Clinical Applications of Coronary Arteriography

By Richard S. Ross, M.D.

A NEW diagnostic test such as coronary arteriography must pass through three stages before its ultimate clinical applicability can be determined. During the first stage, the test is used by its developers on a limited group of patients. During the second stage, the test is applied widely as clinical investigators explore possible new applications. Coronary arteriography is in this second stage at present and has not yet passed into stage three, where the indications, applications, and contraindications are clearly defined. In 1961, we can list areas in which exploratory use has brought promising results. It is possible that when the third stage is reached, the list of clinical applications may be longer, or on the other hand, possibly much shorter than it is today during this period of active exploration.

The most important disease of the coronary arteries is atherosclerosis, but it is in the study of this disease that the usefulness of coronary arteriography is most difficult to define. Currently, coronary arteriography must be considered to be a useful and promising tool for the clinical investigation of coronary atherosclerosis. There are many problems in the interpretation of coronary arteriograms that require solution before a more definite statement can be made. For example, it is relatively easy for an experienced investigator to make a positive diagnosis of coronary atherosclerosis, but it is far less easy to be certain that the arteriographically normal coronary tree is actually normal. False-positive coronary arteriograms are probably rare, but the incidence of false-negative arteriograms cannot yet be estimated. The incidence of false-negative arteriograms can only be determined by careful follow up of patients found to have arteriographically normal coronary arteries. Such a study is essential before the clinical significance of a negative arteriogram can be precisely defined. Postmortem studies will also be useful in estimating the sensitivity of the method in detecting functionally important lesions. There are also problems in the interpretation of positive arteriograms. It is easy to be certain that arteriosclerosis exists, but it is not possible to be certain that the arteriosclerotic lesions demonstrated are responsible for the patient’s symptoms.

These problems in interpretation must be recognized, but should not preclude the cautious use of the technic in clinical situations by experienced investigators. Only by the application of this new method to clinical problems can its true value be established. The most obvious application is in the differential diagnosis of atypical chest pain, where, for example, the best clinician may be uncertain regarding the presence of coronary artery disease. If the chest pain or its implication is incapacitating, an arteriogram is indicated, since a precise diagnosis, whether it be positive or negative, is important. If coronary artery disease is unequivocally demonstrated, therapy will be pursued with more vigor by the physician and followed more conscientiously by the patient. Uncertainty in the mind of the patient and the physician weakens the therapeutic program, especially when it involves inconvenience and discomfort as in the case of dietary and anticoagulant regimens. The significance of an arteriographically normal coronary tree is less certain, but, at the present time, it seems clinically sound to use this information in support of negative clinical evidence. A more benign cause of chest pain can be sought, and the patient unquestionably benefits by the assur-

From The Wellcome Research Laboratory Departments of Medicine and Radiology, The Johns Hopkins University School of Medicine and The Johns Hopkins Hospital, Baltimore, Maryland.

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ance that coronary artery disease has not been found.

Coronary arteriography is sometimes helpful in determining the etiology of cardiac enlargement and congestive heart failure. In this situation, the demonstration of normal coronary arteries indicates that primary cardiomyopathy is more likely than myocardial fibrosis secondary to coronary atherosclerosis. Another application is found in the patient with an abnormal electrocardiogram, which does not of necessity indicate that the heart is abnormal. Inverted T waves, bundle-branch block, and other electrocardiographic findings may sometimes signify coronary artery disease, and at other times be present in an individual with no organic heart disease. Here again if coronary artery disease is proved, the patient will benefit from a strong therapeutic program.

The possibility of surgical attack on coronary atherosclerosis has served as a stimulus for coronary visualization. The surgical results have not been encouraging, but continued interest appears justified. The ideal candidate for endarterectomy would be a young person with localized disease in one vessel, which has resulted in complete occlusion, while other major vessels remained relatively free from disease. Postmortem studies indicate that such patients are rare and that coronary atherosclerosis is a diffuse disease and usually involves long segments of several vessels. Though rare, the ideal patient does exist and should be considered for endarterectomy or other appropriate revascularization technic. Symptomatic and even electrocardiographic improvement has been recorded following endarterectomy, but the procedure cannot be considered as truly effective until persisting patency of the endarterectomized vessel can be demonstrated by arteriography. Rethrombosis has been demonstrated by arteriography following simple endarterectomy in patients who were symptomatically improved.

