Chapter 5

Diagnostic Coronary Angiography

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The ability to directly visualize coronary arteries was a seminal advance in the history of modern medicine and led directly to the development of the concept of transluminal angioplasty (first performed by Charles Dotter in 1964), CABG (first performed by Rene Favaloro in 1967), percutaneous transluminal peripheral angioplasty (first performed by Andreas Gruentzig in 1974), and percutaneous transluminal coronary angioplasty (first performed by Andreas Gruentzig in 1977). With the high prevalence of coronary heart disease (CHD) in industrialized countries and the advances made in its treatment, the use of diagnostic coronary angiography has continued to increase. In 2000, approximately 2,000,000 cardiac catheterizations were performed in the United States. This chapter focuses on the coronary anatomy and the technique of coronary angiography and its clinical use.

CORONARY ANATOMY AND ANOMALIES

The right coronary artery (RCA) arises from the right coronary sinus and runs in the right AV groove (Fig. 5-1). Generally, the conus artery and the sinoatrial artery arise from the RCA. In approximately 85% of individuals, the posterior descending coronary artery arises from the RCA (defined as a right dominant coronary circulation). The left main coronary artery arises from the left coronary sinus. Within a few centimeters of its origin, it divides into the left anterior descending (LAD) coronary artery (in the anterior interventricular groove), the left circumflex coronary artery (in the atrioventricular groove) and, in a minority of cases, a ramus intermedius artery.

Coronary artery anomalies are found in 1 to 1.5% of individuals (Fig. 5-2); most anomalies are benign. The most common anomaly is separate origins from the aorta of the LAD and left circumflex (i.e., absence of a left main coronary artery), which occurs in 0.4 to 1% of individuals and is occasionally associated with a bicuspid aortic valve. Clinically significant anomalies include origin of a coronary artery from the opposite coronary sinus (e.g., left main artery originating from the right coronary sinus), the presence of a single coronary ostium (and hence a single coronary artery), and origin of a coronary artery from the pulmonary artery.

TECHNIQUES

Coronary angiography delineates the course and size of the coronary arteries, identifies coronary anomalies, and provides information on the location and degree of any obstruction (Table 5-1). Coronary angiography is performed by injecting radiopaque contrast dye directly into the ostium of the left and right coronary arteries. Access to the aorta is usually gained via percutaneous puncture of the femoral artery; however brachial, radial, and axillary arteries can also be used for arterial access. Specific preformed catheters are passed over a guide wire into the aortic root; the selection of the catheter to be used depends on the access site and the coronary artery being investigated. The wire is removed and the coronary artery is cannulated with use of fluoroscopic guidance. Contrast dye is injected during cineradiography while blood pressure and ECG are continually monitored and sequential frames are recorded.

Complete evaluation of coronary arteries involves angiography in multiple projections (Figs. 5-3 and 5-4), necessitated by the difficulty of visualizing three-dimensional structures in two dimensions. These views are obtained by rotating the imaging system to different positions around the patient who lies supine on a radiolucent table. Views from the left or the right of the patient can be obtained by varying the degrees of angle. The imaging system can also be rotated from head (cranial) to toe (caudal)
INTRODUCTION

Anterior interventricular (left anterior descending) branch of left coronary artery very short. Apical part of anterior (sternocostal) surface supplied by branches from posterior interventricular (posterior descending) branch of right coronary artery curving around apex.

Posterior interventricular (posterior descending) branch derived from circumflex branch of left coronary artery instead of from right coronary artery.

Posterior interventricular (posterior descending) branch absent. Area supplied chiefly by small branches from circumflex branch of left coronary artery and from right coronary artery.

