Volumes and Compliances Measured Simultaneously in the Right and Left Ventricles of the Dog


ABSTRACT

In 10 normal dogs, the right and left ventricular volumes and compliances were determined in the fresh post-mortem heart. With the use of a Sigma-Motor pump, Ringer's solution at 23°C was simultaneously infused into both ventricles within an hour after death. When the ventricles were full but open to atmospheric pressure, the mean volumes were 35.8 ml/m² for the right and 23.1 ml/m² for the left ventricle; when the transmural pressure was increased by 10 mm Hg, the mean volumes were 56.9 ml/m² for the right and 41.9 ml/m² for the left ventricle; at 20 mm Hg, the values were 60.8 and 48.5 ml/m², respectively. The initial volumes and the increases in volume produced by increase in transmural pressure were affected by the position of the ventricular septum and by the presence of rigor mortis. With infusions into only one ventricle, right and left ventricular volumes were 20 to 74% greater at 10 mm Hg than the values when both ventricles were filled simultaneously. Compliance began to decrease 40 to 60 min after death; at 130 min after death (23°C), the change in volume when the transmural pressure was increased to 10 mm Hg was only about 1/5 of that immediately after death.

ADDITIONAL KEY WORDS

rigor mortis  ventricular septum  pressure-volume curves  unilateral vs. bilateral filling

The purpose of these experiments was to study, in the fresh post-mortem heart, the volume-pressure relationships of the right and left ventricles of the dog. Such relationships previously reported are difficult to interpret, and are of uncertain relevance to conditions in vivo, because the effects of rigor mortis were not always considered and because in previous studies fluid was infused into only one ventricle at a time (1-3). In the present study we have found that volume-pressure relationships are highly dependent upon the state of filling of the contra-lateral chamber. Hence, the values of volume and compliance reported here, using the technique of simultaneous biventricular filling, are probably physiologically more meaningful.

Methods

Ten mongrel dogs weighing between 12 and 23 kg were intravenously anesthetized with sodium pentobarbital, 27 mg/kg. A midsternal incision was rapidly made and the vessels, esophagus, and trachea were transected; the beating heart was then immersed in Ringer's solution at 23°C. The pericardium was incised and slipped to its insertion on the great vessels. The pericardium and other tissues were cut away leaving the atria and ventricles intact. With the use of Ringer's solution, blood was flushed from both ventricles. Polyethylene catheters, PE 240 (o.d. = 0.82 inches; i.d. = 0.062 inches), were inserted into the left and right ventricles via the atrio-ventricular valves. Heavy cotton suture, securely tied at the atrio-ventricular groove, closed off the ventricular inflow tracts. Two other polyethylene catheters, inserted into the right and left ventricles via the pulmonic and aortic valves were securely tied in place by a heavy string at the level of the semilunar valves. Inflow catheters were connected to a Sigma-Motor Circulation Research, Vol. XX, May 1967

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pump; outflow catheters were connected to stopcocks which could be opened either to pressure transducers (CEC 4-307; 0 to 40 cm Hg) or to air (Fig. 1). When opened to air, 8 ml/sec of Ringer's solution at 23°C was simultaneously pumped into the right and left ventricles to the point of overflow. This outflow pressure is termed $P_o$.

Since an accurate determination of volume was of fundamental importance, experiments were carried out in air to facilitate detection of leaks. Experiments were also performed with the heart immersed in a water bath to provide a uniform transmural pressure. The volumes of fluid required to fill the ventricles to $P_o$ were then determined by subtracting the fluid leaving the heart from the amount of fluid pumped into the system. This was denoted as the "fill" volume of the heart. Polyethylene catheters, connected to the inflow system (Fig. 1) were held below the level of the heart so that both ventricles could be passively, rapidly, and completely siphoned drained. These were recorded as the "drain" volumes of the ventricle and were not statistically different from the "fill" volumes. To determine the compliance of the heart, the ventricles were simultaneously filled with fluid to $P_o$. Stopcocks were opened to the transducer, closing off the outflow system; fluid was then simultaneously pumped into the right and left ventricle for approximately 4 sec. The volume-pressure relationship thereby recorded was a continuous curve.

