CARDIAC ANGIOGRAPHY

Part of "17 - Cardiac Catheterization, Cardiac Angiography, and Coronary Blood Flow and Pressure Measurements"

In 1923, Osborn noted that the urinary bladder of luetic patients treated with oral and intravenous sodium iodide became opaque to x-rays because of the absorption of photons by iodine. Contrast medium was first injected through a rubber catheter placed in the right ventricle by Chavez in 1947. *Cineangiography* is the term used to describe the x-ray photographing of cardiac and vascular structures. This term persists even though radiographic images are now stored electronically on digital computer imaging media (e.g., CD-ROM) rather than on cine film.22 Angiographic images are the visual representation of the vascular conduits and networks connected to internal structures (organs) and, at times, predict cardiovascular function. Catheterization and angiography are performed as combined techniques to provide hemodynamic and anatomic data. Optimal angiographic data collection is a series of linked steps. Failure of any link may cause loss of all or part of the data. Angiography begins with the positioning of the patient on the table, performing the angiographic image recording, storing the digital image data, and finally displaying the images for review and analysis.

Angiography is the primary method of defining coronary anatomy in living patients, providing an anatomic map of the site, severity, shape and distribution of stenotic lesions. In addition, the characteristics of distal vessel size, intracoronary thrombus, diffuse atherosclerotic disease, mass of myocardium served, an approximate index of coronary flow, and identification of collateral vessels can be obtained. The presence of coronary spasm can be ascertained by using provocative maneuvers.23 The functional significance of a coronary stenosis can be assessed by measuring coronary flow or pressure directly, using information obtained both at rest and during maximal coronary vasodilatation.24 A full discussion of assessing the functional significance of coronary angiographic lesions is provided later in this chapter.

Included in nearly every coronary angiographic study is left ventriculography. Contrast opacification of the contracting ventricle enables one to make a visual analysis of wall motion. Ventricular systolic and diastolic volume and ejection fraction can be calculated. Examination of the left ventriculogram helps identify viable myocardium. LV wall motion can be further evaluated by the addition of stress such as atrial pacing, pharmacologic agents, or exercise. Assessing viability through augmenting LV contraction by the use of nitrates, catecholamines, or postextrasystolic beats facilitate decisions for revascularization.25,26 and 27 LV angiography also documents mitral regurgitation.

Coronary Arteriography

Sones ushered in the modern era of coronary arteriography in 1958 when he developed a safe and reliable method of selective coronary arteriography.28 The Sones technique used an antecubital brachial artery incision and a woven Dacron catheter. The catheter was maneuvered into the ascending aorta and then the soft, tapered catheter tip was deflected off the aortic valve cusps up to the coronary orifices. Although the Sones technique has been surpassed by percutaneous femoral, brachial, and radial artery techniques with preformed angiographic catheters, manipulative skills and precise knowledge of the aortic root anatomy are still required for all coronary angiographic techniques.

Percutaneous arterial catheterization, described in 1953 by Seldinger,29 was first used to study the coronary arteries, as reported by Ricketts and Abrams in 1962.30 Modification of catheters was made by Amplatz et al.31 and by Judkins32 in 1967. The Judkins technique, the most popular coronary angiographic technique in the world, uses three preformed catheters: one for each coronary artery and a pigtail catheter for the LV injection. The Judkins technique is much easier to learn than the Sones technique (Fig. 17-4). The Judkins technique is highly successful because of the simplicity of using preshaped catheters from the femoral approach as compared to the Sones technique, where the operator must use more manipulation to position the catheter in the coronary ostia from the arm. A multipurpose (Sones-style) catheter is still used but its devotees are few. Coronary angiography can be completed using Judkins catheters from the femoral approach in more than 95 percent of patients.

FIGURE 17-4 Push-pull technique for catheterizing the left coronary artery with the Judkins left catheter. *A*. In the left anterior oblique view, the coronary catheter is positioned in the ascending aorta over a guidewire and the guidewire is removed. The catheter is advanced so that the tip enters the left sinus of Valsalva. If the catheter does not selectively engage the ostium of the left coronary artery, further slow advancement into the left sinus of Valsalva imparts a temporary acute angle at the catheter. *B*. Prompt withdrawal of the catheter allows easy entry into the left coronary artery. (From Braunwald E, Zipes DP, Libby P, eds. *Heart Disease: A Textbook of Cardiovascular Medicine*, 6th ed. Philadelphia: Saunders; 2001. With permission.)

In an attempt to combine the advantages of the Sones and Judkins techniques, the single-catheter percutaneous femoral approach was first applied by Schoonmaker in 1968, and use of this technique was reported by Schoonmaker and King.33 This technique has also become obsolete and replaced nearly completely by the Judkins technique. A detailed description of the Judkins technique also has been published.34

The description of the performance of coronary arteriography provided herein is necessarily brief; more detailed descriptions are available.5,6 and 7,35 Expertise in performing coronary arteriography is achieved by training in an active laboratory and performing hundreds of coronary arteriograms under close supervision. In this way the physician can gain needed skills and an appreciation of the potential hazards of coronary arteriography; The American College of Cardiology/American Heart Association (ACC/AHA) recommendations for the performance of coronary angiography3 are provided in Appendix 17-1.

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Techniques of Cannulating Coronary Arteries and Grafts

LEFT CORONARY ARTERY

A short left main and separate ostia for left anterior descending and circumflex arteries can present problems for cannulation. In these cases it may be necessary to cannulate the left anterior descending (LAD) and circumflex (CX) arteries separately. Slightly advancing the left Judkins catheter or using a left Judkins catheter that is one size smaller (i.e., 3.5 cm from 4.0 cm) permits cannulation of the LAD artery. Slight withdrawal and clockwise rotation of the catheter or use of a left Judkins catheter that is one size larger permit cannulation of the CX artery. An Amplatz-type catheter is especially useful to cannulate the CX artery separately but must be used with care to avoid arterial dissection. An unusually high origin of the left main coronary artery from the aorta usually can be cannulated using a multipurpose catheter or an Amplatz-type catheter (e.g., AL 2). To cannulate the high-origin left main trunk through the brachial approach, a long tapered-tip multipurpose catheter may be used. In patients with a relatively horizontal and wide aortic root with upward takeoff of the left main coronary artery, a large-curve left Judkins catheter (5 or 6 cm), an Amplatz-type left coronary catheter, or a multipurpose catheter may be required.

RIGHT CORONARY ARTERY

The origin of the right coronary artery shows more variation than that of the left coronary artery. A contrast injection low into the right coronary cusp will show the origin of the right coronary artery and help the angiogapher direct the catheter. If the right coronary artery is not seen with this injection, it may be totally occluded or may have an anomalous origin, anteriorly on the aorta or from the left sinus of Valsalva. In this case the orifice usually is located above the sinotubular ridge. A left Amplatz catheter or a left bypass graft catheter can be used successfully to engage the right coronary artery orifice located anteriorly or in the left cusp. Minimal anterior displacement of the right coronary artery from the right coronary sinus is more common. In this case, the right Judkins catheter tip may not be directed toward the right, but appear foreshortened (seen on end) in the left anterior oblique (LAO) view. Directing the catheter tip to the right in the usual fashion using the lateral view permits easy cannulation of the anteriorly directed right coronary Rarely an aortogram will be needed to confirm the presence of the RCA. In a patient with a horizontal and wide aortic root or high ostial origin, cannulation of the right coronary orifice and right coronary cusp may require an Amplatz or multipurpose catheter.

