CARDIAC CATHETERIZATION

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

In 1929, Werner Forssman, a resident surgeon at Eberswalde, Germany, inserted a urologic catheter into his right atrium from a left antecubital vein cutdown he performed on himself using a mirror. After walking downstairs to the radiology suite, the position of the catheter tip was verified by a roentgenogram.1 From this beginning of cardiac catheterization, dramatic and innovative advances in methods and materials have occurred. Catheterization has long since moved from a specialized laboratory to the bedside enabling the clinician to employ physiologic data to guide treatment.2,3 and 4

Cardiac catheterization—the insertion and passage of small plastic catheters into arteries, veins, the heart, and other vascular structures—is performed to acquire radiographic images of coronary arteries and cardiac chambers and to measure cardiovascular hemodynamics (pressures, cardiac output, oximetry data). The catheterization laboratory not only performs diagnostic cardiac imaging but can also examine the aorta, pulmonary veins, and peripheral vessels for diseases, anomalies, or obstructions. Furthermore, in the last two decades, cardiac catheterization has evolved from a strictly diagnostic modality to one of therapeutics through numerous catheter-based interventions (like angioplasty, stenting, and closure of atrial septal defects). Now, a wide variety of palliative and corrective interventions may accompany a diagnostic catheterization study (Table 17-1).

TABLE 17-1 Diagnostic and Therapeutic Interventional Procedures That May Accompany Coronary Angiography

Diagnostic Procedures	Comment
Central venous access (femoral, internal jugular, subclavian)	Access for emergency medications or fluids, temporary pacemaker
Hemodynamic assessment	
Left heart pressures (aorta, left ventricle)	Routine for all studies

Right and left heart combined pressures	Not routine for coronary artery disease; mandatory for valvular heart disease; congestive heart failure (CHF), right ventricular dysfunction, pericardial diseases, cardiomyopathy, intracardiac shunts, congenital abnormalities
Transseptal or LV puncture	Valvular heart disease
Intracoronary pressure/flow	Coronary lesion assessment
Left ventricular angiography	Routine for all studies; may be excluded with high-risk patients, left main coronary or aortic stenosis, severe CHF, renal failure
Internal mammary artery and saphenous vein bypass graft selective angiography	Routine for coronary bypass conduit
Pharmacologic studies	
Ergonovine	Routine for suspected coronary vasospasm
IC/IV/sublingual nitroglycerin	Routine for all coronary angiography
Aortography	Routine for aortic insufficiency, aortic dissection, aortic aneurysm, with or without aortic stenosis, routine to locate bypass grafts not visualized by selective angiography
Renal and peripheral vascular angiography	For renovascular hypertension and peripheral vascular disease
Cardiac pacing and electrophysiologic studies	Arrhythmia evaluation
Therapeutic interventional procedures	
Coronary disease	Percutaneous coronary interventions (e.g., PTCA, stenting)
Valvular stenosis	Balloon catheter valvuloplasty

Atrial septal defect	Atrial septal defect closure
Hypertrophic obstructive cardiomyopathy (HOCM)	Transseptal alcohol septal ablation for HOCM
Arrhythmia	Electrophysiologic conduction tract catheter ablation
Arterial access site closure devices	Available for patients prone to access site bleeding

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Indications and Contraindications

Cardiac catheterization is used to diagnose atherosclerotic artery disease, cardiomyopathy, infarction, and valvular or congenital heart abnormalities. The principal indications for cardiac catheterization are summarized in Table 17-2.

TABLE 17-2 Indications for Cardiac Catheterization

Indications	**Procedures**
Suspected or known coronary artery disease	
New onset angina	LV, COR
Unstable angina	LV, COR
Evaluation before a major surgical procedure	LV, COR

Silent ischemia	LV, COR, ERGO
Positive ETT	LV, COR, ERGO
Atypical chest pain or coronary spasm	LV, COR, ERGO
Myocardial infarction	
Unstable angina post infarction	LV, COR
Failed thrombolysis	LV, COR, RH
Shock	LV, COR, RH
Mechanical complications (Ventricular septal defect, rupture of wall or papillary muscle)	LV, COR, RH
Sudden cardiovascular death	LV, COR, R + L
Valvular heart disease	LV, COR, R + L, AO
Congenital heart disease (before anticipated corrective surgery)	LV, COR, R + L, AO
Aortic dissection	AO, COR
Pericardial constriction or tamponade	LV, COR, R + L
Cardiomyopathy	LV, COR, R + L, BX
Initial and follow-up assessment for heart transplant	LV, COR, R + L, BX

ABBREVIATIONS: AO = aortography; BX = endomyocardial biopsy; COR = coronary angiography; ERGO = ergonovine provocation of coronary spasm; ETT = exercise tolerance test; LV = left ventriculography; RH = right heart oxygen saturations and hemodynamics (e.g., placement of Swan-Ganz catheter); R + L = right and left heart hemodynamics.

SOURCE: From Kern MJ. *The Cardiac Catheterization Handbook*. St. Louis: Mosby; 2003. With permission.

