

CATHETERIZATION OF THE HEART IN MAN WITH USE OF A FLOW-DIRECTED BALLOON-TIPPED CATHETER*

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Abstract Pressures in the right side of the heart and pulmonary capillary wedge can be obtained by cardiac catheterization without the aid of fluoroscopy. A No. 5 Fr double-lumen catheter with a balloon just proximal to the tip is inserted into the right atrium under pressure monitoring. The balloon is then inflated with 0.8 ml of air. The balloon is carried by blood flow through the right side of

the heart into the smaller radicles of the pulmonary artery. In this position when the balloon is inflated wedge pressure is obtained. The average time for passage of the catheter from the right atrium to the pulmonary artery was 35 seconds in the first 100 passages. The frequency of premature beats was minimal, and no other arrhythmias occurred.

DIAGNOSTIC catheterization of the right and left sides of the heart with the use of semi-rigid cardiac catheters has been the routine method for the study of the central circulation in animals and in man. The use of such catheters requires fluoroscopic guidance and the development of marked technical skill in catheter manipulation. Unusual or abnormal positions of the great vessels associated with cardiac dilatation, abnormal rotations or congenital cardiac malformations present difficulties even to experienced laboratory cardiologists.

To meet certain requirements for clinical and therapeutic evaluation of seriously ill patients admitted to the Myocardial Infarction Research Unit of the Cedars-Sinai Medical Center, three major criteria for acceptable placement of catheters within the pulmonary artery were established. No standard procedures fulfilled these criteria, which comprised placement without associated ventricular arrhythmias, prompt and reliable passage to the pulmonary artery and passage without fluoroscopy. Our experience with the passage of small-caliber catheters^{1,2} percutaneously to the pulmonary artery was frequently unsatisfactory. The failure rate approximates 30 per cent, passage often takes 20 to 30 minutes, blood samples are drawn with difficulty, clotting is frequent, and associated ventricular extrasystoles are common.³ Accordingly, we developed a flow-guided balloon catheter of flexible construction as a vehicle to meet these criteria. In principle, the device is similar to that used in dogs by Lategola and Rahn,⁴ which consisted of tubing 3.2 mm in outer diameter (No. 10F equivalent) containing a 1.27-mm tube for inflation of a tip balloon. It is the purpose of this paper to report on the first 100 passages of the prototype of this catheter in patients in

the diagnostic cardiac laboratory and in the intensive-care, coronary-care and myocardial-infarction research units. This approach has proved to be effective and safe and has wide application in the study of the central circulation in man.

CATHETER CONSTRUCTION

The device† is an extruded polyvinyl-chloride catheter, 1.7 mm in outer diameter (No. 5F equivalent), so constructed that a small lumen exists in the wall and parallels the major lumen (Fig. 1). A latex balloon is fastened approximately 1 mm from the catheter tip and connected via a side hole in the shaft to the minor lumen. The bursting volume of these balloons is approximately 3 ml. A 1.0-ml syringe is attached via a special stopcock to the minor lumen for inflation of the balloon with 0.8 ml of air. In situations in which a possibility exists of passage to the arterial system, carbon dioxide should be used as the inflation medium. The major lumen, which extends from the tip of the catheter to a suitable connector, has a calculated mean internal diameter of 0.9 mm standard (No. 6F equivalent).

Preliminary experiments were carried out in dogs that had been used for other studies. The catheter was advanced to the mid-portion of the right atrium, and the balloon inflated. The balloon consistently crossed the tricuspid valve within three seconds of inflation and passed into the pulmonary artery and wedge position within one second thereafter. With initial feasibility demonstrated, studies were initiated in the diagnostic cardiac-catheterization laboratory under fluoroscopic control and in the intensive-care and coronary-care units in which fluoroscopy was not available.

The catheter was inserted through an antecubital-vein cutdown and advanced 35 cm (Table 1). If it did not traverse the veins of the shoulder with ease, the balloon was inflated with 0.4 to 0.6 ml of air, and the catheter withdrawn slightly before advancement. In all but three cases the catheter passed into the superior vena cava and right atrium with pres-