Evaluation of surgical results is an important application of the method. Patency of an endarterectomized vessel has been reported by Crafoord in a patient in whom a saphenous vein graft was used to increase the diameter of the vessel following removal of the occluding material. Flow through the enlarged lumen is enhanced, and thus the likelihood of rethrombosis is decreased.

Recently, arteriography has been employed to evaluate the effects of internal mammary artery transplantation into the myocardium. Significant passage of radiopaque material from the implanted vessel into the myocardium and coronary sinus has been observed. Arteriographic study should be an essential part of the evaluation of any such revascularization procedure.

Atherosclerosis is not the only disease of the coronary arteries that can be studied profitably by arteriography. Coronary insufficiency in a patient with syphilis should be considered a strong indication for coronary visualization. Syphilis involves the ostia and spares the rest of the coronaries, and thus the patient with syphilis should be ideally suited for surgical treatment; indeed, one such case has been treated successfully with dramatic results. Various congenital anomalies are of clinical importance and can be diagnosed by arteriography. Fistulous communications between a coronary vessel and a cardiac chamber may constitute a significant left-to-right shunt or be the site of bacterial endocarditis. Anomalous origin of the left coronary artery from the pulmonary artery is sometimes associated with cardiac enlargement and heart failure in infancy. This malformation can be visualized by arteriography, and the direction of the flow in the vessel may be determined. The latter is important in determining the treatment.

Anomalous distribution of the coronary arteries in the tetralogy of Fallot may be of importance to the cardiovascular surgeon. An anomalous vessel may run across the anterior surface of the right ventricle in an area through which the surgeon may wish to incise the ventricle. The aberrant vessel may run below the surface, and therefore may not be visible at operation. For this reason, some surgeons insist on arteriographic demon-
Coronary arteriography finds application in patients undergoing preoperative evaluation for surgical correction of various forms of valvular heart disease. This is especially important when the patient complains of chest pain. Chest pain closely resembling or identical to angina pectoris occurs in some patients with aortic stenosis, aortic regurgitation, mitral stenosis, pulmonary hypertension, and pulmonary stenosis. In the case of aortic valve disease, it is important to know whether the chest pain is a consequence of valvular abnormality or can be attributed to coexisting coronary artery disease. If the pain is related to the altered hemodynamics, relief can be expected to follow surgery; on the other hand, if there is severe coronary atherosclerosis, improvement cannot be anticipated, and the operative risk will be higher than anticipated. Similar reasoning can be applied to patients with mitral stenosis and the various congenital causes of right ventricular hypertension.

In the case of aortic valve disease, retrograde aortic catheterization and injection of roentgen-opaque material above the valve are usually carried out to study the valvular abnormality, and such a study can easily be extended to include visualization of the coronary tree. Coronary visualization should probably be carried out on all adult male patients being considered for total aortic valve replacement.

Coronary arteriography will find great usefulness in investigation, and it is worth while to speculate about these applications. Of great importance will be studies of the natural history of coronary artery disease. Blumgart, Schlesinger, and Davis\(^1\) correlated clinical information with the pathology studied by postmortem injection. A similar study would appear to be possible with correlation of the arteriographic pattern in intact man with clinical data. The variation in the distribution of the two coronary arteries and the influence of this distribution on the consequences of occlusion will be studied. Collateral patterns with or without occlusive disease can be studied. If considerations of safety permit repeated study of the same patient, invaluable knowledge about the development of collateral vessels, the recanalization of oc-

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**Figure 1**

Electrocardiograms at rest and after single Master's test in patient J.S.
cluded vessels, and the vascularization of infarcted areas will be forthcoming. All these studies of natural history will be rendered more valuable by the acquisition of a method whereby blood flow through the individual arteries can be measured in association with the arteriogram. The method of selective coronary arteriography offers promise of developments in this direction.

It is possible that arteriography will provide a definitive answer to the many pressing questions regarding the efficacy of therapy for atherosclerosis of the coronary arteries. Sones and Shirey have demonstrated the efficacy of nitroglycerin as a coronary vasodilator by arteriography. The influence of other drugs on the caliber of coronary vessels may be similarly evaluated. A study of the influence of dietary therapy on coronary atheromata is not impossible.

It is to be hoped that coronary arteriography will provide a sound basis for the evaluation of function tests. All clinicians are aware of instances in which sudden death from coronary disease occurred a few days after a normal resting electrocardiogram and exercise test have been obtained. Arteriography will help to explain such distressing events by bringing about a better understanding of the lack of sensitivity and errors of the current methods of exercise testing.