In general, cardiac catheterization is an elective diagnostic procedure and should be deferred if the patient is not prepared either psychologically or physically. For urgent procedures, especially if the patient is unstable from a suspected cardiac cause such as acute myocardial infarction, catheterization must proceed. In the event of

decompensated congestive heart failure requiring cardiac catheterization for diagnosis and potential treatment, rapid medical management in the catheterization laboratory may be an expeditious option whereby endotracheal intubation, intraaortic balloon pumping, and vasopressors can be instituted rapidly before angiography and revascularization.

Relative contraindications to cardiac catheterization include fever, anemia, electrolyte imbalance (especially hypokalemia predisposing to arrhythmias), or other systemic illnesses needing stabilization (Table 17-3).

TABLE 17-3 Contraindications to Cardiac Catheterization

Absolute contraindications
Inadequate equipment or catheterization facility
Relative contraindications
Acute gastrointestinal bleeding or anemia
Anticoagulation (or known uncontrolled bleeding diathesis)
Electrolyte imbalance
Infection/fever
Medication intoxication (e.g., digitalis, phenothiazine)
Pregnancy
Recent carebral vascular accident (<1 month)
Renal failure

Uncontrolled congestive heart failure, high blood pressure, arrhythmias
Uncooperative patient

SOURCE: From Kern MJ. *The Cardiac Catheterization Handbook*, St. Louis: Mosby; 2003. With permission.

Preparations for Cardiac Catheterization

The procedure should be explained in simple terms as to what will take place and for what reason each step of the procedure will occur. The operator or his or her assistant, usually a physician, obtains consent. The operator should explain the risks for routine cardiac catheterization to the patient and family. The incidence of major risks of stroke, death, and myocardial infarction is approximately 0.1 percent. The minor risks of vascular injury, allergic reaction, bleeding, hematoma, and infection range from 0.04 to 5 percent and should be discussed. Certain patient groups are at higher risk for complications (Table 17-4). There is no alternative to coronary angiography. Often the patient and family's concern of “not knowing” about coronary disease outweighs the risk of performing the test.

TABLE 17-4 Conditions of Patients at Higher Risk for Complications of Catheterization

Acute myocardial infarction
Advanced age (>75 years)
Aortic aneurysm
Aortic stenosis
Congestive heart failure
Diabetes
Extensive three-vessel coronary artery disease
Left ventricular dysfunction (left ventricular ejection fraction <35%)

Obesity
Prior carebral vascular accident
Renal insufficiency
Suspected or known left main coronary stenosis
Uncontrolled hypertension
Unstable angina

SOURCE: From Kern MJ. *The Cardiac Catheterization Handbook*. St. Louis: Mosby; 2003. With permission.

Patient preparations should be tailored to the specific individual and the associated clinical problems. Patients with diabetes mellitus, renal insufficiency, or previous reported hypersensitivity to iodinated contrast media constitute groups who need special considerations.

For diabetic patients, the dose of neutral protamine Hagedorn (NPH) insulin should be cut by 50 percent, because an overnight fast with their normal morning dose of insulin will cause hypoglycemia. Patients receiving NPH insulin are also at higher risk for protamine reactions. Some diabetic patients will be receiving an antihyperglycemic agent, metformin (Glucophage), an analogue of phenformin that was associated with a risk of lactic acidosis. Rare cases of metformin-associated lactic acidosis have been reported in diabetics with chronic renal insufficiency. Metformin is contraindicated in patients with renal dysfunction, as determined by elevated serum creatinine levels. However, there is no evidence that withholding metformin for 48 h before a contrast procedure in patients with normal renal function provides any clinical benefit. Table 17-5 lists conditions that require special patient preparations.

TABLE 17-5 Conditions Requiring Special Preparations for Cardiac Catheterization

Condition	Management

Allergy	Treat potential hypersensitivity
Prior contrast studies	Contrast premedication
Iodine, fish	Contrast reaction algorithm
Premedication allergy	Hold premedication
Lidocaine	Use Marcaine (1 mg/ML)
Patients receiving anticoagulation	Defer procedure
(INR >1.5)	Vitamin K
	Fresh frozen plasma
	Hold heparin
	Protamine for heparin
Diabetes	Hydration, urine output >50 mL/hr
NPH insulin (protamine reaction)	Glucophage held 48 h
Renal function	If renal insufficiency postpone catheterization
(Prone to contrast-induced	Consider urgency and risks of lactic acidosis renal failure)
Glucophage usage	
Electrolyte imbalance (K^+, Mg^{2+}, or Mg^{++})	Defer procedure, replenish/correct electrolytes

Arrthythmias	Defer procedure, administer antiarrhythmics
Anemia	Defer procedure
	Control bleeding
	Transfuse
Dehydration	Hydration
Renal failure	Limit contrast
	Maintain high urine output
	Hydrate

SOURCE: From Kern MJ. *The Cardiac Catheterization Handbook*, St. Louis: Mosby; 2003. With permission.

