DURING the past few years two basically different approaches have been used for contrast visualization of the coronary arteries: selective coronary arteriography and thoracic aortography. As in other fields of angiography the selective technics are becoming more and more popular, since minute vascular detail is obtained with the injection of a small amount of contrast medium. Selective catheterization of coronary arteries requires considerable skill; it is, therefore, not surprising that modified thoracic aortography is still the most widely used technic for visualization of the coronary arteries.

A review of close to 1,000 thoracic aortograms at the University of Minnesota Hospitals, performed for acquired and congenital heart disease, showed satisfactory visualization of both coronary arteries in the vast majority of the cases. A careful analysis of these studies, which were made by one single injection of contrast medium through a large-bore catheter, showed a wide variation of coronary arterial filling. Some congenital and acquired cardiac lesions seem to enhance demonstration of the coronary arteries, and the special technics described for coronary arteriography actually mimic some of these favorable hemodynamic conditions. Best filling of the coronary artery was observed in patients with severe mitral disease or large intracardiac left-to-right shunts. The decreased cardiac output and decreased stroke volume of the left ventricle result in a prolonged and intense opacification of the sinus of Valsalva and coronary arteries. In patients with large cardiac output or increased stroke volume of the left ventricle (aortic insufficiency, extracardiac left-to-right shunts, tachycardia, etc.) there was marked dilution of contrast medium and consequently poor visualization of the coronary arteries. In the presence of partial aortic obstruction due to coarctation of the aorta or supravalvular aortic stenosis filling of the coronary arteries was excellent.

Therefore, in various methods of coronary arteriography, attempts are made to decrease the cardiac output, prolong the ventricular diastole, or obstruct the thoracic aorta.

**Coronary Arteriography with Phasic Injection of Contrast Material**

During ventricular systole the sudden ejection of blood from the left ventricle tends to wash the contrast medium away from the coronary ostia. During diastole, with its relative lack of flow in the aorta, there is only minimal dilution and consequently a higher concentration of contrast medium reaches the coronary arteries. Fortunately, also the main coronary flow occurs during ventricular diastole. By timing the injection at the end of ventricular systole or beginning diastole, superior filling of the coronary arteries can be obtained with less contrast medium.

A large-bore catheter with side holes is introduced into the surgically exposed femoral or brachial artery and advanced under fluoroscopic control into the sinus of Valsalva. Thirty to 50 ml. of contrast medium are injected during ventricular diastole. The injection apparatus is fired from an electronic delay circuit, which is triggered by the "R-wave" of the electrocardiogram (fig. 1).

More than 100 patients with coronary artery disease have been examined by this technic at the University of Minnesota Hospitals by Thal. Visualization of the coronary arteries was generally good, and there has been no significant morbidity and no mortality.

**Coronary Arteriography with Decreased Cardiac Output**

Obviously, the dilution effect of ventricular systole is directly proportional to the left ventricular stroke volume and the pulse rate.
Figure 1
Coronary arteriogram performed by phasic dye injection. Occlusion of anterior descending, severely diseased right coronary artery and collateral circulation from the left circumflex are well demonstrated.

By artificial reduction of the cardiac output this dilution can be minimized and the contrast visualization of the coronary arteries can be significantly improved. A simple and effective technic of decreasing cardiac output is the Valsalva maneuver. By having the patient exhale forcefully against the closed glottis, cardiac output is decreased by approximately 40 per cent, allowing prolonged and denser opacification of the ascending aorta. A large-bore Polyethylene or Teflon catheter is introduced percutaneously into the femoral or subclavian artery, and 40 to 50 ml. of contrast medium are delivered with a power injector. During general anesthesia cardiac output is simply reduced by elevating the intrabronchial pressure to 40 cm. of water.