SAPHENOUS VEIN BYPASS GRAFTS

In general, saphenous vein bypass grafts are anastomosed to the anterior wall of the ascending aorta (Fig. 17-5). The right coronary artery graft usually is anastomosed a few centimeters above and anterior to the right coronary orifice. Left anterior descending and diagonal grafts usually are anastomosed somewhat higher and slightly to the left. Obtuse marginal grafts are usually the highest and furthest left.

FIGURE 17-5 Usual insertion sites of vein grafts to coronary arteries. The proximal (aortic) anastomosis site of the graft to the right coronary artery is most anterior and usually the lowest. Grafts to the branches of the left coronary artery usually are inserted in a progressively higher and more posterolateral position. Variations frequently occur. (From Tilkian AG, Daily EK. *Cardiovascular Procedures: Diagnostic Techniques and Therapeutic Procedures*, St. Louis: Mosby; 1986. With permission.)

INTERNAL MAMMARY ARTERY GRAFT CANNULATION

The left internal mammary artery (IMA) originates anteriorly from the caudal wall of the subclavian artery distal to the vertebral artery

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origin (Fig. 17-6). The left subclavian artery can be entered using a right Judkins catheter but a more sharply angled catheter tip on the mammary artery catheter is preferred. The right Judkins or IMA catheter is advanced into the aortic arch up to the level of the right brachiocephalic truncus with the tip directed caudally. Subsequently, the catheter is withdrawn slowly and rotated counterclockwise. The catheter tip is deflected cranially, usually engaging the left subclavian artery at the top of the aortic knob in the anteroposterior projection. Once the subclavian artery is engaged, the catheter is advanced over a J-tipped or flexible straight tip guidewire beyond the internal mammary orifice. After the catheter has been advanced beyond the internal mammary artery takeoff, it is withdrawn slowly and small contrast injections are given to visualize the internal mammary artery orifice. The catheter tip should be directed caudally. At the level of the internal mammary orifice a slight counterclockwise rotation and advancement may be necessary to cannulate the artery. In cases with a vertically directed internal mammary artery, an internal mammary artery catheter and a more acute tip angle can be used. Sometimes this catheter cannot be introduced into the subclavian artery because of the tip angle. In this case the subclavian artery can be entered using a right Judkins catheter and then exchanged for an internal mammary artery catheter over an exchange guidewire. Because of the peculiar tip configuration, the internal mammary curve catheter and especially the C-type IMA catheter usually engages into the IMA ostium without much difficulty.

FIGURE 17-6 A guidewire is inserted in the internal mammary graft catheter until it is passed into the left subclavian. It is removed and withdrawn into the internal mammary artery. (From King SB, Douglas JS Jr. *Coronary Arteriography and Angioplasty*. New York: McGraw-Hill; 1985. With permission.)

RIGHT INTERNAL MAMMARY ARTERY GRAFT CANNULATION

Right internal mammary artery cannulation is less common and more difficult than left internal mammary artery cannulation. The right brachiocephalic truncus is entered using a right Judkins catheter by deflecting the tip with a counterclockwise rotation at the level of the brachiocephalic truncus. The catheter is advanced into the subclavian artery. The rest of the manipulation is similar to that described for left internal mammary artery graft cannulation. In patients for whom cannulation of the internal mammary artery is not possible because of excessive tortuosity or obstructive lesions, an internal mammary artery catheter can be introduced through the ipsilateral radial artery. The catheter is advanced beyond the mammary artery orifice over a guidewire. Withdrawing it slowly and making frequent, small contrast injections engage the catheter. A technique for cannulation of the contralateral internal mammary artery from the arm approach using a Simmons catheter also has been described.

*Angiographic Views (*Fig. 17-7 *and* Table 17-18*).*

TABLE 17-18 Angiographic Views for Specific Coronary Artery Segments

Coronary Segment	Origin/Bifurcation	Course/Body
Left main	AP	AP
	LAO cranial	LAO cranial
	LAO caudal[a]	
Proximal LAD	LAO cranial	LAO cranial
	RAO caudal	RAO caudal
Mid-LAD	LAO cranial	
	RAO cranial	
	Lateral	
Distal LAD	AP	
	RAO cranial	
	Lateral	
Diagonal	LAO cranial	RAO cranial, Caudal or straight

	RAO cranial	
Proximal circumflex	RAO caudal	LAO caudal
	LAO caudal	
Intermediate	RAO caudal	RAO caudal
	LAO caudal	Lateral
Obtuse marginal	RAO caudal	RAO caudal
	LAO caudal	
	RAO cranial (distal marginals)	
Proximal RCA	LAO	
	Lateral	
Mid-RCA	LAO	LAO
	Lateral	Lateral
	RAO	RAO
Distal RCA	LAO cranial	LAO cranial
	Lateral	Lateral
PDA	LAO cranial	RAO
Posterolateral	LAD cranial	RAO
	RAO cranial	RAO cranial

[a]Horizontal hearts.

ABBREVIATIONS: AP = anteroposterior; LAD = left anterior descending artery; LAO = left anterior oblique; PDA = posterior descending artery (from RCA); RAO = right anterior oblique; RCA = right coronary artery.

FIGURE 17-7 Nomenclature for radiographic projections. The small black arrowheads show the direction of the x-ray beam. *A*. Anterior, posterior, lateral, and oblique. *B*. If the intensifier is tilted toward the feet of the patient, a caudal view is produced. If the intensifier is tilted toward the head of the patient, a cranial view is produced. *C*. Cranial (CR) and caudal (CA) oblique views. (Redrawn from Paulin S. Terminology for radiographic projects in cardiac angiography. *Catheter Cardiovasc Diagn* 1981;7:341. With permission.)

For all catheterization laboratories, the x-ray source is *under* the table and the image intensifier is directly *on top* of the patient. The x-ray source and image intensifier are moved in opposite directions in an imaginary circle around the patient, who is positioned in the center of this circle. The body surface of the patient that faces the observer determines the specific view. This relationship holds true whether the patient is supine, standing, or rotated.

AP (anteroposterior) position. The image intensifier is directly over the patient with the beam traveling perpendicular back to front, (i.e., from posterior to anterior) to the patient lying flat on the x-ray table. An oblique view is achieved by turning the left/right shoulder forward (anterior) to the camera (image intensifier) or in the cath lab, rotating the *image intensifier toward* the shoulder.

RAO (right anterior oblique) position. The image intensifier is to the right side of the patient.

LAO (left anterior oblique) position. The image intensifier is to the left side of the patient.

Cranial/caudal position. This nomenclature refers to image intensifier angles in relation to the patient's long axis.

Cranial. The image intensifier is tilted toward the *head* of the patient.

Caudal. The image intensifier is tilted toward the *feet* of the patient.

Cranial views are best for the *left anterior descending artery; caudal* views are best for the *circumflex artery*. Cranial and caudal views are used to “open” overlapped coronary segments that are *foreshortened* or obscured in regular views.