Some patients may be suitable for outpatient or same-day-discharge cardiac catheterization. Patients suitable for these studies require careful selection.3 Patients with a high likelihood of needing a coronary intervention after the diagnostic study will require either transportation to a full-service laboratory or have to undergo a second procedure at a later time elsewhere. Although some physicians have performed cardiac catheterization on stable, low-risk patients in

freestanding facilities, the lack of support in this environment is a potential liability.

Techniques of Vascular Access

Vascular access is determined by the anticipated pathoanatomic and clinical conditions of the patient. Whenever possible, previous procedure notes of any difficulties, especially of vascular access, should be reviewed. Preprocedural assessment of all peripheral pulses is mandatory.

PERCUTANEOUS FEMORAL ARTERY PUNCTURE

Percutaneous femoral arterial catheterization is the most widely used vascular access

technique. In patients with claudication, chronic arterial insufficiency, diminished or absent pulses, or bruits over the iliofemoral area, alternate entry sites should be considered (Table 17-6).

TABLE 17-6 Possible Vascular Access Routes

Arterial
Axillary
Brachial
Femoral
Radial
Subclavian—*not* used for cardiac catheterization
Translumbar—*not* used for cardiac catheterization
Venous
Brachial
Femoral
Internal jugular
Subclavian

A detailed explanation of percutaneous femoral puncture technique can be found elsewhere.5,6 and 7 In brief, the proposed entry site into the femoral artery can be verified by fluoroscopy using the tip of a metal clamp and placing it near the medial edge of the middle of the head of the femur (Fig. 17-1). The index finger palpates the artery and a Seldinger needle punctures its front wall. A J -tipped guidewire is introduced into the needle and advanced gently into the artery. After the guidewire is advanced in the aorta, the arterial needle is removed and a valved catheter sheath is inserted over the guidewire. The sheath hub is held firmly in place and the dilator and guidewire are removed together. The sheath is flushed with heparinized saline solution.

FIGURE 17-1 *A*. Anatomy relevant to percutaneous catheterization of the femoral artery and vein. The right femoral artery vein pass underneath the inguinal ligament, which connects the anterior-superior iliac spine and public tubercle. The arterial skin nick (indicated by X) should be placed approximately 1 ½ to two fingerbreadths (3 cm) below the inguinal ligament and directly over the femoral artery pulsation. The venous skin nick should be placed at the same level, but approximately one fingerbreadth medial. (From Baim DS, Grossman W. Percutaneous approach including transseptal and apical puncture. In: Baim DS, Grossman W, eds. *Grossman's Cardiac Catheterization, Angiography, and Intervention*, 6th ed. Baltimore: Lippincott, Williams & Wilkins; 2000. With permission.) *B*. Femoral vein puncture with the needle at a 30- to 45-degree angle aiming medially toward the umbilicus. (From Tilkian AG, Daily EK, *Cardiovascular Procedures: Diagnostic Techniques and Therapeutic Procedures*. St Louis: Mosby; 1986. With permission.)

PERCUTANEOUS FEMORAL VEIN PUNCTURE

The femoral vein is located approximately 1 cm medial to the femoral artery. The procedure for femoral vein percutaneous entry is similar to that for the femoral artery with only several minor differences.

Because venous pressure is low, it may be difficult to see unassisted backbleeding from the needle on entry. A syringe may be

attached to the Seldinger needle and gently aspirated during needle advancement. Once in the vein, the remainder of the venous sheath placement is completed in the same fashion as described for the femoral arterial sheath insertion.

RADIAL ARTERY CATHETERIZATION

Campeau first described the radial approach for coronary angiography in 1989.8 The technique has gained widespread acceptance around the world. Kiemeneij, of the Netherlands, also pioneered the radial approach for coronary interventions.9 The radial approach has several distinct advantages: (1) the radial artery is easily accessible in most patients and is not located near significant veins or nerves; (2) the superficial location of the radial artery makes for easy control of bleeding; (3) no significant clinical sequelae after radial artery occlusion occur in patients with a normal Allen test because of the collateral flow to the hand through the ulnar artery; (4) patient comfort is enhanced by the ability to sit up and walk immediately after the procedure; and (5) the radial artery access provides the most secure hemostasis in the fully anticoagulated patient.

Patients with a normal Allen test (Table 17-7) are candidates for the radial approach with 5F and 6F sheaths and catheters. Small or female patients are more likely to have spasm of the radial artery, but this can be treated effectively with the use of intraarterial nitroglycerin or verapamil. Specially coated hydrophilic sheaths reduce spasm on sheath insertion and removal.

TABLE 17-7 The Allen Test

The Allen test assesses the circulation of an intact palmar arterial arch.

Method:

1. The radial and ulnar arteries are simultaneously occluded while the patient makes a fist.
2. The hand is opened appearing blanched.
3. The ulnar artery is released, and the hand observed for change in color.

Satisfactory ulnar flow is present if color returns to palm in 8 to 10 s or if pulse oximetry normalizes on release of the artery.