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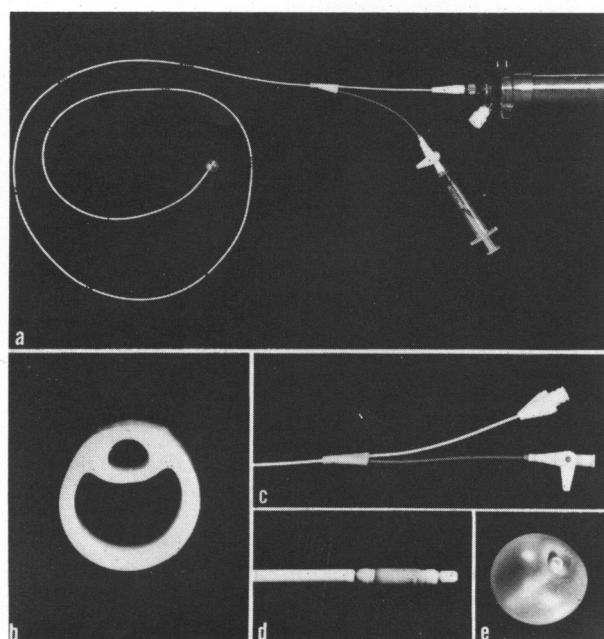


Figure 1. Construction of the Catheter.

In (a) the catheter is attached to a strain-gauge manometer (top right corner). The balloon is inflated. Markers are placed at 10-cm distances along the shaft of the catheter. Inflation of the balloon is accomplished by way of the small side catheter connected to a 1-ml syringe. The catheter in section (b) shows the inflation lumen (minor). Blood sampling or pressure recording is obtained via the major lumen. The connector to the 1-ml syringe (c) is identified by a different color. A one-way stopcock is provided as an integral part of the catheter. Inflation would only be attempted after the integrity of the balloon has been ascertained. The balloon in the deflated node is shown in (d). In (e) the catheter tip is shown with the balloon inflated (note that the catheter tip does not protrude past the inflated balloon surface).

sure and electrocardiographic monitoring. The balloon was then inflated to a total volume of 0.8 ml. When the catheter passed into the right ventricle and pulmonary artery it was allowed to proceed downstream until pressure resembling the pulmonary-artery wedge pressure was obtained (Fig. 2). The balloon was then deflated, and the catheter advanced 1 to 3 cm. When a wedge pressure was required the catheter balloon was reinflated without further manipulation (Fig. 3). An adequate frequency response, with minimal motion artifact, characterized the system (Fig. 4).

In the patients studied in the diagnostic catheterization laboratory, 2 to 5 ml of radiographic contrast material was introduced into the main lumen of the catheter to outline the segment of the pulmonary vascular bed that was obstructed by the balloon. In a series of comparisons in the diagnostic catheterization laboratory and in the animal laboratory, there was no noteworthy difference between the segmental pulmonary-artery pressures so obtained and those obtained by conventional cardiac catheterization using Cournand and Lehmann catheters ad-

Table 1. Technic of Catheterization.

1. Test the integrity of the balloon by inflating with 0.8 ml of air under water, with the use of 1-ml plastic syringe.
2. Insert the catheter via the antecubital vein (by cutdown) under pressure monitoring into the superior vena cava or right atrium (when the catheter is within the thorax, a cough will produce 40 mm or more deflections in the pressure tracing).
3. Inflate the balloon with 0.8 ml of air.
4. Advance the catheter under continuous pressure & electrocardiographic control through the right atrium, right ventricle into the pulmonary artery, until "wedge" pressure is recorded. If more than 15 cm of catheter is advanced into the right ventricle without recording of pulmonary-artery pressure, the catheter is doubling up in the ventricle. It should then be withdrawn to the atrium, & passage begun again.
5. Before each inflation of the balloon to obtain wedge pressure, the syringe should be disconnected from the adapter & reconnected to assure "neutral" position of the balloon before inflation.
6. Inflation of the balloon is associated with a feeling of resistance, so that on release of pressure the barrel slips back. If no resistance is encountered, the integrity of the balloon is disturbed, & inflation should be discontinued at once.
7. On withdrawal, the balloon should be partially deflated (to prevent damage to the valves & supporting structures).

vanced into the true wedge position. Blood withdrawn from the catheter after inflation of the balloon varied in oxygen content between pulmonary capillary and pulmonary arterial-blood saturation. No consistent trend was associated with either the location or the site of "wedging" of the inflated catheter. It is likely that a volume of pulmonary arterial blood remained stationary downstream to the occluding balloon and that this appreciably contaminated the blood obtained from pulmonary capillaries.