THE LEFT CORONARY ARTERY

The ostium of the left coronary artery originates from the left sinus of Valsalva near the sinotubular ridge. The anterior descending artery is usually best visualized in a cranially angulated RAO view. If the orientation of the anterior descending artery is unusually superior, a caudally angulated LAO view or a straight lateral view may be helpful.

The circumflex coronary artery travels in the AV groove, after its right-angle origin from the left anterior descending artery. Its course is quite variable. The artery may terminate in one or more large, obtuse marginal branches coursing over the lateral to posterolateral LV free wall. The circumflex may continue as a large artery in the interventricular groove. In 10 to 15 percent of cases, the circumflex gives rise to a posterior descending artery36 (Fig. 17-8). The artery that supplies the major posterior descending artery is commonly referred to as the *dominant* artery. The circumflex artery in the AV groove is best seen in either caudally angulated LAO or RAO views (Fig. 17-9).

FIGURE 17-8 Diagrams of the anatomy of the right (*A*) and left (*B*) coronary circulation.

FIGURE 17-9 *A*.Diagrammatic representation of the standard RAO view of the left coronary angiogram, the direction of the x-ray beam, and the position of the overhead image intensifier. Most of the left coronary artery is well visualized in this projection, although there is considerable overlap of the middle left anterior descending artery and the diagonal branches. When the left main, circumflex, and diagonal branches have a leftward initial course, the long axis of these arterial segments is projected away from the image intensifier, preventing optimal visualization from the RAO view. The image intensifier is placed anteriorly in an RAO position relative to the patient. (From King et al.36 Reproduced with permission from the publisher, editor, and authors.) *B*. Diagrammatic representation of the LAO left coronary angiogram and the direction of the x-ray beam in this view. The value of this view depends in large part on the orientation of the long axis of the heart. When the heart is relatively horizontal, the left anterior descending (LAD) coronary artery and diagonal branches are seen end-on throughout much of the course. In this illustration, the longitudinal axis is an intermediate position and there is moderate foreshortening of the anterior descending and diagonal branches in their proximal portions (compare with Fig. 17-9E). The LAO projection is frequently inadequate to visualize the proximal LAD and its branches; the left main segment, which is directed toward the image tube and therefore foreshortened, and the proximal circumflex coronary artery, which may be obscured by overlapping vessels, as in this illustration. The LAO projection is frequently used to visualize the distal LAD and its branches, the midcircumflex coronary artery in the AV groove, and the distal right coronary artery that is filling via collaterals from the left coronary artery. The image intensifier is above the patient in an LAO position. (From King et al.36 Reproduced with permission from the publisher, editor, and authors.) *C*. Diagrammatic illustration of the left coronary angiogram in the 45-degree LAO with 30 degrees of cranial angulation and the direction of the x-ray beam used to produce this view. This is the most valuable view of the left coronary artery in most patients. Foreshortening of the left main and proximal left anterior descending and diagonal branches present in the LAO view is usually overcome by cranial angulation of the image intensifier. The proximal left coronary arterial segments are frequently visualized at an angle almost perpendicular from their long axis. The ostium of the left main coronary artery, the most proximal portion of the LAD, and the origin of the diagonal branches are usually well visualized without overlap (compare with Fig. 17-9B). Some overlap may occur with branches of the proximal circumflex coronary artery, and this is frequently overcome by using a 60-degree LAO with 30 degrees of cranial angulation. The value of the LAO with cranial angulation is considerably less when the proximal left coronary artery is superiorly directed, in which case caudal angulation of the image intensifier is frequently helpful. The direction of the x-ray beam in the 45-degree LAO with 30 degrees of angulation is demonstrated. (From King et al.36 Reproduced with permission from the publisher, editor, and authors.) *D*. Diagrammatic illustration of the direction of the x-ray beam and the left coronary angiogram in the 15-degree RAO with 30 degrees of cranial angulation. This view is particularly helpful in analyzing the mid–left anterior descending artery and the diagonal branch points. Overlap with diagonal branches is usually avoided. The origin of the circumflex artery may be well seen, as in this illustration. (From King et al.36 Reproduced with permission from the publisher, editor, and authors.)

THE RIGHT CORONARY ARTERY

The right coronary artery ostium normally is located in the right sinus of Valsalva. It may be high near the sinotubular ridge or above it, in the midsinus, or occasionally low near the aortic valve. The artery commonly courses upward from the plane of the aortic valve and then travels in the right AV groove to reach the posterior LV wall (Fig. 17-10). Along the way, several vessels arise. The conus branch and sinus node arteries branch first, followed by small RV branches, then a large branch that courses over the right ventricle. The right coronary continues to become the posterior descending artery before reaching the crux of the heart (junction of the interventricular and interatrial septa). The posterior descending artery sends branches at right angles into the posterior interventricular groove, providing the perforating branches to the basal and posterior one-third of the septum. A right coronary artery that supplies the major posterior descending branch has been referred to as a *dominant* right coronary artery. The posterior descending artery usually stops before reaching the apex, but it may curl around the apex in association with a short anterior descending artery. After giving rise to the posterior descending artery, the right coronary artery becomes intramyocardial at the crux, gives rise to the AV node artery. The LV branches of the right coronary artery are variable and cover the same area as the posterolateral branches of a large circumflex system. The proximal portion of the right coronary artery is well seen in standard RAO and LAO views. However, because of its horizontal orientation, the origin and length of the posterior descending artery, well seen in the RAO view, is foreshortened in the LAO view. Thus, cranial angulation provides a better view of the PDA.

FIGURE 17-10 *A*. Diagrammatic illustration of the direction of the x-ray beam and the right coronary artery in the 45-degree LAO projection. This view is excellent for visualizing the proximal mid- and distal right coronary artery in the AV groove, since the direction of the x-ray beam is perpendicular to these arterial segments. Ostial lesions of the right coronary artery are now well visualized if the proximal right coronary artery takes an anterior direction from the aorta and therefore originates in a direction parallel to the x-ray beam. This usually can be overcome by turning to a more severe left oblique projection. The posterior descending and LV branches of the right coronary artery, which pass down the posterior aspect of the heart toward the apex, are severely foreshortened because the long axis of these vessels is in the same direction as the x-ray beam. The proximal posterior descending branches can be visualized by cranial angulation of the overhead intensifier or from a right oblique view. The image intensifier is in the standard LAO position. (From King et al.36 Reproduced with permission from the publisher, editor, and authors.) *B*. Diagrammatic illustration of the direction of the x-ray beam and the right coronary artery in 30-degree LAO with 30 degrees cranial angulation. Cranial angulation of the image intensifier overcomes the problem of foreshortening of the posterior decending and left ventricular branches observed in Fig. 17-27. Lesions in the posterior decending or LV brances can be well visualized. When the right coronary artery originates anteriorly from the aorta, the proximal portion of the vessel is frequently well seen in this projection. With anomalous origin of the left anterior decending artery from the right coronary artery, this view is helpful because the standard LAO view produces considerable foreshortening of the anomalous artery. The direction of x-ray beam is the same as in Fig. 17-25. (From King et al.136 Reproduced with permission from the publisher, editor, and authors.)

