Coronary Angiography

Its Role in the Management of the Patient with Angina Pectoris

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SUMMARY

The history, technic, and complications of coronary angiography have been discussed. Myocardial infarction caused by the procedure occurs in 0.3–0.9% of all cases. Two leading groups report an incidence of 1/1000 to 1/2500 deaths related to the procedure. Angiographic anatomy has been described. Indications for the procedure are: intractable angina in patients with or without a history of myocardial infarction and unexplained left ventricular failure or failure due to a left ventricular aneurysm. Among the debatable indications are: unexplained ECG changes, aortic valve disease, preinfarction patterns, cardiogenic shock, and follow-up angiograms after bypass surgery. If immediate surgery is not contemplated, left ventricular failure and a recent myocardial infarction are contraindication to the procedure. The limitations of the procedure are the radiographic resolution and the inconsistent anatomic pattern of minor vessels.

The role of coronary angiography in the management of the patient with angina pectoris has become a matter of utmost importance. This relatively benign procedure is the only available tool which can accurately determine the presence and site of the lesions thought to cause angina. Equally important, it helps to evaluate whether the patient is a candidate for palliative surgery.

The purpose of this paper is to discuss the indications and contraindications, as well as the limitations of the procedure. The technical aspects of the procedure have been dealt with in great length in earlier publications3–5 and only a brief review of these aspects will be given.

History and Technics

Attempts at opacifying the coronary arterial tree were made as early as 1933, only 4 years after Forssmann's introduction of a rubber catheter into the right atrium of his own heart. However, real interest in the subject developed in the early 1950s when numerous indirect methods of coronary angiography were devised. In October of 1958, deliberate attempts to perform selective coronary angiography were initiated by Sones. In 1959, he designed a special catheter, and since then his technic has become widely accepted.5

Sones' technic consists of introducing a straight catheter into the coronary artery via a right brachial artery cutdown. Whereas catheterization of the right coronary artery by this method is usually accomplished easily, the left coronary artery may sometimes be entered with difficulty and one may have to resort to a nonselective injection of contrast into the left sinus of Valsalva rather than into the coronary artery itself.

Under the impetus of radiologists who were more familiar with the percutaneous technic as described by Seldinger,6 a femoral approach was developed initially by Ricketts and Abrams.4 Successful catheterization from the femoral artery is obtained with preshaped catheters, and a separate catheter is used for each coronary ostium. Ricketts' original catheter shapes have been abandoned and replaced by several others. The most widely used technic in the United States is that described by Judkins.3 Other catheters are available; the shapes described by Amplatz1 and Bourassa2 have also found many followers. Preshaped catheters introduced from the femoral artery are very easily passed into the

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coronary ostia. This is particularly true since the introduction of new catheter materials which contain incorporated metal braids, providing improved torque control. The percutaneous femoral and brachial approaches each present certain advantages and, ideally, one should become familiar with both. No one will deny that the preshaped catheters are extremely easy to use and require relatively little skill. The main reason to follow Sones’ method is perhaps its greater safety, although technically it is much more difficult to master. In addition, in the presence of severe atherosclerosis of the iliac arteries or the abdominal aorta, the femoral approach cannot be used.

Although the proponents of each method claim to have a lower ratio of morbidity and mortality, their reported figures of complications are similar.

Complications

Since the introduction of meglumine diatrizoate,† ventricular fibrillation during the intracoronary injection of contrast material has become a rare occurrence (approximately 0.7% of cases). When it happens, it is usually easily overcome by external electrical defibrillation and should not be a contraindication to the continuation of the procedure. The rate of occurrence of myocardial infarction is between 0.3 and 0.9% whereas deaths have been reported in 1/1000 cases. Judkins claims to have had two deaths in approximately 4500 cases (Judkins MP: Personal observation).

Many centers find it difficult to reproduce these figures, and with wider indications for the procedure the incidence of fatalities is increasing, particularly when the examination is done in severely ill patients.

Normal Roentgenographic Anatomy

We are briefly reviewing the normal roentgen anatomy of the coronary artery tree in order to make the subsequent paragraphs

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*Manufactured by Cordis Corporation, Miami, Florida, and by Cook Inc., Bloomington, Indiana.

†Renografin 76, manufactured by E. R. Squibb and Sons, Inc.
more comprehensible for the reader who is not very familiar with this subject. The roentgenologic data can either be recorded on 35-mm cine film or on overhead serial roentgenograms obtained by means of a rapid film changer. In our department, both methods are used in combination because we believe that the two complement each other. The films are exposed with the patient in the right anterior and left anterior oblique projections. In this fashion, the coronary arteries project away from the spine and, furthermore, each vessel is seen from two planes at 90° from one another. This facilitates the reconstitution of a three-dimensional image of the vessel.

