Simultaneously recorded left atrial and pulmonary artery wedge pressures demonstrate that the left atrial pressure pulse can be transmitted across the pulmonary capillary bed and recorded by the wedged catheter. However, such satisfactory wedge tracings are not always obtainable, and in many trials the tracing is featureless, damped or distorted by artifacts and obviously is not a true reflection of atrial pressure events. In a review of the factors which influence transmission of left atrial pressure to the wedged catheter, Wiggers suggested that the manner of lodgment of the catheter tip may be a determinant of the type of pressure waves recorded. This lodgment is clearly delineated by the wedge pulmonary arteriogram. Study of these arteriograms has revealed five different positions of the catheter tip when the usual clinical criteria for the wedge position are satisfied. The purpose of this report is to demonstrate the importance of the catheter tip position in the satisfactory recording of the left atrial pulse curve by that catheter.

Methods

Right heart catheterization was performed on 68 patients in whom there were clinical and laboratory findings suggestive of either acquired or congenital heart disease. In 33 patients a congenital cardiac defect was discovered; in 28, mitral stenosis due to rheumatic heart disease was diagnosed; and in 7 patients no cardiovascular abnormality was discovered. The age of the patients ranged from 10 months to 62 years.

A no. 6 or 7 Courand catheter was manipulated into a peripheral pulmonary artery wedge position under fluoroscopic guidance during a deep inspiration. Criteria for a satisfactory wedge position were the following: (1) observation of a good "snap-back" of the catheter as noted fluoroscopically, and a simultaneous sudden increase in the recorded pressure upon withdrawing the catheter from the wedge position; (2) lack of pulsation of the catheter tip—movement with the heart beat indicates that the tip lies free in a large artery and is not truly wedged; (3) a pressure tracing which is distinctly different in contour from that recorded in the pulmonary artery, and with a mean pressure lower than in pulmonary artery and similar to that expected in the left atrium.

Radiographic exposure for the wedge pulmonary arteriogram was made at full inspiration and during the injection of 2 to 3 ml. of radiopaque dye, as previously reported.

Pressures were recorded by strain gauge on an electronic recorder. The zero pressure reference was taken as 5 cm. below the sternal angle in adults, and the midanteroposterior diameter of the chest in children.

A tracing was considered phasic if the characteristic a, c, and v waves of the left atrial pulse in sinus rhythm, or v wave in atrial fibrillation, were identified. Tracings showing uninterpretable vibrations, no oscillations, or damped pulmonary artery contours were considered unsatisfactory.

Results

Of the 68 arteriograms, the expected position of a wedged catheter, impacted in an artery having a common axis with, and just smaller than, the tip, was identified in 24 instances (position I, fig. 1A).

On 21 occasions, the tip lodged at the bifurcation of an artery which was the same size as the catheter (position II, fig. 1B). In this lodgment, progress of the catheter may have been halted by the bifurcation per se rather than impaction of the tip, yet no regurgitation of dye around the catheter tip was seen.
The catheter impinged against the wall of a sharply angulated artery in 15 of the cases (position III, fig. 1C). Such angulation appeared to result from the thrust of the catheter itself in some instances, whereas in others it seemed more likely that the entire pulmonary arterial tree was gnarled and angulated by disease.

In three cases, the catheter lodged at a point where the artery divided into three or more branches (position IV, fig. 1D). Regurgitation of dye about the tip which indicates incomplete impaction was not seen in these arteriograms.

In five patients, the arteriogram revealed incomplete wedging, the tip lodging in an artery with a larger diameter than the catheter (position V, fig. 1E). Free regurgitation of dye around the catheter outlined the artery proximal to the tip in these arteriograms.

The usual criteria for the wedge catheter position as outlined above were satisfied regardless of the relationships of the catheter tip in the pulmonary artery, except in three cases of position V, in which a sharp "snap-back" was not obtained on withdrawal of the catheter.

The influence of the catheter tip position on transmission of the left atrial pressure contour to the impacted catheter is summarized in table 1. Satisfactory phasic recordings were obtained in 37 of the 68 patients. When the catheter impacted in an artery just smaller than its tip, or lodged in an artery...
TABLE 1

<table>
<thead>
<tr>
<th>Catheter tip position</th>
<th>Phasic tracings</th>
<th>Unsatisfactory tracings</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>18</td>
<td>6</td>
<td>24</td>
</tr>
<tr>
<td>II</td>
<td>15</td>
<td>6</td>
<td>21</td>
</tr>
<tr>
<td>III</td>
<td>1</td>
<td>14</td>
<td>15</td>
</tr>
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<td>3</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>V</td>
<td>0</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>37</td>
<td>31</td>
<td>68</td>
</tr>
</tbody>
</table>

Influence of the Catheter Tip Positions on Transmission of Left Atrial Pressure

of similar size at the point of two or more branches (positions I, II, and IV), a high percentage of phasic tracings were recorded. In contrast, when the arteriogram showed the tip impinged against the wall of a sharply angulated artery, as in position III, or unwedged as in position V, a satisfactory atrial pressure curve was recorded in only 1 of 20 such lodgments.

