Cardiac Ventriculography

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Cardiac ventriculography is used to define the anatomy and function of the ventricles and related structures in patients with congenital, valvular, coronary, and myopathic heart disease (1–5). Specifically, left ventriculography may provide valuable information about global and segmental left ventricular function, mitral valvular incompetence, and the presence, location, and severity of a number of other abnormalities such as ventricular septal defect, hypertrophic cardiomyopathy, or left ventricular mural thrombus. As a result, left ventriculography is a routine part of diagnostic cardiac catheterization in patients being evaluated for coronary artery disease, aortic or mitral valvular disease, unexplained left ventricular failure, or congenital heart disease. Similarly, right ventriculography may provide information about global and segmental right ventricular function and can be especially helpful in patients with congenital heart disease. In reality, however, right ventriculography is rarely performed in an adult cardiac catheterization laboratory.

INJECTION CATHETERS

To achieve adequate opacification of the left or right ventricle, it is necessary to deliver a relatively large amount of contrast material in a relatively short time. In adults, a 6F, 7F, or 8F catheter with multiple side-holes allows rapid delivery of contrast material while allowing the catheter to remain in a stable position during injection, thereby producing no disturbance of cardiac rhythm. In contrast, catheters that have only an end-hole (e.g., Cournand, multipurpose) are not well suited for left ventriculography, because the contrast jet out of the single end-hole causes the catheter to recoil during contrast delivery, resulting in ventricular ectopic beats, inadequate ventricular opacification, and myocardial penetration (so-called endocardial staining) or even perforation.

Pigtail Catheter

The pigtail catheter, as developed by Judkins, has several advantages over an end-hole design for left and right ventriculography (Fig. 12.1). Although its end-hole permits insertion of the pigtail catheter over a J-tipped guidewire, so that it can be advanced safely to the left ventricle from the arm or leg even in the patient with brachiocephalic or iliac arterial tortuosity, the loop shape keeps the end-hole away from direct contact with the endocardium. The presence of multiple side-holes on the several centimeters of catheter shaft proximal to the pigtail loop provides numerous simultaneous exit routes for contrast material, thus stabilizing the catheter within the left ventricle during contrast injection and reducing the magnitude of catheter recoil. These characteristics virtually eliminate the possibility of endocardial staining, since the end-hole usually is not positioned adjacent to ventricular trabeculae, and substantially reduces the occurrence of ventricular ectopic beats. The pigtail usually passes easily across a normal aortic valve, either directly or by prolapsing across the valve leaflets, whereas passage across a stenotic aortic valve requires use of a straight leading guidewire (see Chapter 4). It can usually be passed across a porcine aortic valve bioprosthesis, and more easily than straight catheters such as the NIH or Eppendorf, since the pigtail configuration seems to prevent the catheter from sliding down into the lateral sinuses outside the support struts. Pigtail catheters can also be passed retrograde across a ball valve prosthesis (Starr-Edwards), although its interference with seating of the ball during diastole may cause significant aortic regurgitation. Only the smallest diameter (e.g., 4F) catheter should be used for this purpose, dwell time across the valve should be kept to a minimum, and the patient should be monitored carefully for hemodynamic deterioration until the catheter is withdrawn from the left ventricle. Of course, no catheter should ever be passed across a tilting disc aortic valve prosthesis (Bjork-Shiley, Medtronic-Hall, or St. Jude) because of the risk of catheter entrapment if it were to pass through the minor orifice of the valve.
Examples of ventriculographic catheters in current use (clockwise from the top): pigtail, 8F (Cook); Gensini, 7F; NIH, 8F; pigtail; 8F (Cordis); Lehman ventriculographic, 8F; Sones, 7.5F tapering to a 5.5F tip. The advantages and disadvantages of each catheter are discussed in the text. The Gensini and Sones catheters may cause endocardial staining because of the high-pressure jet of contrast material exiting the end-hole; therefore, ventriculography with them should be performed with special attention to catheter position and rate of contrast injection.

