Mechanics of Selective Coronary Artery Catheterization via Femoral Approach[1]

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At the University of Minnesota Hospitals and the University of Virginia Hospital, selective coronary arteriography is performed by radiologists. The technic originally described by Sones (1) has been modified by introducing specially preformed catheters percutaneously into the subclavian, axillary, or femoral artery. Catheterization through the femoral artery appears to be the most advantageous, and a large experience has been accumulated with this method. The success of the procedure seems to depend largely on exact knowledge of the anatomy and adaptation of the catheter configuration to anatomical variations. The purpose of this communication is to help the novice by describing in detail such important factors in percutaneous transfemoral selective coronary arteriography as the anatomy of the aortic root, catheter materials and shapes, and technic of catheterization.

ANATOMY OF THE AORTIC ROOT

The aortic root is composed of the three bulbous aortic sinuses and the tubular ascending aorta (Fig. 1, *a*). At the junction of the bulbous portion and the tubular aorta, a circumferential thickening of the aortic wall exists, the so-called sinotubular ridge (P. Stanger and E. Edwards, unpublished data). The sinotubular ridge is an important landmark for selective coronary arteriography. Below it lie the sinuses of Valsalva, each of which is bordered largely by the aortic wall and to a lesser degree by the aortic cusp. The superior border of each aortic sinus is represented by an imaginary plane extending from the sinotubular ridge to the free margin of the aortic cusp.

The free margin of each cusp is considerably higher at its commissural attachment than at its central portion. This anatomic feature is of particular importance in selective coronary arteriography since it permits a catheter to lie against the aortic wall of a sinus, traverse the cusp, and enter a coronary ostium on the opposite side. The line where the three cusps are in contact during diastole is referred to as the line of common closure.

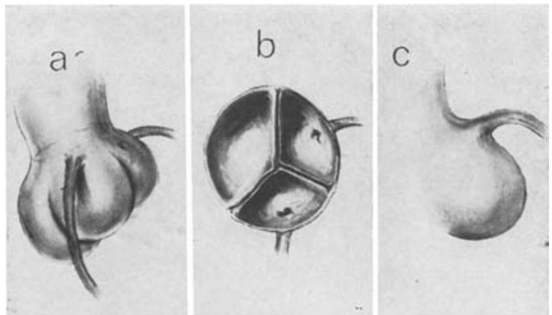

Fig. 1. *a. In situ* position of the aorta with right coronary artery and right sinus anteriorly, left coronary artery posteriorly, and noncoronary sinus to right. Note the junction of tubular and bulbous aorta (sinotubular ridge) at the dotted line. *b.* Coronary arteries usually arise midway from the corresponding cusp but not from opposite sides of the aortic root (mean angle 125°). The noncoronary cusp is slightly larger than the right or left cusp. *c.* Note the funnel-shaped ostium of the coronary artery and the almost perpendicular position of the proximal coronary artery to the curved surface of the aortic wall. Both anatomic features are important in facilitating selective catheterization.

Contrary to common belief, the aortic sinuses are not of equal size. The noncoronary sinus (also referred to as the posterior sinus) is usually slightly larger than either the right or the left sinus. This discrepancy in size is particularly pronounced in senile ectasia and cystic medial necrosis (Fig. 1, *b*). The nomenclature of the sinuses is somewhat misleading. The *in situ* position of the aortic root is such that the so-called right sinus lies anteriorly, the left sinus posteriorly and to the left, and the posterior sinus posteriorly and to the right.

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The measured angle between the coronary arteries, which do not arise from exactly opposite sides of the aortic root, is only 100 to 140°, with a mean angle of 125° (Fig. 1, *b*). Usually the arteries arise fairly high within the sinus of Valsalva but below the sinotubular ridge. Although some variation occurs, each coronary ostium usually lies approximately midway between the commissural attachments of the corresponding cusp (Fig. 1, *b*). There is a slight funneling of the coronary ostium, which facilitates selective catheterization of the ostium (Fig. 1, *c*). The initial portion of each coronary artery is almost perpendicular to the curved surface of the aortic wall of the sinus (Fig. 1, *c*). According to Sones, this angle is very important for semiselective catheterization of the left coronary artery.