In the following description, the arteries are numbered in such fashion that the reader can find the same given point on a vessel in either projection.

Right Coronary Artery (fig. 1)

This artery arises from the right sinus of Valsalva and courses in the anterior atroventricular groove until it reaches the “crux” of the heart on its posterior surface. The first branch originating from the right coronary artery is the conus branch which travels anteriorly to the pulmonary conus. In about 50% of cases, this vessel has its own ostium in the right sinus of Valsalva. The second branch is the sinus node artery which courses posteriorly toward the entrance of the superior vena cava into the right atrium. Subsequently, multiple right ventricular branches arise from the right coronary artery. The largest one is called the right marginal artery or, also, the acute marginal branch. This branch is often an important collateral pathway when either the distal right or the left anterior descending coronary artery is occluded. Once the right coronary artery reaches the crux, it gives its first septal branch, called the artery to the A-V node. At that point the vessel divides, and in

Figure 2

(Left) Right anterior oblique projection of the left coronary artery. (Right) Left anterior oblique projection of the left coronary artery. Abbreviations: 1 = main left coronary artery; 2 = left anterior descending coronary artery; 3 = diagonal branch; 4 = diagonal branch; 5 = distal portion of left anterior descending coronary artery; 6 = circumflex coronary artery; 7 = marginal branch; 8 = distal portion of circumflex coronary artery.
90% of cases the right coronary artery becomes the posterior descending coronary artery, which runs along the diaphragmatic surface in the interventricular groove. As it courses in that groove it supplies branches to the posterior portion of the septum. Other branches arise from the crux. These are the right and left ventricular branches of the right coronary artery, also called the posterolateral branches. Congenital variants are possible and more common on the right than on the left side.

**Left Coronary Artery (fig. 2)**

This artery originates from the left sinus of Valsalva and divides early into two or three major branches which are the left anterior descending, the circumflex, and sometimes a diagonal branch.

The left anterior descending coronary artery (LAD) runs in the anterior interventricular groove where it supplies major branches to the septum. Also originating from the LAD are multiple ventricular branches called the diagonal vessels. These run on the free surface of the left ventricle. The circumflex coronary artery runs in the posterior atroventricular groove where it terminates in 90% of cases. In the other 10% of cases, it gives rise to the posterior descending coronary artery (this is the so-called left dominant pattern). The first major branch arising from the circumflex artery is the left atrial branch. Multiple ventricular branches originate from the circumflex coronary artery, and the largest one is the obtuse marginal branch. Each one of these ventricular branches becomes an extremely important collateral pathway when the LAD is occluded.

**Angiographic Classification of Coronary Artery Disease**

Patients with coronary artery disease can be classified according to the number of major vessels involved (one, two, or three) and severity of narrowing. Patients with narrowing of less than 50% of the arterial lumen diameter are considered to have mild, hemodynamically insignificant disease. Patients with 50–80% narrowing are considered to have moderate atherosclerotic disease, which can account for symptoms of myocardial ischemia even if present in only one major vessel. Patients with 80–99% narrowing have severe disease, and the final category includes all those who have total occlusions.

Figure 3 is an example of a patient with a single stenotic lesion of the LAD. Figure 4 is an example of a patient with stenoses of both the anterior descending and circumflex arteries. Figure 5 illustrates the left and right coronary angiograms in a man with triple-vessel disease. Figure 6 shows a complete obstruction of the left anterior descending artery with distal reconstitution via collateral circulation. Figure 7 shows a nearly completely occluded right coronary artery. The late phase of the study demonstrates patency of the distal portion of the artery, which is, of course, an important consideration if a bypass procedure is contemplated.

**Indications for the Procedures**

These will differ from center to center.
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according to the philosophy of the cardiac team. With the availability of new surgical technics, the number of coronary arteriograms performed has greatly increased. We shall divide this section into unquestionable and into debatable indications.

Unquestionable Indications

Patients who have had a Previous Myocardial Infarction and Still Suffer from Angina

Regardless of age, these patients should be submitted to coronary angiography in the hope of performing palliative surgery. Their operability will depend greatly upon the angiographic findings. These findings will be extremely variable among any large group of patients with angina following myocardial infarction. At one end of the spectrum is the patient with a single localized stenosis of one coronary artery, while at the other end is the patient with severe diffuse disease of all three major vessels. Although lesions which narrow the lumen diameter by 50% or more are considered significant, our experience has shown that patients with a well-documented history of infarction generally have a severe stenosis or occlusion of at least one major coronary artery.