FIGURE 17-25 X-ray generation. (From Baim D, Grossman W, eds. *Grossman's Cardiac Catheterization, Angiography and Intervention*, 6th ed. Philadelphia: Lippincott Williams & Wilkins; 2000:19. With permission.)

FIGURE 17-27 In order to measure the dynamic frequency response of a catheter transducer system, an abrupt transient input dynamic pressure is applied to the catheter tip (a plunger is pulled free of an air-filled syringe); the pressure oscillations are recorded at a fast paper speed and measured. X = height of the initial overshoot; H = end height of the recorded deflection; T = period of a free oscillation, 0.08 s. The natural frequency is 13 Hz; the useful range is 4 Hz. The amplitude ratio of two successive peak amplitudes is 0.59, and the damping coefficient is 0.17. This underdamped system is optimally damped to a coefficient around 0.64 by the addition of a narrow-bore tube between catheter and transducer. (Reproduced with the permission of Irex Corporation.)

Interpretation of the Coronary Arteriogram

The coronary arteriogram should be viewed in a systematic fashion. Because coronary anatomy can be quite variable, the entire LV surface

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and septum should be adequately supplied with vessels. No gaps should exist. If significant vessels are missing, an occluded or anomalous artery is likely. Areas of foreshortening and overlap should be examined in other orthogonal or oblique views to demonstrate the region in question. Several observers should review an arteriogram. As each segment is viewed, a systematic scoring and reporting system is helpful to maintain a consistent and dependable report.

ANGIOGRAPHIC ASSESSMENT OF CORONARY ARTERY NARROWINGS

An angiographic lumen narrowing is commonly referred to as a stenosis which may be due to atherosclerosis, vasospasm, or angiographic artifact (Fig. 17-11). The evaluation of a stenosis relates the percentage reduction in the diameter of the narrowed vessel site to the adjacent unobstructed vessel. The diameter stenosis is calculated in the projection where the greatest narrowing is seen. An exact evaluation of dimensions is impossible and, in fact, the severity of stenotic lesions are roughly classified. It should be noted that the stenotic lumen is compared to a nearby unobstructed lumen, which indeed may have diffuse atherosclerotic disease and thus is “angiographically” normal but may still be diseased (Fig. 17-12). This fact explains why postmortem examinations report much more plaque than is seen on angiography.37,38 and 39 The angiographic "normal" adjacent proximal segments may be larger than distal segments, explaining the large disparity between several observer estimates of stenosis severity.39 Also note that *area stenosis* is always greater than *diameter stenosis* and assumes the lumen is circular when in reality most of the time the lumen is eccentric.40 In 1975, the American Heart Association recommended that the diameter method be adopted for grading coronary artery stenosis.40a A 50 percent reduction in diameter is equivalent to a 75 percent reduction in cross-sectional area, and a 75 percent reduction in diameter is equal to a 90 percent reduction in cross-sectional area.

FIGURE 17-11 LAO view of the right coronary artery (RCA) with high-grade lesion in its midportion.

FIGURE 17-12 Diagrammatic representation of angiographic versus postmortem analysis of coronary artery stenosis. (From Robert WC. Coronary heart disease: A review of abnormalities observed in the coronary arteries. *Cardiovasc Med* 1977;2:29–38. With permission.)

Six categories of coronary narrowing have been commonly used:

1. Normal coronary artery
2. Irregularities of the vessel
3. Narrowing of less than 50 percent
4. Stenosis between 50 and 75 percent
5. Stenosis between 75 and 95 percent
6. Total occlusion

For nonquantitative reports, the length of a stenosis may be simply mentioned (e.g., LAD proximal segment stenosis diameter 25 percent, long or short). Other features of the coronary lesion (e.g., distribution eccentricity, calcification, true length) may not be appreciated by angiography and require intravascular ultrasound imaging (Fig. 17-13).

FIGURE 17-13 Intravascular ultrasound (IVUS) imaging of the coronary artery.

Because of the subjective nature of visual lesion assessment, there is a ±20 percent variation between readings of two or more experienced angiographers, especially for lesions 40 to 70 percent narrowed. Different angiographers may interpret the same angiographic image differently, and the same angiographer may render a different interpretation at a time remote from the first reading.41,42 In addition, there may be disagreement about the number of major vessels with 70 percent stenosis about 30 percent of the time.43 Angiographic narrowings of 40 to 75 percent narrowing do not always correspond to abnormal physiology and myocardial ischemia. For such lesions, noninvasive or direct physiologic measurements of impaired flow validate decisions for revascularization.

QUANTITATIVE ANGIOGRAPHIC ASSESSMENT

The degree of coronary stenosis is usually a visual estimation of the percentage of diameter narrowing using the proximal assumed normal arterial segment as a reference. The ratio of normal to stenosis artery diameter is widely used in clinical practice, is inadequate for a true quantitative methodology. The intraobserver variability may range between 40 and 80 percent, and there is frequently a range as wide as 20 percent on interobserver differences. Quantitative methodologies include digital calipers, automated or manual edge detection systems, or densitometric analysis with digital angiography.44

INTRAVASCULAR ULTRASOUND ASSESSMENT OF CORONARY ARTERY NARROWINGS

Intravascular ultrasound (IVUS) generates a tomographic, cross-sectional image of the vessel and lumen. IVUS enables the operator to make measurements of luminal dimensions, such as minimum and maximum diameter, cross-sectional area, vessel wall and plaque

thickness. Intravascular coronary ultrasound images the soft tissues within the arterial wall enabling characterization of atheroma size, plaque distribution, and lesion composition during diagnostic or therapeutic catheterization.45,46 The ACC/AHA recommendations for intravascular ultrasound imaging are provided in Appendix 17-2.3

ASSESSMENT OF CORONARY SPASM

Coronary spasm can be demonstrated by angiographic narrowing, provoked by mechanical stimulation (Fig. 17-14), methylergonovine maleate, acetylcholine, cold pressor testing, or hyperventilation. The methylergonovine provocative test is the most reliable test for coronary spasm in patients with Prinzmetal variant angina. Optimally, nitrates and calcium antagonists should be withheld for 48 h before testing. Methylergonovine should be administered by an experienced operator in a laboratory with full resuscitative capabilities. Intracoronary acetylcholine has also been used as a provocative test for coronary spasm. Its effectiveness is comparable to methylergonovine. In patients with one episode of variant angina per day, the hyperventilation provocative test is nearly as effective as methylergonovine in causing vasospasm. The end point of a pharmacologic provocative test is focal coronary narrowing, which can be reversed with intracoronary nitroglycerin. In patients with ST-segment elevation with chest pain and a normal coronary angiogram, the diagnosis of coronary spasm is established and provocative tests are not necessary.47

FIGURE 17-14 *A*. LAO view of right coronary injection showing pericatheter spasm. *B*. Same view following nitroglycerin, showing relief of spasm.

