys (fig 6). Besides opacification of the renal arteries, information is gathered on the status of the aortic wall, and presence of aortic aneurysms or severe pathology of the iliac arteries. Occasionally, selective injection via a right Judkins catheter is required, often offering the advantage of direct measurement of the trans-stenotic gradient since the tip often falls beyond the ostial stenosis. Slight angulation to the left (5–10°) may avoid superimposition of the aorta on the renal ostium.

FUTURE PERSPECTIVE

Conventional coronary angiography is currently the gold standard technique for evaluation of patients with suspected coronary artery disease and for defining coronary anatomy before revascularisation. However, rapid improvements in image quality and resolution have made 64 multislice tomography a powerful competitor to coronary angiography. The data available for 16 multislice tomography already indicates a sensitivity and specificity of 95% and 98%, respectively, for the detection of > 50% stenosis in patients with atypical chest pain or stable angina compared with coronary angiography.⁸ It is likely that these non-invasive techniques will take over the diagnostic role of coronary angiography. Initially, this will include the exclusion of significant coronary artery stenoses in patients requiring valve surgery, in those with dilated cardiomyopathy, or in patients with atypical chest pain and equivocal non-invasive tests. Coronary angiography will then become increasingly a

preliminary evaluation before percutaneous revascularisation. Coronary angiography in the UK and many other countries is an essential part of the training programme for all future cardiologists; this practice might change in the near future due to the combined effects of the growth of non-invasive imaging and the diffusion of follow on angioplasty.

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