RED CELL AND PLASMA VOLUMES (CIRCULATING AND TOTAL) AS DETERMINED BY RADIO IRON* AND BY DYE†

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The total blood volume is usually calculated from the plasma volume and the venous hematocrit with the use of the formula:

\[
\text{Total blood volume} = \frac{\text{Plasma volume}}{1 - \text{venous hematocrit}}
\]

The plasma volume has commonly been determined by one of the several dye dilution methods and as performed has been assumed to be accurate to within 5 per cent. The venous hematocrit has been assumed to be representative of the average hematocrit of all the blood in the vascular system. Application of the principles of hydrodynamics to the problems of blood flow and blood volume indicates that neither of these assumptions is valid. The experimental data to be presented confirm the fact that the blood volume values calculated from the plasma volume and venous hematocrit are subject to considerable systematic error.

In the observations subsequently to be described, we shall demonstrate by several techniques: that the mass of red blood cells in the body is approximately 75 per cent of the commonly accepted amount; that few of these cells are immobilized in "reservoirs;" that the mixing time for erythrocytes is much more rapid than that for dyes; and that the usually accepted times for mixing of dyes in the vascular system probably represent mixing in the "axial stream" only, and not in the entire contents of the vessels.

About 100 years ago Peclet (11, 15) pointed out that when a liquid moves over a solid surface a sluggishly moving fluid film exists on the surface of a stationary fluid film. The character of both films is entirely different from that of the main body of moving fluid, and they form a zone between the rapidly moving fluid and the wall,

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acting toward the transportation of heat, vapor, and matter as though they were a separate material. The presence of these films has been verified by many investigators (10), and their properties are controlling factors in many processes. Their characteristics receive important engineering consideration, and they deserve equally as much attention from the physiologist.

An instance of the importance of these films is encountered in a consideration of the mechanics of mixing of particulate matter in a vessel. A plot of the velocity of a fluid against its distance from the wall of the containing vessel shows that there is no motion of the fluid at the boundary wall (13), and that with progression toward the center of the tube the velocity of the motion increases. Near the wall of the vessel the fluid flow is in a path parallel to the wall, and there is no component of velocity at right angles to the latter. Approaching the center of the vessel, however, the fluid elements begin to travel in forward moving spirals although the "net flow" is still parallel to the wall. The path of any given particle now has a large component of velocity at right angles to the vessel wall. Thus, from a condition of "viscous," or "straight line" flow near the wall we have progressed to "turbulent" flow in the center. These two types of flow exert a profound and very different effect upon the mixing of the neighboring fluid layers.

Applying these principles to the problem of hemodynamics it is evident that when blood flows through a blood vessel, two films of plasma exist along the wall of the vessel, one without motion, and the other with a sluggish motion parallel to the wall of the blood vessel. The flow of this film is "viscous" or "straight line," and there is no turbulence or mixing between these films and the rest of the contents of the vessel. Microscopic inspection of small blood vessels shows that these films are for the most part devoid of erythrocytes.

The thickness of the surface films varies inversely with the velocity of flow of the main body of the fluid contents, and the percentage that they constitute of the total fluid contents of a vessel varies inversely with the diameter. In the blood vascular system as the arteries and arterioles become smaller and approach the capillary bed there is no increased velocity of blood flow, but an actual decrease in velocity. There is also a great increase in the number of vessels and a decrease in their diameter. Therefore the surface films might be expected to constitute a progressively increasing proportion of the total contents of small arteries, arterioles, and capillaries. That this should be the case is demonstrated by the following formula.

The total volume of the fluid in a unit length of vessel is \( \pi r_1^2 \) where \( r_1 \) is the radius of the vessel. If \( t \) is the thickness of the combined stationary and sluggish films, which consist of plasma only, then the radius of the body of fluid in axial flow is \( r_1 - t = r_2 \), and the volume of fluid in the axial stream is \( \pi r_2^2 \). The volume of plasma in the films is then \( \pi r_1^2 - \pi r_2^2 \). The fraction (f) of total plasma in the films is then

\[
\frac{\pi r_1^2 - \pi r_2^2}{\pi r_1^2}, \text{ eliminating } \pi.
\]

(1) This may be expressed as \( \frac{r_1^2 - r_2^2}{r_1^2} = f \).