The original pigtail design had a straight shaft leading up to the pigtail end. It was designed to sit directly under the aortic valve, and just in front of the mitral inflow, relying on that inflow to distribute contrast to the apex of the left ventricle. The more recently developed “angled” pigtail catheters, which have a 145° to 155° shaft angle at the distal end (just proximal to the side-holes segment) may be helpful in achieving a central position within the left ventricular long axis, particularly in the patient whose left ventricle is positioned horizontally. This may be improved further if the heart is pulled into a somewhat more vertical orientation by having the patient take and maintain a deep breath during the left ventriculographic injection. Although the angle approximates that formed by the intersection of the left ventricular and ascending aortic long axes, the angled pigtail is especially likely to recoil during injection of a relatively large volume of contrast material. Some authors have suggested that catheter manipulation and overall image quality are better with the angled than with the straight pigtail (6), but adequate ventriculography can be achieved with either shape, so the choice of pigtail design remains a matter of operator preference.

Sones Catheter

The Sones catheter is used widely for left ventriculography when catheterization is performed from the brachial approach, although some operators prefer to use a pigtail catheter, as described in the previous section. The polyurethane Sones catheter (80 cm Cordis SON-II, Sones Technique, Cordis Corporation, Miami, FL) is particularly suitable for left ventriculography because it has four side-holes in addition to its end-hole. The catheter comes in 7F and 8F sizes and tapers to a 5F external diameter near its tip. The catheter accepts an 0.035-inch guidewire, which can be useful in crossing a severely stenotic aortic valve. Techniques for traversing a tortuous subclavian artery system and entering the left ventricle with the Sones catheter are discussed in Chapter 5. For left ventriculography, the Sones catheter should be positioned in an axial orientation (parallel to the ventricular long axis), with its tip midway between the aortic valve and left ventricular apex. Low injection rates (see later discussion) usually minimize the extent and forcefulness of catheter recoil. Catheter recoil may still occur, however, with induction of multiple ventricular extrasystoles and potential danger of endocardial staining. Accordingly, the operator should hold the catheter during injection and be prepared to withdraw it if significant recoil develops.

NIH and Eppendorf Catheters

The NIH and Eppendorf catheters have multiple side-holes and no end-hole (Fig. 12.1). They are easily inserted through an arteriotomy (by the brachial approach) or a percutaneously introduced femoral arterial sheath. The 7F NIH catheter prepared by USCI (Bard Inc., Billerica, MA) is made of woven Dacron with nylon reinforcement and is especially stiff. The polyurethane Cordis NIH catheter (Cordis Corporation, Miami, FL) and the polyethylene Cook NIH Torcon blue catheter (Cook, Bloomington, IN) are much softer and less likely to cause dissection or perforation. The Eppendorf catheter (USCI), of woven Dacron construction is less stiff as well, and the tips of both the Cordis NIH and the USCI Eppendorf catheters are sufficiently soft that they can be gently prolapsed across the aortic valve. In our catheterization laboratories, the Eppendorf catheter and polyurethane and polyethylene NIH catheters are sometimes used for left ventriculography by the brachial approach. In some patients, especially those whose left ventricles are small, left ventriculography with an NIH or Eppendorf catheter induces frequent ventricular premature beats. Despite the absence of an end-hole, endocardial staining occasionally occurs with these catheters, usually in patients in whom the end of the catheter is wedged within the ventricular trabeculae. The NIH and Eppendorf catheters are practical and effective for right ventricular angiography, but the standard pigtail catheter or the Grollman catheter (which has a pigtail tip and an angulated shaft) is now preferred for right ventriculography and pulmonary angiography.

Lehman Catheter
The Lehman ventriculographic catheter has a tapered, closed tip that extends beyond multiple side-holes (Fig. 12.1). The tapered tip may assist the operator in manipulating the catheter through tortuous arteries and across a stenotic aortic valve. Once in the left ventricle, the tip lessens the likelihood of endocardial staining, but, in our experience, this tip increases the chance of ventricular ectopy during the injection of contrast material.

**INJECTION SITE**

The adequate opacification of either ventricle is accomplished only if a large amount of contrast material is delivered in a short time. Satisfactory opacification of the left ventricle can usually be achieved by the injection of contrast material into the left atrium, with cineangiocraphic acquisition as the left ventricle is filled. Although such a left atrial injection might be advantageous because it seldom causes atrial or ventricular ectopic activity, it requires a transseptal catheterization, does not allow an evaluation of mitral valvular incompetence, and may obscure the basal portion of the left ventricle and the aortic valve. The left ventricle may be opacified by aortography in the patient who has significant aortic regurgitation. Similarly, the right ventricle may be opacified satisfactorily by injection of contrast material into the venae cavae or right atrium. These injection sites, however, do not allow an assessment of tricuspid valvular incompetence, and filming the injection in an obliquity that eliminates overlap of the venae cavae, right atrium, and right ventricle is often difficult.

