Pulmonary Arterial Blood Volume and Tissue Volume in Man and Dog

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ABSTRACT

After the injection of an ethyl ether-alcohol solution above the pulmonic valve, the pulmonary arterial circulation time was determined in conscious man by an established body plethysmographic technique and in anesthetized man by a newly developed pneumotachographic method. In the anesthetized dog, estimates of pulmonary arterial circulation time determined by this new method were compared with those simultaneously determined by the plethysmographic method; agreement was good. The usefulness of applying corrective factors for the right-to-left intrapulmonary shunt and the uptake of ether gas from the alveoli into the blood while the ether gas is being evolved from the initial injection was evaluated from the dog experiments. In five humans with normal pulmonary arterial pressures, pulmonary arterial blood volume estimated by these methods was 172 ± 22 (SD) ml. Estimates of pulmonary tissue volume in both dogs and man were much larger than previously reported values determined from the tritiated water space of the lungs but more in keeping with previously published estimates of the total water content of the lungs determined at postmortem examination.

KEY WORDS  ether pneumotachographic method lung density pulmonary circulation time dog lung water mean transit time

Feisal et al. (1) have described a body plethysmographic method for measuring pulmonary arterial circulation time, pulmonary arterial blood volume, lung density, and tissue volume in anesthetized apneic dogs. Their method is based on the principle that ether gas, injected as a solution above the pulmonic valve, can be detected as it arrives at the pulmonary capillaries by a rise in plethysmographic pressure. The method has subsequently been employed to quantify aspects of the pulmonary circulation not readily measurable by other techniques. It has been used (a) to measure the intrapulmonary reaction times of bicarbonate, lactic acid, and tris(hydroxymethyl)aminomethane (2, 3), (b) to estimate the size of gas exchange vessels within the lung (4), and (c) to demonstrate the effects of breathing hypoxic mixtures on the mechanical properties of large pulmonary arterial vessels (5). However, the plethysmographic method has not yet been applied to humans. The purposes of the present study were (a) to determine the feasibility of using the ether plethysmographic method in conscious man, (b) to describe a modification of the technique involving a pneumotachograph and to compare its accuracy with that of the standard plethysmographic method in anesthetized dogs, and (c) to determine the feasibility of using the pneumotachographic method in anesthetized man.

Methods

ETHER PLETHYSMOGRAPHIC METHOD

For the comparison between the ether plethysmographic and ether pneumotachographic methods, an anesthetized apneic dog was enclosed in the body plethysmograph, an airtight chamber, and 0.5-2 ml of an ethyl ether-alcohol solution (1:4) was rapidly flushed into the pulmonary artery with 3-8 ml of saline. The same procedure was used for conscious humans except that, instead of remaining apneic, they exhaled slowly at a relatively constant flow rate (2-3 liters/min) which they regulated by using a visual monitor connected to the output of a Fleisch pneumotachograph. This change in procedure was made because it was difficult for the subjects to remain relaxed with an open glottis during apnea. This maneuver imposed a steady ramp signal on the plethysmographic tracing, but this signal could easily be separated from that which resulted from ether injection. An initial rise in plethysmographic pressure occurred as a result of the saline flush, but the plethysmographic pressure was calibrated as a volume and the volume of saline injected was recovered completely in the pressure waveform (Fig. 1). After the saline flush, a slower rise in plethysmographic pressure caused by the entry of gaseous ether into the alveoli proceeded until a peak was reached. As blood with a decreasing concen-
Arrival time of ether at the capillaries because of differences in flow rates to different parts of the lung. The mid-volume point of the rise in plethysmographic pressure corresponds to the arrival time of half the ether at the capillaries. If ether is uniformly mixed with the blood, the ether concentration in all branches of the pulmonary artery will be equal; thus, the arrival of half the ether indicates the arrival of half the blood at the capillaries. The measurement of median transit time was more rapid and easier to obtain than that of mean transit time, a parameter which might be more accurate if the evolution of ether behaves as a cumulative frequency motion. For the calculation of the mean transit time, it is necessary to perform the following operation on the ether curve:

\[
\text{Mean transit time} = \frac{\int_0^T dV}{\int_0^T dV}
\]

where \( t = \) time and \( dV \) is an element of the volume of ether at any point in time. This analysis is more time consuming, and Feisal et al. (1) did not use it, since their preliminary studies had suggested that the results of both median and mean transit times were similar. Their studies had also pointed out that the pressure-time curve after ether injection was not a true cumulative frequency function, since ether returned to the blood before peak plethysmographic pressure was reached.

