Retrograde Transmission of Left Atrial Pressure Pulses Across the Pulmonary Capillary Bed in Dogs

By Helmut Mueller, M.D., Goffredo Gensini, M.D., Arthur E. Prevedel, M.D., and S. Gilbert Blount, Jr., M.D.

Retrograde transmission of left atrial pressure across the pulmonary capillary bed was studied in dogs employing graduated left atrial pressures. Left atrial pressures below a level of 30 to 35 mm. Hg were transmitted across the pulmonary capillary bed as mean pressures; in the case of higher left atrial pressures the cyclic changes were transmitted with a certain amount of damping. Pressures were recorded both from the tip of a catheter wedged into a peripheral pulmonary artery and from the occluded main artery of one lung. Pressures recorded from the occluded main artery of one lung are a reflection of cyclic left atrial pressure variations and are less damped than those recorded from a wedged catheter tip.

SINCE the original communications of Hellems and associates and of Lagerlöf and Werko the significance of the pulmonary artery wedged pressure has been the subject of considerable controversy. The concept that left atrial pulse pressure waves can be transmitted across the pulmonary capillary bed to a wedged catheter has been suggested by a series of catheterization studies in patients with mitral valvular disease. Direct evidence for the support of this possibility has been obtained from investigations employing simultaneous recordings of the left atrial and pulmonary artery wedged pressures in patients with mitral valvular disease.

There have been, however, definite objections voiced as to the significance of pulse pressure variations noted in the pulmonary artery wedged pressures. Wiggers suggests, on theoretic grounds, that the extensive network of capillaries would damp out the left atrial pulsations when recorded from the other side of the pulmonary capillary bed. These theoretic doubts have been substantiated mainly by the experimental work of Ankeney and Hady and associates. In a recent critical review of this entire subject, Wiggers states that the basic question—"Can retrograde intravascular transmission of pressure pulses take place from the left atrium through capillaries to a wedged catheter?"—is still not settled. It is the object of this communication to present results of experiments designed to answer this fundamental question.

By employing a method which permitted graduated left atrial pressure variations, it was possible to study quantitatively retrograde left atrial pressure transmission across the pulmonary capillary bed. The possibility of recording retrogradely transmitted left atrial pressures by other means was investigated, and the results of pressure determination in an occluded main artery to one lung are presented.

METHODS

A double lumen catheter was introduced into the pulmonary artery of anesthetized dogs via the right jugular vein using routine technic of cardiac catheterization. The tip of the catheter was wedged into a small peripheral branch for recording of the pulmonary artery wedged pressure. The chest was then opened, and an 18 gage needle introduced into the left atrium. Pressures from the left atrium, the wedged catheter tip, and the central pulmonary artery were recorded simultaneously. Statham strain gages of different sensitivity were used as pressure transducers. The Hathaway oscillograph was used for recording. The zero point for the different recordings varied between 7 to 12 cm. above the table according to the level of the left atrium.
The left atrial pressure was altered by varying degrees of aortic constriction. The pulmonary artery was occluded by a ligature proximal to the catheter openings. The experiments were performed in six consecutive dogs with identical results.

RESULTS

I. The Simultaneous Recording of Pulmonary Artery, Pulmonary Artery Wedged and Left Atrial Pressures. The initial phase of figure 1 reveals the simultaneous recording of the pulmonary artery wedged, pulmonary artery and left atrial pressures. The pulmonary artery wedged pressure reveals respiratory variations but no pulse waves, the cyclic changes of the left atrial pressure not being reflected under these normal conditions. The pulmonary artery wedged pressure varied from 8 to 11 mm. Hg and would appear to be determined by the left atrial mean pressure and by the intra-alveolar pressure variations resulting from the positive pressure breathing. The pulmonary artery wedged pressure was of the same order as the mean left atrial pressure under conditions of normal inflation of the lungs.