(2) Equation (1) may be expanded to \( \frac{(r_1 + r_2)(r_1 - r_2)}{r_1^2} = f \).
(3) Now since \( r_1 - r_2 = t \) which is constant for a constant velocity of fluid flow we can substitute (3) in (2): \( \frac{(r_1 + r_2)k}{r_1^2} = f \) and, since \( r_1 \) approximates \( r_2 \) where \( t \) is small, we have \( \frac{2r_1 \cdot k}{r_1^2} = f \) or \( \frac{r_1}{r_1} \times \frac{k}{r_1} = f \); eliminating one \( r_1 \): \( \frac{k_1}{r_1} = f \). Thus, since \( f \) is shown to be indirectly proportional to the radius, as the vessel becomes smaller the fraction of plasma in sluggish movement increases. It is obvious that this relationship does not hold in capillaries where the diameter approaches that of a single red cell. However, Zweifach and Kossmann (18) found that the individual capillaries vary considerably in size, the fluctuations noticed being from 3 to 10 micra in diameter.

It has been observed by many investigators that rapid plasma flow may occur in vessels apparently too small to permit passage of red cells.

The influence of these surface films on determinations of blood volume was first pointed out by Hooper, Smith, Belt, and Whipple (9), who recognized that the hematocrit of capillary blood was considerably lower than that of venous blood due to the existence in small vessels of a central “axial stream” of cell-rich blood, and a peripheral, relatively cell-free “still space.” Using the carbon monoxide inhalation and Welcker viviperfusion methods to determine the volume of erythrocytes (“direct methods”) they demonstrated that the total mass of erythrocytes was 20 to 30 per cent less than the values obtained by calculations based on the plasma volume and venous hematocrit.

Fahraeus (2) emphasized the fact that the blood flowing through a capillary has a much lower ratio between cells and plasma than the blood which flows from its cut end, an observation which is explained by the relatively great velocity of flow of the cell-rich “axial stream,” and the slow flow of the peripheral films.

Using erythrocytes “tagged” with radioactive iron, and determining their dilution in the circulating blood, Hahn, Balfour, Ross, Bale, and Whipple (6) confirmed the fact that the total mass of red blood cells in the body is approximately 25 per cent less than that indicated by the plasma volume-venous hematocrit calculations.

Stead and Elbert (14) recently arrived at the same conclusion by demonstrating the discrepancy between hematocrit and hemoglobin changes produced by bleeding and the amounts of blood removed.

The surface film-axial stream relationship existing in the blood vessels and the differences in type of particle motion within them not only influence the distribution of erythrocytes in these vessels but also operate to retard the passage of dyes from the rapidly moving, turbulent axial stream into the sluggishly moving and stationary peripheral films. This difference in type of mixing has been neglected in the usual plasma volume determination, and has introduced considerable error into the procedure, an error which in turn has been reflected in the blood volume estimation.

Methods

Unexercised, healthy normal or anemic dogs were used for all experiments. To avoid lipemia the food was withheld for 18 hours before plasma volume determinations were made. Plasma volumes were determined by a modification of the brilliant vital red procedure (9). The amount of dye injected was sufficient to produce such a
concentration in the plasma sample that the colorimeter reading was within 10 per cent of the standard diluted dye reading. A single sample of plasma was secured 4 minutes after administration of the dye, care being exercised to avoid stasis in the vein and hemolysis. The anticoagulant used was 1.4 per cent sodium oxalate solution.

The mass of red blood cells was determined by four techniques: (a) by viviperfusion and determination of the total amount of hemoglobin removed (9); (b) by determination of the amount of tagged blood cells which had to be withdrawn to remove completely from the circulation all of the radioactive iron tagged cells (which had previously been built up in the circulation by methods described (7) elsewhere); (c) by determining the dilution of radioactive tagged cells after removal of a known quantity of blood (and radioactive tagged cells) when regeneration of blood had restored the original hematocrit; (d) by determining the dilution in the circulation of injected radioactive tagged erythrocytes (6).

The technique of the modified Welcker viviperfusion method has been described elsewhere (16). The perfusate was collected in isotonic sodium oxalate solution, and the hematocrit of an aliquot determined. Total iron content or radioactive iron concentration and hemoglobin content were determined on packed red cells, (since the use of whole blood for the latter procedure may lead to erroneous results (17)). Hemoglobin determinations were performed according to the method of Newcomer (12).