In a small percentage of cases one or both coronary arteries arise from the tubular portion of the aorta or slightly above the sinotubular ridge. These coronary arteries usually do not emerge perpendicularly to the aortic wall but form an obtuse angle with the tubular ascending aorta (Fig. 2), making selective catheterization quite difficult (Fig. 3). Fortunately this anatomic variation is rare.

In at least 50 per cent of cases three separate coronary ostia are present. The third coronary artery is the small right conal branch, which usually arises directly from the aorta close to the ostium of the right coronary artery. This anatomic variation is of importance in selective catheterization since the right conal branch is quite narrow and may be readily occluded by an incorrectly positioned catheter.

CATHETER MATERIALS

A variety of catheters are commercially available, consisting of clear polyethylene, radiopaque polyethylene, woven Dacron, polyurethane, Teflon, and other plastics. Catheters of all these materials were tested *in vitro* for plastic memory and transmission of torque, the most important physical properties for a catheter in coronary arteriography.

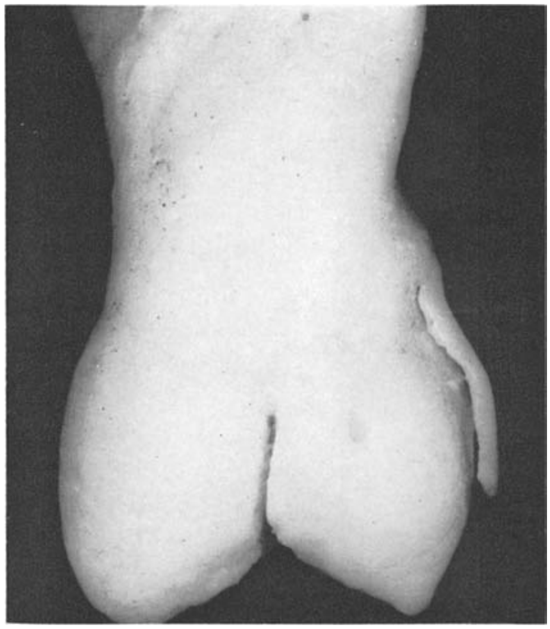

Fig. 2. Silastic cast of aorta with origin of coronary artery above sinotubular ridge. Origin is no longer perpendicular to aortic wall.

A simple test for evaluation of plastic memory was devised. The catheter tip was given a right angle curvature by application of heat. A stiff straight wire was then inserted to straighten the catheter tip, and the catheter was immersed in a 37° C water bath for a certain period, then removed, and the straight wire was withdrawn. After a predetermined time the degree to which the catheter resumed its original shape was measured.

Virgin polyethylene (Clay-Adams) and radiopaque polyethylene (Kifa) showed the best plastic memory. Polyurethane (Ducor, Cordis) was slightly inferior. The plastic memory of Teflon (U. S. Catheter) was found to be poor, and woven Dacron (U. S. Catheter) failed completely to resume its original shape in spite of the fact that the curve was "baked in" by the manufacturer.

Transmission of torque to the catheter tip was tested by determination of the relative torsion coefficient. A disk weighing 1 kg was attached to the suspended catheter, and the number of rotations in a fixed period of time was measured. The best transmission of torsion was