Compensation for the return of ether to the blood prior to its peak evolution can be made by correcting for the elapsed time, the degree of pressure change, and the rate constant of the descending curve following peak plethysmographic pressure. The peak ether volume was delineated and a least-squares fit on the descending curve was performed to obtain its slope. The ether curve was translated as

\[
V'(t) = V(t) - m(t - t_i)
\]

for \( t_i = t_m \), where \( V'(t) \) is the translated function, \( V(t) \) is the original ether curve, \( m \) is the slope, \( t \) is the time, \( t_i \) is the initial time of the inscription of the ether curve, and \( t_m \) is the time of the peak ether volume. This correction is additive to the actual volume of ether measured. Since the volume of ethyl ether gas evolved is a function of the ratio of alveolar volume to pulmonary capillary plus tissue volume (1), this correction sets a lower limit to the estimate of pulmonary tissue volume. Another correction which must be considered is the amount of right-to-left intrapulmonary shunting of blood. The larger the shunt, the less the volume of ether evolved; failure to allow for this correction results in an overestimate of pulmonary tissue volume. In the present study, the significance of these correction factors was systematically examined.

**Ether Pneumotachographic Method**

This method was developed to study apneic subjects on respirators or under anesthesia and is based on a technique described by Wasserman and Comroe (6) and later modified by our group (7). It has been used to estimate nitrous oxide uptake as a prerequisite for calculating pulmonary capillary blood flow. During apnea, the chest becomes analogous to the body plethysmograph and, with a sensitive pneumotachograph at the airway, the evolution of ether gas can be detected as a rise in expiratory air flow superimposed on the cardiogenic oscillations (Fig. 1). Such oscillations of flow are synchronous.
with the heart beat and are as much as 7–15 times larger than the peak flow due to evolution of ether gas. Filtering of these oscillations is probably best accomplished by a low-pass digital filter with a sharp cut-off, since the period of oscillations is much faster than the period of ether evolution. However, the core restrictions in our small digital computer prevented us from using this procedure. Trials of several methods of eliminating the cardiogenic oscillations from the record established that the most reproducible method compatible with our system was to use the cardiogenic oscillation immediately preceding ether injection as a template to subtract the oscillatory content beat by beat throughout the ether evolution. The resultant flow curve was integrated to give the volume of ether gas evolved, and the pulmonary arterial circulation time was computed as it was in the analysis of plethysmographic records. The pneumotachographic method was impossible to use in conscious subjects, since reproducible base-line cardiogenic flow oscillations could not be obtained owing to incomplete relaxation of the thorax.

DATA PROCESSING

A program was written to run on both a standard LINC 8 digital computer with 4K of core and a PDP 12 (Digital Equipment Co.) computer. Analog signals were put into the computer by analog-to-digital converters. Input data included (1) signal from the injection apparatus (Cordis Injector, Cordis Corp.) which delivered saline to flush the ether solution into the pulmonary artery, (2) electrocardiogram, and (3) flow signal from the pneumotachograph or volume signal from the body plethysmograph. The program calculated the mean and the median pulmonary arterial circulation time and displayed the ether curve. The program allowed the user to enter digital values of the volume of liquid ethyl ether injected, the alveolar volume, and the pulmonary capillary blood volume into the computer; thus, calculations of lung density and pulmonary tissue volume as described by Feisal et al. (1) could be performed. In the present study, the partition coefficient used for ether in lung tissue was 12 (8, 9) rather than 15.5 as was used by Feisal et al. (1). Right-to-left intrapulmonary shunt was determined during breathing of 100% O\textsubscript{2}, and this shunt fraction was subtracted from the volume of liquid ethyl ether injected to correct for the volume of the solution not arriving at the alveolocapillary membrane. The raw data were examined at various points in the program before finalizing the display (Fig. 2).