Determination of the red cell volume by either of the depletion techniques (method 2 or 3) was accomplished as follows: An iron depleted anemic dog was fed a single dose of radioactive iron and regeneration of hemoglobin was allowed to proceed until the concentration of this material in the blood was nearly constant. The animal was then bled repeatedly over a period of several weeks until all of the radioactive tagged cells were removed from the circulation. The radioactivity of the blood removed at each bleeding was determined, and the total activity of all the removed blood calculated. The total red blood cell volume was then calculated by dividing the total activity removed by the initial concentration of radioactivity per unit volume of cells.

A modification of this procedure consisted in bleeding the animal several times and allowing blood regeneration to restore the hematocrit to the same level that existed prior to the hemorrhages. Assuming the red blood cell volume to be the same at the same hematocrit level, this volume was then calculated by dividing the total radioactivity removed in the bleedings by the difference in concentration of the isotope in the circulating blood before bleeding and after regeneration.

The donor cell dilution method of determining red blood cell volume has been described briefly elsewhere (6). It has distinct advantages over other methods of cell volume determinations. It can be performed on normal animals or animals with any degree of anemia. The conditions under which it may be carried out are physiological and do not disturb the normal hemodynamics or vascular system. The tagged cells are not subject to loss from the vascular system (as are dyes and carbon monoxide). Erythrocytes "tagged" or "labelled" with radioactive iron were drawn from a donor dog in whom hemoglobin regeneration with radioactive iron had been produced (7). These cells, containing a known amount of radioactive iron, were then administered intravenously (in a period of 30 seconds) to the dog under study (whose own cells
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The radioactive isotope of iron, Fe²⁵⁹, used for these experiments was prepared by deuteron bombardment of iron and had a half period of 47 days. Preparation of samples for radioactivity determination has been described (4, 5).

EXPERIMENTAL OBSERVATIONS

1. The Erythrocyte Volume As Indicated by Viviperfusion

When properly performed viviperfusion very effectively removes practically all red cells from the body. The hematocrit of the perfusate is usually below 1 per cent terminally, and the tissues (with the exceptions of the spleen and bone marrow) are bloodless at autopsy and microscopically. As shown by the iron analyses of Hahn and Whipple (8), the total mass of erythrocytes left in the body after viviperfusion does not amount to more than 1 to 2 per
cent of the total cell mass. Thus the values for erythrocyte volumes shown in Table I are subject to an error of not more than 5 per cent. Comparison of the values for red blood cell volume as determined by viviperfusion is made with the values calculated from the plasma volume-jugular hematocrit. It is evident that in every instance the latter method gives results 15 to 30 per cent higher than those obtained by viviperfusion.

2. The Erythrocyte Volume As Determined by Depletion of Radioactive Iron Containing Cells

In Table II the volume of erythrocytes as calculated from the plasma volume and jugular hematocrit is compared with the volume as determined by depletion of radioactive iron containing cells over a period of weeks by repeated hemorrhages. Since the animals used in this type of experiment were iron deficient and only a single feeding of a small amount of iron was given, all of the radioactive isotope was present in circulating erythrocytes at the beginning of the experiments. Complete removal of these tagged cells reasonably can be assumed to indicate complete removal of all the cells present in the vascular system at the beginning of the experiment. The mass of cells as determined by this procedure is found to be 24 and 39 per cent lower than the values calculated from the plasma volume and jugular hematocrit.

3. The Erythrocyte Volume As Indicated by the Regeneration Dilution of Radioactive Iron Containing Cells

The volume of erythrocytes determined by regeneration dilution of radioactive iron containing cells following removal by bleeding of a known quantity of blood is compared with the values calculated from plasma volume and jugular...
hematocrit in Table II. The latter method gives values considerably higher than those obtained with the dilution method.

4. Erythrocyte Volume Determined by Injection of Tagged Cells

Table III shows the erythrocyte volume as indicated by determinations of dilution of injected radioactive iron containing cells. The rapidity with which these cells are mixed with those of the entire vascular system is evidenced by the almost identical values obtained after 2 minute and 24 hour mixing periods. It is improbable that such rapid and complete mixing would occur if any considerable proportion of the total volume of erythrocytes were immobilized in splenic sinusoids or elsewhere in the body.

