The estimation of red cell volume with ^{51}Cr -labelled erythrocytes and plasma volume with radioiodinated human serum albumin

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SYNOPSIS The validity of a simplified procedure for the direct estimation of both red cell and plasma volume, using ^{51}Cr -labelled erythrocytes and radioiodinated human serum albumin, has been examined. It is suggested that the procedure, involving three venepunctures only, will yield accurate measurements of both compartments.

Knowledge of the red cell and plasma volumes is important in a variety of clinical conditions. In practice, either the red cell or plasma volume is measured directly, and the other compartment then calculated from the haematocrit. The body haematocrit is derived by multiplying the observed venous haematocrit by the body/venous haematocrit ratio. This ratio, however, varies with altitude (Metz, Levin, and Hart, 1962), pregnancy (Caton, Roby, Reid, Caswell, Maletskos, Fluharty, and Gibson, 1951), and disease (Rothschild, Bauman, Yalow, and Berson, 1954; Schreiber, Bauman, Yalow, and Berson, 1954). In any condition associated with fluid retention, the venous haematocrit probably does not reflect accurately the true status of the total blood volume (Fudenberg, Baldini, Mahoney, and Dameshek, 1961). For reliable blood volume studies it is therefore desirable that both red cell and plasma volumes be measured directly.

Red cell volume is measured directly with labelled erythrocytes, the ^{51}Cr method being the most widely used. The plasma volume is usually measured directly with the dye T-1824, or with radioiodinated human serum albumin. The two methods yield comparable results but the radioiodinated serum albumin method has in practice largely replaced the dye method.

The simultaneous measurement of red cell and plasma volumes with ^{51}Cr -labelled erythrocytes and radioiodinated serum albumin involves the counting of mixtures of ^{51}Cr and ^{131}I , and their separation is not easily achieved without equipment not generally

available in the average hospital radioisotope laboratory. This difficulty could be obviated if the ^{51}Cr red cell volume measurement was completed first, and the plasma volume measured with radioiodinated serum albumin immediately after drawing the last ^{51}Cr specimen. Whole blood samples containing ^{51}Cr only, and plasma samples with ^{131}I only, could then be counted in a well-type scintillation counter.

This procedure has possible drawbacks. A significant amount of ^{51}Cr in plasma would invalidate the plasma ^{131}I albumin measurement. Multiple venepunctures would be necessary; after the re-injection of ^{51}Cr -labelled erythrocytes two samples are usually withdrawn, and a further three samples are required to measure the rate of clearance of the radioiodinated serum albumin. The study by Pritchard, Moir, MacIntyre, and Inkley (1955) suggests, however, that the activity of a single sample withdrawn 10 minutes after the injection of radioiodinated serum albumin, multiplied by a factor of 1.015, would give the plasma counts at zero time.

The present investigation was undertaken to test the validity of a simplified method of direct measurement of both red cell and plasma volume by studying (1) the amount of ^{51}Cr in the plasma after the injection of ^{51}Cr -labelled erythrocytes; (2) the significance of the difference in the radioactivity of any two whole blood specimens withdrawn between 10 and 20 minutes after the injection of ^{51}Cr -labelled erythrocytes; and (3) the radioactivity of the plasma at 10-minute intervals after the injection of radioiodinated serum albumin.

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MATERIAL AND METHODS

MATERIAL The subjects studied were 60 healthy young white adult males.

⁵¹CR BLOOD VOLUME Venous blood (15 to 20 ml.) was mixed with 6 ml. acid-citrate-dextrose solution in a sterile container. The blood was centrifuged and the supernatant removed. High specific activity (10 mc./mg. Cr) radioactive chromium 51 obtained from the Radiochemical Centre, Amersham, U.K., in the form of hexavalent sodium chromate, was added to the cells in a dose of 20 to 25 μ c. and the mixture stood at room temperature for 30 minutes. After washing three times in isotonic saline, the cells were resuspended in approximately 25 ml. saline. Exactly 20 ml. of this volume was injected intravenously with a calibrated syringe. At 10 and 15 minutes after the injection, 10 ml. samples of blood were withdrawn and placed in heparinized containers. A 1 : 100 dilution of the residue of the injected blood was made, and 5 ml. aliquots of this standard, and of the 10- and 15-minute samples haemolysed by the addition of powdered saponin, were assayed for radioactivity in a well-type scintillation counter containing a 2-in. thallium-activated sodium iodide crystal.