Ventriculography in the adult therefore is best accomplished by injecting contrast material directly into the ventricular chamber in question. In the left ventricle, the optimal catheter position is the midcavity, provided that ventricular ectopy is not a problem (Fig. 12.2). Such a midcavitory position ensures (a) that adequate contrast material is delivered to the chamber's body and apex; (b) that the catheter does not interfere with mitral valvular function, thereby producing factitious mitral regurgitation; and (c) that the holes through which the contrast material is injected are not wedged within the ventricular trabeculae (possibly causing endocardial staining). In some patients, a midcavitory position induces repetitive ventricular ectopy, especially with an NIH or Eppendorf catheter. In these individuals, the tip of the catheter is best positioned in the left ventricular inflow tract, immediately in front of the posterior leaflet of the mitral valve (Figs. 12.3 and 12.4). This position usually does not cause ventricular ectopy, but mitral regurgitation may be produced if the catheter is too close to the mitral valve. In occasional patients with vigorous ventricular contraction, no stable midventricular position can be found for the catheter. Intermittent bumping of the catheter into the endocardium may cause enough ventricular ectopy to interfere with meaningful ventriculography. If a pigtail catheter is being used, it is sometimes useful to advance the catheter into continuous contact with the left ventricular apex, assuming that there is no evidence of apical aneurysm or mural thrombus. This may allow measurement of left ventricular pressure during stable rhythm, and left ventriculography may even be performed from this position if the rate of contrast injection is reduced to 10 mL/sec (see later discussion).

**FIG. 12.2.**

An example of midcavitory catheter position for 30° right anterior oblique left ventriculography using a pigtail catheter: before the injection of contrast material (A), at end-diastole (B), and at end-systole (C).

**FIG. 12.3.**

An example of left ventricular inflow tract catheter position for 30° right anterior oblique left ventriculography using a pigtail catheter: before the introduction of contrast material (A), at end-diastole (B), and at end-systole (C). Note that this patient has a large anteroapical aneurysm.

**FIG. 12.4.**

An example of left ventricular inflow tract catheter position for 30° right anterior oblique left ventriculography using an Eppendorf catheter: at end-diastole (A) and at end-systole (B).
In the right ventricle, the optimal catheter position is the midcavity, provided that repetitive ventricular ectopy does not occur. If ectopy is uncontrollable, the catheter may be positioned in the outflow tract, below the pulmonic valve. Even here, however, repetitive ventricular ectopy may present a difficult problem. In our experience, right ventriculography is often accompanied by frequent ventricular premature beats regardless of catheter position.

**INJECTION RATE AND VOLUME**

The rapid delivery of an adequate amount of contrast material requires the use of a power injector. There are two types of power injectors. The pressure injector allows one to select the volume of contrast material and its delivery pressure, but the rate of delivery is determined by the lumen size and length of the catheter, the viscosity of the contrast material, and the size of the injector syringe. The rapid delivery of contrast material is facilitated by a large bore and short catheter length, prewarmed contrast material, and an injector syringe of small diameter. The pressure injector is now outmoded and does not have the versatility of the flow injector.

The flow injector (most commonly, the device manufactured by Medrad) allows one to select both the volume and the rate of delivery of contrast material. A pressure sufficient to deliver a selected volume of injectate in a selected time is automatically developed, although a maximal pressure cutoff will shut the injector down immediately if the pressure required exceeds a preset maximum pressure. In most catheterization laboratories, the maximal pressure cutoff is set at 1,000 psi. Of course, this high pressure is not actually delivered to the catheter tip; instead, most of it is dissipated by frictional losses in the shaft of the catheter.

Some injectors permit synchronization of the injection of contrast material with the R wave of the electrocardiogram, so that a set flow rate is delivered in each of several successive diastolic intervals (7). Although this technique has been said to lessen the incidence of ventricular ectopic beats and to minimize the volume of contrast material required for adequate ventricular opacification, our impression is that it offers no clear advantage over nonsynchronized methods.