II. The Effect of Total Occlusion of the Pulmonary Artery Branch Proximal to the Openings of the Double Lumen Catheter. The pulmonary blood flow passes through the pulmonary artery that remains unobstructed. Figure 1 reveals the effect of this occlusion on the simultaneously recorded pressures. The pressure recorded from the wedged catheter reveals no changes following the occlusion of the pulmonary artery branch. The pressure recorded from the distal portion of the occluded pulmonary artery branch reveals the disappearance of the pulsations, and the contour and the level approximate that recorded from the wedged catheter tip. This suggests that the pressure recorded from the occluded pulmonary artery reflects the mean pressure within the left atrium, as does the pulmonary artery wedged pressure. The cyclic changes of normal left atrial pressure are damped out in both the occluded pulmonary artery and in the pulmonary artery wedged pressure.

III. The Effect of Aortic Constriction of Varying Degrees. By varying the degree of aortic constriction the left atrial pressure could be altered both as to level and amplitude of pulsations. As the degree of constriction was increased and the pressure within the left atrium rose to levels of 30 to 35 mm. Hg, the contour of the left atrial pressure revealed an insufficiency pattern apparently caused by the dilatation of the mitral ring. Figure 2 reveals the effect on the simultaneously recorded pressures under these conditions. The pressure changes recorded from the wedged catheter tip and from the distal portion of the occluded pulmonary artery follow and reflect the left atrial pressure changes. When the left atrial pressures reach a level of 30 to 35 mm. Hg, the cyclic variations in this pressure are transmitted across the capillary bed and
Retrograde Transmission through Pulmonary Capillaries

Effect of aortic constriction of varying degrees. Labeling of curves as in figure 1.

Table 1.—Effects of Left Atrial Pressures on those Recorded from Occluded Pulmonary Branch and Wedged Pulmonary Catheter

<table>
<thead>
<tr>
<th>Left Atrium Pressure</th>
<th>Amplitude mm. Hg</th>
<th>Pulmonary Artery Occluded Pressure</th>
<th>Amplitude mm. Hg</th>
<th>Damping mm. Hg</th>
<th>Damping %</th>
<th>Pulmonary Artery Wedged Pressure</th>
<th>Amplitude mm. Hg</th>
<th>Damping mm. Hg</th>
<th>Damping %</th>
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As the left atrial pressure increased, the damping was expressed quantitatively as the difference in the amplitude of left atrial pulse pressure and the amplitude of the transmitted pulse pressures. The percentage of damping was calculated by dividing the amount of damping by the amplitude of the left atrial pulse pressures:

\[
\text{Damping} \% = \frac{\text{L. A. (Amplitude) - Transmitted Pulse (Amplitude)}}{\text{L. A. (Amplitude)}} \times 100
\]
ing decreased, and the differences between the left atrial pressure and the transmitted pressures became smaller. When left atrial pressures reached the order of 70 mm. Hg, no significant damping was evident; the pressures were practically identical as to level and contour, differing only in time relation. The transmitted pressure showed a delay of 0.06 to 0.10 seconds.

IV. Release of Aortic Constriction (fig. 3). The left atrial pressure returns at once to its normal level and contour. The transmitted pressure recorded from the occluded pulmonary artery follows closely and faithfully, and as the left atrial pressure level drops below 30 to 35 mm. Hg the cyclic pulse waves are no longer transmitted. The pressure recorded from the occluded pulmonary artery represents once again the mean of the cyclic left atrial pressure variations. The transmitted pressures, slightly clamped, were recorded both from the tip of a wedged catheter and from the main pulmonary artery to one lung distal to its occlusion. The damping decreased with increasing left atrial pressure; this is explained by the increase of the diameter of the capillary vessels together with loss of their elasticity. It was further shown that the damping effect of the pulmonary capillary bed does not prevent the transmission of left atrial cyclic pressure changes, provided that these pressures exceed a certain critical level (30 to 35 mm. Hg in our experiments). Conclusions of other workers, denying the trans-

**DISCUSSION**

Ankeney found no evidence that the left atrial cyclic pressure variation under normal conditions and after the creation of mitral lesions in dogs were transmitted across the pulmonary capillary bed. However, examination of his data revealed that the peak left atrial pressures did not exceed 23 mm. Hg, and the pulse pressures were less than 10 mm. Hg. Therefore, the question arose whether left atrial pressure elevation of sufficient magnitude had been produced to justify definite conclusions.