The coefficient of variation for each determination averaged less than 10%. The ventricular volumes are expressed as milliliters per square meter of body surface area; the latter was calculated using the nomogram of Smith, using the length from snout to anus and the body weight (4). The values for volume to be reported are defined as follows: $V$ at $P_o$ is the maximum volume accepted by the ventricle under conditions of passive filling as defined above. $V$ at $P_x$ is the ventricular volume at x mm Hg. Changes in volume are designated as differences over a specified pressure range, i.e. $V_{P_o} - V_{P_x}$. Compliance is defined as the change in volume over a change in pressure, $\frac{AV}{\Delta P}$, as used by Guyton (5).

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1 $P_o$ was not atmospheric in experiments carried out in air except at the top of the ventricle. Pressure midway between the top and bottom of the cavity averaged 3 to 4 mm Hg. All other pressures are increments above $P_o$. 

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FIGURE 1

Schematic drawing of the apparatus for the simultaneous determination of the right and left ventricular volumes and compliances.

FIGURE 2

The change in volume ($V_{P_o} - V_{P_x}$) due to rigor mortis. Simultaneously filled ventricles in one heart.

FIGURE 3

Comparison of pressure and volume after uni- and biventricular infusion of Ringer's solution. The volume represented in the horizontal axis is that in excess of the volume present at $P_o$. The panel on the left presents data from the right ventricle. The number (1) refers to the volume-pressure curve produced after simultaneous biventricular continuous injection of fluid, followed in time by (2) injection of fluid into the right ventricle alone, and then by (3) simultaneous biventricular injection. The volume was decreased to $P_o$ between periods 1 and 2, and 2 and 3. In the right hand panel, a similar change occurred between biventricular injection and injection of the left ventricle alone.
VENTRICULAR VOLUMES AND COMPLIANCES

<table>
<thead>
<tr>
<th>Dog no.</th>
<th>Body surface area (m²)</th>
<th>Left pressure (mm Hg)</th>
<th>Right pressure (mm Hg)</th>
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</thead>
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<tr>
<td></td>
<td></td>
<td>0  S  10  15  20</td>
<td>0  S  10  15  20</td>
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<tr>
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<td>15.6 31.7 37.7 41.0 43.2</td>
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<td>2</td>
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</tr>
<tr>
<td>3</td>
<td>0.89</td>
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<td>31.8 47.1 49.9</td>
</tr>
<tr>
<td>4</td>
<td>0.78</td>
<td>30.5 37.9 42.2 45.5 48.2</td>
<td>43.0 52.6 57.1 60.4 63.2</td>
</tr>
<tr>
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<td>43.0 59.6 65.6 68.8 72.1</td>
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<tr>
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<td>38.9 71.8 76.1</td>
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<tr>
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<td>33.7 51.0 52.6 60.4 62.7</td>
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<tr>
<td>9</td>
<td>0.85</td>
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<td>37.3 49.9 53.7 56.3 56.0</td>
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<td>37.4 52.6 57.9 61.5 63.8</td>
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<td></td>
<td>23.1 34.8 41.9 45.4 48.5</td>
<td>35.8 52.2 56.9 59.0 60.8</td>
</tr>
<tr>
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<td>1.64 1.89 3.21 2.35 2.89</td>
<td>1.56 2.78 2.85 2.44 2.86</td>
</tr>
</tbody>
</table>

Results

EFFECTS OF RIGOR MORTIS

Eight experiments were carried out to define the time at which a significant change in the volume-pressure relationship occurred. The most rapid change observed is shown by the plot of $V_{P_{10}} - V_{P_{0}}$ for one experiment (Fig. 2). At room temperature ($23^\circ$C) significant reductions in volume were never seen within 40 min after the time of death of the animal and were gradual over the following 60 min. For the group of eight hearts, 130 min after removal, the $V_{P_{10}} - V_{P_{0}}$ for the right and left ventricles averaged 21% and 17%, respectively, of the same volumes taken after 15 to 30 min.