Posterior interventricular (posterior descending) branch absent. Area supplied chiefly by elongated anterior interventricular (left anterior descending) branch curving around apex.
Coronary Arteries: Arteriographic Views

Left coronary artery: Left anterior oblique view

- Left coronary artery
- Circumflex branch
- Anterior interventricular branch (left anterior descending)
- Diagonal branches of anterior interventricular branch
- Atrioventricular branch of circumflex branch
- Left marginal branch
- Posterolateral branches
  (Perforating) interventricular septal branches

Left coronary artery: Right anterior oblique view

- Left coronary artery
- Anterior interventricular branch (left anterior descending)
- Circumflex branch
- (Perforating) interventricular septal branches
- Left marginal branch
- Posterolateral branches
- Diagonal branch of
  Anterior interventricular branch
- Atrioventricular branch of circumflex branch

Right coronary artery: Left anterior oblique view

- Sinoatrial (SA) nodal branch
- Right coronary artery
- Atrioventricular (AV) nodal branch
- Branches to back of left ventricle
- Right marginal branch
- Posterior interventricular branch
  (posterior descending artery)

Right coronary artery: Right anterior oblique view

- Sinoatrial (SA) nodal branch
- Conus (arteriosus) branch
- Right coronary artery
- Right marginal branch
- Atrioventricular (AV) nodal branch
- Right posterolateral branches (to back of left ventricle)
- Posterior interventricular branch
  (posterior descending artery)
Angiogram of normal right coronary artery (RCA) and normal posterolateral (PL) and posterior descending (PDA) branches.

Angiogram of normal left anterior descending coronary artery (LAD) and left circumflex (LC) artery.

Angiographic demonstration of narrowing of RCA.

Angiogram demonstrating filling of LAD by dye injected into RCA via collateral vessels.
positions. Although there is an almost limitless combination of potential imaging positions, several standard approaches have been developed (as described herein) that allow full visualization of the coronary arteries in most patients.

In all cases, multiple views help to avoid foreshortening of specific areas and the potentially confounding feature of overlapping branches, and are obtained using caudal or cranial angulation in combination with left and right angulation. The most commonly used views for left coronary angiography include right anterior oblique (RAO) with cranial and caudal angulation, and left anterior oblique (LAO) with cranial and caudal angulation. The most commonly used views for RCA angiography include right anterior oblique and left anterior oblique projections with or without cranial angulation. Individual variation in coronary anatomy or location of stenoses often necessitates customization of projections. Standard nomenclature to define coronary segments has been developed by several groups, including the Coronary Artery Surgery Study investigators and the Bypass Angioplasty Revascularization Investigation investigators.

The usual method of analyzing angiograms in clinical practice identifies areas of relative narrowing, and then quantifies the degree of narrowing by comparing the minimal diameter of the narrowed coronary segment with that of an adjacent, normal-appearing reference segment. In many angiography suites, experienced observers estimate the degree of stenosis; however, stenosis can be quantified using calipers or quantitative computer angiography. Because atherosclerotic plaques are often eccentric, orthogonal views are needed to accurately determine the degree of obstruction.

Flow in coronary arteries can be estimated at the time of coronary angiography with a scale developed by the Thrombolysis in Myocardial Infarction (TIMI) investigators. Flow defined as TIMI 0 indicates a completely occluded artery. TIMI 1 flow describes a severe lesion in which dye passes the area of narrowing but does not extend to the distal portion of the vessel. With TIMI 2 flow, the distal vessel is opacified but not as rapidly as would be expected or as rapidly as nonobstructed vessels. TIMI 3 flow is “normal.” The TIMI flow index has shown significant prognostic value. TIMI “frame counts,” the number of frames necessary for dye to reach the distal portion of the vessel, are used as a quantitative index of flow.

Microvascular integrity can be assessed at the time of coronary angiography with use of angiographic myocardial blush scores. These scores, which measure contrast dye density and washout in the area of interest, correlate with LV functional recovery post-MI, and prognosis. In the setting of acute MI, myocardial blush scores add additional prognostic information to TIMI frame score and persistent ST elevation.

Coronary angiography can be performed separately or as part of cardiac catheterization or an interventional procedure. Most patients referred for diagnostic angiography also undergo left-sided heart catheterization and left ventriculography. Increasingly, these patients also undergo angiography of other vascular beds, as indicated. For example, patients with hypertension commonly undergo renal angiography; those with claudication undergo lower extremity artery angiography; and those with left internal mammary artery grafting to the LAD coronary artery undergo subclavian angiography (Fig. 5-5).

