The measurement of instantaneous blood flow in the great vessels in man is of importance in the study of circulatory dynamics. With the pressure-gradient technique, it is possible to estimate instantaneous blood velocity in man. However, in order to compute instantaneous blood flow from blood velocity, the radius of the vessel under study must be known at every instant in the cardiac cycle. Thus, a technique for estimating both the mean vessel radius and the change in radius during a cardiac cycle is needed. It was the purpose of this study to evaluate by an angiographic technique the pressure-radius relationship in the human pulmonary artery and aorta.

**Methods**

Thirteen patients with normal or slightly elevated pulmonary artery pressures were used for the pulmonary vascular study. Right heart catheterization was carried out in the usual manner. The intravascular pressure was obtained with a no. 7 Courmand single-lumen cardiac catheter. The tip of the catheter was placed either in the main or the right pulmonary artery. The catheter was connected to a Statham P23Db strain gauge transducer, and pressures were recorded on an Electronics for Medicine optical recorder. Another no. 7 catheter, which was used for injection of contrast media, was placed in the superior vena cava at the entrance of the right atrium. After the two catheters were in position, the patient was placed on the Sanchez-Perez cassette changer. A 90 per cent solution of Hypaque-M1 was used as the contrast medium in a dosage of 0.8 cc. per Kg. of body weight. A Godlund injector was used to inject the contrast medium. Twelve x-ray films were taken at 0.5-second intervals with an exposure time of 0.1 second or less. Thus, for an average heart rate of 70 beats per minute, the films would include approximately six cardiac cycles. The distance of the x-ray tube from the film was 40 inches. By means of a photocell, the time of exposure of each film was recorded simultaneously with the pulmonary artery pressure.

Twelve subjects with no clinical evidence of cardiovascular disease were used to evaluate the pressure-radius relationship in the descending thoracic aorta. A no. 18 Courmand needle was inserted into the right brachial artery and connected to a Statham P23Db strain gauge by a short piece of polyethylene tubing, and the pressure was continuously monitored. A Teflon catheter (TT 18§) was inserted into the aorta from either the left brachial artery or the femoral artery by means of the Seldinger technique. The tip of this catheter was placed in position in the upper descending thoracic aorta. This catheter was used for the injection of the contrast medium, as well as for measurement of the intravascular pressure. Essentially the same angiographic technique as previously recorded was used to obtain the aortograms. Since the intravascular pressure at the site of the aorta under study could not be measured, this pressure was recorded immediately before the injection of the contrast medium, along with the brachial artery pressure. The ratio of the brachial artery pulse pressure to the central aortic pulse pressure was assumed to have remained constant. After the ratio was determined, the brachial artery pressure was used to calculate any changes in the central aortic pressure that occurred relative to the injection of the contrast medium during the period that the angiograms were taken (fig. 1).

*Automatic Seriograph Corporation, College Park, Maryland.
†Winthrop Laboratories.
‡Schick X-ray Corporation, Chicago, Illinois.
§Supenant Mfg. Co.*
TABLE 1

<table>
<thead>
<tr>
<th>Blood vessel</th>
<th>Number of subjects</th>
<th>Mean pressure (cm. H$_2$O)</th>
<th>Mean radius (cm.)</th>
<th>$\Delta R/\Delta P \times 10^6$ (cm./cm. H$_2$O)</th>
<th>Per cent radius change around mean radius</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right pulmonary artery</td>
<td>13</td>
<td>Average 27.4</td>
<td>Average 1.13</td>
<td>Average 6.75</td>
<td>Average 5.85</td>
</tr>
<tr>
<td></td>
<td>Range 17.7 to 47.6</td>
<td>Range 0.9 to 1.6</td>
<td>S.D. ± 3.44</td>
<td>S.D. ± 2.13</td>
<td></td>
</tr>
<tr>
<td>Left pulmonary artery</td>
<td>5</td>
<td>Average 25.0</td>
<td>Average 1.07</td>
<td>Average 6.09</td>
<td>Average 6.20</td>
</tr>
<tr>
<td></td>
<td>Range 20.4 to 32.6</td>
<td>Range 1.0 to 1.3</td>
<td>S.D. ± 2.38</td>
<td>S.D. ± 2.40</td>
<td></td>
</tr>
<tr>
<td>Main pulmonary artery</td>
<td>4</td>
<td>Average 27.2</td>
<td>Average 1.47</td>
<td>Average 0.91</td>
<td>Average 2.55</td>
</tr>
<tr>
<td>Descending thoracic aorta</td>
<td>12</td>
<td>Average 20.4 to 32.6</td>
<td>Range 1.4 to 1.6</td>
<td>S.D. ± 0.42</td>
<td>S.D. ± 1.27</td>
</tr>
<tr>
<td></td>
<td>Range 98 to 174</td>
<td>Range 1.0 to 1.4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The results are summarized in table 1. The main pulmonary artery was not clearly visualized in all angiograms. Therefore, it was not possible to calculate the ratio $\Delta R/\Delta P$ for this vessel, and only the mean values of radius for this vessel were included in the table. It can be seen that the ratio $\Delta R/\Delta P$ for the descending thoracic aorta is considerably lower than that for the right or the left pulmonary artery. A similar difference between the distensibility of the descending thoracic aorta and the main pulmonary artery has been shown by Patel et al., using a direct method of measurement.