DOG EXPERIMENTS

Twenty-three mongrel dogs (13–30 kg) were anesthetized with sodium pentobarbital (25 mg/kg, iv). They were intubated with a cuffed endotracheal tube, and catheters were inserted in the pulmonary and carotid arteries and a peripheral vein. Ten dogs were paralyzed with intermittent administration of succinyl choline chloride and ventilated with a Harvard respirator. In 5 of these 10 dogs, marked sinus arrhythmia occurred and a bipolar electrode was placed in the right atrium to pace the heart at a regular rate. In 13 other dogs, ventilation was supported by transvenous phrenic nerve stimulation (10). Cardiac pacing was not required in these dogs, since sinus arrhythmia was not encountered. In 7 dogs, both pulmonary arterial and left atrial pressures were measured and cardiac output was estimated by the dye-dilution method using indocyanine green.

A dog was enclosed in a body plethysmograph which had an internal volume of 170 liters (11). Plethysmographic pressure was sensed by a differential pressure gauge (DP 45 ± 1 inches H\textsubscript{2}O, Validyne Corp.). The frequency response of the chamber was flat to 21 Hz. Flow at the airway during apnea was sensed through a...
no. 00 Fleisch pneumotachograph connected to a differential gauge (DP 45 ± 1 inches H₂O) inside the body plethysmograph. The frequency response of the pneumotachographic system was flat to 14 Hz. After calibration of the plethysmograph and pneumotachograph, 0.5-2 ml of an ethyl ether-alcohol solution (1:4) was instilled into a cardiac catheter whose tip was positioned just above the pulmonic valve. A baseline was established for both plethysmographic pressure and pneumotachographic flow for 2-3 seconds during apnea. The ether solution was flushed into the pulmonary artery with 3-8 ml of saline solution through a Cordis Injector triggered to deliver the saline just after the inscription of the R wave of the electrocardiogram (ECG). The data were recorded on magnetic tape and analyzed off-line on a LINC-8 digital computer. (The data could have been analyzed on-line if the computer had been nearby.)

**Ether Circulation Time in Man**

After informed consent for the procedure was obtained, three conscious subjects were studied by the ether plethysmographic method and three anesthetized subjects were studied by the ether pneumotachographic method. The same type of gauges utilized in the dog experiments were employed. The frequency response of the human chamber was flat to 19 Hz. Under fluoroscopic control a cardiac catheter was placed just above the pulmonic valve. The catheter had a sealed tip and multiple proximal side holes to minimize its recoil after the injection of fluid. The accuracy of its position was checked by gently withdrawing it from the pulmonary artery until the right ventricular pressure curve was recorded and then advancing it until the pulmonary arterial pressure tracing was obtained. The catheter’s position was not rechecked until the end of the procedure. Cardiac output was measured by the nitrous oxide plethysmographic method in the conscious subjects and by the nitrous oxide pneumotachographic method in the anesthetized subjects (12, 13). Alveolar volume was measured by the plethysmographic method (14) in the conscious subjects and by a rapid helium rebreathing technique (11) in the anesthetized subjects. Pulmonary capillary blood volume was estimated from carbon monoxide disappearance curves obtained from multiple breath-holding times at two different alveolar oxygen tensions (15). Student’s t-test was used for statistical significance between means.

