Positive Torque Control Cardiac Catheters

By GOFFREDO G. GENSINI, M.D.

CARDIAC catheterization, born with Forsmann's first attempt\(^1\) and later developed by Cournand and Ranges\(^2\) and a multitude of others, is now 35 years old. Its use has been extended to almost every conceivable blood vessel, while a host of improvements have contributed to both its safety and ease of performance.

The cardiac catheter itself, however, has remained fundamentally unchanged during these past 35 years, although a large number of plastic materials have been used in its fabrication and the shape of its tip has been fashioned in a score of different ways. Essentially, however, it has remained a semirigid plastic tube that can be easily pushed or pulled but which will respond in a highly unpredictable and inconsistent way to rotatory movements applied at its hub from the outside. Clearly, a catheter that would faithfully and precisely change the direction of its tip in situ, just as easily as it could be moved back and forth, was needed.

The following is a report on the physical characteristics and clinical use of such an instrument—the positive torque-control cardiac catheter (Positrol).*

**Elastic Properties of Catheters**

Essentially, cardiac catheters may be either hollow plastic tubes of the extruded type or woven Nylon or Dacron tubes with plastic radiopaque coatings (fig. 1).

If the laws of elasticity can be applied to catheters, their response to different load conditions may be determined. It should be realized that a complete description of constraints, geometry, and loads encountered by catheters within the vascular system is very complex. Useful information, however, may be obtained through the analysis of simplified models.

Similar to other structural systems, catheters may be subjected to any combination of deflection, compression, and torsion. Olin\(^3\) found the following formulas adequate for the prediction of deflection (\(\Delta\)) and critical loading (F crit. or Euler's buckling load):

1. \[ \Delta = \frac{F}{E} \left[ \frac{3\pi}{64} \cdot \frac{(D^4 - d^4)}{l^2} \right] - 1^* \]

2. \[ F \text{ crit.} = E \left[ \frac{\pi^3}{64} \cdot \frac{(D^4 - d^4)}{l^2} \right] n \]

In our opinion, however, a more comprehensive equation can be obtained by modifying equation 2 with the use of the multiplying factor \(n\), which refers to different conditions of constraint

2a. \[ F \text{ crit.} = E \left[ \frac{\pi^3}{64} \cdot \frac{(D^4 - d^4)}{l^2} \right] n \]

Practical situations are illustrated in figure 1.

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*\(\Delta\) = deflection; \(D\) = outer diameter of catheter; \(d\) = inner diameter of catheter; \(E\) = modules of elasticity in tension; \(F\) = force acting on catheter; \(G\) = modulus of elasticity in shear; \(l\) = length of catheter; \(m\) = Poisson's ratio; \(Mt\) = torque; \(Ro\) = radius of midwall circumference; \(S\) = wall thickness; \(\theta\) = angle of twist.

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932 Circulation, Volume XXXII, December 1965
2; there the multiplying factor \( n \) acquires the values of 1 in a, 2 in b, and 4 in c.

Situation “a” would be that encountered when a catheter is buckling against an obstacle but is freely hinged at both ends.

Case “b” occurs when the catheter tip becomes wedged in a small branch and buckles on further pushing. Finally, the last situation is encountered when a catheter, fixed at both ends in a lateral direction, is thrust against an obstacle. In practical terms, this means that the relative “stiffness” of a catheter increases suddenly when its tip becomes wedged in a small branch.

Torsion has, so far, not been studied in reference to cardiac catheters; however, the angle of twist produced by a torque applied to the extremity of a catheter fixed at its opposite end may be determined by applying Bredt’s method.\(^6\)

\[
3. \quad \theta = \frac{Mt \cdot 1}{G2\pi R o^3 S}
\]

where \( G = \frac{m}{2(m + 1)} E \)

It appears that the factors influencing the elastic properties of catheters are the modules of elasticity \( E \) and \( G \) of the materials used, the length of the catheter, and the thickness of its wall. Furthermore, as all catheters are made of viscoelastic materials, the temperature and the loading time will modify their characteristics. A material of a given composition may also acquire different properties according to the manufacturing process (i.e., orientation of the molecules obtained with various physical methods, incorporation of radiopaque particles etc.).

Catheters of the extruded type (fig. 1a), generally have properties which, other factors being equal, are mainly dependent upon the modules of elasticity of the single polymer used.

The woven catheters, made in layers of different materials (fig. 1b), are built up by a long manufacturing process. This lends itself to appropriate modifications and combinations of materials that may efficiently influence their ultimate physical characteristics.

**Construction of Positive-Control Catheters**

The ideal catheter should have a relatively flexible tip and fairly rigid body. A flexible tip, buckling easily against any obstacle, follows the curvature of the blood vessels and minimizes trauma to the intima or endocardium. A rigid body prevents proximal buckling of the catheter shaft such as may happen in the large blood vessels or cardiac cavities. Furthermore, for a given torque, the angle of twist should be close to zero. It should be evident that these rather contrasting features are unattainable in an extruded catheter, made up by a single piece of plastic material: there the module of elasticity and the thickness of the wall are identical throughout its length, and a soft tip is accompanied by a soft body, a tendency to buckle, and a large angle of twist.