RESULTS

Table 2 shows the results of 60 catheter passages in the intensive-care areas without fluoroscopy and 40 passages in the diagnostic laboratory. In the

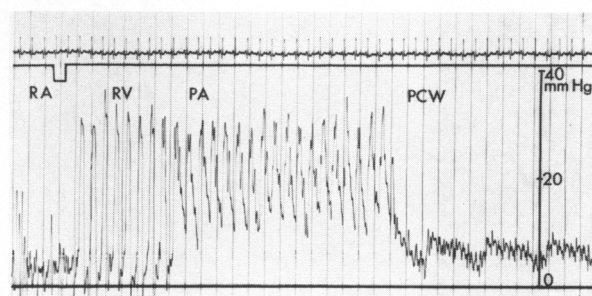


Figure 2. Passage of the Flow-Directed Balloon Catheter to the Pulmonary-Artery Wedge Position.

The time lines are one second apart. At the marker, with the catheter in the right atrium, the flow balloon was inflated. Within one second it passed to the right ventricle, traversed this chamber during nine successive beats and then passed distally into the pulmonary artery in approximately 15 seconds to the wedge position. Note the complete absence of cardiac irregularities.

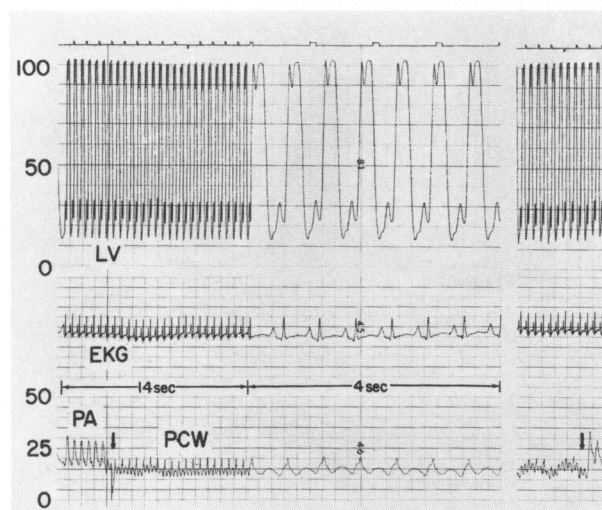


Figure 3. Simultaneous Recording of Left Ventricular (LV) Pressure, Electrocardiogram and Pressure from the Pulmonary-Artery (PA) Catheter in a Patient with Acute Myocardial Infarction.

In the lower panel the first arrow indicates inflation of the pulmonary-artery balloon with 0.8 ml of air. Pulmonary capillary pressure (PCW) is then recorded as the balloon obstructs the small pulmonary artery in which it lies. The second arrow indicates deflation of the balloon, and pulmonary-artery pressure is again obtained. The position of the catheter itself is unchanged during this procedure.

intensive-care units the catheter successfully entered the pulmonary artery in 95 per cent of the attempts. There was one failure to enter the right ventricle in the clinical-care units, when the catheter was not advanced to the right atrium. In two other patients, both with severe power failure, the catheter repeatedly fell back from the pulmonary artery to the right ventricle. Pulmonary capillary wedge pressure was obtained in 72 per cent of these patients. Aside from two failures to reach the wedge position in the first two patients, five failures were associated with pulmonary hypertension, and two occurred in patients with severe cardiogenic shock.

In the diagnostic catheterization laboratory, the catheter failed to enter the pulmonary artery in five attempted passages, and in three additional passages, it did not reach the pulmonary capillary wedge position. All these patients had a large right

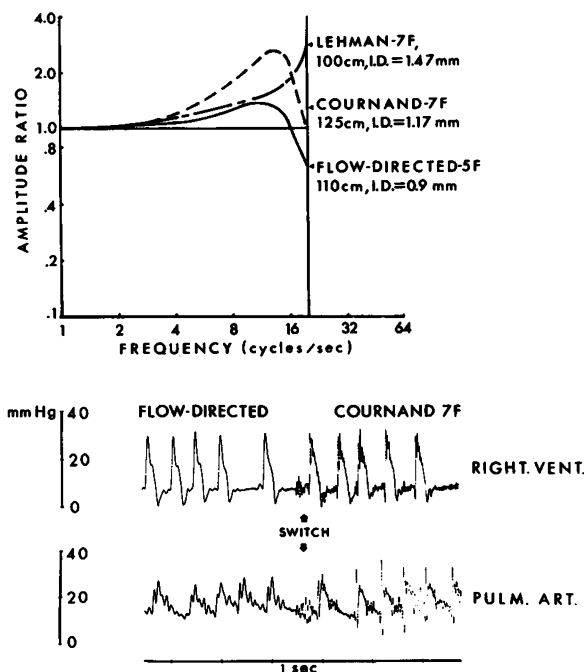


Figure 4. Dynamic Response of Flow-Directed Catheter.

