The Relationship between Pulmonary Artery Wedge Pressure and Left Atrial Pressure in Man

By DANIEL C. CONNOLLY, M.D., JOHN W. KIRKLIN, M.D., AND EARL H. WOOD, M.D., PH.D.

In 17 patients with atrial septal defect, in 12 patients with mitral stenosis and in four patients with unilateral lung tumor but without evidence of mitral valve disease, a similarity in pressure pulse contours in the left atrium and pulmonary artery wedge position was obtained at cardiac catheterization. It is concluded that the pulmonary artery wedge pressure pulse is a reasonably accurate reflection both in magnitude and in contour of the left atrial pressure pulse in man during normal respiration and also during assisted respiration at operation.

Numerous reports have been published concerning the relationship between the pulmonary artery wedge pressure and the left atrial pressure. Good correlation and considerable variation in the correlation have been variously reported between these pressures, measured consecutively in patients with atrial septal defect or simultaneously in experimental animals, so that considerable uncertainty still exists concerning the significance of pulmonary artery wedge pressures. Simultaneous recordings of pulmonary artery wedge and left atrial pressures in humans have been reported in previous communications from this laboratory.

It is the purpose of this paper to present our experience with the comparison of pulmonary artery wedge pressure and left atrial pressure measurements in 33 patients. In 17 cases these pressures were measured consecutively during routine cardiac catheterization of patients with atrial septal defect, and in 16 cases the pressures were measured simultaneously during operation on patients with mitral stenosis or lung tumor.

Method

During cardiac catheterization of the patients with atrial septal defect the procedure and recording systems were those previously described. The recording of pulmonary artery wedge pressure during operation for mitral stenosis was carried out by the introduction of a no. 5 (100 cm.) cardiac catheter through a thin-walled no. 15 gage needle, inserted through the wall of the pulmonary artery. The catheter was subsequently advanced and wedged in the periphery of the lung.

Left atrial pressure was recorded by means of a finer catheter introduced through a thin-walled no. 18 gage needle inserted into the lumen of the left superior pulmonary vein. A plastic Peterson-type arterial catheter (manufactured by the Albert Afford Company, Barrington, N. J.) was used (0.5 mm. inside diameter; 1.0 mm. outside diameter; length 80 cm.). The dynamic responses of these catheter-manometer systems have been found to be adequate for the recording of central arterial pressure pulses.

In the four cases of left lung tumor, the pulmonary artery catheter was in each case wedged in the normal right lung.

A four-channel direct-writing recorder (manufactured by Sanborn Company) and specially adapted Model P6-15G-250 strain gauges (Statham Company) were used for the recording of pressures. The resonant frequency of these gauges when attached to a 100 cm. no. 5 catheter was 15 cycles per second and the damping coefficient approximately 0.4 of critical; when attached to the arterial catheter the resonant frequency was 12 cycles per second and the damping coefficient approximately 0.4 of critical.

The midanteroposterior chest level at the juncture of the third intercostal space with the sternum was taken as the zero level for pressure measurements.

Integrated mean pressures were measured with a
compensating polar planimeter over one or two complete respiratory cycles.
In all cases the patients were under general anesthesia and respirations were assisted while the chest was open, that is, during the time the pressures were recorded.

Results
In the 17 patients with atrial septal defect in whom tracings of left atrial and pulmonary artery wedge pressures were recorded consecutively, a good correlation was obtained between the two pressures although these were measured with an average intervening time interval of 55 minutes (range: 3 to 163 minutes). The average mean pulmonary artery wedge pressure of 8 mm. Hg was not significantly different from the average left atrial pressure of 7 mm. Hg, the range of differences being 0 to —2 mm. Hg (table 1). In spite of discrepancies between the left atrial and wedge pressure in individual patients, a similarity in maximal and minimal pressures (table 1) and a close similarity in contour were noted in most instances, suggesting that, in fact, identical components were present in the pulse contours recorded from these two sites (fig. 1). In the few cases in which no resemblance was noted between the contours, the discrepancy was probably attributable to the presence of gross artefact or very marked respiratory fluctuation in the wedge contour.

Table 1—Comparison of Pressures Recorded Consecutively from the Left Atrium and Pulmonary Artery Wedge Position in 17 Patients with Atrial Septal Defect

<table>
<thead>
<tr>
<th>Patient</th>
<th>Pulmonary artery wedge pressure, mm. Hg</th>
<th>Left atrial pressure, mm. Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max.</td>
<td>Min.</td>
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<tr>
<td>1</td>
<td>16</td>
<td>8</td>
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<td>2</td>
<td>12</td>
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<td>15</td>
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<td>4</td>
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<tr>
<td>16</td>
<td>25</td>
<td>15</td>
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<tr>
<td>17</td>
<td>8</td>
<td>3</td>
</tr>
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</table>

Fig. 1. Comparison of consecutive recordings from the left atrium and pulmonary artery wedge position in two patients with atrial septal defect during routine cardiac catheterization. In each case there is a similarity in the pressure pulse contours although, in the upper tracing, there is a significant difference between the magnitude of the two pressures, presumably due to a change in left atrial pressure occurring in the interval between the two pressure recordings.
Fig. 2. Comparison of simultaneous pressure recordings from the left atrium and pulmonary artery wedge position from four patients during mitral commissurotomy. All four patients had mitral stenosis without mitral insufficiency. Auricular fibrillation was present in the patients whose records are shown in the first and last columns. Note the close similarity between the contour and the pressure in each instance.

