The Blood Volume of Normal Women

By G. R. WADSWORTH

UNTIL RECENTLY, estimates of blood volume in women have been based solely upon measurements of plasma volume. Such measurements showed that the plasma volume of women, per unit body weight, was only slightly less than that of men. However, since the packed cell volume is lower in women, red cell volume was calculated to be distinctly lower. Recently two studies have been published in which the red cell volume of women was estimated directly, using P32-labeled red cells (Berlin et al. and Hedlund). They confirmed that red cell volume, per unit body weight, is lower in women than in men but differed as to the exact value: Berlin et al. found the average red cell volume of sixteen women to be 1562 ml. (26.9 ml. per Kg.) whereas Hedlund found that in seven women to be 1460 ml. (24.0 ml. per Kg.). In neither of these two studies was plasma volume measured directly so that no information was obtained about the relationship in women between "body hematocrit" and venous hematocrit.

A recent study of the relationship between body hematocrit and venous hematocrit in subjects of both sexes with venous hematocrits ranging from 9 per cent to 82 per cent showed that the relationship did not vary with venous hematocrit. Seventeen of the twenty-eight estimations were made in women and inspection of the data shows that the ratio in women did not differ significantly from the ratio in men. Nevertheless in view of the small number of previous investigations it was considered worthwhile to measure red cell volume and plasma volume in a group of healthy women.

MATERIAL AND METHODS

Simultaneous estimations of red cell volume using P32-tagged red cells and of plasma volume using Evans Blue dye (T-1824) were made in eight women. They were all sedentary workers leading a normal active life and were 20 to 35 years old. In each instance their blood volume was measured about two weeks after the last menstruation.

The subject, having fasted for at least the previous 12 hours, remained recumbent for 30 minutes before the investigation was begun and remained so until it was completed. About 20 ml. of blood was withdrawn from an antecubital vein into a syringe previously moistened with heparin; this sample provided undyed plasma for a control and for the preparation of standards in the subsequent estimation of plasma volume. The syringe was then removed, leaving the needle in the vein. A known amount (about 20 ml.) of a 0.075 per cent solution of Evans Blue (I.C.I. Batch PD/RS 92/51) in saline was then injected through the needle from a syringe calibrated "to deliver". In the same way this was immediately followed by the injection of a known volume (about 20 ml.) of a suspension in plasma-saline of the subject's own red cells tagged with P32. The dose of radioactivity injected was about 2 μe. in each case. Blood was withdrawn from the other arm at 15 minutes, 30 minutes and...
TABLE 1.—The Red Cell Volume, Plasma Volume and Total Blood Volume of Eight Normal Women

<table>
<thead>
<tr>
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<th>Mean and S.D. (±)</th>
<th>Mean and S.D. (±)</th>
<th>Mean and S.D. (±)</th>
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<tbody>
<tr>
<td></td>
<td>ml.</td>
<td>ml/Kg.</td>
<td>L/Sq. meter</td>
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<tr>
<td>Red cell volume (P²⁺-tagged cells)</td>
<td>1347 (±140)</td>
<td>23.4 (±2.02)</td>
<td>0.817 (±0.072)</td>
</tr>
<tr>
<td>Plasma volume (Evans Blue)</td>
<td>2488 (±345)</td>
<td>43.1 (±5.29)</td>
<td>1.511 (±0.196)</td>
</tr>
<tr>
<td>Total blood volume (R.C.V. + P.V.)</td>
<td>3835 (±457)</td>
<td>66.48 (±6.80)</td>
<td>2.328 (±0.251)</td>
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45 minutes after the injection. The concentration of dye and the radioactivity in these samples was then determined.

The technique of measuring red cell volume described by Chaplin was followed exactly. When the mean radioactivity of unit volume of red cells in counts per minute of the three post-injection samples was plotted against time on a semi-logarithmic graph, it was found that the three points could very nearly be joined by a straight line. The slope of this line corresponded to a loss rate of 6 per cent per hour, as previously found by Reeve and Veall.

All estimations were therefore corrected for this loss rate in calculating the activity at zero time.

Estimations of dye concentration were made in a photo-electric colorimeter using cells of 1 cm. depth. Standard solutions of the Evans Blue were made up in the subject's pre-injection plasma, using a calibrated pipet and an "Agha" microsyringe. The concentration of these solutions was such that they gave readings on the colorimeter very close to those of the post-injection plasma samples. When the curve of dye-concentration was plotted against time on a semi-logarithmic graph, it was impossible to fit all points exactly to a straight line. However the nearest straight line fitted by inspection had a slope corresponding to a mean dye loss of 10 per cent per hour which agreed with the findings of other investigators.

Statistical analysis showed that the difference in dye concentration between the 30 and 45 minute samples was that expected from a loss rate of 10 per cent per hour but that the difference in concentration between the 15 and 30 minute samples was significantly greater than expected ("t" = 3.7; P < 0.001). It was concluded that the data could best be compared with the findings of other workers by assuming that dye-concentration declines in a simple exponential fashion and observed dye-concentrations were converted to zero time, assuming a loss rate of 10 per cent per hour.

Packed red cell volumes were measured in Wintrobe tubes centrifuged at a radius of 15 cm. for 55 minutes at 3,000 r.p.m.; observed values were corrected for trapped plasma as described by Chaplin and Mollison.

RESULTS

The results of the estimations of red cell volume and plasma volume are summarized in table 1.

The mean observed packed red cell volume was 39.8 per cent. The percentage ratio of total volume of red cells to total volume of red cells plus plasma (“body hematocrit”) was calculated in each instance, and a mean value of 35.2 per cent was found. The mean ratio, body hematocrit : venous hematocrit, when venous hematocrit values were corrected for trapped plasma, was 0.898 (S.D. 0.04).

DISCUSSION

The present findings for plasma volume agree closely with those of von Porat who found a mean plasma volume in men of 46.2 ml. per Kg. and in women, of 44.8 ml. per Kg. Furthermore, comparison of the present figures with those found in normal men by Brady et al. shows that the plasma volume per kilo body weight (measured by Evans Blue) is not different in the two series (“t” =
0.77; P > 0.4), whereas the red cell volume per kilo body weight (measured by P32-tagged cells) is higher in the men than in the present series of women by a significant amount ("t" = 3.38; P < 0.001). It was concluded that the present findings supported the view that the smaller blood volume per unit body weight of women compared with that of men is largely due to the smaller red cell volume per unit body weight in women and corresponds to the sex difference in venous hematocrit values.

Chaplin, Mollison and Vetter found a mean body hematocrit:venous hematocrit ratio of 0.910 (S.D. 0.026) over a wide range of venous hematocrit values in a series of men and women. The present mean ratio (0.898) was not significantly different from this ("t" = 1.01; P > 0.1).

SUMMARY
Measurements of red cell volume and plasma volume in eight normal women confirm that, in relation to body weight, red cell volume is distinctly lower in women than in men and plasma volume only slightly lower. The relationship between body hematocrit and venous hematocrit (0.90) was found not to be significantly different from that of men.

SUMMARIO IN INTERLINGUA
Mesurationes del volumines erythrocytic e plasmatic de octo feminas normal confirm a le supposition que relative al peso corporee le volumine erythrocytic in feminas es distinctemente plus basse que in homines sed que le volumine plasmatic es solo levemente plus basse. Le relation inter le datos del hematocrite pro corpore e venas in le feminas investigate esseva 0,90 e non differeva significativamente ab illo constatate in homines.

REFERENCES
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