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ANGIOGRAPHICALLY ESTIMATED CORONARY BLOOD FLOW (TIMI FLOW)

Myocardial blood flow has been assessed angiographically using the Thrombolysis in Myocardial Infarction (TIMI) score for qualitative grading of coronary flow. TIMI flow grades 0 to 3 have become a standard description of angiographic coronary blood flow in clinical trials. In acute myocardial infarction trials, TIMI grade 3 flows have been associated with improved clinical outcomes. The four grades of flow are described as follows:

1. Normal distal runoff (TIMI-3)
2. Good distal runoff (TIMI-2)
3. Poor distal runoff (TIMI-1)
4. Absence of distal runoff (TIMI-0)

The quantitative method of TIMI flow uses cineangiography with 6F catheters and filming at 30 frames per second. The number of cine frames from the introduction of dye in the coronary artery to a predetermined distal landmark is counted. The TIMI frame count for each major vessel is thus standardized according to specific distal landmarks. The first frame used for TIMI frame counting is that in which the dye fully opacifies the artery origin and in which the dye extends across the width of the artery touching both borders with antegrade motion of the dye. The last frame counted is when dye enters the first distal landmark branch. Full opacification of the distal branch segment is not required. Distal landmarks used commonly in analysis are (1) for the LAD, the distal bifurcation of the left anterior descending artery; (2) for the circumflex system, the distal bifurcation of the branch segments with the longest total distance; (3) for the right coronary artery, the first branch of the posterolateral artery.

The TIMI frame count can further be quantitated for the length of the left anterior descending coronary artery for comparison to the two other major arteries; this is called the corrected TIMI frame count (CTFC).48 The average left anterior descending coronary artery is 14.7 cm long, the right 9.8 cm, and the circumflex 9.3 cm, according to Gibson et al.48 CTFC accounts for the distance the dye has to travel in the LAD relative to the other arteries. CTFC divides the absolute frame count in the LAD by 1.7 to

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standardize the distance of dye travel in all three arteries. Normal TFC and CTFC for LAD is 36±3 and CTFC 21 ±2; for the CFX, TFC = 22 ±4; for the RCA, TFC = 20 ±3. TIMI flow grades do not correspond to measured Doppler flow velocity or the CTFC. High TFC may be associated with microvascular dysfunction despite an open artery. CTFC of <20 frames were associated with low risk for adverse events in patients following myocardial infarction. A contrast injection rate increase of ≥1 mL/s by hand injection can decrease the TIMI frame count by two frames. The TIMI frame count method provides valuable information relative to clinical responses after coronary interventions.

COLLATERAL CIRCULATION

The reopacification of a totally or subtotally (99%) occluded vessel from antegrade or retrograde filling is defined as collateral filling. The collateral circulation is graded angiographically as follows:

Grade	Collateral Appearance
0	No collateral circulation
1	Very weak (ghostlike) reopacification
2	Reopacified segment, less dense than the feeding vessel and filling slowly
3	Reopacified segment as dense as the feeding vessel and filling rapidly

It is useful but difficult to establish the size of the recipient vessel exactly, whether the collateral circulation is ipsilateral (e.g., same side filling, proximal RCA to distal RCA collateral supply) or contralateral (e.g., opposite side filling, LAD to distal RCA collateral supply). Identification of exactly which region is affected by collateral supply will influence decisions regarding management of stenoses in the artery feeding the collateral supply. Collateral vessel evaluation is important for making decisions regarding which vessels might be protected or lost during coronary angioplasty.49

PITFALLS IN CORONARY ARTERIOGRAPHY

There are a number of pitfalls in coronary arteriography that should be avoided.

Short Left Main or Double Left Coronary Orifices

When the left main orifice is very short or absent, selective injection of the anterior descending or circumflex arteries may be done. The absence of circumflex or anterior descending artery filling, either primarily or through collaterals from the right coronary artery, may indicate that the artery was missed by subselective injection, or an anomalous location.

Ostial Lesions

The left and right coronary artery orifices need to be seen on a tangent with the aortic sinuses. Some contrast reflux from the orifices is needed to fully opacific the ostium to see whether an ostial narrowing is present. Catheter pressure damping is an additional indication of an ostial stenosis.

Myocardial Bridges

The anterior descending, diagonal, and marginal branches occasionally run intramyocardially. The overlying myocardium may compress the artery during systole. If the coronary artery is not viewed carefully in diastole, this bridging may give the appearance of an area of stenosis.50

Foreshortening

Foreshortening is the viewing of a vessel in plane with its long axis. Vessels seen on end cannot display a lesion along its length. When possible, review arteries that are seen coming toward or away from the image intensifier in angulated (cranial/caudal) views. Dense opacification of segments seen end-on may produce the appearance of a lesion in an intervening segment.

Coronary Spasm

Catheter-induced spasm may appear as a lesion (Fig. 17-14). When spasm is suspected (usually at the catheter tip in the right coronary artery), intracoronary nitroglycerin (100 to 200 µg) should be given, and the angiogram should be repeated in 1 to 2 min. Spontaneous coronary artery spasm may also present as an atherosclerotic narrowing. When this is suspected, obtain an

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angiogram before and again after nitrates. If clinically indicated, provocation with ergot derivatives will identify most patients with spontaneous coronary artery spasm.

Totally Occluded Arteries or Vein Grafts

Absence of vascularity in a portion of the heart may indicate total occlusion of its arterial supply. Collateral channels often permit visualization of the distal occluded artery. Vessels filled solely by collaterals are under low pressure and may appear smaller than their actual lumen size. This finding should not exclude the possibilities for surgical anastomosis.

Anomalous Coronary Arteries

Coronary arteries may arise from anomalous locations, or a single coronary artery may be present.51 Only by ensuring that the entire epicardial surface has an adequate arterial supply can one be confident that all branches have been visualized. Misdiagnosis of unsuspected anomalous origin of the coronary arteries is a potential problem for any angiographer. As the natural history of a patient with an anomalous origin of a coronary artery may be dependent on the initial course of the anomalous vessel, it is the angiographer's responsibility to define accurately the origin and course of the vessel. It is an error to assume a vessel is occluded when in fact it has not been visualized because of an anomalous origin. It is often difficult even for experienced angiographers to delineate the true course of an anomalous vessel.

For the most critical anomaly, the anomalous left main artery originating from the right cusp, a simple “dot and eye” method for determining the proximal course of anomalous artery from an RAO ventriculogram, an RAO aortogram, or selective RAO injection is proposed52 (Table 17-19). The RAO view best separates the normally positioned aorta and pulmonary artery. Placement of right-sided catheters or injection of contrast in the pulmonary artery is unnecessary and often misleading. Figure 17-15 diagrams the four common pathways of anomalous left coronary arteries.

TABLE 17-19 Radiographic Appearance of Anomalous Origin of the Left Main Coronary Artery from the Right Sinus of Valsalva

	RAO AORTOGRAPHY OR VENTRICULOGRAPHY			
Course of Anomalous Left Main Coronary	**Dot**	**Eye**	**LAD Length**	**Septal Arising from LMCA**
Septal	-	+(upper CFX) (lower LMCA)	Short	Yes
Anterior	-	+(upper LMCA) (lower CFX)	Short	No

Retroaortic	+ (posterior)	-	Normal	No
Interarterial	+(anterior)	-	Normal	No

ABBREVIATIONS: + = present; - = absent. Posterior and anterior are in reference to the aorta root.

LAD = left anterior descending coronary artery; LMCA = left main coronary artery; CFX = circumflex coronary artery.