Arterial puncture using a short 20-gauge needle, a 0.025-in. guidewire, and a radial artery sheath system (24 cm) is performed in a manner similar to femoral artery puncture. The point of puncture is over the radial artery pulsation on the wrist. After puncture, the small guidewire is inserted followed by a long arterial sheath. During arterial sheath insertion, 5000 U of heparin, 2 mL of 1% lidocaine, and 200 µg of nitroglycerin are often given through the partially positioned sheath. An additional intraarteriolar vasodilator—such as diltiazem, verapamil, papaverine, or adenosine—may be necessary to minimize spasm of the radial artery. After vascular access has been secured, angiographic and hemodynamic data are obtained, as discussed below.

Access Site Hemostasis

After the catheterization procedure has been completed and the catheters removed, the sheath is flushed. If heparin has been given, an activated clotting time (ACT) is obtained; if this is >200 s, protamine sulfate may be given before sheath removal (25 to 50 mg protamine IV reverses 10,000 U heparin). Caution should be used in giving protamine to patients receiving NPH insulin, who may have higher likelihood of a protamine reaction (Table 17-8).

TABLE 17-8 Characteristics and Treatment of a Protamine Reactiona

Characteristics
Shaking

Flushing Chills Back, chest, or flank pain Vasomotor collapse Treatment 1. Morphine (2 mg IV) or meperidine (25 mg IV), 2. Diphenhydramine (25 to 50 mg IV) 3. Saline administration 4. Support of low blood pressure
[a]Protamine reactions are usually self-limited (<1 h).

To remove the femoral artery sheath, gentle pressure is applied over the puncture site while the sheath is removed, taking care not to crush the sheath and “strip” clot into the distal artery. Firm downward pressure is applied for 15 to 30 min, periodically evaluating distal pulses. After manual hemostasis is achieved, an adhesive bandage is used to cover the wound. Large pressure dressings are generally ineffective to prevent bleeding and obscure the puncture site. Additional methods to secure postprocedure arterial hemostasis include mechanical pressure clamps and vascular closure devices.

Four vascular closure devices are currently available.10,11 and 12 These devices reduce the time to obtain hemostasis and early ambulation.

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Collagen, either plugs (Vasoseal and Angioseal) or liquid (Duett) can be delivered directly to the arterial puncture site through a special sheath system (Vasoseal or Duett) or anchored inside of the vessel (Angioseal). A percutaneous vascular suture delivery system (Perclose) also provides hemostasis and permits early ambulation. These devices may especially be helpful in anticoagulated patients and patients with back pain or an inability to lie flat. The advantages and disadvantages are summarized in Table 17-9. All vascular closure devices should be used with caution in patients with peripheral vascular disease or low arterial puncture (at or below the femoral bifurcation). Femoral angiography with an oblique angle will demonstrate the puncture site and any artery disease. Patients at high risk for groin hematoma and arterial complications who may need longer pressure application or may benefit with a vascular closure device are listed in Table 17-10.

TABLE 17-9 Advantages/Disadvantages of Vascular Closure Devices

Device	Mechanism	Vascular Closure Devices Advantages and Limitations
AngioSeal	Collagen seal	Secure hemostasis
		Anchor may catch on side branch
Duett	Collagen-thrombin	Stronger collagen-thrombin seal
		Intraarterial injection of collagen-thrombin
Perclose	Sutures	Secure hemostasis of suture
		Device failure may require surgical repair
VasoSeal	Collagen plug	No intraarterial components
		Positioning wire may catch on side branch

TABLE 17-10 Patients Who May Benefit from a Vascular Closure Device

Obese patients
Patients with hypertension

Elderly

Women

Patients with aortic insufficiency

Patients who have undergone prior arterial puncture

Patients with advanced peripheral atherosclerosis

Patients who suffer from coagulopathy or those receiving anticoagulant or antiplatelet agents

SOURCE: From Kern MJ. *The Cardiac Catheterization Handbook*. St. Louis: Mosby; 2003. With permission.

For radial artery hemostasis, sheath removal utilizes a plastic bracelet with a pressure pad placed around the wrist.9 While pressing the pad over the puncture site, the sheath is then gently withdrawn and the bracelet tightened. The bracelet should be tight enough to ensure hemostasis but not occlude the flow to the hand. An hour or two later, the patient is checked and the bracelet is loosened. The patient can be discharged 2 h later and the bracelet removed at home.

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Equipment in the Catheterization Laboratory

CATHETERS FOR ANGIOGRAPHY AND HEMODYNAMICS

Numerous shapes and sizes of catheters are available to the angiographer. Basic, routine catheters that are preshaped for normal anatomy are available for both the radial and femoral approaches. There is an array of shapes and sizes to aid the angiographer when abnormal anatomy is present (Fig. 17-2).

FIGURE 17-2 *A*. Left heart catheters in common use for selective coronary arteriography and ventriculography. (From Kern MJ. *Cardiac Catheterization Handbook*. St Louis: Mosby; 2003. With permission.) *B*. Various special-purpose catheters for right and left heart catheterization. (Modified from Tilkian AG, Daily EK. *Cardiovascular Procedures: Diagnostic Techniques and Therapeutic Procedures*. St. Louis: Mosby; 1986. With permission.)