**INDICATIONS**

The most common indication for coronary angiography is to determine the presence, location, and severity of atherosclerotic lesions. Coronary angiography provides essential infor-
INTRODUCTION

DIAGNOSTIC CORONARY ANGIOGRAPHY

Atherosclerotic obstruction of subclavian artery

Retrograde blood flow from left anterior descending (LAD) coronary artery to subclavian artery via left internal mammary (LIMA) creating “steal” and myocardial ischemia

LIMA

LIMA–LAD anastomosis

Stent placement restores flow to subclavian and via LIMA–LAD anastomosis also restores myocardial perfusion, relieving ischemic symptoms

Initial left coronary artery angiography in a patient with prior bypass surgery with complaints of increasing angina. Angiogram demonstrates retrograde flow of dye up LIMA into subclavian artery (arrow).

Poor opacification of artery distal to stenosis and minimal appearance of dye in LIMA

Stent relieves obstruction and restores normal blood flow

Scans reprinted from Circulation 2002;105:184e, doi:10.1161–01.CIR 0000017400.13819.4D.
mation in the diagnosis of CAD, in determining prognosis, and in decision-making regarding revascularization. Neither percutaneous coronary intervention nor CABG can occur without coronary angiography. More rarely, coronary angiography is used to diagnose anomalies, muscular bridging, fistula, spasm, emboli, aneurysms, and arteritis.

Indications for coronary angiography in a random sample of 100 consecutive patients at the University of North Carolina are listed in Table 5-2. The most common indication was for evaluation of symptomatic CAD—either stable angina or acute coronary syndrome. Less common indications include valvular heart disease; congestive heart failure; evaluation before heart, lung or liver transplant; periodic evaluation after heart transplant; and congenital heart disease. Indications for coronary angiography not included on this list are being a sudden cardiac death survivor, history of ventricular tachycardia, abnormal results of stress tests in high-risk occupations (e.g., pilot), history of postrevascularization ischemia, and being a prospective heart transplant donor whose age and risk factor profile suggest possible CAD.

### Table 5-2
**Indications for Coronary Angiography**

<table>
<thead>
<tr>
<th>Percent of Patients</th>
<th>No. Patients (%)</th>
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<tbody>
<tr>
<td>Exertional Angina</td>
<td>51</td>
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<tr>
<td>Non–Q-wave MI</td>
<td>18</td>
</tr>
<tr>
<td>Congestive heart failure</td>
<td>9</td>
</tr>
<tr>
<td>Primary treatment of ST-elevation MI</td>
<td>7</td>
</tr>
<tr>
<td>Valvular heart disease</td>
<td>6</td>
</tr>
<tr>
<td>Cardiogenic shock</td>
<td>2</td>
</tr>
<tr>
<td>ST elevation post administration of thrombolytic agents (rescue angioplasty)</td>
<td>1</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>6</td>
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<tr>
<th>Annual evaluation after heart transplantation</th>
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<tr>
<td>Hypertrophic cardiomyopathy with chest pain</td>
</tr>
<tr>
<td>Constrictive pericarditis</td>
</tr>
<tr>
<td>Congenital heart disease</td>
</tr>
<tr>
<td>Preoperative evaluation for proximal aortic and/or aortic arch aneurysm repair</td>
</tr>
<tr>
<td>Preoperative assessment for aortic dissection repair</td>
</tr>
<tr>
<td>Evaluation prior to heart, lung, or liver transplantation</td>
</tr>
<tr>
<td>Ventricular arrhythmias and/or survival of sudden cardiac death</td>
</tr>
<tr>
<td>Abnormal stress tests in high-risk occupations (e.g., pilot)</td>
</tr>
<tr>
<td>Postrevascularization ischemia</td>
</tr>
<tr>
<td>Prospective heart transplant donor whose age and risk factor profile suggests the possibility of coronary artery disease</td>
</tr>
<tr>
<td>Patient who is at high risk for coronary disease when other cardiac surgical procedures (e.g., pericardectomy) are planned</td>
</tr>
</tbody>
</table>