Figure 4

Two-vessel disease. Right anterior oblique projection of the left coronary artery. White arrow points to a lesion of the LAD. Black arrows point to areas of stenosis of the circumflex coronary artery. Note that this patient has a left dominant pattern. (The posterior descending coronary artery arises from the circumflex coronary artery.) This pattern makes the lesions of the circumflex artery especially threatening.
Figure 5

(Left) Three-vessel disease. Right anterior oblique projection of the left coronary artery. Long black arrow points to a severe stenosis of the LAD. Short black arrow points to a lesion of the circumflex coronary artery. Arrowhead points to the distal right coronary artery fed via septal collaterals. (Right) LAO projection of the right coronary artery. See complete occlusion of the right coronary artery (black arrow).

Patients with Angina without a History of Infarction

Regardless of electrocardiographic findings this group of patients should certainly be submitted to coronary angiography. Some of these patients will have demonstrable coronary artery disease in spite of negative clinical tests. Others will have normal coronary arteries by angiography. The management of those with a positive arteriogram will be based primarily upon surgical considerations.

Patients with normal angiograms may or may not have coronary artery disease, but in either case they are not candidates for surgical repair. The likelihood of having coronary artery disease in the presence of a normal arteriogram has been discussed by James.10 Occlusion of a relatively small branch of a major vessel might not be detectable since the anatomic arrangement of the small branches of the coronary arteries is inconstant. Indeed, small-vessel disease beyond the resolution of the radiographic method is possible, particularly in patients with diabetes. Anomalies of the oxyhemoglobin dissociation have also been incriminated as causing angina.11 In any event, patients with normal coronary angiograms have an excellent prognosis.12

Patients in Unexplained Left Ventricular Failure

These patients present with left ventricular failure, an enlarged heart, and no apparent clinical explanation for the problem. The findings are usually caused either by coronary artery disease or cardiomyopathy. Coronary angiography helps greatly in distinguishing between these two conditions. In the absence of angiographic evidence of coronary artery disease, when valvular disorders have been excluded, enlargement of the left ventricle...
Complete occlusion of the left anterior descending coronary artery. The LAD is, however, reconstituted (long white arrow) via collaterals (short white arrows). In this instance, the left marginal artery is the main collateral pathway to the LAD.

Failure might be due to a left ventricular aneurysm after a massive infarction of the left ventricle. Angiography in those cases helps to determine which coronary arteries have remained patent. In our experience, patients with complete occlusion of the LAD who subsequently developed left ventricular aneurysms have had near-normal right and circumflex coronary arteries. This is probably the main reason for their survival. If severe stenosis or complete occlusion of a major...
coronary artery is present, visible collateral circulation to the distal segment of the artery may or may not have developed, depending largely upon how acutely the obstruction occurred. Slow, progressive narrowing of the artery favors the development of collaterals. Although there is still some debate about the significance of coronary collaterals, we have found that an efficient collateral circulation protects against ventricular aneurysm formation. It is rare to find an aneurysm within the distribution of an obstructed coronary artery if collaterals have adequately revascularized that area. Conversely, an aneurysm will almost invariably develop if there is complete obstruction of a major coronary artery without any collateral supply to its distal segment.

Debatable Indications
Patients without a History of Myocardial Infarction and without Angina but with Electrocardiographic Abnormalities of Recent Onset

These patients usually come to the attention of the physician during a yearly checkup which reveals minor electrocardiographic changes possibly attributable to myocardial ischemia (minor conduction abnormalities, slight S-T elevation, etc.). The purpose of performing the study is to rule out serious but silent disease. If these patients present any atherosclerotic changes, they are generally of minimal degree.

We have seen in our practice a number of airline pilots who in the course of a routine annual examination demonstrated minor electrocardiographic changes and were grounded because of these findings. A normal coronary angiogram returned many of them to flying status.

Patients with Aortic Valve Disease

It is well known that aortic stenosis often causes anginal pain. In adult patients with this disease, it behooves the physician to exclude coronary atherosclerosis as the real culprit for the angina, rather than a decreased left ventricular stroke volume. Therefore, many
surgeons will submit this group of patients to coronary angiography. An additional benefit of the procedure is to inform the surgeon as to the state of the left coronary artery which, in most instances, will be perfused during cardiopulmonary bypass. If the patient has significant atherosclerotic lesions of the left coronary artery, the stenotic areas should be bypassed prior to the replacement of the aortic valve and the heart perfused through the vein bypass.