Cine left ventriculography is accomplished using an injection rate and volume that depend on (a) the type and size of catheter, (b) the size of the ventricular chamber to be opacified, (c) the approximate ventricular stroke volume, and (d) the preventricular hemodynamics. A number of years ago, we asked our colleagues in several laboratories to tell us their usual parameters for left ventricular injection using various catheters and either femoral or brachial techniques, and these parameters are listed in Table 12.1. As can be seen, there is a fairly wide spectrum of injection rates and volumes for the pigtail catheter for either a femoral or a brachial approach. For the pigtail, Eppendorf, and NIH catheters, an injection rate of 10 to 16 mL/sec (higher for high cardiac output and large ventricular chamber) and a total volume of 30 to 55 mL (depending on ventricular size) represent average values from Table 12.1. The current injection parameters used most commonly with pigtail catheters are 30 to 36 mL at 10 to 12 mL/sec. If a Sones catheter is used for left ventriculography, the rate of injection of contrast material should not exceed 7 to 12 mL/sec, to minimize the chance of recoil and staining.

In the patient with hemodynamic evidence of severe left ventricular dysfunction (mean pulmonary capillary wedge pressure higher than 25 mm Hg), left ventriculography should be performed with the use of a low-osmolar contrast agent. Nonionic contrast agents, discussed in Chapter 2, have substantially improved the safety of left ventriculography in patients with depressed myocardial function, severe coronary artery disease, and/or aortic stenosis. Compared with high-osmolar agents (e.g., sodium meglumine diatrizoate), the low-osmolar agents produce only minor decreases in ionized calcium in the coronary circulation and therefore have a minimal myocardial depressant effect (8–11). They should generally be used for performing ventriculography in patients with elevated left ventricular filling pressures due to coronary artery disease, cardiomyopathy, or severe aortic or mitral regurgitation. If filling pressures are markedly elevated, left ventriculography should be performed during the administration of an acutely imposed “protective regimen” of sublingual nitroglycerin or during the intravenous infusion of nitroglycerin or sodium nitroprusside. If the pulmonary capillary wedge pressure is greatly elevated because of mitral stenosis, left ventriculography should be preceded by the intravenous administration of morphine sulfate and furosemide. Failure to take a highly elevated preventricular pulmonary capillary wedge pressure seriously can lead to disastrous consequences, such as intractable pulmonary edema and even death. In our experience, the left ventricular end-diastolic pressure is not as reliable a predictor of impending pulmonary edema as the wedge pressure because (as discussed elsewhere) the left ventricular end-diastolic and mean pulmonary capillary
Before the power injection of contrast material, one should take appropriate precautions in filling and firing the power injector to prevent air embolism. In our catheterization laboratories, a Medrad Mark IV power injector with a 130-mL translucent syringe is used. These syringes are made of siliconized plastic so that the contrast medium and any air can easily be seen. The injector is loaded with contrast material through a short U-shaped straw while the syringe barrel is pointed upward. With the injector still in the vertical position, a 30-inch length of sterile roentgenography tubing is connected to the syringe and all air is expelled from the syringe and tubing. This is done by holding the load switch in the forward position as the operator taps the syringe and its Luer-Lok connector to discharge all air bubbles. Only then is the injector head inverted, and a “running connection” is made between the roentgenography tubing and the catheter hub. Specifically, a fluid-to-fluid connection is accomplished by touching the meniscus of blood is spurting from the hub of the catheter to the meniscus of contrast material exiting the roentgenography tubing as the technician depresses the forward position of the load switch or manually advances the syringe plunger of the injector. After the connection is made, the injector operator presses the reverse position of the load switch or manually retracts the plunger until the “interface” between contrast material and blood in the roentgenography tubing can be seen and verified to be free of air bubbles. Before the left ventriculographic run, a test injection of a small amount of contrast material is performed under fluoroscopic visualization. This enables the physician to (a) assess catheter and patient position, (b) confirm that ventricular ectopy does not occur, and (c) exclude a reaction to contrast material (if this is the patient's first exposure to it). If the catheter is repositioned, another test injection is recommended.

The physician performing the catheterization should look closely at the injector syringe to be sure that it is filled with contrast medium, free of air, and oriented in the desired “nose-down” direction. This physician should grasp the catheter at the point of its insertion into the body during the power injection of contrast material, so that it may be pulled back instantaneously if ventricular extrasystoles, myocardial staining, or other untoward events develop during injection. The physician operator must have good visualization of the fluoroscopic screen during ventriculography, and the technician or other individual firing the injector should be prepared to abort the injection on command from the physician operator in the event of an untoward occurrence. In many laboratories, the physician performing the catheterization holds the connection between catheter and roentgenography tubing tightly in one hand during the power injection to prevent uncoupling of this connection.