The graph (above) shows the frequency response of the flow-directed and other catheter systems; this system appears to overshoot + 15 per cent at 8 to 12 cycles per second. The tracing (below) demonstrates comparative pressures recorded in the dog on a single strain gauge, switched at the arrow via a stopcock from the test catheter to a Cournand No. 7F in the same location.

ventricle, dilated pulmonary artery and marked pulmonary hypertension.

Successes

Table 2 also demonstrates the average time from inflation to passage to the pulmonary artery, in the cases in which passage was accomplished with success. In addition, it shows the frequency of occurrence of *any* ventricular premature contractions, as evidenced by a detailed examination of the continuous record obtained in each patient from the time of inflation of the balloon until the pulmonary artery was reached.

These observations demonstrate that with certain specific exceptions, catheterization of the pulmonary

Table 2. Results of Passages of Catheters in the Intensive-Care, Clinical-Care and Diagnostic Catheterization Units.

UNIT	NO. OF PATIENTS	NO. OF PASSAGES ATTEMPTED	PERCENTAGE PASSED TO PULMONARY ARTERY	PERCENTAGE PASSED TO PULMONARY WEDGE	PERCENTAGE OF PATIENTS WITH PREMATURE VENTRICULAR CONTRACTIONS	AVERAGE PASSAGE TIME (SEC)
Intensive care & clinical care	37	60	95	72	11	49
Diagnostic catheterization	33	40	88	92	15	16
Totals	70	100				
Averages			92	80	13	36

artery by this technic can be accomplished in a short time with little disturbance in cardiac rhythm.

Complications

In no case in which the catheter was used in the diagnostic laboratory was evidence of thrombosis noted on its withdrawal. In one, the balloon was found not to be intact after use.

In the clinical-care units, the integrity of the balloon was disturbed in 10 cases, varying from tiny perforation to frank rupture. In no patient were there any symptoms or complications referable either to the use of the balloon catheter or to the fact that it was not intact on withdrawal. In all cases of balloon failure, the catheter had been allowed to remain in place for several days and had previously been used one or more times. For this reason, we intend not to reuse such catheters when an adequate supply becomes available. In two patients thrombosis occurred in relation to the balloon catheter. In one the catheter had been allowed to remain in place for approximately 14 days in a patient with cardiogenic shock. A thrombus had formed in the superior vena cava and enveloped the shaft of the catheter, with a protrusion down into the right atrium. This patient, who died with the catheter in situ, had evidence of pulmonary emboli, some of which could have come from material on the catheter. However, this patient was similar to others with low cardiac output who exhibit pulmonary embolus and probably a high level of spontaneous thrombosis. In the second, a small clot was present on the tip of the catheter when it was withdrawn after 48 hours of monitoring.

DISCUSSION

The preliminary studies reported above indicate that catheterization of the right ventricle and pulmonary artery can be accomplished rapidly and safely without fluoroscopy in seriously ill patients. This device therefore meets the criteria enumerated in the introduction. Furthermore, there are obvious applications for its use in routine diagnostic cardiac catheterization. Relatively inexperienced personnel have now been able to pass catheters to the pulmonary artery in a far shorter time than can be done with conventional catheters manipulated by skilled operators. It is of interest that these advantages were recognized by Lategola and Rahn,⁴ but apparently never applied in clinical practice.

Cardiac arrhythmias with the use of this device are less frequent than with other types of catheters, probably owing to the nature of its construction. On inflation the balloon surface becomes flush with the catheter tip. All cardiac catheters used heretofore have a point tip, which has transmitted a relatively substantial force when the catheter was made to impinge upon the endocardium, either by manipulation or by the action of the beating heart itself. In the inflated mode the point disappears, and the

forces are dispersed over a broader and softer surface. It would be anticipated, therefore, that subendocardial injury or damage known to accompany a great number of cardiac catheterizations will be largely avoided, with elimination of the associated disturbances of cardiac rhythm.

Premature ventricular contractions were the *only* arrhythmia encountered in passage of the catheter. In the catheterization laboratory, although premature ventricular contractions occurred in 15 per cent, in all but one patient, only a *single* premature ventricular contraction was recorded. In the intensive-care areas, the rate of premature ventricular contractions was 11 per cent. There were several runs of multiple premature ventricular contractions, but no episodes of sustained ventricular tachycardia occurred.