Patients with a Preinfarction Pattern

A certain number of patients with no previous history of coronary artery disease develop angina and electrocardiographic changes suggesting a preinfarction pattern. The electrocardiographic pattern described by Prinzmetal\textsuperscript{13} is supposed to be indicative of a single lesion of a major coronary artery. Figure 3 shows an example of such a patient who was recently studied at our institution and was taken to surgery immediately thereafter.

Coronary angiography in these patients is not without danger,\textsuperscript{14} and could well result in a massive infarction. This group of patients should only be studied if immediate surgery is contemplated. More and more clinicians are coming to feel that angiography and surgery should be performed on an emergency basis in these cases.

Patients with Acute Myocardial Infarction and Cardiogenic Shock

In view of the extremely poor prognosis for patients in cardiogenic shock, several centers have recently submitted patients of this type to coronary angiography and immediate surgical repair.\textsuperscript{14, 15} Theoretically, a new source of blood may improve left ventricular function and prevent extension of myocardial necrosis and thus permit the patient to survive the acute episode. Although emergency coronary angiography is dangerous and time consuming, the surgeon cannot perform an operation without anatomic definition of the lesion. If angiographic equipment is available in the operating room, these patients might ideally be examined on the operating table immediately after the induction of left ventricular fibrillation.

Follow-up Angiograms after Surgery

When the Vineberg procedure was in fashion, the patients used to be reexamined approximately 1 year after their surgery by selective catheterization of the internal mammary artery. This approach allowed a more scientific assessment of the results of the procedure.

Since the advent of the bypass procedures, it has been the practice in our institution to examine some of the patients 2 weeks after surgery and subsequently on a yearly basis.\textsuperscript{16} This has allowed us to objectively assess the patency of the graft (fig. 8). Only in this fashion can the ultimate value of this relatively new procedure be objectively determined.\textsuperscript{17}

Patients with a History of Myocardial Infarction who are Now Asymptomatic

Individuals who have suffered previous myocardial infarction are at greater than normal risk of subsequent infarcts or sudden cardiac death. Thus some clinicians feel that any such patient under the age of 50 years should be studied angiographically, even though he may be symptom free. Coronary angiograms will document the presence of atherosclerosis and may reveal that the patency of some vessels is seriously jeopardized. These patients may be candidates for prophylactic surgery.

Contraindications to the Procedure

Prior to coronary angiography, a complete cardiac workup should be obtained. The procedure should not be performed in the presence of cardiac failure, except in those cases, as indicated above, where immediate surgery is contemplated (patients in shock, with aneurysms, or patients in intractable failure). Injection of contrast material into the coronary arteries and into either ventricular chamber is toxic for the myocardium and
results in acute elevation of the end-diastolic pressure. This toxicity may produce intractable ventricular failure and pulmonary edema. Likewise, angiography should not be performed if the patient is hypokalemic from digitalis and diuretic therapy. A failing ventricle is more irritable and may fibrillate during the selective injection of the coronary artery. A low blood potassium level increases cardiac irritability. Prior to the procedure, blood potassium should be brought into the normal range. Finally, before coronary angiography, a recent electrocardiogram should be compared to previous ones. If a significant change has occurred, the procedure should be postponed until a stable cardiac state is obtained, unless immediate surgery is contemplated.
Limitations of the Procedure

When postmortem coronary angiograms are compared by the experienced angiographer to findings at postmortem examination, the correlation of the two methods appears to be excellent. Kemp, in studying the cinearteriograms of 29 patients who died sometime after the examination, found only three errors of functional significance. Our experience with a similar study also seems to indicate that coronary angiography is able to supply very accurate anatomic detail. The information obtained, however, depends upon a certain number of factors of utmost importance.

The radiographic technic, although easily mastered, must be strictly controlled. Equipment, radiographic factors, and processing of the film must be checked constantly. Any changes in these elements may produce an unsatisfactory study. If all these factors are under control, the final limiting technical factor is the resolution of the radiographic technic. Kemp found that by using cineangiography he could see on still frames vessels measuring 0.5 mm in diameter. Rapid serial roentgenograms allow visualization of structures much smaller, particularly when one uses X-ray tubes with very small focal spots.

There are, however, other factors which are unrelated to radiographic technic which may lead to error. Thus, as already mentioned above, each vessel must be seen at least in two planes. If a vessel contains an eccentric plaque, the lesion may be completely missed if it is only radiographed in one plane. In addition, the inconsistent pattern of the minor vessels makes it difficult to exclude the absence of one of those vessels if there is not a remaining stump.

Finally, the limited amount of contrast material that can be used with impunity during each injection precludes opacification of many of the smaller branches. Because of this latter factor and the limited radiographic resolution, one cannot exclude small-vessel disease of the coronary arteries.

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