Proper catheter positioning is important to avoid extrasystoles during ventriculography, as discussed earlier in this chapter. If extrasystoles develop, it is our policy to withdraw the ventriculographic catheter immediately after the first extrasystole, for a distance of approximately 2 to 3 cm. This usually results in a quiet position for the remainder of the 3- to 4-second contrast injection, and it is particularly effective when the Sones catheter is being used for left ventriculography; this technique has not resulted in ventricular staining in a very large experience.

Instructions to the patient regarding respiration during contrast ventriculography vary from laboratory to laboratory. Previously, imaging systems were often inadequate to give good definition of the left ventricular silhouette unless ventriculography was performed during deep inspiration to move the diaphragm out of the radiographic field. With modern imaging systems, excellent definition of the ventricular silhouette can be achieved without performing ventriculography during held deep inspiration. Left ventriculography done during normal quiet breathing allows physiologic interpretation of left ventricular volumes, angiographic stroke volume, and calculated left ventricular regurgitant fraction in cases of valvular regurgitation. In the catheterization laboratory at Parkland Memorial Hospital (Dallas, Texas), most left ventriculograms are performed after the patient simply has stopped breathing (without first inspiring deeply).

**FILMING PROJECTION AND TECHNIQUE**

As a general rule, biplane ventriculography is preferable to single-plane ventriculography because it allows one to obtain more information at essentially no additional risk to the patient. For example, in the patient with coronary
artery disease, biplane left ventriculography is superior to single-plane left ventriculography in providing information on the location and severity of segmental wall motion abnormalities. In the patient with congenital heart disease, biplane right ventriculography allows one to assess accurately the anatomy of the right ventricular outflow tract, the pulmonic valve, and the proximal portions of the pulmonary artery. Biplane ventriculography does have several disadvantages, including (a) the increased expense of biplane cineangiographic equipment, (b) the reduced quality of cineangiographic imaging in each plane that results from the radiation scatter caused by the opposite plane, (c) the additional time required to position the biplane equipment appropriately, especially when the brachial approach is used, and (d) the additional radiation exposure to personnel in the room.

FIG. 12.5.

Left ventriculogram in a 30° right anterior oblique projection (end-systolic frame) showing a large anterior wall aneurysm. The patient was a 65-year-old man who had a massive myocardial infarction (peak creatine kinase measurement, 4,460 units) and showed subsequently a progressively enlarged cardiac silhouette on roentgenography. Catheterization 4 weeks after infarction demonstrated a large anterior wall left ventricular (LV) aneurysm, with LV pressure 95/40 mm Hg, pulmonary capillary wedge pressure 34 mm Hg, and occlusion of the left anterior descending artery proximal to the first septal perforator. Ejection fraction was 18%, and the other coronary arteries were normal.

Whether performing biplane or single-plane ventriculography, one should use projections that provide maximal delineation of the structure of interest and minimal overlapping of other structures. Most laboratories doing biplane left ventriculography prefer a 30° right anterior oblique (RAO) and a 60° left anterior oblique (LAO) view. The 30° RAO projection eliminates overlap of the left ventricle and the vertebral column; allows one to assess anterior, apical, and inferior segmental wall motion; and places the mitral valve in profile, thus providing a reliable assessment of the presence and angiographic severity of mitral regurgitation. As seen in Fig. 12.5, the 30° RAO projection allows excellent visualization of the extent of an anterior wall aneurysm of the left ventricle in a patient with isolated proximal occlusion of the left anterior descending artery. The 60° LAO view allows one to assess ventricular septal integrity and motion, lateral and posterior segmental function, and aortic valvular anatomy. To prevent the foreshortening of the left ventricle that commonly occurs with LAO views and visualize the entire length of the interventricular septum in profile, 15° to 20° cranial angulation should be added to the 60° LAO view.

If biplane cineangiographic equipment is not available, the single-plane projection that provides the best delineation of structures of interest should be used. For example, the 30° RAO projection allows a reliable assessment of mitral regurgitation, whereas a 45° to 60° LAO view (with cranial angulation of 15° if possible) provides the opportunity to visualize a ventricular septal defect and the associated left-to-right shunting.