**Results**

**Comparison of Ether Plethysmographic and Pneumotachographic Methods in Dogs**

In 60 simultaneous determinations from 16 dogs, only 10% of the mean transit time measurements by the pneumotachographic method varied more than 10% from the plethysmographic determination (Fig. 3). However, 13% of the pneumotachographically determined ether volumes varied more than 20% and 17% of the volumes varied more than 10% from the plethysmographic estimation (Fig. 4). In two successive measurements within a 3-minute period, both pulmonary arterial circulation time calculated from either mean or median transit times and volume of ether evolved calculated by either method varied less than 10% from the mean value for the respective method. For example, 35 sequential pairs of median transit time determinations had a mean of 0.98 ± 0.36 (SD) seconds for the first trial and a mean of 0.98 ± 0.36 seconds for the second trial. The mean difference between the trials, disregarding algebraic sign, was 0.08 ± 0.08 seconds.

In 110 determinations from 28 dogs the pulmonary arterial median transit time (1.22 ± 0.44 [SD] seconds) determined by the plethysmographic technique was consistently less in paired observations than the mean transit time (1.29 ± 0.48 seconds, P < 0.001). The ether curve was corrected by adding the ether gas evolved as a function of the rate constant of the descending curve following peak plethysmographic pressure. This correction gave the following results: in 70 determinations from 10 dogs, the mean transit time rose from 1.44 ± 0.42 seconds to 1.51 ± 0.67 seconds (P < 0.001) and the median transit time rose from 1.36 ± 0.42 seconds to 1.43 ± 0.58 seconds (P < 0.001). The volume of ether evolved by the plethysmographic method prior to the correction for loss to the blood was 8.9 ± 2.8 (SD) ml and after correction 9.9 ± 3.5 ml (P < 0.001).

In six dogs, there were no significant changes in
ether circulation time

either the pulmonary arterial circulation time or the volume of ether gas evolved as measured by the plethysmographic method whether the measurement was made with an open or an occluded airway at the functional residual capacity position.

**PULMONARY TISSUE PLUS CAPILLARY VOLUME IN DOGS**

Duplicate values for pulmonary tissue plus capillary volume varied by less than \(10\%\) in 14 dogs and by less than 15\% in the remaining 3 of the 17 dogs measured. In Table 1, the value of the sum of pulmonary tissue plus capillary volume is listed for the first 10 dogs studied; the volume of ether evolved was corrected for right-to-left intrapulmonary shunting and the rate constant of the ether redissolving in the blood after peak volume was reached. A value for pulmonary capillary blood volume was calculated from previously published values for dogs (16); this value was then subtracted from the combined pulmonary tissue plus capillary volume to estimate tissue volume alone. Values for pulmonary tissue volume were quite variable and ranged from 4.2 ml/kg to 12.2 ml/kg with a mean of 8.3 ml/kg. In these first 10 dogs, pulmonary arterial pressure was within normal limits. To exclude a hemodynamic factor as the cause of the variability of pulmonary tissue volume measurements, pulmonary arterial pressure, left atrial pressure, and cardiac output were measured in dogs 11–17 (Table 1). All these parameters were within normal limits +20%  +10% and the variability of pulmonary tissue volume did not differ from that for the first 10 dogs.

**PULMONARY ARTERIAL BLOOD VOLUME AND TISSUE VOLUME IN MAN**

The injection of an ethyl ether–alcohol solution into the pulmonary artery of the conscious subject did not produce subjective symptoms except the taste of ethyl ether at about the time when the peak evolution of ethyl ether was being recorded. None of the subjects coughed. In both the conscious and anesthetized subjects, pulmonary arterial pressure, left atrial pressure, and cardiac output were measured in dogs 11–17 (Table 1).

![Comparison of 60 simultaneous determinations from 16 dogs of volume of ether evolved by the ether pneumotachographic and plethysmographic methods.](image)