Table 2.—Comparison of Pressures Recorded Simultaneously from the Left Atrium and Pulmonary Artery Wedge Position during Operation

<table>
<thead>
<tr>
<th>Patient</th>
<th>Additional diagnosis</th>
<th>Relation to commissurotomy</th>
<th>Left atrial pressure, mm. Hg</th>
<th>Pulmonary artery wedge pressure, mm. Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>After</td>
<td>Max.</td>
<td>Min.</td>
</tr>
<tr>
<td>1</td>
<td>Moderate mitral insufficiency</td>
<td>After</td>
<td>49</td>
<td>31</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Before</td>
<td>52</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>Minimal mitral insufficiency</td>
<td>Before</td>
<td>29</td>
<td>13</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>After</td>
<td>21</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>Minimal mitral insufficiency</td>
<td>Before</td>
<td>21</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>After</td>
<td>21</td>
<td>10</td>
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<td>7</td>
<td></td>
<td>Before</td>
<td>27</td>
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<td>Before</td>
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<td>12</td>
<td></td>
<td>After</td>
<td>27</td>
<td>15</td>
</tr>
<tr>
<td>13</td>
<td>Carcinoma left lung</td>
<td></td>
<td>22</td>
<td>7</td>
</tr>
<tr>
<td>14</td>
<td>Granuloma left lung</td>
<td></td>
<td>18</td>
<td>5</td>
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<tr>
<td>15</td>
<td>Carcinoma left lung</td>
<td></td>
<td>18</td>
<td>8</td>
</tr>
<tr>
<td>16</td>
<td>Carcinoma left lung</td>
<td></td>
<td>21</td>
<td>11</td>
</tr>
</tbody>
</table>
A convincing comparison of the pressures and contours from these two sites could be obtained only by recording the two pressures simultaneously. Simultaneous recordings of left atrial and pulmonary artery wedge pressure were obtained in 12 patients with mitral stenosis during mitral commissurotomy, and in a further group of four patients with left lung tumor, who underwent thoracotomy.

In all 12 patients with mitral stenosis, a close similarity between the simultaneously recorded pulmonary artery wedge and left atrial pressure pulses was noted both in contour and in magnitude. This similarity was not affected by respiration nor by the presence of arrhythmias. In addition a close correspondence in the magnitude of the pressures during all phases of the cardiac cycle was noted. Typical recordings from four of these patients are shown in figure 2, and comparison of the simultaneously recorded maximal, minimal and mean pressures are given in table 2.

In the four patients with lung tumor, in whom pulmonary artery wedge pressure tracings were obtained from the right (normal) lung simultaneously with left atrial pressure, a similar correspondence between the pressures was obtained (fig. 3 and table 2). The similarity between the contours of left atrial and pulmonary artery wedge pressures is less striking than that recorded in the patients with mitral disease but still grossly evident (fig. 3). In general, the pulmonary artery wedge pressure pulse contour suggests a slightly damped version of the left atrial contour with the addition of artefact, doubtless due to the motions and impacts on the wedged catheter imparted by the beating heart. Since the left atrial catheter is introduced via a pulmonary vein so that the tip lies just within that chamber, it is less subjected to motion caused by the heart beat. The amplitude of the left atrial pulse is usually somewhat greater, both at its upper and at its lower limit, than is that of the pulmonary artery wedge pulse (table 2).

The relation between mean left atrial pressure and mean pulmonary artery wedge pressure, in all 16 patients in whom simultaneous recordings were made, is shown in figure 4.
Fig. 4. Comparison of simultaneous left atrial and pulmonary artery wedge pressures recorded during operation in 16 patients. Recordings on patients with mitral stenosis are plotted as solid circles before and as hollow circles after commissurotomy. Lines connect the precommissurotomy and postcommissurotomy values in the five patients in whom such recordings were made. Recordings made on the normal lung of the four patients with left lung tumor are plotted as solid squares. Note that in all instances the points lie close to, if not on, the line of identity between the two pressures.

(In five of the patients with mitral stenosis, these pressures were measured both before and after mitral commissurotomy.) In all instances the points lie close to or on the line of identity between the two pressures. The maximal recorded difference between the mean pressures was 5 mm. Hg in a patient with mitral stenosis, and this discrepancy diminished after commissurotomy. The maximal difference measured between the mean pressures in patients with left lung tumor was 2 mm. Hg.

These results obtained in humans demonstrate that, at least under the circumstances of these measurements, the pulmonary artery wedge pressure pulse is a reasonably accurate reflection of that of the left atrium, both in magnitude and in contour. In spite of this close correlation between pulmonary artery wedge pressure and left atrial pressure obtained in man, recordings of wedge pressure contours have been unreliable in our hands as a means of differentiating mitral stenosis and mitral insufficiency.

