A MONTHLY SCIENTIFIC PUBLICATION OF THE AMERICAN HEART ASSOCIATION, INC.

MODERN CONCEPTS OF CARDIOVASCULAR DISEASE

Editor: E. COWLES ANDRUS, M.D. Associate Editor: RICHARD S. ROSS, M.D.
Editorial Office: JOHNS HOPKINS HOSPITAL, BALTIMORE 5, MARYLAND

Vol. XXXI JULY 1962 No. 7

Cine Coronary Arteriography *

■ F. Mason Sones, Jr., M.D.
Earl K. Shirey, M.D.

Department of Pediatric Cardiology and Cardiac Laboratory
Cleveland Clinic
Cleveland, Ohio

During the past four years, the technique of cine coronary arteriography has been developed in an effort to provide a more objective and precise standard of diagnosis for human coronary artery disease. Heretofore, the diagnosis of coronary atherosclerosis has been primarily dependent on the physician's interpretation of the efforts of distressed patients to describe chest pain, and upon recognition of transient or chronic electrocardiographic changes which usually indicate the presence of myocardial ischemia or necrosis. Although conscientious, knowledgeable, history-taking and electrocardiographic study require no apologist for their contributions to understanding, their limitations have been responsible, even in the hands of experts, for the production of iatrogenic disability on the one hand, and unjustified reassurance on the other, in a significant number of patients. A safe and dependable method for demonstrating the physical characteristics of the human coronary artery tree, which could be applied in any phase of the natural history of coronary artery disease, was needed to supplement available diagnostic methods.

Direct coronary artery catheterization has been used for deliberate selective opacification of individual coronary arteries in more than 1,020 patients. The results obtained in a characteristic group of patients are demonstrated in a motion picture entitled: "Cine Coronary Arteriography," prepared for distribution by the Committee on Professional Education of the American Heart Association in September 1962. Preliminary studies performed in our laboratory from 1956 through the first six months of 1958 on dogs and humans without clinical evidence of coronary artery disease have demonstrated that dependable opacification of the normal coronary artery tree could not be achieved by conventional aortographic techniques. Doses of contrast media, ranging from 40 to 60 cc., were injected into the aortic root under pressures of 10 Kg./cm.^{2} with a Gidlund pressure syringe, and provided adequate visualization of major branches of the right and left coronary arteries in fewer than 70 per cent of the patients studied.[1]

The use of acetylcholine to produce asystole and facilitate improved coronary perfusion with smaller doses of contrast media was explored by Lehman and associates.[2] This seemed undesirable because of the variable response of different patients to similar doses of the drug, and because we feared the consequences of its use in patients with unknown degrees of myocardial ischemia.

Dotter and associates[3] proposed the introduction of a balloon catheter into the ascending aorta to produce temporary aortic occlusion, while injecting a small dose of contrast sub-

* From the Department of Pediatric Cardiology and Cardiac Laboratory, Cleveland Clinic, Cleveland, Ohio.

stance above the aortic valve. While this undoubtedly resulted in effective concentrations of dye reaching the coronary circulation, the combined hazards of sudden obstruction to left ventricular outflow and accidental displacement of the balloon made routine application seem undesirable.

In October 1958, the first deliberate efforts to perform "selective" coronary arteriography were made in our laboratory. Serial doses of 20 to 30 cc. of contrast medium were injected under a pressure of 4 Kg./cm.^{2} into a catheter after its tip was carefully placed first in one, then the other, anterior sinus of Valsalva. This insured the introduction of a large volume of dye into the immediate vicinity of each coronary orifice during the interval of three to six heart cycles. In a series of 137 patients studied by this method, visualization of each coronary artery was considered to be adequate in more than 90 per cent. Ventricular arrhythmias, which had been feared as a consequence of transient asymmetrical myocardial hypoxia with this method of delivery, failed to materialize in this group of patients. During this experience, clear-cut demonstration of intercoronary collaterial channels was first observed in the living human. It was also noted that coronary artery orifices could occasionally be catheterized without causing injury to the patient.

In April 1959, a special catheter was fabricated at our request by the United States Catheter and Instrument Company for this specific purpose. The shaft of this thin-walled radiopaque woven catheter is 2.7 mm. in external diameter (8 French) to provide enough rigidity for dependable manipulation in the systolic jet immediately above the aortic valve. The tip is open and four side openings are arranged in opposed pairs within 7 mm. of its distal end. The shaft is sharply tapered to an external diameter of 1.6 mm. (5 French) at a point 5 cm. from its tip. This provides an extremely flexible "finger tip" which may be curved upward into the coronary orifices by pressure of the more rigid shaft against the aortic valve cusps. This maneuver is demonstrated in the motion picture previously described. It has been possible to enter both coronary arteries in 954 of 1,020 patients studied. In no instance has failure to enter at least one vessel occurred. Since each artery is routinely photographed in multiple projections, a total of 7,207 individual arteriograms were recorded in this group of patients.