The influence of catheter tip position, mean pulmonary artery pressure, and the pathogenesis of pulmonary hypertension on the frequency of phasic tracings is shown in figure 2. Favorable tip positions are associated with phasic tracings in approximately one-half of the patients with normal pulmonary artery pressure and in patients with elevated pulmonary artery pressure due to congenital heart disease. However, in patients with pulmonary hypertension due to mitral stenosis and elevation of left atrial pressure, favorable tip positions always result in a phasic tracing. Of the hypertensive group, unfavorable tip positions occur much less frequently in patients with mitral stenosis than in patients with congenital heart disease.

The lobe of the lung in which the catheter lodged did not appear to influence catheter tip position or the frequency of phasic tracings.

Discussion

The arteriographic studies show that unfavorable positions of the catheter tip which preclude a phasic recording occurred in 20 of the 68 trials and accounted for 19 of 31 unsatisfactory tracings. Thus, impaction of the catheter tip against the wall of a sharply angulated artery (position III) and incomplete wedging of the tip (position V) provide an adequate and previously undemonstrated explanation for unsatisfactory wedge tracings. In the former position, the catheter tip is occluded by the arterial wall and only artifacts can be recorded (fig. 3). In three of these instances, an intermittently phasic tracing was registered, as respiratory movements temporarily relieved the angulation of the tip against the arterial wall, thereby allowing periodic transmission of a left atrial pulse. In position V, pulmonary arterial pressure is not completely isolated from the tip, and there is no opportunity to record pure left atrial pressure events. These unfavorable catheter tip positions were not usually appreciated by application of the criterial for a wedged catheter and were

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discovered only later by study of the arteriogram.

In patients with pulmonary hypertension due to congenital heart disease, unfavorable catheter positions were frequently encountered, and always occurred when the mean pulmonary artery pressure was greater than 50 mm. Hg. The unsatisfactory tracings in these patients were due to unfavorable catheter positions, probably resulting from fundamental changes in the internal structure or elasticity of the 2.5-mm. pulmonary arteries which prevent satisfactory wedging of the catheter, rather than from interference with pressure transmission by obstructive lesions produced by thrombosis, arteriolar narrowing or occlusion, or communications with systemic vessels.

When the left atrial pressure is normal, unsatisfactory wedge tracings were frequent despite a good catheter position. Under these conditions, tracings were characterized either by vibratory artifacts which obscure pressure waves or by damped and featureless recordings. The vibratory artifacts occur fortuitously in all pressures recorded by catheters passed through the heart, but may more readily obscure left atrial pressure contours when the pressure is normal than when elevated with heightened $a$, $c$, or $v$ waves. Damped and featureless recordings from a favorably positioned catheter result from failure of the wedged vascular bed to transmit cyclic left atrial pressures to the catheter tip. Under these conditions, atrial pressure pulses apparently are damped by undistended and partially collapsed smaller vessels when wedging interrupts blood flow through the segment. Elevated left atrial pressure presumably maintains vascular channels capable of cyclic pressure transmission since phasic tracings were uniformly recorded from a favorably positioned catheter in patients with mitral stenosis. In contrast to the congenital heart disease patients, severe pulmonary hypertension did not interfere with satisfactory wedging in this group.

**Summary**

Pulmonary artery wedge pressures and wedge pulmonary arteriograms were obtained in 68 patients with either mitral stenosis, congenital heart disease, or no demonstrable heart disease. The arteriogram defines five catheter tip positions in the wedged artery. Tip positions unfavorable for left atrial pressure transmission occurred in 20 of the 68 trials and accounted for 19 of the 31 unsatisfactory tracings. Favorable tip positions were found in 48 instances and resulted in 36
phasic tracings. Unsatisfactory tracings in patients with pulmonary hypertension and congenital heart disease are shown to result primarily from unfavorable catheter tip positions. In these patients structural changes in the larger pulmonary arteries may prevent proper wedging. Increased left atrial pressure assures transmission of a cyclic left atrial pulse to a properly impacted catheter regardless of the degree of associated pulmonary hypertension. It is concluded that the fortuitous position assumed by the catheter tip in the wedged artery and the level of the left atrial pressure are factors of major importance in the satisfactory recording of the left atrial pulse curve by the wedged catheter.

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References
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