During the past decade, significant improvements have evolved in our approach to the problems of the patient with coronary heart disease. The fundamental reason for these changes has been the establishment of an improved basic standard of diagnosis, selective coronary arteriography.

At this point in time, selective coronary arteriography has been generally accepted as a useful technic for demonstrating the morphologic characteristics of the coronary arteries in patients with suspected or known coronary atherosclerosis. More than 13 years have passed since the first selective coronary arteriogram was performed in the spring of 1959, by deliberately passing a specially designed cardiac catheter into the orifices of each coronary artery and opacifying them with small doses of contrast media. Passage of the media through the vessels was recorded on 35-mm motion-picture film at a rate of 60 frames/sec utilizing the intensified image produced by a 12.7-cm (5-inch) fluoroscopic image intensifier.

Details of the technics utilized and their application to the first 1000 patients studied were published in July of 1962.¹ Now, over a decade later, after completion of more than 23,500 coronary arteriograms in the study of more than 18,000 patients, it seems appropriate to review what has been accomplished and to consider what lies ahead.

When adequately performed and interpreted, coronary arteriography reveals the exact location and relative severity of obstructive lesions in visible branches of the coronary arteries. The origin and distribution of functioning compensatory collateral arterial channels in patients with severe obstructive lesions are easily demonstrated. When the coronary arteries are proven to be free of obstructive lesions or irregularities in lumen diameter, coronary atherosclerosis may be excluded as a cause for chest pain, abnormalities of heart rhythm, electrocardiographic aberrations, or myocardial insufficiency.

Left ventriculography, performed at the time of coronary arteriography, provides objective demonstration of normal left ventricular function if all segments of the chamber contract normally. Transmural scar tissue replacement in any segment of the ventricular wall is easily recognized. Subendocardial scar tissue replacement in segmental areas of the chamber can usually be identified when hypokinesis of the involved segment and distortion of its endocardial surface are demonstrated.

Utilization of these technics has provided fundamental benefits for patients with coronary atherosclerosis and for physicians dedicated to the solution of their problems.

First, it has provided an objective basic standard of diagnosis not previously available. This has gradually stimulated desirable changes in our general approach to problems of patients with coronary heart disease. They are no longer regarded as an amorphous, totally unpredictable, group of people with “angina pectoris” who may have survived a variable number of “incidents” or “heart attacks.” Instead, they have become individu- uals with specific definable, obstructions of varying severity in their coronary arteries.
the obstructions are mild or moderate in severity, the patient may be placed on appropriate dietary and drug regimens. Similar therapeutic approaches may be in order for patients with more severe or complete obstructions if they show effectively functioning collateral channels from one or more sources to distal radicles of the obstructed vessels, and if their functional capacity to perform usefully in their chosen way of life is not significantly impaired. For patients with severe arterial obstructions, inadequately compensated by collateral channels, our surgical colleagues can now effectively create new sources of blood to underperfused segments of the myocardium before sudden death due to arrhythmia or irreversible myocardial injury has occurred.

Secondly, selective coronary arteriography has been most useful in excluding the presence of coronary atherosclerosis in a large number of patients with chest pain or nonspecific electrocardiographic changes that had been mistakenly attributed to the presence of significant coronary heart disease by their physicians. Almost one third of the patients studied in our laboratory have fallen into this category. The majority of these proved to have perfectly normal hearts. Their symptoms were noncardiac in origin. They have been returned to full and productive activity without restriction. They and their physicians have been freed of the burden of prolonged and unnecessary medical management which was completely misdirected. They have been spared the incapacitating anxieties and restrictions which were an inevitable sequel to the diagnosis of coronary heart disease.