Judkins-Type Coronary Catheters

The Judkins catheters have unique preshaped curves and tapered end-hole tips. The

Judkins left coronary catheter has a double curve. The length of the segment between the primary and secondary curve determines the size of the catheter (i.e., 3.5, 4.0, 5.0, or 6.0 cm). The proper size of the left judkins catheter is selected depending on the length and width of the ascending aorta. The ingenious design of the left Judkins catheter permits cannulation of the left coronary artery without any major catheter manipulation except the slow advance of the catheter under fluoroscopic control. The catheter tip follows the ascending aortic border and falls into the left main coronary ostium, often with an abrupt jump. In the words of its inventor, “The [Judkins] catheter knows where to go if not thwarted by the operator.” A left 4-cm Judkins catheter fits in most adult patients. When catheter size is adequate, the catheter tip is aligned with the long axis of the left main coronary trunk. A smaller (3.5-cm) catheter in the same patient will tip upward toward the anterior descending artery and a larger (5.0-cm) catheter will tip downward into the circumflex ostium.

The Judkins right coronary catheter is sized by the length of the secondary curve and comes in 3.5-, 4.0-, and 5.0-cm sizes. The 4.0-cm catheter is adequate in the majority of cases. The right Judkins catheter is advanced into the ascending aorta (usually with LAO projection) with the tip directed caudally.

Amplatz-type catheters

The left Amplatz-type catheter (Fig. 17-2) is a preshaped half circle with the tapered tip extending perpendicular to the curve. Amplatz catheter sizes (left 1, 2, and 3 and right 1 and 2) indicate the diameter of the tip's curve. In the LAO projection, the tip is advanced into the left aortic cusp. Further advancement of the catheter causes the tip to move upward into the left main trunk. It is necessary to push the Amplatz catheters slightly to disengage by backing the catheter tip upward and out of the left main ostium. If the catheter is pulled instead of first being advanced, the tip moves downward and into the left main or circumflex artery. Unwanted deep cannulation might tear this branch or the left main trunk. *Amplatz catheters have a higher incidence of coronary dissection than Judkins-style catheters.*

The right Amplatz (modified) catheter has a smaller but similar hook-shaped curve. The catheter is advanced into the right coronary cusp. As with Judkins right catheters, the catheter is rotated clockwise for 45 to 90 degrees. The same maneuver is repeated at different levels until the right coronary artery is entered. After coronary injections, the catheter may be pulled, advanced, or rotated out of the coronary artery.

Multipurpose Catheters

These catheters are mostly straight catheters with an end hole and two side holes placed close to the tapered tip. Preshaped, mildly angled configurations are also available. The multipurpose catheter can be used for both left and right coronary injections and left ventriculography.

Special-Purpose Femoral Catheters for Bypass Grafts

The right coronary vein graft catheter is similar to a right Judkins catheter with a wider,

more open primary curve allowing cannulation of vertically oriented coronary artery vein graft. The left vein graft catheter is similar to the right Judkins catheter with a smaller and sharper secondary curve, allowing easy cannulation of left anterior descending [coronary artery] (LAD) and left circumflex vein grafts, which usually are placed higher and more anterior than the right coronary grafts with a relatively horizontal and upward takeoff from the aorta. The internal mammary artery graft catheter has a peculiar hook-shaped tip configuration that facilitates the engagement of internal mammary artery grafts, especially in patients with a very vertical origin of the internal mammary artery.

Ventriculography Catheters

The pigtail catheter has a tapered tip, preshaped 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. A pigtail catheter with an angled (145-degree) shaft is also available for horizontally oriented hearts. Another variation on the pigtail catheter is one with a helical tip with inward-directed side holes (Halo catheter, Angiodynamics, Inc.). Unlike a pigtail catheter, it has all side holes located at the coiled end and the end of the catheter points inward, reducing ectopy during ventriculography. The multipurpose catheter is also used for femoral ventriculography, but the high-pressure contrast jet from the end hole often produces significant

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ventricular tachycardia; rarely, myocardial tissue contrast staining or perforation occurs.

A comprehensive discussion of left heart catheter types and techniques can be found elsewhere.5,6 and 7 The new operator should concentrate on mastering a few types of catheters and gain extensive experience in using them effectively.

Right Heart Catheters

For right heart catheterization, a balloon-tipped flotation catheter (Fig. 17-2), originally designed by Drs. H.J.C. Swan and W. Ganz, is the most widely used. The balloon tip allows the catheter to float through the right side of the heart safely and easily in a majority of cases. The balloon “wedges” in the distal pulmonary artery to measure pressure and accurately reflects left atrial and ventricular filling pressures. Thermodilution cardiac output measurements are exclusive to this type of catheter. The balloon-tipped catheter can be introduced through any venous access route. The balloon is inflated with room air. The balloon-tipped catheters do not provide good torque control, making catheterization of the

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pulmonary artery in patients with right atrial or ventricular enlargement, pulmonary hypertension, or tricuspid regurgitation difficult from the femoral approach.