For routine left or right ventriculography, we perform cineangiography at 30 frames per second, using the 9-inch field of view. This allows us to visualize the entire ventricle within the field. In many patients, ventriculography performed with a greater degree of magnification (e.g., 6-inch intensifier) is not adequate for assessment of the entire ventricular silhouette together with the left atrium and ascending aorta.

ANALYSIS OF THE VENTRICULOGRAM

The most common analysis of the left ventriculogram is a qualitative assessment of global and regional systolic function. Analysis should use a normal sinus beat that follows a previous normal sinus beat, and in which the ventricle is well opacified. Use of ectopic beats or postectopic beats will give a false impression of ventricular function. The ejection fraction (see Chapters 16 and 17) may be estimated as normal (50% to 69%), hyperdynamic (more than 70%), mildly hypokinetic (35% to 49%), moderately hypokinetic (20% to 24%), or severely hypokinetic (less than 20%). Regional wall motion can also be graded as being normal, hypokinetic, akinetic, or dyskinetic for each of the segments seen in the RAO projection (anterolateral, apical, inferior, and posterobasal segments) and in the LAO projection (basal septal, apical septal, apical lateral, and basal lateral segments). Using the area-length method described in Chapter 16, actual end-diastolic and end-systolic volumes can be calculated, and from them the actual ejection fraction (the percent of blood volume present at end-diastole that is ejected by end-systole).
The degree of mitral regurgitation can be estimated (on a scale of 1 + to 4 +) by looking for leakage of contrast material from the left ventricle back into the left atrium and the relative opacification of the left atrium, in the RAO projection (see Chapter 29). Comparison of the angiographic stroke volume (end-diastolic volume minus end-systolic volume) with the forward stroke volume (cardiac output divided by heart rate) in patients with aortic or mitral regurgitation allows calculation of the regurgitant volume and regurgitant fraction (angiographic stroke volume minus forward stroke volume, as a percentage of angiographic stroke volume). Mild (1+) mitral regurgitation is usually associated with a regurgitant fraction of less than 30%; moderate (2+), 30% to 39%; moderately severe (3+), 40% to 49%; and severe, greater than 50% (13).

INTERVENTION VENTRICULOGRAPHY

Segmental dysfunction of the left ventricular wall can be caused by ischemia or infarction. Over the years, several techniques have been described that allow one to determine during left ventriculography whether an asynergic segment of the left ventricle is ischemic or infarcted. With each of these techniques, segments whose abnormal wall motion is caused by ischemia show improvement in systolic motion, whereas segments whose abnormal wall motion is caused by infarction fail to improve.

First, left ventricular segmental wall motion can be improved substantially by the administration of catecholamines (14). Two left ventriculograms are performed—the first in the resting (baseline) state, and the second during a steady-state infusion of epinephrine (1 to 4 mg/min) or dobutamine (10 to 15 µg/kg per minute). Segments that are ischemic and, as a result, hypokinetic or akinetic on baseline ventriculography improve their contractile pattern during epinephrine infusion; in contrast, segments that are asynergic due to infarction show no alteration in contractility when stimulated by epinephrine.

Second, left ventricular segmental wall dysfunction can be improved by nitroglycerin (15), either by improving collateral blood flow, reducing myocardial oxygen consumption to fall within available supply, or simply reducing the afterload against which the left ventricle must eject. Here, also, two left ventriculograms are performed, one before and the other after sublingual administration of nitroglycerin, when there is evidence of a nitroglycerin-induced fall in systemic arterial pressure. Segments of the left ventricle in which contraction is abnormal on the baseline ventriculogram but improves after nitroglycerin administration are reversibly injured (i.e., ischemic), whereas those in which asynergy is present before nitroglycerin and is not altered by it are most likely irreversibly damaged (i.e., infarcted). Segments in which motion improves with nitroglycerin generally maintain this level of improvement after successful surgical revascularization; in contrast, segments in which contractile function is not influenced by nitroglycerin are not improved by revascularization.