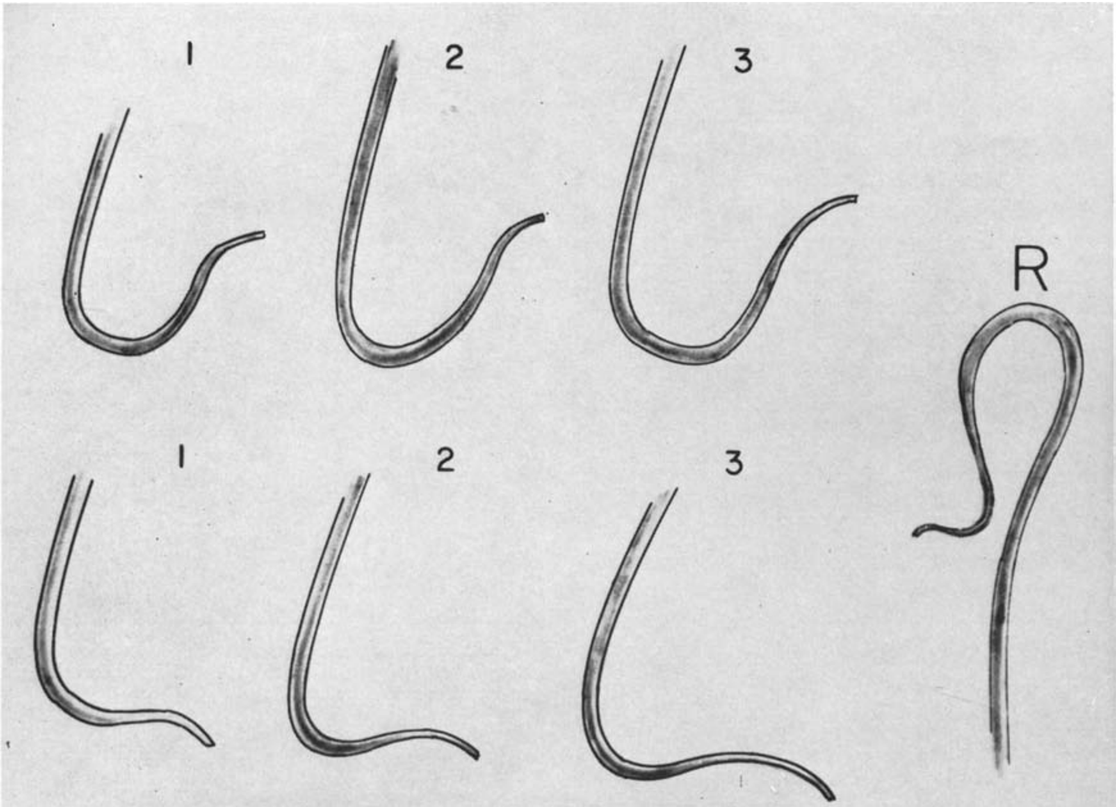

Fig. 3. Top row—left coronary artery catheters, sizes 1, 2, and 3. Note the hook shape and tapered tip. Lower row—right coronary artery catheters, sizes 1, 2, and 3. The hook shape is less pronounced and generally smaller. R. Additional curvature given to right coronary catheters conforming to aortic arch.

accomplished with woven Dacron of the "Positrol" design (U. S. Catheter, Sones), followed closely by polyurethane with incorporated wire mesh (Ducor, Cordis). Teflon proved to be superior to radiopaque polyethylene (Kifa), and clear polyethylene (Clay-Adams) showed the poorest torque characteristics.

CATHETER SHAPES

The shape of the catheter has been described previously by Wilson *et al.* (2). Specially shaped catheters are used for right and left coronary arteries since, with the transfemoral approach, consistent catheterization of both coronaries with one single catheter is difficult or impossible. Both right and left coronary artery catheters have a tip with a small outside diameter (approximately F5) in order to prevent accidental occlusion of stenotic coronary ostia. Both catheters are so shaped that spontaneous antegrade advancement into the distal coronary artery is eliminated. This is of particular importance if the patient has to be moved over a biplane angiographic apparatus (2).

Three catheters with varying curvature sizes are used, depending upon the anatomy of the sinus of Valsalva. Selection of the proper curvature size is of great importance since even in experienced hands too small or too large a catheter may preclude successful coronary artery catheterization. If the correct catheter is used both coronary arteries can be entered almost immediately (Fig. 3).

Both catheters are shaped in such a fashion that their tips always point perpendicularly to the bulbous portion of the aorta, allowing true selective catheterization and preventing dislodgment.

For the catheterization of the left coronary artery the catheter is braced against the noncoronary cusp, the lowest of the three aortic cusps. Because the distance between the posterior cusp and the left coronary artery is the greatest (Fig. 4, *b*), left coronary catheters are more hook-shaped and generally larger than right coronary catheters.

For catheterization of the right coronary artery the catheter is braced in the left cusp, which lies approximately at the same level and just opposite the right coronary artery. Consequently, right coronary catheters show a shallower and generally smaller curve (Figs. 3 and 4, *a*). To secure an anterior position of the catheter tip, the right coronary artery catheter is given an additional curvature conforming to the aortic arch (Fig. 3, R).