Recently a survey has been completed of 274 men younger than 40 years of age in whom coronary arteriography was performed longer than 7 years ago because of symptoms or electrocardiographic changes indicative of myocardial ischemia (Proudfit W: Personal communication). Of these, 130 showed normal arteriograms or demonstrated only minor lumen irregularities in major vessels. Among these 130 patients, four (3.07%) developed myocardial infarction within 7 years. None of them died. The earliest infarct occurred 43 months after angiographic study. The mean time of occurrence for the four patients was 61% months after angiography. This means that, in a population of young men suspected of having symptoms of myocardial ischemia, demonstration of normal coronary arteriograms provides better than 96% assurance that myocardial infarction will not occur within 5 years. In such patients, the possibility of death due to the complications of coronary atherosclerosis within 7 years is even more remote.

A smaller number of those patients who were under treatment for coronary atherosclerosis and had normal coronary arteriograms proved to have primary myocardial disease, pericarditis, or subaortic hypertrophic stenosis. In these, therapeutic regimens and objectives could be appropriately modified.

Thirdly, selective coronary arteriography has provided a basis for the development of surgical technics which have been devised to provide new collateral channels to underperfused segments of the myocardium or to directly bypass obstructions in proximal segments of the major coronary arteries.

In 1962, two patients with single internal mammary artery implants performed by Dr. Arthur Vineberg in Montreal, Canada, were proven to have developed effective collateral channels from their implanted internal mammary arteries to distal segments of their occluded anterior descending coronary arteries. These were demonstrated by selective opacification of the implanted mammary arteries.

We have been able to perform postoperative angiographic studies at intervals ranging from 6 months to 5 years in more than 1000 patients in whom internal mammary artery implants have been performed. Seventy percent of the implanted internal mammary arteries were demonstrated to be communicating effectively with distal radicles of the severely obstructed coronary arteries. In 22%,
the implanted arteries were demonstrated to be patent within the myocardium, but no flow could be demonstrated from them to distal segments of the coronary artery tree. Eight percent of the implanted internal mammary arteries were obstructed.

In January, 1962, Dr. Effler performed the first endarterotomy with patch graft reconstruction for severe segmental obstruction of the left main coronary artery proximal to its bifurcation. This procedure was subsequently used in 163 patients with severe localized obstructions in the right or left coronary arteries. We have been able to perform postoperative studies on 94 of these patients at intervals of from 1 month to 31⁄2 years after operation. Fifty-six percent of the previously severely obstructed arteries proved to be widely patent or demonstrated only minor narrowing. Sixteen percent were severely obstructed and 29% had progressed to occlusion.

Since 1967, until September 1, 1971, 1577 single saphenous vein bypass grafts from aortic root to a coronary artery beyond its obstruction have been performed at the Cleveland Clinic for lesions of the right or left coronary arteries. Multiple saphenous vein grafts have been performed on 962 patients. Not enough time has elapsed to permit statistically significant angiographic assessment of this group of patients. In a small group with an average 3-year follow-up, the bypass graft patency rate has exceeded 80%. More meaningful data in this group of patients will be available to us within the coming year.

We have reason to believe that all of our postoperative studies are statistically biased in a negative direction. When postoperative patients develop a recurrence of angina pectoris, or myocardial infarction, they are usually anxious to return to the hospital for repeated study. We are equally anxious to meet this responsibility. On the other hand, many of those who are completely asymptomatic are not easily persuaded to return. Admittedly, in a clinically oriented environ-

ment, with a constant 3–4-month backlog of symptomatic patients awaiting admission to the hospital at all times, our efforts to persuade asymptomatic postoperative patients to return are less active than they perhaps should be.

**Indications for Coronary Arteriography**

Ideally, coronary arteriography and left ventriculography should be an essential part of the routine diagnostic study of any patient suspected of having coronary atherosclerosis. The study should be performed as soon as possible after the recognition of symptoms or electrocardiographic changes which are interpreted by his physician as being possibly due to obstructive lesions in the coronary circulation causing myocardial ischemia.

If acute myocardial infarction occurs as the first clinically recognizable event in the patient's history, coronary arteriography should be performed as soon as the myocardial injury has healed and the patient's functional status has stabilized. This usually evolves in 4–6 weeks from the onset of infarction.