**TABLE III**

*Circulating and Total Red Cell Mass Determined by the Radioactive Donor Cell Method*

<table>
<thead>
<tr>
<th>Dog</th>
<th>Activity in recipient cells</th>
<th>Average activity concentration 4, 6, and 10 min.</th>
<th>Circulating red cell volume</th>
<th>Total RBC volume</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Activity injected cells</td>
<td>Counts/min. per 100 ml. RBC</td>
<td>counts/min. % ml. ml.</td>
<td></td>
</tr>
<tr>
<td>39-307</td>
<td>905</td>
<td>233 196 209 206 222</td>
<td>208 (8 days)</td>
<td>204 445 405</td>
</tr>
<tr>
<td>40-149</td>
<td>705</td>
<td>231 183 187</td>
<td>208 (5 days)</td>
<td>185 380 340</td>
</tr>
<tr>
<td>39-196</td>
<td>1260</td>
<td>438 427 430 440</td>
<td>453 (3 days)</td>
<td>432 292 278</td>
</tr>
<tr>
<td>39-144</td>
<td>128</td>
<td>58 48 51 42 54</td>
<td>48 (4 days)</td>
<td>47 272 237</td>
</tr>
<tr>
<td>39-88</td>
<td>761</td>
<td>162 168 157 168 148</td>
<td>148 (3 days)</td>
<td>164 465 513</td>
</tr>
<tr>
<td>39-194</td>
<td>1135</td>
<td>310 286 289 302</td>
<td>292 389</td>
<td></td>
</tr>
<tr>
<td>39-193</td>
<td>491</td>
<td>98 87 88 78</td>
<td>84</td>
<td></td>
</tr>
<tr>
<td>39-299</td>
<td>558</td>
<td>334 386</td>
<td>311</td>
<td>360 155 180</td>
</tr>
<tr>
<td>40-183</td>
<td>865</td>
<td>187 198</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td>39-196</td>
<td>1680</td>
<td>398 410</td>
<td>420 410</td>
<td></td>
</tr>
<tr>
<td>4-E</td>
<td>1680</td>
<td>537 480</td>
<td>315 350</td>
<td></td>
</tr>
</tbody>
</table>

Average: .......................................................... 355 350

* Scale of four Geiger counter.

**DISCUSSION**

Our results indicate that the total erythrocyte volume as determined by direct procedures is 10 to 40 per cent less than the volumes derived by the plasma-jugular hematocrit method. The total blood volume can be ascertained by adding the cell volume (determined by radioactive tagged erythrocyte method) and the plasma volume (determined by dye dilution method). The average hematocrit value for the entire contents of the vascular system can then be determined by dividing the directly determined cell volume by the
total blood volume. This average hematocrit is invariably considerably (about 20 per cent) lower than that of the large vessels. To compensate for the relatively greater number of cells present in the large vessels, the cell-plasma ratio in the small vessels must, therefore, be even less than that of the average. The theoretical explanation for this finding has been presented above in the discussion of the peripheral plasma films.

No significant fraction of the erythrocyte volume can be immobilized in the spleen, liver, or other regions, since the volume of cells in rapid circulation (as indicated by the values for erythrocyte volume determined after only 2 or 4 minutes mixing of injected, radioactive tagged cells) is practically identical with the total volume of erythrocytes (indicated by the volume found after 24 hour, or longer, periods of mixing). It is improbable that such complete mixing could occur so rapidly if many cells were immobilized, and it appears that practically all red blood cells in the dog are in active circulation. Similar conclusions have recently been drawn by Ebert and Stead (1).

Since there is no evidence that any considerable fraction of the erythrocyte volume is immobilized, it may be concluded that all the red blood cells of the dog are in active circulation and that the circulating erythrocyte volume is practically identical with the total erythrocyte volume. Since the cell-plasma ratio of the rapidly flowing axial streams in various vessels is fairly constant, the jugular hematocrit may be assumed to be representative of this ratio for the rapidly circulating ("axial stream") blood, and the actual rapidly circulating blood volume may be calculated by dividing the cell volume (as determined with the donor cell method) by the jugular hematocrit. The rapidly circulating blood volume as determined in this manner is considerably lower than the total blood volume ascertained by the addition of the cell volume (directly determined by the isotope dilution method) and the plasma volume (from the dye procedure). Tables IV and V summarize these differences.

The amount of plasma in rapid circulation ("rapidly circulating plasma volume") can be calculated from these values by subtracting the determined cell volume from the calculated rapidly circulating blood volume. In similar fashion, if the value for plasma volume as determined by the dye method is accepted as representative of the total plasma volume, the difference between this value and "the rapidly circulating plasma volume" is a measure of the fraction of the plasma in relatively sluggish circulation. This fraction amounts to 6 to 37 per cent in the series of animals listed in Tables IV and V.