The forming of polyethylene and Teflon catheters has been described previously. Polyurethane can be shaped in similar fashion by immersing the catheter tip in mineral oil heated to 120 to 130°C. A satisfactory, narrow tapered tip can be obtained by pulling a regular Ducor No. 7 or No. 8 catheter over a guide wire (0.035 diameter) in heated oil. To shape the catheter, immersion in boiling water for thirty seconds and then cooling in room air are adequate. The same oil bath can be employed to curve the catheter tip with use of a forming wire.[2] The catheters can be

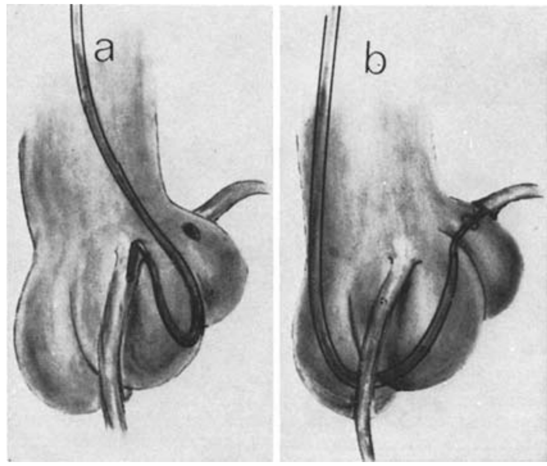

Fig. 4. *a*. Right coronary artery catheter in place braced against left aortic cusp, which lies directly opposite right coronary artery. *b*. Left coronary artery catheter in place braced against posterior cusp, which lies lower and further away from left coronary ostium. Left coronary artery catheters consequently are more hook-shaped and have a larger curve (Fig. 3).

[2] Now available commercially through Cordis Inc.

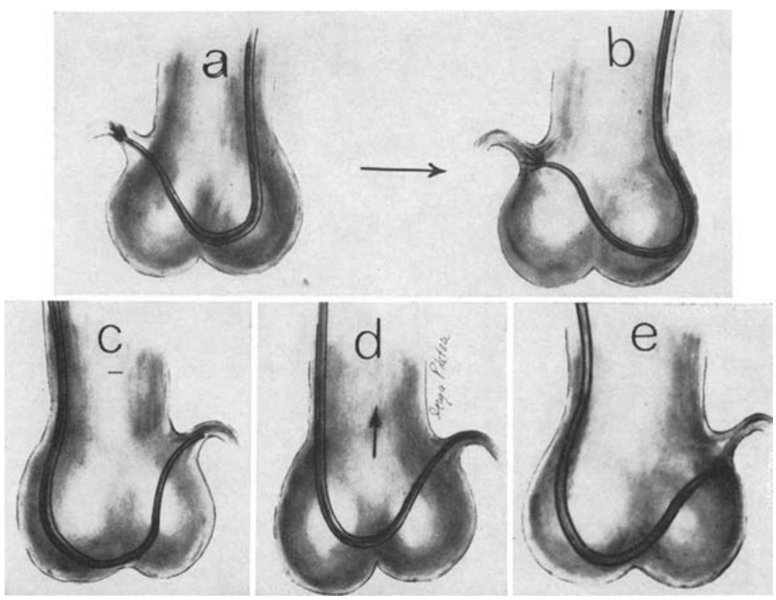

Fig. 5. *a*. Catheter has entered the coronary artery but recoils during the injection of contrast medium or during systolic or diastolic valve motion. *b*. Catheter is too small and has not been braced properly against the opposite coronary sinus. *c* and *d*. Catheter tip has entered the coronary ostium, and displacement is prevented by a slight withdrawal of the catheter (arrow, *d*), thus exerting some pressure against the superior wall of the coronary artery. *e*. In spite of pressure exerted against the aortic sinus, the catheter tip does not reach the coronary ostium, indicating the catheter is too small.