EFFECT OF UNI- AND BIVENTRICULAR INJECTION

The responses are characterized by the example shown in Figure 3. This demonstrates that the volume-pressure relationship with biventricular injection lies to the left of that observed when one ventricle alone is injected. In seven experiments the percentage increase of the right and left ventricular volumes after univentricular injection as compared with biventricular injection ranged from 2 to 23% at $P = 0$ and from 20 to 74% for the $V_{P_{10}} - V_{P_{0}}$. The differences were highly significant. Clearly then, when the fluid is

![Figure 4: Ventricular volume-pressure relationship in the normal dog after simultaneous biventricular continuous injection of Ringer's solution.](http://circres.ahajournals.org/)

![Figure 5: Ventricular volume recorded at 0 and 10 mm Hg pressure in the normal dog. Each symbol represents the average ventricular volume of an individual experiment.](http://circres.ahajournals.org/)
pumped into only one ventricle at a time, the volume-pressure curve is markedly different from that when both ventricles are infused at approximately the same pressure.

**VENTRICULAR VOLUME-PRESSURE RELATIONSHIP**

After simultaneous injection of fluid into both ventricles, the right ventricular volume-pressure curve always lay to the right of the left ventricular curve (Fig. 4). In 10 experiments at P₀, the mean volume for the right ventricle was 36 ml/m² ± 1.6 SE and for the left ventricle was 23 ml/m² ± 3.1 SE (Fig. 5 and Table 1). At P₁₀, the mean volume for the right ventricle was 57 ml/m² ± 3.1 SE and for the left ventricle was 42 ml/m² ± 2.1 SE. The change in ventricular volumes Vᵢ₋₁₀ – Vᵢ₀ for the right ventricle was statistically greater than for the left ventricle (P < 0.005). However, the change in ventricular volumes Vᵢ₋₁₀ – Vᵢ₀ for the right ventricles was not significantly different from the left ventricle (P > 0.05).

**Discussion**

To obtain information readily applicable to the functional ventricle from determination of volumes and compliances certain factors must be recognized. We have demonstrated that the volumes accepted by the cardiac ventricles during a simultaneous bi-ventricular infusion are significantly less than the volumes determined with infusion into one ventricle alone. The mean magnitude of this difference is of the order of 30%; greater effects were observed at higher pressures. This difference in ventricular volumes may be attributed to a passive shift in the ventricular septum.

Since rigor mortis significantly decreases the ventricular volume-pressure ratio (6-9), post-mortem, volume-pressure studies must take into account this factor. In our experiments at 23°C, only one heart showed such effects in less than 1 hour, although marked effects were present at 2 hours. This is consistent with the observations of Griggs et al. (1), who found a reduction similar to that observed by us at 2 hours. However, Brecher et al. (10) reported no change in the volume-pressure curves 3 hours after death. The apparent discrepancy may be attributed to the lower temperature of their Ringer solution (10°C). In support of this thesis, Griggs et al. (1) and Kolder et al. (2) demonstrated that a decrease in temperature increased the time of onset of rigor mortis.

Clearly, therefore, several factors must be defined for meaningful conclusions relevant to volume. It is generally agreed that values for chamber volume reported without values for filling pressure are of limited worth. Our study demonstrates, in addition, that if univentricular injection is employed and the effect of rigor mortis is ignored, conclusions as to significance of volumes are open to serious question. Recent studies of ventricular volumes have been deficient in one or all of the factors mentioned above (3, 9). Parenthetically, an investigator employing univentricular injection may obtain values more closely related to the in vivo state if he has allowed the establishment of rigor mortis. The above considerations serve to limit the usefulness of many observations in which the ventricular chambers were measured after death (3, 9-11).

Under the conditions of the present study, at a definitive pressure, left ventricular volumes were always less than the volumes of the right ventricle. This may be simply attributed to the greater amount of muscle fibers or connective tissue present in the left ventricle. However, since this condition also pertains to a transmural pressure of P₀, the actual inner wall dimension "unfolded" but unstretched, represented by V at P₀, has to be less. Furthermore, the compliance of the left ventricle (ΔV/ΔP) was less than that of the right.

We herein report values for ventricular volumes from P₀ to P₂₀ obtained under conditions more closely applicable to the in vivo state than heretofore. Values obtained in this manner have not been reported previously and are not available for comparison. In other studies, values obtained have seldom been reported in a uniform format. Our...
method gives a useful estimate of ventricular volumes and compliances in the post-mortem heart.

References
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