Since all of the aorta distal to the arch was visualized in the angiogram (fig. 2), it was possible to measure the vessel diameter at various sites. It can be seen in figure 3 that the diameter of the aorta decreases progressively from the upper descending aorta to the bifurcation.

The instantaneous blood flow, $Q$, is given by the product of the mean cross-sectional velocity, $v$, and the instantaneous cross-sectional area:

$$Q = \pi r^2 v,$$

where $r$ is instantaneous value of the vessel radius. A change in radius of 6 per cent during a cardiac cycle, as was found in the
right pulmonary artery, if ignored, could introduce an error of about 12 per cent in the flow value computed from the velocity at a given instant. Thus, in order to obtain a more nearly correct value for instantaneous flow, the value of radius must be known at every instant. At the present time, there is no good method for measuring instantaneous radius or diameter in the intact subject. Angiography can provide a rough estimate of the mean vessel size, and if combined with simultaneous pressure measurement, it will also permit a rough estimate of the instantaneous value of the radius during a cardiac cycle.

Greenfield et al. found, by direct measurement, ΔR/ΔP values for the main pulmonary artery of $8.72 \times 10^{-3}$ cm./cm. H$_2$O (personal communication) and $1.82 \times 10^{-3}$ cm./cm. H$_2$O for the ascending aorta. The vessel radius was measured by Greenfield et al. by sewing an electrical caliper to the vessel wall in patients undergoing surgery. It is interesting to note that these results are similar to ours when allowance is made for the fact that we studied the descending thoracic aorta and the major branches of the main pulmonary artery. The similarity of our data with those measured by the direct technique lends further support to the validity of the angiographic technique.

**Summary**

The radius of the pulmonary arteries and of the descending thoracic aorta in man was measured by angiographic techniques. Simultaneously with angiography, pressure measurements were carried out, permitting calculation of radius-pressure (ΔR/ΔP) relationships. The results obtained by this method are similar to those obtained by other methods in which the vessel radius was measured more directly.

**Acknowledgment**

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**References**

2. Barnett, G. O., Greenfield, J. C., Jr., and Fox, S. M.: Technique of estimating the instantaneous aortic blood velocity in man from the


Book Reviews


This volume contains papers presented by noted physiologists and clinicians from Germany, Holland, Sweden, Switzerland, and Italy at a symposium in Bremen, Germany. The presentations deal with basic theories, methodological possibilities, and clinical applications of determining the oxygen content in the arterial blood by means of photo-electric measuring devices. Actually, as Dr. Kramer explains in the preface, oxymetry, as used today, comprises three independent investigational methods: (1) photo-electric measurement of the oxygen saturation of hemoglobin in the circulating or drawn blood (this constitutes the original method of oxymetry); (2) photo-electric plethysmography; and (3) photo-electric measurement of dye concentration curves. The papers which were presented can be divided into these three categories. The material is necessarily very technical and probably of interest primarily to scientists and clinicians working with the described methods. For those, however, it constitutes a worthwhile reference work on theories, methods, and practical results. Each paper is followed by a bibliography. Interesting discussions are appended to some of the presentations.


This book represents the proceedings of an informal discussion convened jointly by the Faraday Society and the British Society of Rheology. The first part of the book defines many terms in common usage in rheology and describes some of the complex behavior which is shown by solutions containing large molecules. This is followed by 21 papers on properties of blood, i.e., on anomalous viscosity, differential flow velocities, wall adherence, turbulence, rheodichroism, thrombelastography, and sedimentation. The properties of fluids other than blood are also discussed.
Pressure-Radius Relationship in Large Blood Vessels of Man
Peter C. Luchsinger, Murray Sachs and Dali J. Patel

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