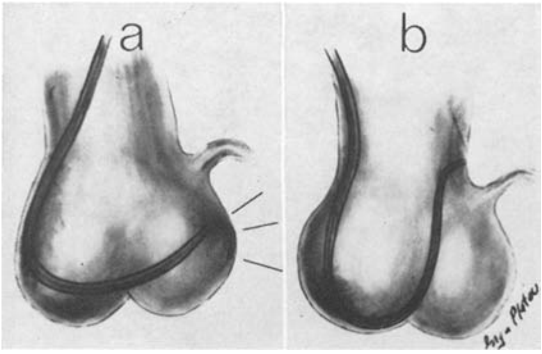

Fig. 6. *a*. Buckling of the catheter tip (arrows) in a deep sinus of Valsalva with too large a catheter. *b*. The catheter tip extends beyond the coronary ostium, indicating a rather small aorta in relation to catheter size.

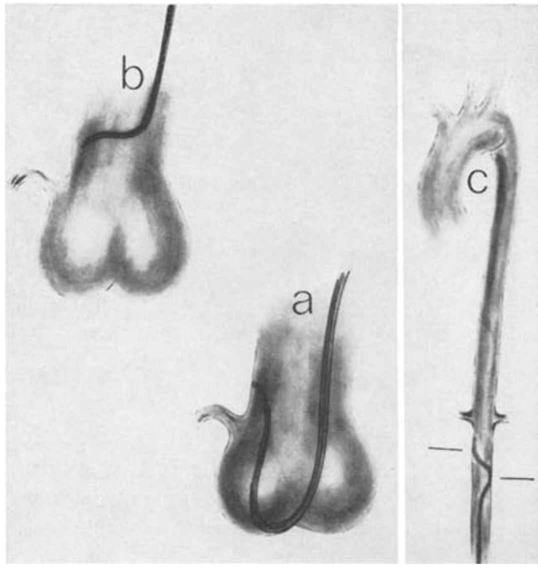

Fig. 7. *a*. Catheter has assumed a tight J-configuration, preventing its tip from entering bulbous aortic sinus. *b*. Guide wire has been introduced, straightening curvature. Catheter tips point downward toward the sinus of Valsalva. *c*. Catheter withdrawn into distal abdominal aorta in order to straighten its curvature by molding.

reused following gas sterilization, but the catheter as well as a perfectly straight guide wire should be siliconized to minimize friction.

CATHETERIZATION TECHNIC

The patient is premedicated with sedatives (barbiturates, Visteril, etc.) and, probably most important of all, with 500 mg of Pronesthyl, minimizing the occurrence of cardiac arrhythmia. Ventricular fibrillation has been a rare occurrence in our experience (less than 1 per cent).

The catheter is introduced percutaneously into the femoral artery[3] in routine fashion and advanced into the ascending aorta under fluoroscopic control, using small test injections of methylglucamine diatrizoate (60 per cent Renografin). Since the shape of the catheter is adapted to the anatomy of the aorta, very little manipulation is necessary, and if the catheter size fits the aortic root, even inexperienced angiographers can catheterize the coronary arteries with ease.

Experience, however, is required to recognize the reasons for the failure of a successful catheterization. This is usually caused by too small or too large a catheter or, less commonly, by variations in the anatomy of the coronary ostia. If the catheterization has not been successful within five minutes, the reason for failure must be recognized and the proper catheter must be selected. Most commonly the catheters are either too small or too large, and correction usually results in immediate success.

The signs of too small a catheter are:

1. The catheter tends to slip through the valve as soon as slight pressure is exerted against the aortic cusp. If this should happen on several occasions, the next larger catheter is introduced.
2. The catheter recoils from the coronary ostia during injection of contrast medium, or dislodgment occurs due to motion of the aortic valve (Fig. 5, *a* and *b*).
3. The catheter cannot be "locked in place" by withdrawing it slightly after it has entered the coronary ostium (Fig. 5, *c* and *d*).
4. The coronary artery cannot be "reached" with the catheter tip in spite of pressing it firmly against the aortic cusp (Fig. 5, *e*). (High origin of coronary artery.)

As soon as the coronary ostium is entered one has to make sure that the coronary artery is not partially or completely

[3] Introduction of the Ducor catheter is facilitated by use of a dilator to widen the arterial puncture hole.

occluded. Good position is evidenced by: (*a*) free pulsatile blood flow from the catheter and (*b*) normal washout of a small bolus of contrast medium injected as a test dose. If the catheter is occluding the ostium, the injected contrast medium will not wash out. If safety precautions are observed, continuous monitoring of pressures is not necessary, since spontaneous advancement of the catheter does not occur. The catheter can remain in the coronary ostium without danger of occlusion or dislodgment for a long time.