**TABLE 1**

<table>
<thead>
<tr>
<th>Dog</th>
<th>Weight (kg)</th>
<th>Lung density (g/ml)</th>
<th>(V_T + V_r) (ml)</th>
<th>(V_T) (ml)</th>
<th>(V_r/kg) (ml/kg)</th>
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<tbody>
<tr>
<td>1</td>
<td>15.9</td>
<td>0.18</td>
<td>145</td>
<td>30</td>
<td>115</td>
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<td>2</td>
<td>13.6</td>
<td>0.18</td>
<td>98</td>
<td>26</td>
<td>72</td>
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<tr>
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<td>0.20</td>
<td>119</td>
<td>31</td>
<td>88</td>
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<tr>
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<td>20.5</td>
<td>0.16</td>
<td>180</td>
<td>29</td>
<td>141</td>
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<tr>
<td>5</td>
<td>20.4</td>
<td>0.23</td>
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<td>39</td>
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</tr>
<tr>
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<td>26.0</td>
<td>0.13</td>
<td>304</td>
<td>49</td>
<td>255</td>
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<tr>
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<td>16.0</td>
<td>0.27</td>
<td>226</td>
<td>30</td>
<td>196</td>
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<tr>
<td>9</td>
<td>19.1</td>
<td>0.14</td>
<td>117</td>
<td>36</td>
<td>81</td>
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<tr>
<td>10</td>
<td>18.3</td>
<td>0.16</td>
<td>195</td>
<td>31</td>
<td>164</td>
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<tr>
<td>11</td>
<td>27.3</td>
<td>0.29</td>
<td>432</td>
<td>52</td>
<td>380</td>
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<tr>
<td>12</td>
<td>24.1</td>
<td>0.17</td>
<td>172</td>
<td>46</td>
<td>136</td>
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<tr>
<td>13</td>
<td>21.4</td>
<td>0.15</td>
<td>159</td>
<td>41</td>
<td>118</td>
</tr>
<tr>
<td>14</td>
<td>27.3</td>
<td>0.17</td>
<td>217</td>
<td>52</td>
<td>165</td>
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<tr>
<td>15</td>
<td>23.2</td>
<td>0.23</td>
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<td>230</td>
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<tr>
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<td>20.4</td>
<td>0.17</td>
<td>256</td>
<td>39</td>
<td>217</td>
</tr>
<tr>
<td>17</td>
<td>15.9</td>
<td>0.18</td>
<td>140</td>
<td>30</td>
<td>110</td>
</tr>
</tbody>
</table>

**MEAN** 20.8 (±4.7) 216 (±9) 177 (±64) 8.3 (±2.8)

\(V_T\) is the pulmonary tissue volume and \(V_r\) is the pulmonary capillary tissue volume.

* Based on value of 1.9 ml/kg from ref. 16.

and the variability of pulmonary tissue volume did not differ from that for the first 10 dogs.
ties ranged from 0.07 to 0.22 g/ml and combined pulmonary capillary plus tissue volume ranged from 221 to 438 ml with a mean of 330 ml (200 ml/M²B.S.A.).

Discussion

PULMONARY ARTERIAL BLOOD VOLUME

The injection of ethyl ether dissolved in alcohol into the pulmonary artery of man appears to be a safe procedure. We injected 0.2–0.4 ml of ethyl ether in alcohol, whereas Fraser et al. (17) used 0.1–0.2 ml of ethyl ether and followed it with a saline flush to detect right-to-left intracardiac shunts. No ill effects were observed in the 109 subjects undergoing the latter procedure. However, their normal subjects generally coughed after ethyl ether injection into the pulmonary artery. The studies of Feisal et al. (1) suggest that the cough in their subjects might be related to formation of bubbles of ether gas in the blood when the liquid is injected; bubbles do not form when the ethyl ether is dissolved in alcohol.

This report describes the first estimates of pulmonary arterial blood volume in man from determinations of ether circulation time. Values of pulmonary arterial blood volumes in our five subjects with normal pulmonary arterial pressures ranged from 135 to 198 ml with a mean of 172 ml; in one subject with pulmonary hypertension, the value was only 90 ml. This lower value corresponded to the generalized narrowing of the pulmonary arterial vessels seen in the lobar arteries and the smaller arteries on chest roentgenogram and in the histologic examination of the lung biopsy. Preliminary reports of the determination of pulmonary arterial transit time by scanning the activity of radioiodinated macroaggregated serum albumin from the