The observation of balloon rupture in 10 cases was a matter of concern to us. In no case were symptoms and complications identified referable to this failure. It appears likely that the process of cleaning the delicate latex and of resterilization was responsible for failure of the balloon catheter. In spite of this finding, we have continued to use air for the inflation of the balloon in patients in the clinical facilities. The simplicity of the technic and the absence of complications consequent on the introduction of less than 1 ml of air into the right side of the heart and pulmonary circuit appear to justify this approach. However, in cases in which passage of the catheter to the left side of the circulation and arterial tree is contemplated or possible, carbon dioxide will be used as the inflation medium. This is technically simple in the environment of a diagnostic laboratory.

Adherence to the instructions in Table 1 allows prompt recognition of the occurrence of balloon rupture in situ. Failure of the syringe to encounter appreciable resistance and failure to "spring back" when the empty syringe is connected to the minor lumen provides a clear indication of balloon rupture, and air should not be introduced into the system.

The initial stimulus to the development of this system was for the care and study of acutely ill patients in whom fluoroscopy was not readily available or who were not in condition to be readily moved to a diagnostic facility. We now use the system for the accurate management of fluid-volume control in patients with a wide variety of serious illnesses, including noncardiac conditions such as bacteremia, acute pancreatitis and severe blood loss.

The effectiveness and simplicity of use of this device has prompted us to engage in several other human applications. First of all, it is now used routinely in catheterization of the right side of the heart and pulmonary artery in the diagnostic laboratory. Catheters of a sufficient size (No. 7 Lehman equivalent) with a suitable balloon are being de-

veloped for pulmonary and forward angiography. On several occasions the ability of this catheter to enter the pulmonary artery was demonstrated under circumstances ordinarily difficult. For example, in a patient with a persistent left superior vena cava, the balloon catheter inserted from the left arm was inflated when it failed to progress beyond the left border of the mediastinum. It proceeded down the left superior vena cava, through the coronary sinus and right atrium and passed through the right ventricle to the pulmonary artery within eight seconds. After withdrawal of the balloon attempts to catheterize the heart with the use of an angiographic catheter proved to be unsuccessful. Similar considerations pertain to complex anomalies of the great vessels in infants and children with serious congenital heart disease, particularly the malformation of "corrected" transposition of the great arteries, the dextrocardias, dextroversions and the transposition complexes — all situations in which the balloon catheter may be anticipated to pass into desired locations in the central circulation with much greater ease than heretofore.

Insertion of the catheter into the left side of the heart has not yet been attempted. However, passage either through a patent foramen ovale or an atrial septal defect or via a trans-septal technic offers the ready ability to enter the left ventricle by the flow principle. This will avoid manipulations of the catheter within the cavity of the left atrium.

The specific use of this type of catheter in infants

and children offers considerable promise. Although cardiac perforation or identified damage of the sub-endocardial layer has not frequently been reported⁵ changes can often be observed at autopsy within a few hours or days of diagnostic catheterization. For this reason small flexible catheters have been recommended for use in patients in the newborn and infant age group to avoid these complications. Suitable catheters with a small balloon vehicle (0.2 to 0.3 ml) are under construction.

The balloon catheter also appears to be an ideal vehicle for one of the most important applications in the management of the acutely ill patient — specifically, the effective and prompt placement of pacing electrodes in the right ventricle without the use of fluoroscopy and without the hazards and delays frequently associated with current technics.

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HYDROXYPROLINEMIA*

An Apparently Harmless Familial Metabolic Disorder

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Abstract In a family with hydroxyprolinemia the *proposita* was a 31-year-old woman whose disorder was characterized by the accumulation of large amounts of free hydroxyproline in the plasma, with overflow into the urine. Biochemical studies suggested that the accumulation of free hydroxyproline in the *proposita*, as in the only previously reported case, was due to deficiency of hydroxyproline oxidase, the enzyme that normally converts free hydroxyproline to Δ^1 -pyrroline-3-hydroxy-5-carboxylic

acid. Unlike the previous patient, the *proposita* was not mentally retarded, and did not seem to have any clinical abnormality that could have been due to the metabolic defect. Studies on 20 relatives indicated that an apparently healthy 27-year-old brother of the *proposita* likewise had hydroxyprolinemia, and his two-year-old daughter had slightly elevated endogenous hydroxyproline values. The pedigree was consistent with autosomal recessive inheritance.

HYDROXYPROLINEMIA is a metabolic disorder characterized by the accumulation of large

amounts of free hydroxyproline in the plasma, with overflow into the urine. The only patient^{2,3} previously described as having this disorder was a mentally retarded girl, who also had a slightly increased number of erythrocytes in the urine. Her mother was likewise mentally retarded but had no abnormality of hydroxyproline metabolism. Therefore, it was not possible to determine whether there was a causal relation between the mental retarda-

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