superior or inferior vena cava or high right atrium. The balloon is then inflated, providing a relatively solid (nonliquid) element which is directed by the flowing stream of blood. The inflated balloon, with a diameter of about 11 mm, is flow-guided through the right atrium and tricuspid valve into the right ventricle. From there it finds its way into the main pulmonary artery and into a branch of the pulmonary artery. When it reaches a pulmonary vessel slightly smaller in diameter than the inflated balloon it stops, much like a pulmonary embolus. When fluoroscopically controlled, the balloon guidance system will flow from the right atrium to the pulmonary artery in about 10 to 20 seconds.

When the balloon is deflated, the catheter shaft will recoil slightly into a larger pulmonary artery since the flowing blood now does not have the "mass" on which to act. When it is slowly and briefly inflated again, it has impact once more on a smaller artery and permits a wedge measurement—one of the most significant readings provided by the catheter.

The balloon is important in avoiding endocardial irritation and arrhythmias: When it is inflated for passage through the right ventricle, the balloon protrudes over the catheter tip, which maintains its place in "the hole in the balloon doughnut."

Pressure Tracings Needed

The apparatus requires manometers and display units as well as electrocardiographic monitoring. A fluoroscope, although it can be dispensed with at the bedside, facilitates effective placement in some cases. Pressure tracings are needed, not only to assist in positioning the catheter tip, but to provide data useful in diagnosis. An increase in respiratory cycle pressure variations on the tracings indicates that the tip has reached the thorax. The balloon is then inflated and a recording made of the maximum and minimum pressures in the atrium. As it enters the tricuspid valve and passes into the right ventricle a similar recording is made. Pressure tracings then show the pulmonary artery pressure contour, and advancement is continued until a pressure is identified which approximates pulmonary artery diastolic levels. The balloon is then deflated and phasic pulmonary artery pressure should reappear. The pressure levels in the pulmonary artery are then measured again.

The balloon flotation catheter may be left in place up to a maximum of 48 hours in management of the critically ill, but re-use is questionable because cleaning and sterilization may cause deterioration of the latex balloon. The balloon must always be deflated for withdrawal of the catheter.

The flow-directed catheter is particularly useful in measuring the pressure in the pulmonary veins when wedged with its balloon. This reading is of critical importance in clinical practice in that it provides information on the level of pulmonary congestion and on the transfer of fluid at the pulmonary capillary level. In addition, pulmonary venous pressure relates closely to left atrial pressure and, in the absence of mitral valve disease, to left ventricular diastolic pressure. For clinical purposes the mean wedge pressure provides highly relevent data of practical significance.

Most Valuable Parameter

The principal data obtained from using the catheter include the filling pressures of the right and left ventricle, $\Delta P/\Delta T$, and the cardiac output. Of these, left ventricular filling pressure appears to be a most valuable parameter of cardiovascular function on which to base therapeutic decisions and on which to evaluate their effectiveness.

A knowledge of cardiac output as a basic component of cardiovascular function has always been accepted as important by the cardiovascular physiologist. However, many clinicians have doubted the value of precise data on cardiac output levels and changes. Now that this variable can be measured with the balloon flotation catheter without particular difficulty or increased hazard to the patient, the significance of such measurements in clinical practice is becoming recognized more widely.

Several definable states of cardiovascular function can now be identified in pathophysiologic terms, and specific therapies can be indicated on a hemodynamic basis. For instance, normal cardiac output associated with a normal left ventricular filling pressure does not require specific cardiovascular therapy, and indicates that abnormal symptoms or signs suggestive of cardiovascular dysfunction may have another basis. Changes may occur later, and the comparison of data can be significant.

From the basic balloon flotation catheter have come other developments permitting more complex measurements. The thermodilution catheter incorporates a thermistor which allows measurement of cardiac output by the thermodilution principle.

Pediatric catheters have permitted catheterization of the heart with less risk of perforation or major arrhythmias in critically ill infants with congenital heart disease. And special balloon-tipped catheters are used for rapid bedside temporary pacing. Some surgeons have predicted that the balloon flotation catheter ushers in an era in which monitoring of critically ill surgical patients will become accepted as being indispensable. □