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ETHER CIRCULATION TIME

Pulmonary Arterial Blood and Tissue Volume in Man

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age</th>
<th>Diagnosis</th>
<th>Method</th>
<th>Mean transit time (sec)</th>
<th>( V_{PA} ) (ml)</th>
<th>( Q_c ) (l/min)</th>
<th>LD (g/ml)</th>
<th>( V_T + V_C ) (ml)</th>
<th>( V_C ) (ml)</th>
<th>( V_T ) (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JG</td>
<td>29</td>
<td>Functional systolic murmur</td>
<td>Plethys</td>
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<td>162</td>
<td>5.31</td>
<td>0.12</td>
<td>438</td>
<td>80</td>
<td>358</td>
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<tr>
<td>DR</td>
<td>21</td>
<td>Postoperative pulmonic valvulotomy</td>
<td>Plethys</td>
<td>1.48</td>
<td>198</td>
<td>8.03</td>
<td>0.08</td>
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<td>Coronary artery disease</td>
<td>Pneumo</td>
<td>2.17</td>
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<td>Pneumo</td>
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<tr>
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<td>66</td>
<td>Tetanus</td>
<td>Pneumo</td>
<td>1.94</td>
<td>135</td>
<td>4.18</td>
<td>0.22</td>
<td>385</td>
<td>48</td>
<td>237</td>
</tr>
<tr>
<td>MEAN</td>
<td></td>
<td></td>
<td></td>
<td>2.12</td>
<td>172</td>
<td>5.21</td>
<td>0.12</td>
<td>330</td>
<td></td>
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<tr>
<td>± SD</td>
<td></td>
<td></td>
<td></td>
<td>±0.57</td>
<td>±22</td>
<td>±1.58</td>
<td>±.05</td>
<td>±88</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Normal Pulmonary Arterial Pressure

Mean transit time indicates pulmonary arterial circulation time. \( V_{PA} \) is the volume of blood in the pulmonary arterial tree, \( Q_c \) is the pulmonary capillary blood flow, LD is the lung density, \( V_T \) is pulmonary tissue volume, and \( V_c \) is pulmonary capillary blood volume. Plethys = plethysmography and Pneumo = pneumotachography.

Pulmonary Hypertension

| BR      | 62  | Primary pulmonary hypertension | Plethys | 2.35                   | 90                | 2.30             | 0.20      | 705                  | 15             | 690         |

Mean transit time indicates pulmonary arterial circulation time. \( V_{PA} \) is the volume of blood in the pulmonary arterial tree, \( Q_c \) is the pulmonary capillary blood flow, LD is the lung density, \( V_T \) is pulmonary tissue volume, and \( V_c \) is pulmonary capillary blood volume. Plethys = plethysmography and Pneumo = pneumotachography.

opening of the pulmonic valve to the periphery of the lung are in close agreement with the present studies in both dogs and humans. Lewis and Herrera (18) compared the scanning technique in dogs with the ether plethysmographic method and found that 20 of 25 determinations of pulmonary arterial transit time fell within 20% of a line of identity. They also found (19) that the average pulmonary arterial blood volume in man ranged from 149 ml to 215 ml with a mean of 182 ml. Since the method of Lewis and Herrera (18, 19) depends on injection of the tracer into the right atrium and does not involve enclosing the subject within a body plethysmograph, it may be more practical to use if only pulmonary arterial circulation time and not an estimate of pulmonary tissue volume is desired. Indeed, the complexity of enclosing volunteer subjects within a body plethysmograph with a catheter in the pulmonary artery has made us abandon the method in conscious humans. The method of detecting ether gas evolution by measuring the flow at the airway with a sensitive pneumotachograph eliminates the need for a body plethysmograph but cannot be used in conscious subjects because training them to relax their chests during apnea while the glottis is held open is extremely difficult. However, this method is ideal for use in anesthetized humans and also should be applicable to subjects on mechanical respirators who often have a Swan-Ganz catheter in the pulmonary artery for monitoring the pressure within this vessel. It can be used in cases of mild but not marked sinus arrhythmia but cannot be employed when atrial fibrillation or ectopic beats are present.