A woven catheter offers the opportunity of varying the thickness of the wall toward the tip (as for example, in Sones’ and Shirey's catheters). More important, by the incorporation of a tight but porous stainless-steel braid within the wall of the catheter, it may be possible to maintain a desirable deflection.
(Δ) while considerably reducing the angle of twist (θ) for a given torque applied at the hub. Essentially, this is the principle of the positive control cardiac catheter, as diagrammatically shown in fig. 1c. Cardiac catheters incorporating the positive control features have been built in the Cournand, Gensini, and Sones type. The external appearance and lateral flexibility of these catheters are identical to the conventional models.

Characteristics of Positrol Catheters

The torsion properties of the conventional and Positrol catheters have been tested on a specially designed torsion meter. The principle of this meter is simple. The catheter, fixed at its hub on a stationary Luer-lock, is passed through a drill chuck mounted on ball bearings and it is held in place by tightening the chuck. Measurements are made at 50 mm. from the hub.

A Kiddle-Sipp torsimeter, rotating around the axis of the chuck, transmits its movement to the catheter by way of its measuring arm.

Torque is read in grams at 90, 180, 270, and 360 degrees.

Sixty catheters were tested, for a total of 960 determinations of torque.

The results of these tests for representative catheters size 7 or 7½ F are shown in figure 3. The remarkable resistance of the new Positrol to torsion is readily apparent when compared to conventional and extruded Teflon catheters.

Clinical Results

The Sones, Gensini, and Cournand positive-control cardiac catheters have been tested in a series of 41 cases (some patients had more than one procedure): Coronary arteriography, 20 patients; renal arteriography, 7; superior mesenteric artery, 3; hepatic arteriography, 2; splenic arteriography, 2; inferior mesenteric artery, 1; right and left iliac arteries, 3; cerebral arteriography, 2; right heart catheterization with selective intubation of right and left pulmonary artery, 1. There have been no incidences of vessel spasm, thrombosis, or any complication directly or indirectly related to the use of these catheters. A rather appealing feature of these new instruments is their outward complete resemblance to the ordinary catheters and the fact that no special gadgetry, technics or handling procedures are needed or desirable in connection with these new tools. They are handled in exactly the same way one has learned to handle ordinary cardiac catheters; they simply go wherever you want them to.

Fluoroscopy time needed for the intubation of the right and left coronary arteries, according to the Sones' technic, has been decreased from 50 to 80 per cent.

The right and left coronary arteries were opacified with only 45 seconds of fluoroscopy time, in one of the 20 cases reported.

Figure 3

Results of tests for representative catheters.

Circulation, Volume XXXII, December 1965
Visualizations of the right and left renal, hepatic, splenic, superior and inferior mesenteric arteries were obtained in only two minutes 50 seconds of total fluoroscopy time.

Tortuosity of the aortic arch (two cases), found to be utterly impassable to ordinary cardiac catheters, was easily overcome by the new Positrol.

Summary and Conclusions

The materials, fabrication methods, and elastic properties of cardiac catheters are briefly reviewed.

A new construction method resulting in the production of cardiac catheters with high torque resistance is outlined. These catheters are flexible yet resistant to buckling, and within reasonable limits, have the highly desirable property of rotating their tip in situ by almost the exact number of degrees applied at the hub from the outside.

Clinical trials in 41 patients have demonstrated that radiation exposure to the patient and the operator may be reduced from 50 to 80 per cent by the extremely easy manipulation of catheters, selective catheterization of relatively small vessels is facilitated, and previously impassable tortuosity of the aortic arch may be readily overcome.

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References


Stephen Hales

The practical and social aspects of his scientific studies came to the fore in the sixth decade of his life. They are typified by his inventions for the improvement of ventilation of jails, ships, and hospitals. For example, he used large bellows, operated manually or by a windmill, to improve the ventilation in crowded quarters. Although it is difficult to determine whether lives were saved by these devices, they surely provided more tolerable living conditions.

Hales received the Copley Medal of the Royal Society in 1739 for his relatively unimportant experiments on the solubility of urinary tract stones. Although observations in natural science were the primary interest of Parson Hales, he did not fail to discuss theology when offered the opportunity. He delivered the annual Croonian sermon for the Royal College of Physicians at the age of 70, reaffirming his dedication to his vocation, even though he is best remembered for his avocational contributions.—STEPHEN HALES. Statistical Essays: Containing Haemastatics; or, An Account of Some Hydraulick and Hydrostastical Experiments Made on the Blood and Blood-Vessels of Animals. Vol. 2. London, W. Innys and R. Manby, 1733.
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