FIGURE 17-15 *A*. Diagram of septal course of anomalous left coronary artery. *M* = Left main; *S* = septals; *C* = circumflex; *L* = left anterior descending artery. *B*. Diagram of anterior course of anomalous left coronary artery. *C*. Diagram of retroaortic course of anomalous left coronary artery. *D*. Diagram of interarterial course of left main coronary artery. (From Kern MJ. *Cardiac Catheterization Handbook*. St. Louis: Mosby; 2003. With permission.)

Complications of Coronary Arteriography

Minor complications of coronary angiography include local arterial complications, arterial occlusion or stenosis, hematoma formation, false aneurysm, and infection. Major complications are potentially lethal and include thromboembolic events or depression of myocardial function due to infarction or acute ischemia.

Left Ventriculography

Left ventriculography is the standard method for evaluating LV performance in the cardiac catheterization laboratory. The normal pattern of LV contraction is a uniform and almost concentric inward movement of all points along the endocardial surface during systole. Harrison introduced the term *asynergy*, which has been used to indicate a disturbance of the normal contraction pattern. The Ad Hoc Committee for Grading of Coronary Artery Disease of the American Heart Association52a has recommended that five RAO segments and two LAO left ventricular segments be defined and characterized as to wall motion (Fig. 17-16). Herman et al.52b classified LV asynergy according to the severity of the contractile abnormality.

FIGURE 17-16 LV wall silhouette in RAO and LAO views.

VENTRICULAR WALL MOTION ANALYSIS

There are three distinct types of asynergy (Fig. 17-17):

FIGURE 17-17 *A*. Types of ventricular asynergy. *B*. Diagrammatic representation of the zones of the left ventricular inner wall in the right anterior oblique (RAO) above and left anterior oblique (LAO) below left ventriculograms. (*A* from Herman MV et al. Localized disorders in myocardial contraction. Asynergy and its role in congestive heart failure. *N Engl J Med* 1967;227:225. With permission. *B* from Yang SS: *From Cardiac Catheterization Data to Hemodynamic Parameters*, 3d ed. Philadelphia: FA Davis; 1987. With permission.

1. *Hypokinesia*—a diminished but not absent motion of one part of the LV wall (also called weak or poor contraction).
2. *Akinesia*—total lack of motion of a portion of the LV wall (i.e., no contraction).
3. *Dyskinesia*—paradoxical systolic motion or expansion of one part of the LV wall (i.e., an abnormal bulging outward during systole).

There are several methods for analyzing LV wall motion. A point system based on the regional severity of abnormal wall motion from the Coronary Artery Surgery Study (CASS) 52a is used to produce a wall motion *score* reflecting overall LV function. The RAO and LAO left ventriculrogams are divided into five segments. Points are assigned as follows: normal contraction = 1 point; moderate hypokinesis = 2; severe hypokinesis = 3; akinesis = 4; aneurysm-dyskinesis = 5. A normal score is 5. Higher scores indicate more severe wall motion abnormalities.

For determination of quantitative regional wall motion abnormalities, three methods have been commonly employed: (1) *Long axis method*. Determination of the major long axis and division of the long axis into equal segments with perpendicular lines; (2) *Center point method*. Midpoint of the major axis and division of the lines radiating out from the center point; (3) *Center line method.* A center line is established between the end-diastolic and end-systolic borders, 100 perpendicular chords are drawn, and shortening of these chords determines wall motion abnormalities. Results are corrected using a normal motion value for each chord length. Some of these methods of determining regional wall motion abnormality use computer planimetry available currently on most advanced x-ray systems.

INDICATIONS FOR LEFT VENTRICULOGRAPHY

1. Identify LV function for patients with coronary artery disease, myopathy, or valvular

heart disease.

2. Identify ventricular septal defect.
3. Quantitate degree of mitral regurgitation.
4. Quantitate mass of myocardium for regression of hypertrophy or other similar research studies.

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VENTRICULOGRAPHY TECHNIQUES

Catheters

The two most common ventriculography catheters are the pigtail and multipurpose sidehole catheters. *The pigtail catheter* has a tapered tip, shaped to make a full circle, 1 cm in diameter. Five to twelve side holes are located on the straight portion of the catheter above the curve. The catheter is placed in front of the mitral valve with the loop directed away from the valve (in the RAO position). A slight rotation, advancement, or withdrawal may be necessary to find a position that does not cause frequent premature ventricular contractions (Fig. 17-18).

FIGURE 17-18 Judkins method of left ventricular catheterization: (1) Having crossed the aortic valve, the pigtail catheter will be in position. (2) The catheter is withdrawn 2 to 3 cm and rotated 70 to 90 degrees counterclockwise. (3) The coiled loop will be in the inflow tract of the mitral valve. (4) If the catheter moves excessively in this position, it should be advanced until it is stable. (From Judkins MP, Judkins E. Coronary arteriography and left ventriculographic Judkins technique. In: King SB III, Douglas JS Jr, eds. *Coronary Arteriography and Angioplasty*. New York: McGraw-Hill; 1985:201. With permission.)

The multipurpose catheter with sideholes is also used for ventriculography. This catheter should be positioned freely in the left ventricular chamber so that the high-pressure contrast jet does not produce ventricular tachycardia, contrast injection in the myocardial tissue (contrast staining), or perforation (Fig. 17-19). The pigtail catheter (and halo-modified pigtail) is safer and produces less ectopy contrast staining and perforation than a multipurpose catheter.

FIGURE 17-19 Multipurpose catheterization of the left ventricle in the 35-degree right anterior oblique projection. When positioned correctly (*center*), the catheter tip should be near the tip of the papillary muscles; aiming toward the apex. If it is touching the inferior or inferolateral wall (*left*) it should be rotated clockwise. If it is touching the anteroseptal wall (*right*), it should be rotated counterclockwise. (From King SB, Douglas JS Jr. *Coronary Arteriography and Angioplasty*, New York: McGraw-Hill; 1985. With permission.)

Left Ventriculography Views

Standard left ventriculographic views are (1) a 30-degree RAO that visualizes the high lateral, anterior, apical, and inferior LV walls and (2) a 45- to 60-degree LAO, 20 degrees of cranial angulation that best identifies the lateral and septal LV walls. The degrees of axial obliquity and cranial angulation are used as follows: (1) The 40-degree left anterior oblique (LAO) and 30-degree cranial position (four-chamber view) outlines the posterior third of the ventricular septum, the valve plane in AV canal defects, and the four heart chambers without superimposition. (2) The 60-degree LAO and 30-degree cranial position (long-axial view) outlines the anterior two-thirds of the ventricular septum, the membranous ventricular septum, and the LV outflow tract. The LAO with cranial angulation provides a view of the interventricular septum, projected on edge and tilted downward to give the best view of ventricular septal defects and septal wall motion. An elongated RAO view, which is useful for seeing the RV infundibulum and supracristal ventricular septal defect, is obtained by a 30-degree axial RAO and 40 degrees of cranial angulation. The main pulmonary artery and its bifurcation are seen in the frontal position with 30 degrees of cranial angulation; a steep LAO position with marked cranial angulation is also used.