To prevent spontaneous dislodgment or advancement and recoil during the injection of contrast medium, the catheter is "locked in place" by withdrawing it slightly from the aortic cusp (Fig. 5, *c* and *d*).

The sigrs of too large a catheter are:

1. The catheter tip does not readily ascend from the sinus of Valsalva if pressure is exerted against the aortic cusp but tends to buckle (Fig. 6, *a*). This phenomenon is particularly common with very deep sinuses and too large a catheter.

2. The catheter extends beyond the origin of the coronary ostium and assumes a hairpin configuration (Fig. 6, *b*).

If a J-configuration occurs (Fig. 7, *a*), the catheter tip cannot enter the bulbous portion of the aorta. This situation can be corrected: (*a*) the guide may be reintroduced and advanced into the curvature of the catheter, with some straightening (Fig. 7, *b*); (*b*) the catheter can be withdrawn into the abdominal aorta for one minute, with some resultant straightening due to "molding" (Fig. 7, *c*); (*c*) the catheter may be advanced into the ventricle and slowly withdrawn across the aortic valve (Fig. 8); (*d*) the catheter may be replaced with the next smaller size.

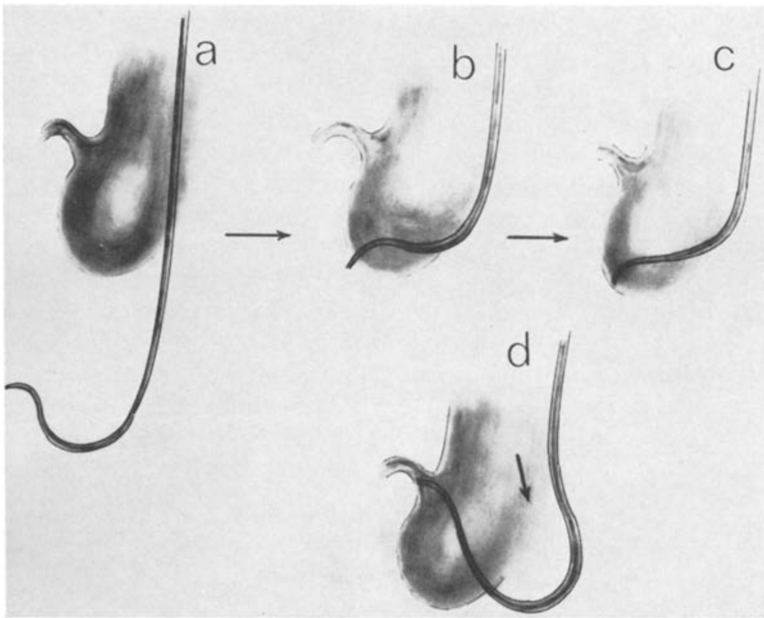

Fig. 8. Catheter advanced into left ventricle and slowly withdrawn through aortic annulus as in *b* and *c*. Catheter tip is now below sinotubular ridge, and coronary artery is easily entered by gentle pressure against aortic sinus (arrow in *d*).

CONTRAST MEDIUM

The safest contrast media for selective coronary arteriography are believed to be the methylglucamine diatrizoate salts (60 to 76 per cent Renografin), which are injected manually with a disposable plastic syringe in amounts from 6 to 12 cc depending upon the coronary anatomy.

DISCUSSION

Of the technics advocated for coronary

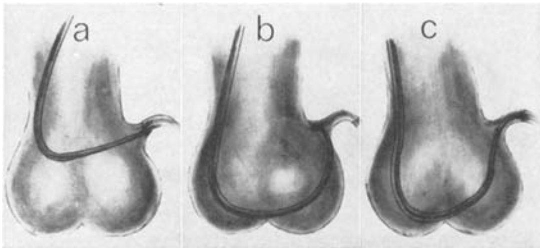

Fig. 9. *a*. Direct advancement of catheter into left coronary artery difficult and not desirable because spontaneous advancement into smaller coronary branches may cause occlusion. *b*. Semiselective injection commonly used for left coronary artery with Sones technic. Angiographic results, however, are not as good as with indirect catheterization, as shown in Figure 9, *c* with a specially shaped catheter.

arteriography, the selective injection (1) yields the best results. This method, however, requires surgical exposure of the brachial artery, a procedure usually not carried out by radiologists. Consequently, the adaptation of the percutaneous catheterization technic, which is simpler and less time-consuming, appeared to be desirable.