Coronary Arteriography during Cardiac Arrest and Its Modifications
Arnulf made an important accidental discovery. While doing aortograms in animals, he obtained an outstanding coronary arteriogram in a dog in which accidental cardiac arrest occurred just prior to the injection. He used this knowledge to describe a new way of coronary arteriography during cardiac arrest induced by the injection of acetylcholine (fig. 3). Acetylcholine is an apparently harmless drug, which is rapidly destroyed in the human body; it has also been used by psychiatrists for shock treatment. Arnulf advocates the intravenous injection of a large amount (3 mg. per kilo body weight), resulting in cardiac arrest of several seconds' duration. As soon as asystole has occurred, as seen on the electrocardiogram, 20 ml. of contrast medium are injected via catheter or needle into the ascending aorta. In spite of an apparently wide margin of safety a prolonged cardiac arrest may persist requiring the injection of atropine through the catheter as an antidote. According to Arnulf this was necessary in only 1 of 24 examined patients. Since the
publication of this classic work, the basic technic has been modified in several ways:

1. Acetylcholine can be injected directly through the catheter into the sinus of Valsalva. By doing so, much smaller amounts are required and cardiac arrest occurs almost immediately following the injection.7

2. After acetylcholine asystole has been induced, atropine may be injected together with the contrast medium to terminate the cardiac arrest.

3. An external or internal pacemaker may be used to disrupt the pharmacologically induced cardiac arrest at will8 (fig. 4).

**Occlusion Aortography**

A Dotter-balloon catheter is introduced into the surgically exposed brachial artery and advanced into the ascending aorta. It is inflated with carbon dioxide, and contrast medium is injected proximally to the occluded aorta. The injection is made during acetylcholine-induced cardiac arrest.9

**Semi-selective Technic**

Selective and semi-selective technics have replaced some of the above-mentioned methods of coronary arteriography that require complex equipment. By delivering the opaque substance close to the origin of or directly into the coronary arteries, superior visualization can be obtained with a smaller amount of contrast medium. A simple semi-selective technic is placement of the catheter tip into the right or left coronary sinus. By doing so
there is preferential filling of the coronary artery arising from the injected sinus (fig. 5). This technic is reliable and relatively simple, especially if the catheter is introduced through the brachial or subclavian artery rather than through the femoral.

Williams\textsuperscript{10} described the loop catheter which allows semi-selective opacification of both coronary arteries with one single injection. The catheter ring is positioned just above the sinus of Valsalva, and the jet of contrast medium is directed downward and laterally through numerous lateral side holes. The catheter can be introduced percutaneously, and usually manual injection is adequate, with positioning of the catheter properly just above the coronary ostia. If the contrast medium is delivered with a power injector, the side holes in the catheter loop have to be arranged differently in order to prevent displacement by recoil. Good opacification of the coronary arteries can be obtained by this simple technic, especially by combining this procedure with the Valsalva maneuver (fig. 6).

**Selective Coronary Arteriography by Percutaneous Arterial Catheterization**

By far the best demonstration of anatomic detail is obtained by selective injection of the coronary arteries. By inserting the catheter into the surgically exposed right brachial artery Sones\textsuperscript{11} has applied this technic in a large group of patients. More and more angiographic procedures and even coronary arteriography are carried out by radiologists who prefer to introduce the catheter percutaneously rather than by surgical arteriotomy. If the catheter is introduced percutaneously into the femoral artery, the left coronary artery can be entered with fair consistency,
but catheterization of the right coronary artery is extremely difficult. Percutaneous catheterization of the brachial artery is usually not satisfactory because of the rather commonly present arterial spasm and consequently decreased maneuverability of the fairly long catheter. The development of an infraclavicular subclavian artery catheterization technic proved practical for this procedure, since the subclavian artery is a large vessel that does not go into arterial spasm, allowing good control over a very short catheter.

