Pulmonary Artery Wedge Catheter Position as a Site for Injection of Indicator Substance

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The use of indicator-dilution curves during cardiac catheterization has greatly clarified the hemodynamics of various congenital cardiovascular malformations. As presently used, the combination of indicator-dilution curves and oximetry is usually sufficient to establish a definitive diagnosis. In some subjects with small left-to-right intracardiac shunts, however, the usual diagnostic methods are inadequate. In attempts to prove the existence of small shunts additional diagnostic procedures may be required such as the placement of 2 catheters in the right side of the heart or catheterization of the left side of the heart. The present study reports the injection of indicator substance with the catheter in the pulmonary wedge position as an additional diagnostic aid.

Material and Methods

In mongrel dogs, a cardiac catheter was wedged in the pulmonary artery, and, with use of the Westinghouse intensifier, sufficient quantities of Renographin or Hypaque were injected to outline graphically the course followed by a wedge injection. Some animals were killed immediately after the procedure, and the area of the lung in which the catheter had been wedged was excised for microscopic section. In a single dog a plastic tube was inserted between the right and left ventricles in a manner similar to that used by Dillon and Schreiber. The tube was gripped in an adjustable clamp, and the thorax was closed with the clamp protruding so that the size of the interventricular shunt could be controlled externally. The shunt was reduced progressively until its presence could no longer be identified clearly on the curve inscribed after injection of indicator into the pulmonary artery. Then a curve was obtained with injection into the catheter wedged in the pulmonary artery to determine whether or not the shunt could still be demonstrated. The human subjects were infants, children, and adults having routine diagnostic cardiac catheterization.

The volume of the system from the point of injection of the indicator to the end of the catheter was maintained at sufficient size to contain only slightly more fluid than the quantity of indicator to be used. The catheter was wedged, the indicator was introduced cautiously into the system, and the system was closed so that the indicator remained trapped. At the proper signal a sufficient excess of saline solution was injected to wash the indicator substance through the catheter, the pulmonary capillaries, which it obstructed, and into the pulmonary vein. The arterial sampling site was the femoral artery, and the arterial specimen was withdrawn at a rate of 25 ml per minute with a Harvard Apparatus Company constant withdrawal pump. The indicator substance was Indocyanine green (Cardio-green), and all indicator-dilution curves were made with the Waters Conley cuvette oximeter modified for use of Cardio-green.

Results

Examination of microscopic sections from the region of the dogs' lungs where the catheter had been wedged revealed that there were small areas of hemorrhage and some staining of the lung with dye (fig. 1). The area involved, however, was not large and did not appear to be severely injured, even though several injections had been made through the excised segment. In our clinical experience none of the subjects has shown signs of localized pneumonia or infarction after the "wedge injection," which would make us believe that this procedure is contraindicated.

Cinefluorography during injection of radiographic contrast substances revealed that in-
Injection into the pulmonary artery cast a relatively dense shadow in the artery but was not seen thereafter because of dilution (fig. 2). When the injection was made in the wedge position, however, the small vessels at the end of the catheter were distended sharply and the contrast substance could be seen clearly in the pulmonary vein draining this segment of the lung (fig. 3).

In the dog it was demonstrated that under the same hemodynamic conditions the recirculation of indicator that had come through the artificially created "ventricular septal defect" could be seen more readily on the indicator-dilution curve made with injection in the wedge position than on the curve made with injection into the pulmonary artery (fig. 4).

It has been possible in several clinical cases to demonstrate diagnostically abnormal curves with injection at the wedge position when the dilution curve done with injection into the pulmonary artery was equivocal. An illustrative case history may be cited. A 3-year-old boy who had grown and developed normally, was found to have a palpable systolic thrill and grade-III systolic murmur in the lower left intercostal spaces parasternally. His electrocardiogram was within normal limits, and on roentgenographic examination the heart was at the upper limits of normal in size with a questionable increase in the pulmonary vascularity. Cardiac catheterization revealed normal pressures in the right side of the heart and in the femoral artery. Oxygen saturations were 70 per cent in the mid right atrium and high right ventricle and 74 per cent in the pulmonary artery. (As calculated in volumes per 100 ml. of blood this is an increase in oxygen content from 10.6 to 11.3.) Indicator-dilution curves from the right pulmonary artery and from the right pulmonary artery wedge position are shown in figure 5. Although there may be early recirculation on the washout slope of the indicator-dilution curve done with injection into the right pulmonary artery proper, there is no doubt that this early recirculation is seen more clearly on the indicator-dilution curve made with injection into the wedge position. The indicator-dilution curves done with injection at comparable positions on the left pulmonary artery confirmed those on the right.

There would be some doubt from the routine catheterization of this subject that a shunt existed, whereas the clinical picture was that of a small ventricular septal defect. When the "wedge injection" indicator-dilution curves (fig. 5) are considered, however, the clinical diagnosis of a small ventricular septal defect seems confirmed. Final proof of this diagnosis by cardiac surgery has not yet been accomplished, since the child's physical state appears too satisfactory to justify surgical intervention at this age.