Materials and Equipment

The contrast media most frequently employed have been 90 per cent Hypaque and 85 per cent Cardiografin. More than 3,500 arteriograms have been performed by direct injection of each of these compounds into human coronary arteries. Although they are difficult to handle because of high viscosity, adequate opacification of individual vessels is constantly achieved with doses of 2 to 5 cc. and they cause less frequent side effects than previously available media.

For routine clinical study, all coronary arteriograms performed in this laboratory are photographically recorded on 35 mm. Eastman Cineflure negative film with Arriflex cameras at a rate of 60 frames per second. The cameras are eqiupped with color corrected F 2.0 lenses with a focal length of 75 mm. to photograph the output of 5-inch Philips image amplifiers capable of amplifying light from 1,200 to 3,000 times. After a prolonged experience with 11-inch, 9-inch, and 8-inch image amplifiers equipped with 16 and 35 mm. cameras, we are convinced that the 5-inch amplifier and 35 mm. camera described above is the best combination of equipment commercially available for this purpose. The 5-inch field is large enough to cover adequately the distribution of individual coronary arteries by moving the amplifier no more than 2 inches during each exposure. Its small area insures a homogeneous background density within the heart silhouette, which simplifies the problem of obtaining dependable light measurement for precise photographic exposure. It insures the smallest possible x-ray dose to the patient, and provides better photographic reproduction of small structures than any other combination of equipment available for high-speed x-ray motion picture recording. Paradoxicaliy, the 5-inch amplifier is considerably less expensive than its larger counterparts.

Exposed film is processed immediately in a Fisher Processall Model S-XR-6, using Ethol-90 developer and Kodak Rapid X-ray Fixer at a speed of 4 feet per minute. Processed 35 mm. negative film is routinely available for viewing within an hour of exposure. A Tage-Arno 35 mm. viewer is used for this purpose and has been satisfactory for all routine diagnostic study. It provides a projected image which can be comfortably observed by one to four persons at any desired speed, from still projection of individual frames, to a rate of 50 frames per second. It does not scratch or tear film.

Although still photographs cannot provide the information imparted to the observer by careful motion study, individual frames which most clearly demonstrate the anatomical characteristics of each arteriogram are selected. These are reproduced as enlarged positive prints on photographic paper two by three inches in size. These prints are mounted and incorporated in duplicate reports for the hospital chart, the referring physician, and the laboratory file.

Standard of Performance

Using the techniques, equipment, and materials described, the following standard of performance may be anticipated:

1. All branches of the coronary artery tree should be visualized down to distal radicals with a lumen diameter of 100 to 200 μ.

2. Total occlusion and partial segmental narrowing which obstructs the lumen diameter by more than 20 per cent should be clearly defined in all vessels with an internal diameter larger than 1 mm.

3. The origin and distribution of functioning intercoronary collateral arterial channels larger than 100 μ should be defined. Collateral channels arising above obstructed arterial segments which perfuse distal branches of the same vessel should be recognized.

4. Segmental narrowing due to functional coronary artery constriction should be distinguishable from fixed organic obstructions by repeated visualization before and after the use of amyl nitrite or nitroglycerin.

5. Functional segmental arterial obstructions due to extrinsic pressure by perivascular myocardial bands, which constrict during ventricular systole, should be distinguishable from fixed organic intraluminal obstructions.

6. Calcification in the coronary artery tree should be defined.

7. When the internal mammary arteries are selectively opacified, the presence of extracoronary myocardial perfusion from distal radicals of these vessels should be demonstrable.

8. Coronary arteriovenous fistulae and fistulous tracts into cardiac chambers are demonstrable when they exist.

9. When left ventriculography is performed, the presence and physical characteristics of myocardial aneurysms, septal perforations, and mitral regurgitation, due to myocardial infarction, are recognized.

INDICATIONS FOR CORONARY ARTERIOGRAPHY

Clinical application of cine coronary arteriography is indicated when a problem is encountered which may be resolved by objective demonstration of the coronary artery tree, provided competent personnel and adequate facilities are available and the potential risks are acceptable to the patient and his physician. The largest group of patients which may be studied with benefit are those in whom the diagnosis of coronary artery disease is suspected, but ill-defined, or questioned because of atypical clinical features.

The pitfalls encountered in the assessment of such problems are so numerous that diagnostic errors are usually accepted with stoic resignation when they are uncovered by the passage of time. Instances of sudden death or acute myocardial infarction due to unrecognized coronary artery disease occur with distressing frequency within a month following the reassurance of a "complete check-up and normal electrocardiogram." On the other hand, patients with chest pain accompanied by minor electrocardiographic changes may pursue a restricted existence for years in anticipation of "a heart attack," following the sincere, but mistaken, diagnosis of angina pectoris or coronary insufficiency.

Normal coronary arteriograms have been demonstrated in a number of such patients following years of well-intentioned treatment with vasodilators, sedatives, or anticoagulant drugs. In some, the combination of pain, unresolved hopelessness, and personality maladjustment, compounded by poor medical management, led to narcotic addiction. In others, pericardial poudrage, internal mammary artery ligation, or the production of myxedema with radioactive iodine, had been needlessly performed.