In spite of the shorter distance and the consequently better manual control of the catheter as it is introduced into the right subclavian or right axillary arteries, persistent catheterization of the left coronary artery proved difficult by this approach, and commonly only a semiselective injection could be accomplished. The transfemoral catheterization technic has therefore been the procedure of choice for selective coronary arteriography, and this has proved simple, provided the catheter has been properly shaped to the anatomy of the aortic root.

Basically, the coronary arteries can be injected in three different ways: by antegrade advancement of the catheter (Fig. 9, *a*), by bracing a curved catheter against the coronary ostium (Fig. 9, *b*), and by retrograde advancement (Fig. 9, *c*).

Direct catheterization (Fig. 9, *a*), commonly performed for the right coronary artery by the Sones technic, yields excellent results. It can, however, be used only for cineangiography since the catheter may inadvertently intrude further into the coronary artery and cause occlusion of the smaller distal coronary artery if the patient is over a film-changer without visual control.

The semiselective injection usually performed for the left coronary artery with the Sones catheter is feasible because of the perpendicular origin of the coronary artery from the wall of the sinus of Valsalva. If the coronary arteries arise above the sinotubular ridge, this procedure is unsuccessful, and a "cuspogram" is usually obtained. The technic, however, is less satisfactory than true selective injection (Fig. 6) with specially preformed catheters.

The best angiograms are obtained with a true selective catheterization of the coronary ostium over a distance of approximately 1 cm. Due to the shape of the described catheter, further advancement into the coronary artery is impossible and the catheter may be "locked in place" by slight withdrawal as soon as its tip has entered the coronary ostium (Fig. 5, *c* and *d*). Once in position, the catheter can remain in place for a long period, provided free pulsatile blood flow is obtained. The patient therefore can be positioned over the biplane angiographic apparatus or in various oblique positions for ciné studies without fear of coronary artery occlusion, dislodgment of catheter, or spontaneous advancement into the more distal smaller coronary branches.

Of the catheter materials, the polyethylenes (Clay-Adams-Kifa) and particularly polyurethane (Ducor) are preferred over Teflon or woven Dacron. In spite of the excellent torque characteristic of the woven Dacron (Sones, Positrol catheter), its poor plastic memory precludes its use for transfemoral coronary arteriography. Although polyurethane has a slightly inferior plastic memory, its excellent torque characteristics seemed to outweigh this disadvantage, making it at the present time the catheter material of choice. With polyurethane, furthermore, whipping of the catheter does not occur upon rotation, an undesirable characteristic of polyethylene and particularly of Teflon.

SUMMARY AND CONCLUSION

Coronary arteriography is rapidly and simply performed *via* percutaneous transfemoral catheterization. Exact knowledge of the anatomy of the sinus of Valsalva and adaptation of catheter shape to the anatomy are of paramount importance. Since the anatomy of the aortic root varies, small, medium, and large curved catheters should be available. Right and left coronary artery catheters are shaped in such a manner that the danger of accidental occlusion of the coronary ostium, spontaneous dislodgment, or spontaneous advancement into the coronary artery is minimized. The catheter can therefore remain in place for a long time, and biplane angiography can be performed in addition to cineangiography.

Evaluation of various commonly used catheter materials showed an excellent plastic memory of polyethylenes and a good memory in polyurethane. The plastic memory of Teflon and particularly of woven Dacron were found too poor for transfemoral selective coronary arteriography.

The torque characteristics of catheters with an incorporated wire mesh (Positrol and Ducor) are far superior to standard catheters made from extruded tubing, particularly polyethylenes.

Once the technic is mastered, selective coronary arteriography can be performed readily and rapidly by radiologists trained in catheterization procedures and basic electrocardiography. With some practice an almost 100 per cent success rate can be achieved.

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