The previously described laws of hydrodynamics apply to the passage of dyes between the various fluid layers of the circulating blood as well as to the mixing of erythrocytes. The passage of dyes from the central turbulent stream into the peripheral films occurs only by the slow process of diffusion. Since we have demonstrated that these peripheral films may constitute a very considerable proportion (21 per cent) of the total amount of plasma, appreciable
### TABLE IV

**The Partition of Plasma in the Vascular System by Radio Iron**

<table>
<thead>
<tr>
<th>Dog</th>
<th>Weight</th>
<th>Jugular hematocrit</th>
<th>Jugular volume</th>
<th>Blood volume circulating</th>
<th>Plasma volume circulating</th>
<th>Plasma volume by dye</th>
<th>Plasma volume difference</th>
<th>Total plasma volume in slow circulation per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>39-307</td>
<td>9.5</td>
<td>51.4</td>
<td>445</td>
<td>865</td>
<td>420</td>
<td>480</td>
<td>60</td>
<td>13</td>
</tr>
<tr>
<td>39-144</td>
<td>14.5</td>
<td>44.0</td>
<td>255</td>
<td>580</td>
<td>325</td>
<td>485</td>
<td>160</td>
<td>33</td>
</tr>
<tr>
<td>39-88</td>
<td>17.0</td>
<td>53.7</td>
<td>465</td>
<td>865</td>
<td>400</td>
<td>520</td>
<td>120</td>
<td>23</td>
</tr>
<tr>
<td>39-194</td>
<td>10.0</td>
<td>40.0</td>
<td>389</td>
<td>970</td>
<td>580</td>
<td>720</td>
<td>140</td>
<td>19</td>
</tr>
<tr>
<td>39-199</td>
<td>14.3</td>
<td>21.3</td>
<td>155</td>
<td>730</td>
<td>575</td>
<td>645</td>
<td>70</td>
<td>11</td>
</tr>
<tr>
<td>40-183</td>
<td>13.5</td>
<td>48.0</td>
<td>460</td>
<td>960</td>
<td>500</td>
<td>585</td>
<td>85</td>
<td>15</td>
</tr>
<tr>
<td>39-196</td>
<td>15.1</td>
<td>38.2</td>
<td>420</td>
<td>1100</td>
<td>680</td>
<td>645</td>
<td>-35</td>
<td></td>
</tr>
<tr>
<td>4-E</td>
<td>16.0</td>
<td>34.9</td>
<td>315</td>
<td>800</td>
<td>485</td>
<td>725</td>
<td>240</td>
<td>33</td>
</tr>
<tr>
<td>33-329</td>
<td>15.6</td>
<td>49.0</td>
<td>400</td>
<td>815</td>
<td>415</td>
<td>700</td>
<td>285</td>
<td>41</td>
</tr>
<tr>
<td>3-A</td>
<td>37.5</td>
<td>115</td>
<td>305</td>
<td>190</td>
<td>235</td>
<td>45</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>4-A</td>
<td>36.9</td>
<td>115</td>
<td>310</td>
<td>195</td>
<td>285</td>
<td>90</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>5-A</td>
<td>6.2</td>
<td>38.0</td>
<td>125</td>
<td>330</td>
<td>205</td>
<td>295</td>
<td>90</td>
<td>31</td>
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<tr>
<td>37-186</td>
<td>6.4</td>
<td>37.4</td>
<td>130</td>
<td>350</td>
<td>220</td>
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<td>65</td>
<td>23</td>
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<tr>
<td>38-320</td>
<td>14.9</td>
<td>23.5</td>
<td>160</td>
<td>680</td>
<td>520</td>
<td>760</td>
<td>240</td>
<td>32</td>
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<tr>
<td>40-167</td>
<td>14.5</td>
<td>51.3</td>
<td>495</td>
<td>1160</td>
<td>665</td>
<td>680</td>
<td>15</td>
<td>2</td>
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<tr>
<td>39-161</td>
<td>8.3</td>
<td>48.6</td>
<td>285</td>
<td>585</td>
<td>300</td>
<td>320</td>
<td>20</td>
<td>6</td>
</tr>
<tr>
<td>36-196</td>
<td>30.7</td>
<td>290</td>
<td>745</td>
<td>455</td>
<td>565</td>
<td>110</td>
<td>19</td>
<td></td>
</tr>
</tbody>
</table>