In figure 1 are seen the resting and exercise electrocardiograms on a 44-year-old man with anginal pain. There are no electrocardiographic abnormalities, yet in figure 2 it can be seen that extensive coronary artery disease is present. This is a retouched photograph of a spatial model of the coronary circulation made from colored pipe cleaners. There was diffuse disease of the right coronary artery as revealed by cineangiography, but this vessel was patent throughout. The circumflex branch of the left coronary was the site of a complete occlusion near its origin. The dotted line indicates the course of the occluded vessel. The distal circumflex was perfused by blood that passed from the left main coronary through an atrial branch serving as a collateral vessel and bridging the area of occlusion. Thus, in this individual, a major vessel was totally occluded, and yet the exercise test was normal, presumably because of the adequate collateral circulation that had developed.

Useful information about the mechanisms of the electrocardiographic changes in coronary disease may result from coronary arteriography. Striking electrocardiographic changes are produced by the selective injection of roentgen-opaque material into the coronary arteries. If lead II of the electrocardiogram is recorded, selective injection of the right coronary artery is followed by inversion of the T wave, whereas injection of the left coronary results in peaking of the T waves (fig. 3). When the right coronary artery is occluded near its origin and its distal branches are supplied by collateral vessels arising from the anterior descending, this normal pattern is not seen. In this situation, injection of contrast material into the left coronary artery is followed first by T-wave peaking and later by inversion as the contrast material passes through the left and right circulations respectively. This electrocardiographic pattern has been useful in confirming
the presence of collateral connections, which may be difficult to identify arteriographically.\textsuperscript{12} Animal experiments have demonstrated that these electrocardiographic changes, which persist for 30 to 45 seconds, are not accompanied by significant hemodynamic changes.

During the conduct of arteriography, the left ventricle is often entered as the catheter is manipulated above the aortic valve. Measurements of left ventricular pressure made during the conduct of arteriography have been employed in the study of left ventricular hemodynamics in patients with angina pectoris with special reference to the effects of nitroglycerin.\textsuperscript{12}

My closing remarks concern the methods of coronary arteriography. The Sones method of selective injection of the vessels appears to us to give the most information about the coronary tree.\textsuperscript{11} First, selective injection of one vessel and then the other yields information that cannot be obtained when both vessels are opacified simultaneously by injection into the aortic root. Second, selective injection requires only 5 or 6 ml of opaque material; therefore several injections can be made with the patient in different positions. The coronary vessels surround an essentially spherical structure and, therefore, several projections are necessary for adequate visualization of all the vessels. Third, the selective injection cineangiographic method permits the operator to observe the contrast material flowing into the artery and to regulate the injection appropriately. If results are unsatisfactory, a repeat injection is possible immediately.

It is necessary to add that the selective injection method is not easily learned. In only one half of our first 25 cases did we obtain satisfactory filling of both vessels. The method is not without hazard, and the investigator must be aware of the risks and be prepared to deal with emergency situations that may develop. With a great deal of help from Dr. Sones, we have overcome some of the earlier difficulties and have reduced the risks. Satisfactory filling of both coronary arteries was obtained in 36 of the total group of 49 stud-

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\caption{Figure 3}
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ies. Two patients developed transient ventricular fibrillation, which was promptly terminated. No deaths have occurred during the conduct of the procedure. One patient died a few hours after the conclusion of an uneventful procedure that demonstrated extensive and diffuse disease of all vessels. We still, however, consider this a procedure for clinical investigation and are careful in selecting our patients. As experience increases, we will undoubtedly apply the procedure more widely.

In summary, the magnitude of the coronary artery disease problem is such that further efforts to improve results and reduce risks are worth while.

\textbf{References}

Conjectures and Some Conclusions

It would perhaps be a not inept hypothesis and conjecture, nor altogether deviating from the truth, which should compare a muscle fibre to a small Leyden jar, or other similar electric body, charged with two opposite kinds of electricity; but should liken the nerve to the conductor, and therefore compare the whole muscle with an assemblage of Leyden jars. Moreover that a double and opposite electricity can occupy one and the same muscle he will readily grant not contrary to the truth who has considered that a muscular fibre, although at first sight very simple, nevertheless is composed of diverse solid and liquid parts, which produce in it no slight variety of substance. — Luigi Galvani.

Commentary on the Effect of Electricity on Muscular Motion. Translated by Robert Montraville Green, M.D. Cambridge, Massachusetts, Elizabeth Licht, Publisher, 1953, p. 61.