The percentages reflect the relative volume at the University of North Carolina based on a random sample of 100 consecutive patients. MI indicates myocardial infarction.
USE OF CORONARY ANGIOGRAPHY IN THE EVALUATION OF PATIENTS WITH CHEST PAIN—CLINICAL PRACTICE

The American Heart Association and American College of Cardiology publish guidelines on the indications for coronary angiography (http://circ.ahajournals.org/cgi/content/full/99/17/2345). Use of coronary angiography in specific conditions is assigned a rating (Table 5-3) of the weight of evidence that (1) supports the indication (class I and IIa), (2) argues against the indication (class III), or (3) is insufficient to support or refute the indication (class IIb). Because there are risks associated with coronary angiography, patients with class III indications should rarely, if ever, undergo the procedure. Referral for angiography with class II indications is a decision that involves the preferences of the referring physician and the patient; many patients with class IIa indications are referred for angiography, whereas it is less common for patients with class IIb indications to undergo coronary angiography. Despite the guidelines, marked differences exist in practice patterns among individual physicians, geographic regions within the United States, and different countries. In some areas, coronary angiography is considered to be the standard of care for particular conditions, whereas noninvasive approaches are favored elsewhere.

The two most important issues in the evaluation of patients with suspected ischemic chest pain are the identification of the extent of CAD and the delineation of LV function. This can be done either directly (e.g., cardiac catheterization) or indirectly (e.g., exercise treadmill testing). If patients have stable, exertional symptoms, an exercise treadmill test can provide diagnostic and prognostic information. In addition to ECG findings, the test provides information on symptoms during exercise, blood pressure response, and duration of exercise. Combining ECG monitoring with either nuclear imaging (to determine myocardial perfusion) or echocardiographic imaging (to determine LV function) during exercise enhances the sensitivity and specificity of treadmill testing (see chapters 4 and 6). Imaging is essential in patients in whom the ECG response cannot be interpreted (e.g., left bundle branch block or Wolfe-Parkin-son-White syndrome). It is also extremely helpful in situations in which the sensitivity and/or specificity of exercise ECG is reduced, for example, in middle-aged females or concomitant with LV hypertrophy. Pharmacologic stress testing coupled with imaging is available for patients unable to exercise.

Evidence for flow-limiting CAD on stress testing is an indication to proceed to coronary angiography. Occasionally, further evaluation is not needed if patient symptoms are controlled by medical therapy and if information from the stress test (e.g., duration of exercise, extent of ischemia) suggests that patient prognosis is good. Rarely, patients with normal results of stress tests are referred for coronary angiography. These are patients with typical symptoms in whom results of the stress test are thought to be falsely negative.

Table 5-3
Summary of AHA/ACC Classification Regarding Appropriateness of Procedures

<table>
<thead>
<tr>
<th>Class</th>
<th>Definition</th>
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<tbody>
<tr>
<td>I</td>
<td>There is evidence and/or general agreement that coronary angiography is useful and effective.</td>
</tr>
<tr>
<td>IIa</td>
<td>There is conflicting evidence and/or a divergence of opinion about the usefulness/efficacy of performing coronary angiography, but the weight of evidence/opinion is in favor of usefulness/efficacy.</td>
</tr>
<tr>
<td>IIb</td>
<td>There is conflicting evidence and/or a divergence of opinion about the usefulness/efficacy of performing coronary angiography, with the usefulness/efficacy of coronary angiography being less well-established by evidence/opinion.</td>
</tr>
<tr>
<td>III</td>
<td>There is evidence and/or general agreement that the procedure is not useful/effective and in some cases may be harmful.</td>
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</tbody>
</table>

With permission from J Am Coll Cardiol 1999; 33:1756–1903. Table created using data in text ACC/AHA Guidelines for Coronary Angiography.
In selected patients with stable symptoms and in all patients with unstable symptoms, cardiac catheterization is performed without prior stress testing. Included in this group are patients with symptoms highly typical of angina, congestive heart failure, prior MI, and prior revascularization and/or with symptoms at a low level of exertion (class III or IV). In addition, patients with unstable symptoms should be referred directly for catheterization. In particular, patients with unstable angina, recent non-Q-wave MI or acute ST-elevation MI should be referred for urgent or emergent angiography, with possible use of percutaneous intervention (see chapter 8).