For right heart angiography, the Berman catheter, a large-lumen, balloon-tipped angiographic catheter with side holes placed proximally to the balloon, is introduced easily into the right heart. Keeping the balloon inflated increases the catheter stability during angiography. A regular pigtail catheter, or one with a special obtuse angle (Grollman), can also be used for right ventriculography.

THE FLUOROSCOPIC IMAGING SYSTEM

Passage of catheters and acquisition of angiographic data requires a high-resolution image-intensifier television system with digital cineangiographic capabilities. The components are mounted on a C arm, which is a semicircular support with the x-ray tube beneath the patient and the image intensifier above. Rotation of the C arm allows viewing over a wide range of different angles. The patient is placed in the center of the semicircle, which can be moved 180 degrees around the patient. Some laboratories have two C arms perpendicular to one another (called “biplane” arms) and use a double monitoring system, providing simultaneous visualization of the heart from two different angles (Fig. 17-3).

FIGURE 17-3 The cardiac catheterization laboratory. The operators stand on the patient's right side facing the fluoroscopic and hemodynamic monitors. The fluoroscope is positioned over the patient's left shoulder to produce a left anterior oblique (LAO) cranially angulated view of the heart. The image intensifier can be rotated to other positions (e.g., caudal or right anterior oblique (RAO) as well to visualize the cardiac structures from any angle.

THE PHYSIOLOGIC MONITOR AND RECORDING SYSTEM

During catheterization, it is necessary to monitor and record electrocardiographic and hemodynamic signals. Digital recording systems incorporate physiologic data with digital angiographic data.

CONTRAST POWER INJECTOR

A high-pressure contrast media injector is needed to administer a large bolus (20 to 50 mL) of contrast media into the left ventricle (10 to 20 mL/s), pulmonary arteries (10 to 25 mL/s), or aortic arch (40 to 60 mL/s). When properly set and flushed, the power injector can be used to inject contrast into the coronary arteries (3 to 8 mL/s). Some injector systems also incorporate a pressure transducer and have replaced traditional manifolds with stopcocks.

“CRASH CART” AND DEFIBRILLATOR

Every cardiovascular laboratory is equipped with an emergency crash cart containing emergency drugs, oxygen, airways, suction apparatus, and other emergency equipment. A defibrillator should be charged and ready for use during a procedure.

STERILE EQUIPMENT AND SUPPLIES

The angiographer works from a sterile pack or tray that contains the various supplies needed to perform the procedure. The pack will contain syringes and needles, local anesthetic, basins for flushing solutions, small drapes and towels, clamps, scalpels, pressure manifolds and connecting tubings, and the like.

Radiographic Contrast Media

CHARACTERISTICS OF CONTRAST MEDIA

All contrast media contain three iodine molecules attached to a fully substituted benzene ring. The fourth position in the standard ionic agent is taken up by sodium or methylglucamine as a cation; the remaining two positions of the benzene ring have side chains of diatrizoate, metatrizoate, or iothalamate. All media are excreted predominantly by glomerular filtration. The normal half-time of excretion is 20 min; biliary excretion is 1 percent. A dose of 0.5 to 1.0 mL/kg of medium is selected based on total body weight, size of the heart chambers, systemic blood flow, degree of left-to-right shunting, severity of pulmonary vascular disease, and clinical status of the patient. The vasodilator effect and the transient decrease in systemic vascular resistance are directly related to the degree of osmolality of the contrast medium used. Transient hypervolemia and depressed contractility are related to both osmolality and ionic charge and in part responsible for the elevation of left atrial and left ventricular (LV) end-diastolic pressure after contrast injection.

To reduce the osmotic effects of contrast medium, the number of dissolved particles must be decreased or the molal concentration of iodine per particle must be increased. New-generation, nonionic, monomeric, and ionic dimeric contrast agents have approximately the same viscosity and iodine concentration but have only one-half or less of the osmolality of the ionic agents.13,14 and 15 Ionic contrast media produce hypotension by peripheral arterial vasodilation, transient myocardial dysfunction, and decreasing circulating volume and blood pressure after osmotic diuresis. Initially contrast media increase circulating fluid volume by osmotically shifting fluid into vascular space. The advantages of the nonionic, low-osmolar agents include less hemodynamic loading, patient discomfort, binding of ionic calcium, depression of myocardial function and blood pressure, and possibly fewer anaphylactoid reactions.13,14 and 15 Currently, nonionic, low-osmolar agents are preferred in all patients, but especially in adults with extremely poor LV function; in patients with renal disease, especially those with diabetes; and in patients with a history of serious reaction to contrast media or with multiple allergies.

Table 17-11 provides a summary of commonly used contrast agents for coronary and left ventricular angiographic studies. Although thousands of studies have been performed safely with conventional high-osmolar/ionic agents, considerable data exist indicating that low-osmolar/nonionic agents may be safer and provide satisfactory diagnostic quality, especially for high-risk patients16 (Table 17-12).