$$\text{Red cell volume} = \frac{\text{volume injected (ml.)} \times \text{counts/min./ml. standard} \times \text{dilution of standard} \times \text{haematocrit}}{\text{mean of counts/min./ml. of 10- and 15-minute samples} \times 100}$$

$$\text{Total blood volume} = \frac{\text{red cell volume} \times 100}{\text{venous haematocrit} \times \text{body venous haematocrit ratio}}$$

$$\text{Plasma volume} = \text{total blood volume} - \text{red cell volume}$$

¹³¹I ALBUMIN BLOOD VOLUME Radioiodinated human serum albumin was obtained from the Radiochemical Centre, Amersham, U.K. Carrier albumin was added to a concentration greater than 200 μ g. per ml. With the 15-minute ⁵¹Cr sample, an additional sample ('pre-

¹³¹I plasma') was withdrawn to determine any radioactivity in the plasma due to ⁵¹Cr. Following this exactly 10 ml. of a solution of ¹³¹I albumin (3 μ c.) was injected intravenously with a calibrated syringe, and three blood samples collected in heparinized containers 10, 20, and 30 minutes later. These samples were centrifuged and the plasma ('post-¹³¹I plasmas') removed. Thyroid uptake of ¹³¹I was blocked by the prior administration of potassium iodide. Aliquots (5 ml.) of a 1 : 100 dilution of the ¹³¹I albumin solution injected and of the pre-¹³¹I and post-¹³¹I plasmas were assayed for radioactivity in the well counter.

Any counts in the pre-¹³¹I plasma were subtracted from those of the post-¹³¹I plasmas and the latter then plotted on semi-log. paper and extrapolated to zero time.

$$\text{Plasma volume} = \frac{\text{volume injected (ml.)} \times \text{counts/min./ml. standard} \times \text{dilution of standard}}{\text{counts/min./ml. at zero time}}$$

$$\text{Total blood volume} = \frac{\text{plasma volume} \times 100}{100 - (\text{venous haematocrit} \times \text{body venous haematocrit ratio})}$$

$$\text{Red cell volume} = \text{total blood volume} - \text{plasma volume}$$

The venous haematocrit was estimated from venous samples collected into dried sequestrene, and centrifuged at 12,000 g. in duplicate capillary tubes in an International microhaematocrit centrifuge.

The body haematocrit was calculated as follows:

$$\text{Body haematocrit} = \frac{\text{red cell volume} (^{51}\text{Cr}) \times 100}{\text{red cell volume} (^{51}\text{Cr}) + \text{plasma volume} (^{131}\text{I albumin})}$$

RESULTS

The results are shown in Tables I to IV. The mean number of counts in the plasma due to ⁵¹Cr, expressed as a percentage of the counts due to ¹³¹I at zero time, is $0.93 \pm 0.17\%$. The difference in the mean red cell volumes calculated from the two ⁵¹Cr samples

TABLE I

COUNTS IN PLASMA DUE TO ⁵¹ CR EXPRESSED AS PERCENTAGE OF COUNTS DUE TO ¹³¹ I AT ZERO TIME						
No.	(1) ⁵¹ Cr in Plasma (counts/min.)		(2) ¹³¹ I in Plasma at Zero Time (counts/min.)		(1)/(2) × 100	
	Mean	Range	Mean	Range	Mean	Range
60	27.5 ± 4.7	0-143	3438.8 ± 273.9	1175-10403	0.93 ± 0.17	0.5-8