CONTRAINDICATIONS

The only absolute contraindication to coronary angiography is lack of patient consent. However, relative contraindications reflect greatly increased associated risks in certain conditions. Acute renal failure or severe preexisting renal dysfunction, especially in diabetic individuals, identifies patients at high risk for contrast-induced nephropathy. Severe coagulopathy, active bleeding, or both limit the ability to anticoagulate the blood of patients for interventional procedures and increase the risk of vascular complications. Decompensated heart failure can lead to respiratory failure when the patient is required to remain supine during the procedure. Electrolyte abnormalities and/or digitalis toxicity can predispose the patient to malignant arrhythmias during contrast injection. Other relative contraindications include patient inability to cooperate, active infection, allergy to contrast agents, uncontrolled hypertension, severe peripheral vascular disease, and pregnancy.

LIMITATIONS

Coronary angiography outlines the lumen of the vessel but is unable to provide any information on wall thickness. Proper interpretation of stenosis severity involves identification of an appropriate reference segment with which to compare the abnormal section. Furthermore, even with the identification of a proper reference section, studies have shown that experienced observers are limited in their ability to consistently identify hemodynamically significant coronary stenoses.

These limitations have led to the development of technologies to supplement coronary angiography, including intravascular ultrasound and pressure wire analysis. Intravascular ultrasound provides two-dimensional cross-sectional images in which the three layers of the vessel (intima, media, and adventitia) can frequently be identified (see chapter 2). Luminal cross-sectional area, wall thickness, and plaque area can be identified and quantified. Additionally, calcium, thrombus, and dissection planes can be imaged. Intravascular ultrasound is clinically useful in the assessment of complex coronary lesions, left main coronary artery lesions, and results of interventional procedures.

COMPLICATIONS

The risk of major complications during coronary angiography, defined as death, MI, or stroke, is approximately 0.3%. If the definition is expanded to include vascular complications, arrhythmias, and contrast reactions, the rate is still less than 2%. Conditions that increase risk include shock, acute coronary syndrome, renal failure, left main CAD, severe valvular disease, increased age, peripheral vascular disease, prior anaphylactoid reaction to contrast media, and congestive heart failure. The risks of cardiac catheterization with coronary angiography are outlined in Table 5-4. Complication rates were remarkably consistent across registries from the 1980s. More recent registries have focused on complications associated with coronary interventions.

FUTURE DIRECTIONS

During the 40 years that diagnostic cardiac catheterization has been performed, continual
INTRODUCTION

modifications of catheters, imaging approaches, and points of access have enabled the procedure to be performed more quickly and safely. Many investigators are now examining whether noninvasive approaches to coronary artery imaging (based on improvements in MRI or CT) will lessen the need for, or even replace, diagnostic coronary angiography. Regardless of whether it is the routine use of noninvasive imaging or further modifications of invasive imaging, one can be certain that further reduction in the morbidity and mortality rates associated with defining coronary anatomy will be achieved.

REFERENCES


| Table 5-4 Complications of Coronary Angiography |
|-----------------|--------|--------|--------|
| Year            | 1982   | 1989   | 1990   |
| N               | 53,581 | 222,553| 59,792 |
| Death, %        | 0.14   | 0.10   | 0.11   |
| MI, %           | 0.07   | 0.06   | 0.05   |
| CVA, %          | 0.07   | 0.07   | 0.07   |
| Arrhythmia, %   | 0.56   | 0.47   | 0.38   |
| Vascular, %     | 0.57   | 0.46   | 0.43   |
| Total, %        | 1.82   | 1.74   | 1.70   |

Rates of complications of coronary angiography and cardiac catheterization as reported by registries of the Society for Cardiac Angiography and Intervention.
CVA indicates cerebrovascular accident or stroke; MI, myocardial infarction.