Catheterization technics and landmarks are as follows:

A horizontal line is drawn perpendicularly through the midsternal line approximately one finger below the jugular notch (fig. 7). The skin is infiltrated with a local anesthetic at this level approximately one finger laterally to the midelavicular line. A small "nick" through the skin is made with a no.-11 knife blade, and a 6-inch, wide-lumen, no.-18 thin-walled needle with a snuggly fitting Teflon rider is used for arterial puncture (fig. 8A). The catheter needle is directed obliquely upward and medially toward the subclavian artery, which is palpated with the index finger of the other hand in the supraclavicular fossa. The subclavian artery is usually easily palpable at a point where it crosses the first rib. The upward direction of the needle and the fact that the subclavian artery is punctured over or preferably laterally to the first rib minimize the occurrence of pneumothorax. The pulsating artery is localized with the needle tip and punctured with a short, jabbing motion. As soon as free arterial blood flow is obtained the needle is removed, and the catheter is advanced intra-arterially. Almost invariably the catheter enters the mouth of the vertebral artery, which is a desirable feature if vertebral angiography is contemplated. In order to pass the Teflon catheter into the innominate artery a soft, sharply curved, spring stylet is gently introduced as a guide (fig. 8B). The Teflon tubing is now replaced by a curved radiopaque polyethylene catheter by Seldinger's technic. The coronary arteries are catheterized according to

![Figure 9](http://circ.ahajournals.org/)

**Figure 9**

Selective coronary arteriogram. Single spot film obtained at the end of injection.

Sones and injected manually with contrast medium. In our experience a single radiograph made at the end of the injection by means of the spot film device or overhead tube proved adequate (fig. 9). Following the procedure the catheter is withdrawn and the subclavian artery is compressed against the first rib in the supraclavicular fossa for approximately 10 minutes. Adequate compression is indicated by disappearance of the radial pulse. Because of the easy compressibility of the subclavian artery against the first rib, hematomata have been very rare in our experience, which is still limited to approximately 100 catheterizations.

**Discussion**

Coronary arteriography in patients with coronary artery disease and consequently impaired coronary flow is one of the most difficult angiographic procedures. Simple thoraciac aortography is considered very adequate for visualization of normal coronary arteries, but in the presence of occlusive coronary artery disease contrast filling is commonly unsatisfactory. The term "coronary arteriography" as a special procedure and the described spe-
cial technics are, therefore, justified and indicated for visualization of the diseased coronary artery system.

Thoracic aortography with its modifications allows visualization of both coronary arteries with one single injection. The commonly used, rapid biplane radiography is very useful, since atheromatous plaques may be overlooked unless they are seen in profile in the anteroposterior or lateral projection.

One of the major drawbacks of modified thoracic aortography is superimposition of the opacified aorta upon the first portion of the coronary arteries. True profile views of the origin of right or left coronary arteries can be obtained only if proper oblique projections are made. Obviously, adequate visualization of the mouth of the coronary arteries is of great practical significance, since localized atheromatous disease in this location is amenable to surgery. Sometimes, due to rotation of the heart, almost the entire left main coronary artery may be obscured by the opacified aorta in the anteroposterior projection (fig. 2). Because of this major drawback of thoracic aortography, it is not surprising that the selective injection technic has become more popular in recent years. It is simple and provides the best anatomic and hemodynamic information without the use of complex, cumbersome electronic equipment. The origin of the injected coronary artery can usually be well seen by regurgitation of contrast medium into the sinus of Valsalva. The hemodynamic alteration of coronary artery disease and especially the collateral circulation can best be effectively studied by selective injection combined with cineradiography. By eliminating the cutdown on the brachial artery and introducing the catheter percutaneously into the subclavian or axillary artery, the technic can be further simplified and made available to radiologists.

Summary and Conclusions

Various methods of coronary arteriography have been briefly reviewed. Most of these technics represent modifications of thoracic aortography. The complexity of some of the proposed procedures, inadequate visualization of the origin of the coronary arteries, and inconsistent results have paved the way for the selective catheterization technic, which appears to be the procedure of choice in the hand of experts.

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