Coronary arteriography should be routinely employed in the study of patients who first present with chronic symptoms of myocardial ischemia with or without history of prior myocardial infarction if the heart is not enlarged and the patient is free of congestive manifestations.

Coronary arteriography and left ventriculography should be essential components in the preoperative assessment of patients with aortic stenosis if surgical intervention is under consideration. Many of these patients with angina considered to be due to aortic valve obstruction actually have severe, but often correctable, coronary artery obstructions.

We have encountered a small number of patients who were terrified of the possibility of sudden death because of an unusually high incidence of mortality due to coronary heart disease among their close relatives or because they were aware of gross abnormalities of
lipid metabolism. Such patients have been studied without incident, and the results have usually been reassuring.

Similar studies have been performed on a number of commercial airline pilots who developed changes in their electrocardiographic pattern which disqualified them from flying status. Demonstration of normal coronary arteriograms has permitted the majority of them to return to active flying. In a few others, appropriate surgical intervention has permitted their return to productive work, but they have not been permitted to fly.

Sequential progress angiographic studies are being performed in progressively increasing numbers in several categories of patients.

In the early phases of the development of new surgical techniques for myocardial revascularization postoperative patients are restudied before they leave the hospital, usually on the ninth or tenth postoperative day. When enough experience has been accumulated to permit standardization of the procedure, such studies are deferred for progressive time intervals. Ideally an attempt is made to study a representative group of surviving patients in each category at intervals of 1, 3, and 5 years postoperatively. The difficulties encountered in accomplishing this have been mentioned. Precedence is routinely given to repeated progress examination of any postoperative patient who shows evidence of functional deterioration.

In patients with mild or moderate atheromatous lesions who are not candidates for surgical intervention, repeated studies are done whenever their functional status shows clinical evidence of deterioration. If their functional status remains stable, as many as possible are restudied in 3 years. In this fashion, we are slowly accumulating a mass of data which should ultimately be of value in providing a better understanding of the natural history of coronary atherosclerosis.

A program to use selective coronary arteriography for the study of large numbers of asymptomatic men beyond the age of 40 years would undoubtedly yield a significant number with potentially incapacitating or lethal arterial obstructions before irreversible myocardial injury or fatality evolved. These would benefit by the timely application of appropriate medical and surgical treatment directed toward solution of their individual problems. In those demonstrating normal vessels a very high level of assurance concerning the individual's continued survival and unimpaired functional capacity would be obtained.

At this time the potential benefits which may be reasonably anticipated from the development of such a program makes it a desirable objective toward which our efforts should be directed. Available human and physical resources needed for the ultimate development of such a program should be deliberately and methodically activated. At present the primary focus of these resources must be directed toward the needs of the symptomatic patient. Only when these needs have been fulfilled will broader application of coronary arteriography to the asymptomatic population become feasible.

Contraindications to Coronary Arteriography

In clinical application we do not believe that coronary arteriography and left ventriculography should be performed in patients with established acute myocardial infarction if symptoms have been present for longer then 6 hours. In general, such patients should be treated conservatively and angiographic studies should be deferred for 4-6 weeks from the onset of infarction. The possibility of dislodging soft mural thrombi from the left ventricle is feared in this group of patients.

On the other hand, we do not hesitate to study patients who are experiencing episodes of rest pain or coronary insufficiency if there have been no recent changes in the QRS complexes or significant enzyme elevations. Hundreds of patients in this category have been studied with no higher incidence of complications than were experienced in the more stable group of patients.

There is little reason to study patients with significant cardiomegaly due to diffuse scar
tissue replacement following multiple previous myocardial infarctions. We have studied a large number of such patients referred by physicians who have often observed their downhill course for years and "after all measures of medical management have failed" now hope for a surgical miracle. Such hopes are usually doomed to failure because it is impossible to revascularize a scar. These patients are uniformly disappointed when their physicians tell them they are not surgical candidates and must continue with medical management. An effort to sustain their morale is made by emphasizing to them that compensatory collateral channels are present which may be further developed by continuing medical therapy. Hopefully, experience with these patients will convince their physicians to seek help for their patients in an earlier phase of the disease, when the option to utilize effective revascularization techniques is still available to them.