By employing a method that would permit greater and graduated left atrial pressure variations, it was found that there was no retrograde transmission of left atrial cyclic pressure variations below 30 mm. Hg, confirming the observations of other investigators. The cyclic changes, however, were transmitted across the pulmonary capillary bed when the left atrial pressure exceeded this critical level. The transmitted pressures, slightly damped, were recorded both from the tip of a wedged catheter and from the main pulmonary artery to one lung distal to its occlusion. The damping decreased with increasing left atrial pressure; this is explained by the increase of the diameter of the capillary vessels together with loss of their elasticity. It was further shown that the damping effect of the pulmonary capillary bed does not prevent the transmission of left atrial cyclic pressure changes, provided that these pressures exceed a certain critical level (30 to 35 mm. Hg in our experiments). Conclusions of other workers, denying the trans-
mission of left atrial cyclic pressure changes across the pulmonary capillary system, were derived from experiments producing left atrial pressures below this critical level.

Pulmonary artery wedged pressures obtained in humans with mitral valvular disease often reflect the cyclic changes occurring in the left atrium with pressure levels no greater than 20 to 25 mm. Hg. This would indicate in these patients a critical level for left atrial cyclic pressure transmission lower than in our experiments. This might be expected as a result of long-standing pulmonary venous hypertension leading to dilatation of the pulmonary capillaries and an accompanying decrease of their elastic properties.

When the capillary bed is considered as an extensive network of extremely small tubes with a high resistance, it is difficult to conceive of small pressure pulses being transmitted across such a system. However, the capillary system represents a parallel arrangement of high resistances, and when the number of parallel connected resistances is increased, the total resistance of the system decreases according to the formula, \( \frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \frac{1}{r_n} \). Thus, our observation that left atrial pressure waves may be recorded less damped from an occluded pulmonary artery appears to find its logical explanation.

The left atrial pressure recorded from a catheter tip wedged in a peripheral pulmonary artery is conducted by a smaller number of capillaries than a recording obtained from a large, occluded pulmonary artery, and, therefore, in accordance with the above formula the total resistance would be greater in the first instance.

**SUMMARY AND CONCLUSIONS**

A double lumen catheter was introduced into the pulmonary artery of anesthetized dogs and then wedged into a small peripheral branch. The chest was opened and a needle introduced into the cavity of the left atrium. All pressures were recorded simultaneously. The level of the left atrial pressure was altered by varying degrees of aortic constriction, and one pulmonary artery was completely constricted by a ligature placed proximally to the openings in the catheter.

Left atrial pressures below 30 to 35 mm. Hg were transmitted across the pulmonary capillary bed to the tip of the wedged catheter and to the occluded pulmonary artery as mean pressures, while with higher pressures the cyclic changes were transmitted. The pressure waves showed a certain degree of damping when recorded from the pulmonary artery side. As the left atrial pressures increased, the degree of damping decreased.

The pressure contours obtained from the occluded pulmonary artery were less damped than those recorded from the tip of the wedged catheter, and, therefore, they appear to be a more sensitive reflection of the cyclic changes occurring within the left atrium.

The transmission of left atrial pressure waves across capillary vessels with high resistance and damping properties is explained by the fact that the capillary system represents a parallel connection the total resistance of which is small. The left atrial pressure recorded from the occluded artery of one lung is transmitted across its entire capillary system and, therefore, appears less damped than a pressure recorded from a wedged catheter conducted through but one segment of the total pulmonary capillaries.

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Circ Res. 1954;2:426-431
doi: 10.1161/01.RES.2.5.426

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