Third, left ventricular segmental wall motion can be influenced by postextrasystolic potentiation (16). A single ventricular premature beat is introduced during left ventriculography and is followed by a compensatory pause and then a potentiated beat. Segmental wall motion during one of the preceding sinus beats is compared with that of the postextrasystolic beat. Left ventricles with asynergic wall motion during a preceding sinus beat that improves on the potentiated beat are ischemic, whereas those in which asynergy is similar on the preceding sinus beat and on the postextrasystolic beat are infarcted. Augmentation ventriculography by this technique offers the advantage that both baseline and potentiated left ventricular wall motion can be characterized on a single ventriculogram. Postextrasystolic potentiation may be provided by introducing a timed stimulus (delivered through a right ventricular pacing catheter) or by pullback of a right ventricular catheter during left ventriculography. It is probably unwise to attempt to induce the ventricular extrasystole by manipulating the left ventriculographic catheter during the injection of contrast material, because such manipulation may cause endocardial staining.

Other types of intervention ventriculography may be of use in the patient with chronic left ventricular volume overload caused by aortic or mitral regurgitation. In the patient with aortic regurgitation and well-preserved left ventricular function, angiotensin in a dose sufficient to increase left ventricular systolic pressure by 20 to 50 mm Hg causes no change in left ventricular ejection fraction (17). In the patient whose aortic regurgitation has caused a loss of left ventricular contractile reserve, a similar amount of angiotensin causes a fall in left ventricular ejection fraction of more than 0.10. Thus, left ventriculography during “afterload stress” may provide additional information about left ventricular functional capability. Alternatively, intervention ventriculography using sodium nitroprusside may be used in patients with mitral regurgitation, aortic regurgitation, or dilated cardiomyopathy to assess the potential benefit of chronic vasodilator therapy.
COMPLICATIONS AND HAZARDS

Although complications of cardiac catheterization and angiography are discussed in detail in Chapter 3, certain specific points relevant to ventriculography are presented here.

Complications of Injection

Arrhythmias

Ventricular extrasystoles occur frequently during ventriculography and are usually caused by mechanical stimulation of the ventricular endocardium by the catheter or a jet of contrast agent. Such extrasystoles can usually be eliminated or at least minimized by repositioning the catheter. Although short runs of ventricular tachycardia occur during an occasional ventriculogram, they almost always cease promptly when the catheter is removed from the ventricle. Rarely, the ventricular tachycardia caused by ventriculography is sustained even after catheter removal. It should be treated quickly with a bolus of intravenous lidocaine and, if necessary, direct current countershock. Ventricular fibrillation has been reported to be induced by an improperly grounded power injector (18).

Intramyocardial Injection

(Endocardial Staining)

Deposition of contrast material within the endocardium and myocardium (so-called endocardial staining) is usually caused by improper positioning of the ventriculographic catheter so that it passes under one of the papillary muscles or so that a side-hole lies firmly against the endocardium. Although a small endocardial stain usually causes no problem, a large stain may lead to medically refractory ventricular tachyarrhythmias, including ventricular tachycardia or fibrillation. In the catheterization laboratory at Parkland Memorial Hospital, about 3,500 left ventriculograms have been performed with a pigtail catheter. A very small endocardial stain occurred in only one case, and it was not accompanied by ventricular tachyarrhythmias. Rarely, the power injection of contrast material causes myocardial perforation, with resultant leakage of blood and contrast material into the pericardial space and the development of cardiac tamponade. This must be treated by emergency pericardiocentesis, and immediate consultation must be obtained from a cardiothoracic surgeon.

Fascicular Block

Because of the proximity of the anterior fascicle of the left bundle to the left ventricular outflow tract, transient left anterior fascicular block may occur during retrograde left-sided heart catheterization. In the patient with underlying right bundle branch block and left posterior fascicular block, complete heart block may occur as the catheter is advanced into the left ventricle (19). Although temporary pacing is usually required, catheter-induced fascicular block usually resolves within 12 to 24 hours. Transient complete left bundle branch block is an extremely rare complication of retrograde left heart catheterization (20).

Embolism

The inadvertent injection of air or thrombus probably poses the greatest risk associated with ventriculography. The presence of thrombi on or within the ventriculographic catheter is minimized by (a) frequent flushing of the catheter with a solution containing heparin and (b) systemic heparinization of the patient when the ventriculographic catheter is first introduced. Some operators still administer 5,000 units of heparin intravenously when the first arterial catheter (brachial or femoral) is introduced into the aorta, whereas others omit heparin and substitute careful and frequent catheter flushing and a rapid procedure as ways to reduce the risk of embolism.