TABLE 17-11 Commonly Used Iodinated Contrast Agents in Cardiac Angiography

Product Category	Proprietary Name	Genetic Constituent	Ratio to Iodine to Osmotically Active Particles	Calcium Chelation	Anticoagulation Effect

High-osmolar, ionic	Renografin-76	Diatrizoate and citrate	1.5	(+)	(+++)
High-osmolar, ionic	Hypaque-76	Diatrizoate only	1.5	(-)	(+++)
Low-osmolar, ionic	Hexabrix	Ioxaglate	3.0	(-)	(+++)
Low-osmolar, nonionic	Isovue	Iopamidol	3.0	(-)	(+)
Low-osmolar, nonionic	Omnipaque	Iohexol	3.0	(-)	(+)
Low-osmolar, nonionic	Optiray	Ioversol	3.0	(-)	(+)

KEY: (+) = present; (+++) = strongly present; (-) = absent.

SOURCE: From Peterson KL, Nicod P. *Cardiac Catheterization: methods, diagnosis, and therapy*. Philadelphia: Saunders; 1997. With permission.

TABLE 17-12 Indications for Low-Osmolar/Nonionic Contrast Agents

Unstable ischemic syndromes

Congestive heart failure
Diabetes
Renal insufficiency
Hypotension
Severe bradycardia
History of contrast allergy
Severe valvular heart disease
Use for internal mammary artery and peripheral vascular injections

CONTRAST MEDIA REACTIONS

The Committee on Safety of Contrast Media of the International Society of Radiology report that in more than 300,000 patients the overall incidence of adverse reaction was <5 percent. Adverse reactions

were found in 10 to 12 percent of patients with a history of allergy and in 15 percent of patients with reported reaction on previous examination. From these reports major life-threatening reactions do not tend to recur on reexamination, whereas minor reactions are more likely to be repeated.

There are three types of contrast allergies (Table 17-13): (1) minor cutaneous and mucosal manifestations, (2) smooth muscle and minor anaphylactoid responses, and (3) major cardiovascular and anaphylactoid responses. Major reactions involving laryngeal or pulmonary edema often are accompanied by minor or less severe reactions. Although some reactions to a pretest contrast dose may be violent (but rarely life-threatening), pretesting has been found to be of no value in determining who will have an adverse reaction. Nonionic contrast media has replaced ionic contrast media for most patients to minimize chance of allergic and other adverse contrast reactions.

TABLE 17-13 Anaphylactoid Reactions to Contrast Medium

- Cutaneous and mucosal
  - Angioedema
  - Flushing
  - Laryngeal edema
  - Pruritus
  - Urticaria
- Smooth muscle
  - Bronchospasm
  - Gastrointestinal spasm
  - Uterine contraction
- Cardiovascular
  - Arrhythmia
  - Hypotension (shock)
  - Vasodilatation

Patients reporting allergic reactions to contrast media should be premedicated with prednisone and diphenhydramine. The routine for the laboratory may vary, but common dosages include 60 mg prednisone the night before, and 60 mg of prednisone the morning of, along with 50 mg oral diphenhydramine given at the time of call to the catheterization laboratory. Pretreatment with corticosteroids has been found to be helpful in reducing all types of reactions except those characterized predominantly by hives. Premedication may not prevent the occurrence of adverse reactions completely. Additional routine treatment of patients with prior allergic reactions with an H_2 blocker (e.g., cimetidine) does not appear to have any benefit. Patients with known prior anaphylacoid reactions to contrast dye should be pretreated with steroids and an H_1 blocker.

CONTRAST-INDUCED RENAL FAILURE

Patients with diabetes or renal insufficiency or those who are dehydrated from any cause are at risk for contrast-induced nephropathy (CIN). Advanced preparations to limit CIN include hydration and maintenance of large-volume urine flow (>200 mL/h). These patients

should be hydrated intravenously the night before the procedure. Following the contrast study, intravenous fluids should be liberally continued unless intravascular volume overload is a problem. Furosemide (Lasix), mannitol and calcium channel blockers are not helpful in reducing CIN (see Table 17-14). Fenoldopam and *N*-acetylcysteine given intravenously before the procedure are associated with reduced CIN in some studies,16a,16b,16c but not in others.16d A decreased urine output after the procedure which is not responsive to increased intravenous fluids indicates that renal insufficiency is probable. A consultation with a nephrologist is often helpful. All types of contrast agents (ionic, nonionic, or low-osmolar) are associated with a similiar incidence of contrast-induced nephropathy.

TABLE 17-14 Summary of Contrast Induced Renal Failure Prophylaxis Trials

Beneficial	Deleterious	Conflicting Data	No Effect
IV hydration	Furosemide (without volume replacement)	Calcium channel blockers	Hemodialysis
Forced duresis	Ionic contrast	Dopamine	Atrial natriuretic peptide
Nonionic contrast	Endothelin receptor blocker	Theophylline	Allopurinol
Acetylcysteine	Mannitol (without volume replacement)	Captopril	
PGE-1			
Fenoldopam			

SOURCE: From McCullough, PA, Mauley HS. Prediction and prevention of contrast nephropathy. *J Intervent Cardiol* 2001;14:547–558. With permission.