### TABLE V

**Partition of Plasma in the Vascular System at Various Hematocrit Levels**

<table>
<thead>
<tr>
<th>Dog</th>
<th>Weight</th>
<th>Hematocrit</th>
<th>Jugular volume determined</th>
<th>Blood volume circulating</th>
<th>Plasma volume circulating</th>
<th>Plasma volume by dye</th>
<th>Plasma volume difference</th>
<th>Total plasma volume in slow circulation per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>40-183</td>
<td>13.5</td>
<td>53.2</td>
<td>525</td>
<td>985</td>
<td>460</td>
<td>580</td>
<td>120</td>
<td>20</td>
</tr>
<tr>
<td>39-196</td>
<td>15.1</td>
<td>38.2</td>
<td>420</td>
<td>1100</td>
<td>680</td>
<td>645</td>
<td>-35</td>
<td></td>
</tr>
<tr>
<td>36-196</td>
<td>10.7</td>
<td>48.7</td>
<td>410</td>
<td>840</td>
<td>430</td>
<td>480</td>
<td>50</td>
<td>10</td>
</tr>
</tbody>
</table>
difference in time of mixing in the axial stream and total fluid may be predicted. Also, since dyes are presumably lost from the circulation by various processes, if the time interval between samples is great enough to allow for complete diffusion, results obtained by these methods are likely to be falsely high. Theoretically, there should be a complex type of time curve for the concentration of dye in the blood, since at least three processes are taking place simultaneously:

1. Turbulent mixing of the dye in the large vessels and in the axial stream of small vessels.
2. Diffusion of the dye into the peripheral sluggishly moving and stationary plasma films.
3. Loss of dye through removal by the reticulo-endothelial system and excretion through the biliary tract.

Conceivably each of these processes might be demonstrated graphically if concentration of dye is plotted against time, providing that all or any two did not have rates of such a character that the curves approached similarity despite varying order of functions. Actually such differences in the curves of plasma volume determinations can be demonstrated. Inspection of the curves of various investigators using the Evans blue (T-1824) as well as the brilliant vital red dye, indicates at least two phases of distribution of dye in the vascular system; and personal observations indicate that a third may well be present. Gibson and Evans (3) divide their curve into two components which they term the “mixing phase” and the “disappearance phase.” The intersection of the tangents of these curves is assumed to represent the true mixing time of the dye in all the plasma, and the point of intersection of the extrapolated tangent with the ordinate is claimed to indicate the value for the optical density (a function of the true plasma volume) at the time of dye injection. More careful study of the character of these curves indicates that three distinct phases may be demonstrated. Not only the slopes, but also the shapes of these curves differ, the first two (comprising the mixing curve) being exponential, while the disappearance curve is almost linear.

The two phases of the mixing curve are produced by the mixing in the axial stream, and the diffusion mixing of the peripheral plasma films. Careful analysis indicates that the latter process may frequently extend over a time much longer than that commonly assumed to allow complete mixing. Calculations based on dye dilutions at periods before complete mixing has occurred yield plasma volumes which are low. In spite of this fact, however, the plasma volumes so determined are still considerably higher than the rapidly circulating plasma volumes.

The rapidly circulating and sluggishly flowing plasma fractions are not to be considered as separate entities, inasmuch as there is constant (although slow) interchange between them. They do, however, greatly influence consideration of blood flow and blood volume.
SUMMARY

1. Application of the principles of hydrodynamics to the problem of blood flow and blood volume indicates that the calculation of blood volume and cell volume from the venous hematocrit and plasma volume (as determined by the dye method) is subject to considerable error.

2. This conclusion is borne out by determinations of total cell volume by viviperfusion and with the use of radioactive iron tagged erythrocytes, which have shown the erythrocyte volume to be only 70 to 75 per cent of the volume indicated by the previously mentioned calculations.

3. The average hematocrit of the entire vascular system is considerably lower than the hematocrit of the large vessels, and the cell-plasma ratio of the smaller vessels is still less.

4. In the dog there are no considerable stores of immobilized erythrocytes, and the total erythrocyte volume and circulating erythrocyte volume are identical.

5. The "rapidly circulating blood volume" can be determined by dividing the erythrocyte volume by the venous hematocrit, and is found to be considerably less than the total blood volume.

6. The concept of the "rapidly circulating plasma volume" is introduced, and it is found to be approximately 80 per cent of the total plasma volume.

7. The volume of plasma in the peripheral, cell free, sluggishly moving plasma films, plus that contained in small vessels in which no red cells are present, is also determined and found to be approximately 20 per cent of the entire plasma volume.

8. The existence and magnitude of these fractions of the blood plasma volume should receive consideration in studies of blood flow and blood volume.

BIBLIOGRAPHY

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