Cine coronary arteriograms have been routinely performed in patients with aortic valve disease who gave a history of syncopal attacks or retrosternal distress. This has made it possible to rule out coronary disease as a possible cause of symptoms in some patients. In others, only mild valve obstruction associated with severe and unrecognized coronary artery disease was demonstrated. In these patients, an unnecessary and potentially lethal surgical attack on the aortic valve was avoided. Accidental division of anomolous major coronary artery branches has been observed in patients with congenital heart disease during right ventriculotomy. For this reason, cine coronary arteriograms are routinely performed to define the origin and distribution of major branches of the coronary artery tree during the course of heart catheterization and cine cardioangiography in these patients.

As surgical techniques directed toward improving myocardial perfusion evolve to a stage of clinical application, cine coronary arteriography should provide an anatomical basis for

the selection of patients in whom specific surgical procedures may be helpful. It has also been of value in demonstrating the success or failure of such procedures in postoperative patients. Recently, it has been possible to demonstrate that left internal mammary arteries implanted into the left ventricular wall by the method of Vineberg[4] were effectively perfusing the left ventricle, five to seven years after operation. In a series of more than 20 patients, it has been impossible to demonstrate myocardial perfusion from branches of the internal mammary arteries following pericardial poudrage and partial coronary sinus ligation. Similar negative results have been encountered in patients after internal mammary artery ligation.

Serial studies performed on patients in all phases of the natural history of coronary atherosclerosis will ultimately provide a better understanding of its complications and the evolution of compensatory mechanisms which permit survival.

COMPLICATIONS

Ventricular fibrillation occurred in twelve of 1,020 patients. Two of three patients treated by emergency thoracotomy and open-chest cardiac massage expired. The third survived after a stormy postoperative course. Since June 1960, nine patients have been treated with external cardiac massage by the method of Kouwenhoven and associates.[5] One spontaneously reverted to normal sinus rhythm after 20 seconds of massage. The remaining eight required one to three shocks with an external defibrillator to restore normal rhythm. In all of these, subsequent coronary arteriograms were performed in the opposite coronary artery, which had not been visualized, as soon as functional stability was re-established. Left ventriculograms were also performed on five of these patients who had valvular heart disease subsequent to defibrillation. The arrhythmia did not recur. Except for first-degree burns on the chest wall from the defibrillator electrodes, there were no complications; all nine patients have survived. Effective treatment, promptly applied under adequate control, has reduced this formidable complication to the status of a reversible incident without residual injury.

Death due to ventricular asystole followed sudden functional constriction of the left coronary artery in a third patient, whose right coronary artery was totally obstructed. The mortality rate attributed to cine coronary arteriography in 1,020 patients has been 0.29 per cent.

Acute posterior myocardial infarction occurred in one patient with severe generalized coronary atherosclerosis, due to dissection of the right coronary artery. This developed ten minutes after the catheter was removed from its orifice and was verified by subsequent opacification of the vessel. The patient recovered. There have been no other instances of myocardial injury.

Segmental occlusion at the site of brachial arteriotomy has occurred in six to seven per cent of the patients. Collateral circulation has been adequate in all of these to prevent tissue loss. A few of this group have complained of claudication and sensitivity to cold, but the majority are asymptomatic three months after the procedure.

With increasing experience, the potential risks of coronary arteriography should be further reduced by improved technical performance. The hazards have seemed acceptable in view of the objectives attained. The use of cine coronary arteriography in the immediate future will be limited by the availability of adequately trained and equipped personnel to perform safely and reliably interpret the procedure. These limitations will be gradually overcome by the human and technical resources available. It must be emphasized, however, that inept performance, inadequate instrumentation, and overimaginative or undiscerning interpretation provide the means of opening a Pandora's box of misinformation which may plague the physician, harm his patients, and retard evolution of a better understanding of human coronary artery disease. These hazards can be minimized only by the exercise of our best judgment, care, and technical skill in the application and further refinement of the techniques described. If this is done, we and our patients will profit by the availability of an objective diagnostic standard for defining the presence of coronary atherosclerosis.

REFERENCES

1. **Sones, F. M.:** Cinecardioangiography. In Clinical Cardiopulmonary Physiology, ed. 2, edited by B. L. Gordon. New York, Grune and Stratton, 1960, pp. 130-144.
2. **Lehman, J. S., Boyer, R. A., and Winter, F. S.:** Coronary arteriography. Am. J. Roentgenol. **81:** 749, 1959.
3. **Dotter, C. T., and Frische, L. H.:** An approach to coronary arteriography. In Angiography, vol. 1, edited by H. L. Abrams. Boston Little, Brown and Company, 1961, pp. 259-273.
4. **Vineberg, A.:** Surgery of coronary artery disease. Progr. Cardiov. Dis. **4:** 391, 1962.
5. **Kouwenhoven, W. B., Jude, J. R., and Knickerbocker, G.G.:** Closed-chest cardiac massage. J.A.M.A. **173:** 1064, 1960.