**Comment**

It is of considerable practical importance as well as academic interest to know whether the pulmonary artery wedge pressure can be used as a reliable index of left atrial pressure in man. This is particularly true in conditions in which left atrial and pulmonary venous pressures are elevated, such as mitral stenosis, mitral insufficiency, left ventricular failure and constrictive pericarditis. Estimates of mitral valve area have been calculated taking the pulmonary artery wedge pressure to represent left atrial pressure. In addition, the pulmonary artery wedge pulse contour has been reported to be useful as a means of detecting the presence of mitral insufficiency. Thus it is necessary to establish the relationship between the pulmonary artery wedge and left atrial pressure pulses.

Since the original reports of the similarity between the pulmonary artery wedge pressure and left atrial pressure found in dogs by Hellems and associates and by Dow and Gorlin, and in a patient with atrial septal defect by Lagerlöf and Werkö, numerous investigators have tried to substantiate these findings. (For references see reference 1.)

Reports that these findings cannot be substantiated in dogs are at direct variance with the reported close correspondence between left atrial and pulmonary artery wedge pressures found in man by the use of various techniques.

It is difficult to explain these discrepancies between the studies on dogs and on man on a technical basis alone. The results obtained by Haddy and associates seem suspicious from the point of view of the possibility of frequent partial obstruction of the catheters, possibly by clots. It is difficult otherwise to explain their persistently elevated pressures after flushing and also to explain the finding of a pressure in a "well-wedged catheter" which exceeded pulmonary artery pressure by 13.8 mm. Hg. In human catheterization studies variations
in pressure subsequent to flushing the catheter-
manometer system would, in most laboratories,
constitute basis for rejection of the pressure
obtained as not representing a true wedge
pressure.

It is possible that there are sufficient differ-
ences in the pulmonary vasculature of dog and
man so that a species difference exists in the
relationship between left atrial and pulmonary
artery wedge pressures. It is of interest in this
regard that although fully arterialized blood
samples can usually be withdrawn from a
wedge catheter in man, it is a rare circum-
stance to be able to withdraw blood from a
catheter wedged in a pulmonary artery of a
dog.

The absence of phasic change in wedge
pressure tracings may be due to use of an
insufficiently high degree of sensitivity of the
recording apparatus. When a recording system
was used which could be switched immediately
from low to high sensitivity, a wedge pressure
pulse tracing relatively devoid of phasic
variation could be obtained on low sensitivity
(1 mm. Hg = 0.4 mm. deflection), whereas
on switching immediately to the high sensi-
tivity recording apparatus (1 mm. Hg = 2.4
mm. deflection) a venous-type pulse pattern
could be detected in the same pulse contour.
Use of an overdamped, very low frequency
manometer-catheter system may also obscure
pressure pulse contours.

The criticism of the term "pulmonary
capillary pressure" seems justified, since it
has been reported that very gross differ-
ces in pressure can be measured at opposite
ends of the pulmonary capillary bed. Our
findings in patients in whom recordings of
pulmonary vein wedge pressure were obtained
show that the pulmonary vein wedge pressure
approaches the pulmonary artery pressure
when the pulmonary vascular resistance is
low, and that a marked difference between
these two pressures exists when the pulmonary
vascular resistance is high (unpublished ob-
servations). These results are logical when one
considers that the wedge catheter pressure is
the pressure measured at the point where the
vessel in which the catheter is wedged connects
with one in which the flow is still free. In the
case of the catheter wedged in the branch of
the pulmonary artery, evidently no anastomo-
ses occur between the arteries or arterioles
beyond the tip of the catheter so that the
pressure measured is that of the left atrial-
pulmonary venous system. When a catheter
is wedged in the pulmonary vein, the pressure
measured is some unknown combination of
the pressure in collateral venous and capillary
connections to the vein distal to the point at
which the catheter is wedged, and represents
the pressure in the pulmonary artery minus
the pressure expended in overcoming the
pulmonary vascular resistance down to the
point beyond the wedged catheter tip at which
blood flow is still occurring.

For these reasons the less anatomically
descriptive term "pulmonary artery (or vein)
wedge pressure" is preferable to the confining
and inaccurate term "pulmonary capillary
venous (or arterial) pressure."

SUMMARY

Similar pressure pulse contours in the left
atrium and pulmonary artery wedge position
were obtained at cardiac catheterization in 17
patients with atrial septal defect. Although
not recorded simultaneously, a reasonably
close correspondence was observed between
the pressures recorded from these two posi-
tions.

In 12 patients with mitral stenosis studied
by direct recordings of pressure at operation,
simultaneous left atrial and pulmonary artery
wedge pressures corresponded closely, both in
magnitude and in contour.

In four patients with unilateral lung tumor,
and without evidence of mitral valve disease, a
similar close correspondence between simul-
taneously measured left atrial and pulmonary
artery wedge pressure was observed.

It is concluded that the pulmonary artery
wedge pressure pulse is a reasonably accurate
reflection both in magnitude and in contour
of the left atrial pressure pulse in man during
normal respiration and also during assisted
respiration at operation.
REFERENCES

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