Discussion

The hypothesis on which this study was undertaken was that, with injection into the pulmonary wedge position, the "central volume" would be reduced to the smallest size that could be obtained with a cardiac catheter passed through the right but without entering the left side of the heart. Injection at this site should produce a curve with an earlier appearance time, a sharper peak, and a narrower spread. This hypothesis was confirmed.
Consecutive pictures from a cineangiogram have been mounted to show the course of the indicator during an injection through a cardiac catheter with its tip lying free in the pulmonary artery. Although the pulmonary artery and its branches are outlined clearly, the dye is so diluted on its return through the pulmonary veins that it cannot be seen. The second cardiac catheter is in the "wedge position" and the obstructed wedge of lung contains some contrast substance that has not been washed out from previous injections.

in the dog by indicator-dilution curves and by cineangiocardograms showing that injection through the wedge position outlines clearly the small vessels distal to the tip of the catheter and the pulmonary vein prior to its entry into the left atrium, and, if the period of injection is relatively short, the indicator substance reaches the left side of the heart in a relatively concentrated form (fig. 3). Since a high, peaked concentration of indicator traverses the left atrium and ventricle, the fraction of indicator carried through a cardiac defect by a left-to-right shunt should be relatively concentrated. Hence both the "general" and "shunt" circulation curves are sharpened, and their peaks may be iden-
Consecutive pictures from a cineangiogram have been mounted to show the course of the indicator during an injection through a cardiac catheter with its tip in the wedge position. The other cardiac catheter is lying with its tip free in the pulmonary artery. The small pulmonary vessels distal to the "wedged" catheter were filled with contrast substance that extended, essentially undilated, into the pulmonary vein draining the "wedged segment." Saline was not injected to wash out the obstructed segment of vasculature and considerable quantity of contrast substance remained in the pulmonary vessels. This is seen to clear slowly in a manner that might distort the washout slope of an indicator-dilution curve, pointing up the necessity of an adequate "flush" through the system after the injection of indicator.

In normal human subjects the "wedge injection" curves are as described for the dog and show no abnormality in their washout slope providing the indicator is washed through by sufficient volume of fluid (5 ml.) that the catheter and the section of the lung distal to it in the wedge position are well cleared of indicator. If this is not done, it appears clinically and from the cineangiocardiographic studies (fig. 3) that indicator substance may remain in the vessels obstructed by the wedged catheter and drain slowly into the circulation, distorting the washout slope of the indicator-dilution curve.
These indicator-dilution curves were obtained from a dog with a tube inserted between the right and left ventricle to simulate a ventricular septal defect. The amount of shunt was reduced progressively until the "RPA" curve was obtained by injecting Indocyanine green into the pulmonary artery and recording the indicator-dilution curve at the femoral artery. Immediately thereafter, without changing the shunt, the "RPAW" indicator-dilution curve was obtained after injection in the "wedge position." The RPAW curve shows the earlier appearance time, sharper peak, and narrower spread, and reveals the "shunt" recirculation more clearly, demonstrating the principle of "wedge injection." The curves are actual size and were superimposed photographically.

The passage of the indicator through the obstructed segment is dependent, not only upon the rate of blood flow through the segmental vein from collateral vessels that bypass the vessels obstructed by the wedged catheter, but also the rate of flow through this segment of the indicator and the fluid that is used to wash the indicator through the catheter. Hence, the exact portion of the "central volume," which is calculated from the curve, will depend to some extent on whether the indicator flows more rapidly through the pulmonary vein draining the segment into which the injection is made than blood flows through the other unobstructed pulmonary veins. In the absence of specific knowledge of what blood is "temporally coincident" with the injected indicator the calculation of the "central volume" could conceivably be distorted by almost as much as the volume of the pulmonary venous tree.

The significance of shunts that are too small to be shown by the standard methods of catheterization may be questioned. Very small shunts, however, may be present in subjects with marked pulmonary hypertension but with sizable defects, and it may be important to demonstrate these shunts in order to differentiate patients with septal defects from those with idiopathic pulmonary hypertension. Furthermore, some of the subjects in the present series who had the expected physical findings of a small ventricular septal defect were not shown to have any abnormality by the standard method of catheterization, including multiple indicator-dilution curves. Injection of indicator substance through the wedge position clearly indicated early recirculation on the washout slope of the curve and a central shunt. Similar, or perhaps even greater discrimination may be afforded the indicator-dilution methods by use of 2 cardiac catheters in the right side of the heart with performance of simultaneous dilution curves.
from a peripheral artery and a right-sided chamber proximal to the site of injection, or by left heart catheterization and injection of indicator into either the left atrium or the left ventricle, but these methods are more complicated. The demonstration of such a small lesion by an objective method is intellectually more satisfying than the statement that such a lesion exists but is too small to be demonstrated.

Conclusions

The pulmonary wedge position is described as a site for injection of indicator-dilution substance because it presents the most central point in the circulation that can be attained during right heart catheterization without actually entering the left side of the heart. Injection at this site furnishes a small "central volume" and produces curves that for the same quantity of dye injected present a sharper peak concentration, a shorter build-up and disappearance time, and therefore a curve the morphology of which is more rigidly set than those obtained by injection at more proximal sites in the right side of the heart. Because the curve is sharper, small recirculation curves on the washout slope are more readily apparent; therefore smaller shunts can be detected during diagnostic cardiac catheterization.

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Knowledge and Wisdom

The young man knows the rules, but the old man knows the exceptions.—OLIVER WENDELL HOLMES, M.D. Medical Essays, 1861.
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