PULMONARY TISSUE VOLUME

It is difficult to compare our values for pulmonary tissue volume in man to previously reported values which were determined from either inspiration of soluble gases (20, 21) or estimation of pulmonary extravascular water space by the indicator-dilution technique using tritiated water (22). Pulmonary capillary blood volume, a prerequisite for calculating pulmonary tissue volume from the space measured by the ether method, was not measured in all our subjects. Furthermore, only one of our subjects had a normal cardiopulmonary system, although four of the remaining five with cardiac disease had normal pulmonary arterial pressures at rest. Pulmonary tissue volume determined by ether injection appears to be between the value for the space measured by the tritiated water indicator-dilution method (22) and the larger value determined from inspiration of soluble gases (20, 21). In one of our subjects with primary pulmonary hypertension, the combined pulmonary tissue plus capillary volume was about twice the mean value for the rest of the group. This finding might have been related to the low-output cardiac failure present in this patient.

The variability in duplicate measurement of pulmonary tissue plus capillary volume by the ether plethysmographic method was approximately the same as the variability for determining the pulmo-

**TABLE 2**

Pulmonary Arterial Blood and Tissue Volume in Man

Mean transit time indicates pulmonary arterial circulation time. \( V_{PA} \) is the volume of blood in the pulmonary arterial tree, \( Q_c \) is the pulmonary capillary blood flow, LD is the lung density, \( V_T \) is pulmonary tissue volume, and \( V_c \) is pulmonary capillary blood volume. Plethys = plethysmography and Pneumo = pneumotachography.
nary extravascular water space by the tritiated water indicator-dilution technique. This variability cannot be accounted for by the presence of hemodynamic pulmonary edema; the explanation is uncertain. Correlation between the value determined from ether plethysmography and that obtained from morphometry will have to be undertaken. Morphometry in dogs yields a pulmonary extravascular water content of 3.5 ml/kg body weight (23), which is slightly less than one-half the value of pulmonary tissue volume determined by the ether plethysmographic method (Table 1). Since the tritiated water indicator-dilution technique estimates only about 50% of the water content of the lungs at autopsy (23), the ether plethysmographic method appears to more closely reflect the total water content of the lungs. This finding is consistent with data obtained in man from the transient uptake of nitrous oxide by a plethysmographic method which gives values for pulmonary tissue volume (21) about twice those reported for the tritiated water indicator-dilution studies (22).

ETHER CIRCULATION TIME

As reported by Feisal et al. (1) and confirmed in the present study, the mean transit time for ether solution from the pulmonic valve to the capillaries is slightly greater than the median transit time. In addition, Feisal et al. (1) have pointed out that some ether might return to the blood before peak pressure is reached and consequently the ether curve should be corrected for the pressure decay at every point as a function of elapsed time, the degree of pressure change, and the rate constant of the descending curve. They have also stated that both these corrections involve an improvement in accuracy to 5% and that the routine use of these corrections does not justify the longer method of calculation. The present study showed that these corrections could not be neglected. The mean pulmonary arterial transit time was about 6% longer than the median transit time and the correction for pressure decay added another 5% to the mean transit time. Therefore, failure to account for these corrections would result in underestimating pulmonary arterial blood volume by 11%.

LUNG DENSITY

The mean value of lung density (0.16 g/ml) determined in our 10 dogs was lower than the mean value of lung density (0.23 g/ml) found in 12 dogs by Feisal et al. (1). However, in the present study a smaller value was chosen for the partition coefficient of ethyl ether and the right-to-left intrapulmonary shunt was corrected for; therefore, the mean value of lung density was lower. The density of the lung in humans is generally less than it is in dogs because the lung volume is proportionally much larger than the tissue volume. This apparent structural difference between human and canine lung remains unexplained.

Acknowledgment

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References


Pulmonary Arterial Blood Volume and Tissue Volume in Man and Dog
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