Biplane ventriculography may be available in some catheterization laboratories. It involves increased radiation and more time spent positioning equipment. These considerations are offset by providing

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more information with less contrast media, an important consideration in children and patients with renal failure. If a biplane system is unavailable, patients with coronary disease affecting the lateral wall should have a second left ventriculogram in the 45- to 60-degree LAO, 20-degree cranial view. Almost every such patient can tolerate an additional 30 to 40 mL of contrast.

VENTRICULAR VOLUME MEASUREMENT

LV volume is estimated from the opacified image of the LV cavity. Although a single-plane mode using the frontal or RAO projection often is adequate,53,54 biplane view image pairs including frontal and lateral, right and left anterior oblique, or half-axial left anterior oblique and conventional RAO may be more precise.55,56 In the classic biplane technique, each image of the LV cavity is treated as an ellipse. The long axis of the ventricle (L_m) and the two mutually perpendicular short axes at its midpoint (D_a and D_i) are measured, and

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the volume (V) is calculated from the formula for volume of an ellipsoid (Fig. 17-20):

FIGURE 17-20 Dimensions of the left ventricular (LV) cavity in end-diastole used for the calculation of the ventricular volume by the area-length method, biplane technique. A-P = anteroposterior plane; A_A, A_L = area, A-P and area lateral plane (planimetry); L_A, L_L = length or long axis of the left ventricle (measured); D_a, D_i = diameter of short axis, A-P lateral plane (xsderived); L_m = maximum length or long axis whether from the lateral A-P or lateral plane; h = wall thickness, LV. See text for formulas. (Left and middle portion of figures from Sandler and Dodge. Right portion of figure from Dodge HT. Hemodynamic aspects of cardiac failure. *Hosp Pract* 1971; January:91. Illustration by B. Tagawa and

A. Miller. Reproduced with permission from the publishers and authors.)

Also

In the single-plane method, the long axis and one short axis are measured; the second nonvisible short axis is assumed to equal the first; thus

More often, in either the biplane or single-plane method, the short-axis dimension is derived from the measured long axis and the area (*A*) of the LV shadow, treated as an ellipse (area-length method of Dodge). Since

then,

and volume can be calculated from only the measured area and long axis by substituting for D, obtaining:

Corrections must be made for magnification due to the divergence of the x-ray beam[55] using a calibrated grid or circular reference marker. Digital ventriculography provides rapid, computer-dervied ventricular volumes. Techniques for calculation of ventricular volumes have been validated using geometric and nongeometric count-based radionuclide methods as well as with magnetic resonance imaging.[56]

The methods for determination of ventricular volume by biplane ventriculography are described elsewhere.[57,58] Important parameters of LV volume measurements include: LV end-diastolic volume (normally 70 ± 20 mL/m^2), the end-systolic volume (24 ± 10 mL/m^2), and the ejection fraction (0.67 ± 0.08). LVEF values below 0.55 are considered abnormal. Diastolic LV wall thickness measured by angiography is 9 mm for women and 12 mm for men, and LV wall mass is 76 g/m^2 for women and 99 g/m^2 for men.[58]

The major measurements of left ventricular contractility are the ejection fraction (EF) and stroke volume (SV). Ejection fraction (EF, %) is calculated as

The stroke volume is calculated as

SV = EDV – ESV

where EDV is end-diastolic volume, ESV is end-systolic volume, and SV is stroke volume. The velocity of circumferential fiber shortening (VCF, cm/s) is calculated as

where D_{ed} is diameter end diastole, D_{es} is diameter end systole, and LVET is LV ejection time (ms).

ANGIOGRAPHIC ASSESSMENT OF VALVE REGURGITATION

1. Left ventricular opacification visualizes mitral but not aortic valvular regurgitation. For the aortic valve, contrast injections made low in the aortic root serve to quantify aortic regurgitation. In mild degrees of aortic regurgitation, a fine regurgitant jet or puff is noted; opacification is limited to the LV outflow tract, clearing with each systole (grade 1), or faint, persistent, incomplete opacification of the LV cavity (grade 2) occurs. In grades 3 and 4, no distinct jet is seen, and dense complete opacification of the left ventricle occurs either progressively or in one or two diastolic cycles, and LV density exceeds aortic density in the severe case (Fig. 17-21).

FIGURE 17-21 Angiographic evaluation of aortic regurgitation, right anterior oblique view. When the left anterior oblique view is used, overestimation of the aortic regurgitation occurs. (From Pujadas G. *Coronary angiography in the Medical and Surgical Treatment of Ischemic Heart Disease*. New York: McGraw-Hill; 1980. With permission.)

2. For the mitral valve, LV injection in the RAO view detects and quantifies mitral regurgitation. The angiographic criteria for grading mitral regurgitation are highly subjective. Mild grades 1 and 2 mitral regurgitation have a narrow-to-moderate width regurgitant jet of slight to moderate density with minimum-to-moderate opacification of the left atrium clearing quickly. Grades 3 and 4 have no well-defined jet with intense and persistant left atrial opacification (Fig. 17-22). The left atrium appears denser than the left ventricle or aorta in grade 4 mitral regurgitation. If there is associated mitral valve prolapse, shown best in a lateral projection, all or a portion of one or both leaflets

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balloons may appear above the mitral annulus in systole. A normal mitral valve may be transiently regurgitant if ectopic beating occurs.

FIGURE 17-22 Angiographic evaluation of mitral regurgitation. (From Pujadas G. *Coronary Angiography in the Medical and Surgical Treatment of Ischemic Heart Disease*. New York: McGraw-Hill; 1980. With permission.)

Mitral regurgitation can also be quantitated by calculating a regurgitant fraction as follows:

The total stroke volume obtained by left ventriculography is used to assess the severity of mitral and aortic valve regurgitation. Total stroke volume minus forward stroke volume equals regurgitant stroke volume. The regurgitant fraction equals regurgitant stroke volume divided by total stroke volume. Severe valvular regurgitation has a regurgitant fraction of 0.50 or greater.

The angiographic quantitation of valvular regurgitation is shown in Table 17-20.

TABLE 17-20 Angiographic Quantitation of Valvular Regurgitation

	Mitral Regurgitation		**Aortic Regurgitation**
	Mild LA opacification; clears rapidly, often jet-like	+	Small regurgitant jet only; LV ejects contrast each systole
++	Moderal LA opacification, <LV	++	Regurgitant jet faintly opacifies LV cavity; not cleared each systole
+++	Diffuse contrast Regurgitant; LA Opacification = LV; LA Significantly enlarged[a]	+++	Persistent LV Opacification = aortic root density; LV enlargement[a]
++++	LA opacification > LV, persistent; systolic pulmonary vein opacification may occur; often marked LV enlargement[a]	++++	Persistent LV Opacification > aortic root concentraton; often marked LV enlargement[a]

[a]Chronic regurgitation.
KEY: ++ = mild; +++ = moderate; ++++ = severe.
ABBREVIATIONS: LA = left atrium; LV = left ventricle.