TABLE II

DIFFERENCE IN RED CELL VOLUME CALCULATED FROM TWO SEPARATE SAMPLES WITHDRAWN AFTER INJECTION OF ⁵¹ CR-LABELLED ERYTHROCYTES						
No.	Red Cell Volume (ml./kg.)				% Difference	
	Specimen 1		Specimen 2		Mean	Range
	Mean	Range	Mean	Range		
60	33.28 ± 0.66	23.8-51.9	33.41 ± 0.72	23.2-49.1	1.18 ± 0.16	0.4-5

TABLE III

COMPARISON BETWEEN PLASMA VOLUME CALCULATED BY EXTRAPOLATION TO ZERO AND BY MULTIPLYING COUNTS IN 10-MINUTE SAMPLE BY A FACTOR OF 1.015

No.	Plasma Volume (ml./kg.)				% Difference	
	Extrapolation to Zero Time		10-minute Sample $\times$ 1.015		Mean	Range
	Mean	Range	Mean	Range		
48	44.12 $\pm$ 0.74	34.6-56.4	44.47 $\pm$ 0.78	36.4-55.9	1.85 $\pm$ 0.26	0.7-0

TABLE IV

COMPARISON OF DIRECT MEASUREMENT OF RED CELL AND PLASMA VOLUMES WITH THAT DERIVED FROM HAEMATOCRIT¹

No.	Red Cell Volume (ml./kg.)		Plasma Volume (ml./kg.)	
	⁵¹ Cr Erythrocytes	Radiiodinated Serum Albumin	Radiiodinated Serum Albumin	⁵¹ Cr Erythrocytes
60	33.34 $\pm$ 0.69	32.59 $\pm$ 0.58	45.16 $\pm$ 0.46	45.70 $\pm$ 0.99

¹The differences are not statistically significant.

is 0.13 ml./kg. and is not statistically significant ($P = >0.05$). In comparing the plasma volume calculated by correcting the 10-minute ¹³¹I sample with that obtained by extrapolation to zero time, only curves where the three values fell on one straight line were considered; this was the case in 48 out of 60 subjects studied. The difference in the means of 0.35 ml./kg. is not statistically significant ($P = >0.05$).

DISCUSSION

The results confirm the validity of a simplified method of measuring both red cell volume and plasma volume directly. Following the injection of labelled erythrocytes, only a single sample of blood need be taken for the calculation of red cell volume. Although the number of counts in the plasma due to ⁵¹Cr is generally insignificant, it is advisable to draw an extra sample at this time as a blank for the radioiodinated serum albumin plasma volume. After the withdrawal of this specimen, the radioiodinated serum albumin solution can be injected through the same needle, and 10 minutes later a single sample drawn

from another vein. The radioactivity of this sample, when multiplied by a factor of 1.015, does not yield a significantly different figure from that obtained by drawing multiple samples and extrapolating to zero time. This procedure, however, would be invalid in conditions where intravascular mixing is delayed, or where there is abnormally rapid plasma clearance of albumin as in nephrosis or protein-losing gastroenteropathy.

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REFERENCES

- Caton, W. L., Roby, C. C., Reid, D. E., Caswell, R., Maletskos, C. J., Fluharty, R. G., and Gibson, J. G. (1951). *Amer. J. Obstet. Gynec.*, **61**, 1207.
- Fudenberg, H., Baldini, M., Mahoney, J. P., and Dameshek, W. (1961). *Blood*, **17**, 71.
- Metz, J., Levin, N. W., and Hart, D., (1962). *Nature (Lond.)*, **194**, 483.
- Pritchard, W. H., Moir, T. W., MacIntyre, W. J., and Inkley, S. R. (1955). *Circulat. Res.*, **3**, 19.
- Rothschild, M. A., Bauman, A., Yalow, R. S., and Berson, S. A. (1954). *J. appl. Physiol.*, **6**, 701.
- Schreiber, S. S., Bauman, A., Yalow, R. S., and Berson, S. A. (1954). *J. clin. Invest.*, **33**, 578.