Occasionally, a patient is referred for catheterization in whom (from noninvasive testing) a thrombus in the left ventricular apex is suspected. If left ventriculography is required in such a patient, great care should be taken to position the ventriculographic catheter in the left ventricular inflow tract, avoiding the apical portion completely.
Partially organized thrombi may be dislodged from the left ventricular cavity by the catheter tip or by the force of a power injection. Accordingly, the ventricular angiographic catheter should not be advanced to the left ventricular apex except under exceptional circumstances (e.g., suspicion of idiopathic hypertrophic subaortic stenosis).

Complications of Contrast Material

For 20 to 30 seconds after ventriculography with a high-osmolar agent, the patient will experience a “hot flash” owing to the powerful vasodilation caused by the contrast material as it distributes throughout the arterial tree (see Chapter 2). Transient nausea and vomiting may also occur in 20% to 30% of patients. With low-osmolar contrast agents, these complications are uncommon. The immediate but short-lived hemodynamic effects of ventriculography with ionic contrast agents include a modest fall in systemic arterial pressure, a reflex increase in heart rate, and a transient depression of left ventricular contractility; these resolve within 1 to 2 minutes.

ALTERNATIVES TO CONTRAST VENTRICULOGRAPHY

Echocardiographic Visualization of the Left Ventricle

Two-dimensional echocardiography may be used as an alternative to contrast ventriculography to assess global and regional left ventricular performance. Echocardiography is noninvasive, does not require exposure to radiation, and does not add to the contrast load of coronary angiography in patients at high risk for contrast-induced renal dysfunction. In a minority of subjects, echocardiography fails to provide adequate images owing to extreme obesity or an increased anteroposterior chest dimension. In most, however, adequate images of the left ventricle can be acquired in multiple short- and long-axis planes to evaluate segmental and global left ventricular function as well as the degree of mitral regurgitation. Two-dimensional echocardiographic imaging also allows determination of left ventricular volumes using a modification of Simpson's rule, based on analysis of orthogonal long-axis views. If only a single view is available, the area-length method may be applied to the end-diastolic and end-systolic images. The left ventricular volumes provided by echocardiography are somewhat smaller and the estimates of mitral regurgitation somewhat higher than those obtained with contrast ventriculography (13)(21). Because two-dimensional echocardiography can be used to determine left ventricular wall thickness, it is an excellent method for quantitating left ventricular mass.

Magnetic Resonance Imaging Ventriculography

In preliminary assessments, magnetic resonance imaging (MRI) has also appeared to be a reliable alternative technique for measuring ventricular dimensions and evaluating regional wall motion. MRI images are acquired in a gated fashion throughout the cardiac cycle, and end-diastolic and end-systolic frames are identified. Because these images are acquired in multiple planes, a detailed assessment of regional wall motion can be accomplished in almost all subjects regardless of body shape or size. Left ventricular volumes are calculated using Simpson's rule (i.e., volume = Sigma area × slice thickness), with each area determined from consecutive short-axis slices through the ventricle. Alternatively, ventricular volumes may be determined by acquiring a single long-axis image and applying the area-length method (as with contrast ventriculography). The use of Simpson's rule requires lengthy image acquisition, whereas the area-length method relies on geometric assumptions that may be invalid in some subjects. In general, MRI provides values for left ventricular volumes that are similar to those obtained with contrast ventriculography (22)(23). As with two-dimensional echocardiography, MRI provides an accurate quantitation of left ventricular wall thickness, from which mass is easily calculated, and it may be particularly valuable when a high degree of anatomic localization is required (24).

Electromechanical Mapping

Originally developed for electrophysiology, the Biosense electromechanical mapping catheter (Biosense-Webster, Diamond Bar, CA) uses tip sensors to measure the relative strength of electromagnetic fields emitted by three coils positioned under the patient support, and thereby calculate the exact position of the catheter tip in three dimensions (25)(26). When the catheter is placed in contact with the left ventricular endocardium, the unipolar electrogram can
be recorded from multiple locations within the left ventricle. Recording the motion of the catheter over the cardiac cycle allows calculation of cardiac volumes (including those at end-diastole and end-systole), local wall motion, and wall shortening. Areas of myocardial infarction show poor local shortening with low unipolar voltage. In contrast, areas with severe ischemia show reduced local shortening with retained unipolar voltage. Although more time-consuming than contrast ventriculography, electromechanical mapping may provide more detailed assessment of ventricular function and a highly accurate way to deliver local therapies (direct myocardial revascularization, local drug injection) to ischemic areas of the left ventricle.

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