Cineangiographic studies should be deferred in grossly obese patients until appropriate weight reduction has been attained. The diagnostic quality of cineangiograms performed on patients who are more than 40 lb overweight is usually inferior because of excessive scatter radiation reaching the film.

The most important limiting factor to broad utilization of coronary arteriography remains the lack of adequate numbers of well-trained physicians to perform and interpret the studies. The safe performance of consistently superior studies demands a high level of technical competence. At present it appears that at least 2 years of special training are required to provide a cardiologist or radiologist with enough experience to perform such studies independently. This responsibility should not be entrusted to enthusiastic but inadequately trained individuals. The risk of mortality attributable to this study in the classes of patients for whom it is indicated should be lower than 1:1000. When significantly higher rates are encountered, inept performance, poor judgment, or both, must be assumed.

These studies should not be performed with equipment that is incapable of consistently producing films of adequate diagnostic quality. Large-field (20–23 cm) image amplifiers and 16-mm motion-picture cameras should not be used for this purpose. At present, the best commercially available systems combine 15-cm image amplifiers with 35-mm cameras equipped with cinemoscope gates and 100-mm focal-length lenses. X-ray generators capable of providing 60 square wave pulses of 1–10 msec/sec in duration should be used. By eliminating motion blurring on film at slow frame rates, these systems provide excellent diagnostic cineangiograms in adult patients at 30 frames/sec. Without sacrificing quality, this has permitted a 50% reduction in X-ray dose to the patient, with equivalent reduction in film cost, processing, and storage.

It must be emphasized that the foregoing comments regarding indications and contraindications are pertinent to clinically oriented examinations that are directed toward providing information that is specifically pertinent to solution of the patient's problem. They are confined to pressure measurement in the ascending aorta and left ventricle, selective opacification of both coronary arteries in appropriate projections to assure that all major segments of the coronary tree are adequately visualized in a plane perpendicular to the X-ray beam, and left ventriculography. In the study of postoperative patients, selective opacification of grafts or internal mammary arteries is added as indicated by the individual problem. In the vast majority of instances, in the hands of skilled technicians, such studies are accomplished with no more than 15 min of intravascular catheter manipulation. Strict adherence to this protocol, more than any other factor, is responsible for minimizing stress, morbidity, and mortality for the patients involved.

At this time, there are several important developments pertinent to this field which appear to hold great promise.

A new image-amplifier tube phosphor made of cesium iodide capable of resolving 40 line pairs per centimeter has evolved through its testing phases and will soon be commercially
available. Its resolving capacity is approximately three times better than that of presently available image amplifiers. This may pave the way for the use of 16-mm photography to produce films which are of equivalent quality to today’s 35-mm product.

A completely new mechanical system for performance of cineangiographic studies is now in its final prototype phase of development. Essentially, it consists of a stand which rotates the image amplifier and X-ray tube around the patient, who lies supine on a cart. The cart mobilizes the patient making it possible to perform the cutdown on his brachial artery in a small anteroom adjacent to the laboratory. He is then moved into the laboratory for actual performance of the study. On completion of the procedure he is immediately removed to a second anteroom for closure of the artery and skin. Using this system with three carts makes it possible to perform three times the number of routine diagnostic studies that can be accomplished today in a conventional laboratory. This will significantly improve our position in the logistical battle we face in dealing with large numbers of patients with coronary atherosclerosis.

Finally, aortic balloon counterpulsation systems are reaching a stage of development which should soon permit their use for the effective support of patients within the first few hours of onset of acute myocardial infarction. These systems may provide the time margin of support needed to define the exact location of the responsible obstructions and to perform appropriate bypass grafting before irreversible myocardial injury has occurred. In terms of evolution, this appears to be the next great problem that may be overcome in the ongoing struggle against coronary atherosclerosis.

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