RIGHT VENTRICULOGRAPHY

RV volume is estimated by applying Simpson's rule or the area-length method to the cavity silhouettes after biplane angiography.59 The end-diastolic volume of the right ventricle in normal persons is 81 ± 12 mL/m^2. The opacified left atrial shadow is represented as an ellipsoid, so the left atrial volume also can be calculated in the biplane mode; the normal left atrial maximal volume is 63 ± 16 mL with a mean volume of 35 ± 8.7 mL. Indications for right ventriculography include (1) documentation of tricuspid regurgitation; (2) RV dysplasia for arrhythmias; (3) pulmonary stenosis; (4) abnormalities of pulmonary outflow tract; and (5) right-to-left ventricular shunts.

COMPLICATIONS OF VENTRICULOGRAPHY

Cardiac arrhythmias, especially ventricular tachycardia and ventricular fibrillation, require immediate cardioversion. Intramyocardial "staining," injection of contrast into the myocardium, is generally transient and of no clinical importance unless it is deep or perforating (emergency pericardiocentesis may be required). Arrhythmias and staining are more common with end hole catheters than any pigtail catheters. Embolism from thrombi or air may occur. These events are minimized with careful catheter and injection syringe preparation, flushing,

and debubbling. Contrast-related complications including allergic-type vasomotor collapse may occur during this procedure. Transient hypotension (<15 to 30 s) was common with ionic contrast media.

Other Cardiovascular Angiographic Studies

RIGHT ATRIAL ANGIOGRAPHY INDICATIONS

1. Defining the tricuspid valve in Ebstein's anomaly and tricuspid atresia or stenosis.
2. Myxoma or thrombus.
3. Juxtaposition of right atrial appendage in cyanotic congenital heart disease.
4. The right atrial border in pericardial effusion or tumor.

5. Atrial septal defect with right-to-left shunting.

ASCENDING AORTOGRAPHY

Although cut film is an established radiologic method, for cardiac catheterization laboratories cineangiography is acceptable in patients with suspected dissection of the aorta. Indications and contraindications are shown in Table 17-21.

TABLE 17-21 Indications and Contraindications for Ascending Aortography

Indications
Aortic aneurysm/aortic dissection
Aortic insufficiency
Nonselective coronary or bypass graft arteriography
Supravalvular aortic stenosis
Brachiocephalic or arch vessel disease
Coarctation of the aorta
Aortic to pulmonary artery or right heart (e.g., sinus of Valsalva fistula) communication
Aortic or periaortic neoplastic disease
Arterial thromboembolic disease
Arterial inflammatory disease
Contraindications
Contrast media reaction
Injection into false lumen of aortic dissection
End-hole catheter malposition
Inability to tolerate additional radiographic contrast media

Radiographic Projections for Aortography

LAO OR LATERAL PROJECTION

This view is excellent for identifying dissection of the ascending aorta extending up to the neck vessels, optimally delineating the aortic arch, opening the aortic curvature, and providing clear views of the innominate, common carotid artery, and left subclavian arteries. The coronary arteries at the root of the aorta are displayed in a semilateral projection.

RAO PROJECTION

The descending thoracic aorta, and the ascending aorta may be superimposed across the arch in the AP or LAO projection. The RAO view is more helpful in delineating the effect of dissection on the lower thoracic arota and intercostal arteries as well as the origin of bypass grafts to the left coronary system. There are no advantages to cranial or caudal tilts for viewing the aorta. In nonselective coronary arteriography in which aortic root angiography may help to identify a vein graft takeoff, the cranial and caudal angulation may provide some increased detail.

ABDOMINAL AORTOGRAPHY

Indications for abdominal aortography are shown in Table 17-22. A lateral projection is commonly needed for anteriorly angulated aneurysm, especially if stent graft repair of abdominal aortic aneurysm is being considered. Evaluation of peripheral lower extremity disease requires identification of iliac bifurcation and common femoral artery patency before subselective injections. The contraindications of abdominal aortography are the same as thoracic aortography Figure 17-23 shows typical findings in abdominal aortography in a patient with peripheral vascular disease.

TABLE 17-22 Indications for Abdominal Aortography

Nonselective evaluation of renal arteries and mesenteric vessels
Abdominal aneurysm or dissection
Abdominal aortic atherosclerotic disease
Vascular assessment prior to IAB[a] counterpulsation
Initial evaluation of claudication
Evaluation of cause of difficult catheter movement for coronary angiography

[a]Intraaortic balloon.

FIGURE 17-23 Aortography of the lower abdominal aorta demonstrating bilateral iliac stenosis at its origin from the most distal part of the abdominal aorta. (From Kern MJ. *Cardiac Catheterization Handbook*, St. Louis: Mosby; 2003. With permission.)

PULMONARY ANGIOGRAPHY

Pulmonary angiography, the visualization of vascular abnormalities of the lung vessels (e.g., intraluminal defects representing pulmonary

emboli, shunts, stenosis, AV malformation, and anomalous connections), should be preceded by the measurements of right heart pressures.

PERIPHERAL VASCULAR ANGIOGRAPHY

Once the techniques of coronary angiography have been mastered, peripheral vascular angiography is not difficult. Digital subtraction angiography is the method of choice for identifying peripheral vascular disease. However, cineangiography can provide satisfactory information if the filming time, frame rates, and contrast dosages are properly established. Cine angiography is also helpful to detect the speed of vessel opacification and collateral filling.

Based on clinical signs and symptoms of arterial insufficiency to the legs, suspected obstructions of vessel are often screened with noninvasive studies (i.e., ankle brachial index) before angiography is performed. Small-diameter (5F) catheters are satisfactory. Reduced volume of contrast (10 to 20 mL over 1 to 2 s) are injected during filming with panning down the artery, following the course to the most distal locations. Angulated views may be necessary to open bifurcations and overlying vessels that obscure the vessel origin. When possible, angiographic filming should extend at least to the ankle. Nonionic contrast agents are less painful than ionic media for peripheral angiography.

The area most frequently involved in peripheral atherosclerotic disease involves the distal superficial femoral artery at the abductor canal (Fig. 17-24). The calf (tibial), and knee (popliteal) arteries are the next most commonly involved vessels after the superficial femoral artery. Disease in the deep femoral artery (femoral profunda) is rare. Pathways of collateralization are often rich and varied in patients with chronic distal femoral artery disease, especially in total occlusions of the superficial femoral artery that reconstitutes at or below the knee, close to the branching trifurcation of the tibial and deep peroneal arteries. Determining the level of reconstitution of collateralized vessels and distal runoff is crucial in determining the feasibility of revascularization.

FIGURE 17-24 Peripheral vascular anatomy.

RENAL ARTERIOGRAPHY

Selective renal arteriography evaluates the renal artery origins and vasculature. Selective arterial injections provide the most detail and are easily obtained with a JR4 catheter. For screening aortography, the renal artery origins usually arise at L1 vertebra (just below the T12 ribs). The 30-degree ipsilateral oblique projection often provides the best view of the renal artery ostia in a majority of patients. Acutely angled takeoffs of the renal artery may require specially shaped catheters or an arm approach. Atherosclerotic disease of the renal artery usually involves the proximal one-third of the renal artery and is seldom present without abdominal atherosclerotic plaques. Delayed imaging to see the nephrogram is essential to exclude accessory renal arteries and to screen for presence of severe parenchymal disease. Measurement of a pressure gradient across ostial proximal lesion is recommended to determine the need for intervention.