Complications of Cardiac Catheterization

Table 17-15 lists the major and minor complications of cardiac catheterization. For diagnostic catheterization, analysis of the complications in more than 200,000 patients indicates the incidence of risks as follows: death, <0.2 percent; myocardial infarction, <0.05 percent; stroke, <0.07 percent; serious ventricular arrhythmia, <0.5

percent; and major vascular complications (thrombosis, bleeding requiring transfusion, or pseudoaneurysm), <1 percent17,18,19 and 20 (Table 17-16). Vascular complications are more frequent when the brachial approach is used. Risks are higher in well-described subgroups.

TABLE 17-15 Complications of Cardiac Catheterization

• Major
Cerebrovascular accident
Death
Myocardial infarction
Ventricular tachycardia, fibrillation, or serious arrhythmia
• Other
Aortic dissection
Cardiac perforation, tamponade
Congestive heart failure
Contrast reaction/anaphylaxis/nephrotoxicity
Heart block, asystole
Hemorrhage (local, retroperitoneal, pelvic)
Infection
Protamine reaction
Supraventricular tachyarrhythmia, atrial fibrillation
Thrombosis/embolus/air embolus

Vascular injury, pseudoaneurysm
Vasovagal reaction

TABLE 17-16 Incidence of Major Complications of Diagnostic Catheterizations

	Percent
Death	0.11
Myocardial infarction	0.05
Neurologic	0.07
Arrhythmia	0.38
Vascular	0.43
Contrast	0.37
Hemodynamic	0.26
Perforation	0.03
Other	0.28
Total (patients)	1.98

SOURCE: Modified from Noto TJ, Johnson LW, Krone R, et al. Cardiac catheterization 1990: A report of the Registry of the Society for Cardiac Angiography and Interventions (SCA&I), *Cathet Cardiovasc Diagn* 1991;24:75–83 and Uretzky BF, Weinert HH. *Cardiac Catheterization: Concepts, Techniques, and Applications*. Walden, MA: Blackwell; 1997. With permission.

COMPLICATIONS OF ARTERIAL ACCESS

The most common complication from femoral catheterization is hemorrhage and local hematoma formation, increasing in frequency with the increasing size of the sheath, the amount of anticoagulation, and obesity. Other common complications (in order of decreasing frequency) include retroperitoneal hematoma, pseudoaneurysm, arteriovenous (AV) fistula, arterial thrombosis, stroke,19 sepsis with or without abscess formation, and cholesterol or air embolization.20 The frequency of these complications is increased in obese patients; high-risk procedures; critically ill elderly patients with extensive atheromatous disease; patients receiving anticoagulation, antiplatelet, and fibrinolytic therapies; and concomitant interventional procedures. Compared to the femoral approach, the radial approach causes significantly fewer vascular complications.

A retroperitoneal hematoma should be suspected in patients with hypotension, tachycardia, pallor, a rapidly falling hematocrit postcatheterization, lower abdominal or back pain, or neurologic changes in the leg with the puncture. This complication is associated with *high femoral arterial puncture* and *full anticoagulation*.18 Pseudoaneurysm is a complication associated with *low femoral arterial puncture* (usually below the head of the femur). With ultrasound imaging techniques the pseudoaneurysm can easily be identified and nonsurgical closure performed. Manual compression of the expansile growing mass guided by Doppler ultrasound with or without thrombin or collagen injection is an acceptable therapy for femoral pseudoaneurysm.21

PROTAMINE REACTIONS

Protamine is commonly used in reversing the systemic effects of heparin. Minor protamine reactions may appear as back and flank pain or flushing with peripheral vasodilation and low blood pressure. Major protamine reactions simulate anaphylaxis. Although rare, major reactions involve marked facial flushing and vasomotor collapse, which may be fatal. The incidence of major protamine reactions in NPH insulin-dependent diabetics is 27 percent, compared to 0.5 percent in patients with no history of insulin use. It is recommended that diabetics on NPH insulin and patients with allergies to fish undergoing cardiac catheterization do so without use of protamine or, when necessary, that protamine be administered cautiously in anticipation of a major reaction.

COMPLICATIONS OF RIGHT HEART CATHETERIZATION

Right heart catheterization may be complicated by arrhythmia due to stimulation of the right ventricular (RV) outflow tract, which may result

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in atrioventricular block, or, rarely, right bundle branch block (Table 17-17). Significant but transient ventricular arrhythmias occur in 30 to 60 percent of patients undergoing right heart catheterization and are terminated when the catheter is readjusted. Sustained ventricular arrhythmias have been reported, especially in unstable patients or those with electrolyte imbalance, acidosis, or concurrent myocardial ischemia. In patients with left bundle branch block, a temporary pacemaker may be needed if right bundle branch block occurs during right heart catheterization.

TABLE 17-17 Complications of Right Heart (Pulmonary Artery) Catheterization

	Major	**Minor**
Access	Pneumothorax	Hematoma
	Hemothorax	Thrombosis
	Tracheal perforation (subclavian route)	
	Sepsis	Cellulitis
Intracardiac	Right ventricular perforation	Ventricular arrhythmia
	Heart block (right bundle branch block) pulmonary rupture	
	Pulmonary infarction	