JOURNAL OF APPLIED PHYSIOLOGY
Vol. 37, No. 2, August 1974. *Printed in U.S.A.*

Calculation of percentage changes in volumes of blood, plasma, and red cells in dehydration

D. B. DILL AND D. L. COSTILL
Laboratory of Environmental Patho-Physiology, Desert Research Institute, University of Nevada System, Boulder City, Nevada 89005; and Human Performance Laboratory, Ball State University, Muncie, Indiana 47306

DILL, D. B., AND D. L. COSTILL. *Calculation of percentage changes in volumes of blood, plasma, and red cells in dehydration.* J. Appl. Physiol. 37(2): 247–248. 1974.—Observations on hematocrit (Hct) and hemoglobin (Hb) were made in six men before and after running long enough to cause a 4% decrease in body weight. Subscripts B and A were used to denote before dehydration and after dehydration, respectively. Relations were derived between BV_B, BV_A, Hb_B, Hb_A, Hct_B, and Hct_A with which one can calculate the percentage decreases in BV, CV, and PV, as well as the concentration of hemoglobin in red cells, $g \cdot 100\ ml^{-1}$ (MCHC). When subjects reach the same level of dehydration the water loss from the various body compartments may vary reflecting difference in salt losses in sweat. Changes in PV calculated from the increase in plasma protein concentration averaged −7.5% compared with −12.2% calculated from changes in Hb and Hct. The difference could be accounted for by a loss of 6% plasma protein from the circulation.

hematocrit; hemoglobin; exercise; sweat; body temperature

WHEN MAN is acutely dehydrated plasma volume (PV) decreases: Adolph has postulated that only protein-free filtrate leaves the bloodstream and that the increase in concentration of protein in plasma can be used to calculate the percentage decrease in PV (1). However, Dill et al. (3) have shown that this postulate is not valid for all subjects, at least in desert walks of 1 h or more. On the other hand, the protein of red cells, hemoglobin, cannot leave the red cells let alone the blood. This suggests using measurement of concentration of hemoglobin in blood and percentage of red cells in blood before and after dehydration to estimate percentage changes in volumes of plasma and of red cells.

METHODS

Six trained men ran on a motor-driven treadmill for 2 h at from 60 to 75% of $\dot{V}O_{2\,max}$. The ambient temperature was 22.2 ± 0.4°C and the relative humidity 40–45%. Venous blood was drawn from the antecubital vein of the reclining subject before exercise and 30 min after the run. The hematocrit (Hct) was measured in triplicate with a microhematocrit centrifuge and corrected for 4% plasma trapped with the packed red cells. Hemoglobin (Hb) was measured by the cyanmethemoglobin method. Standard Hb curves were established with a standard supplied by Hycel, Inc. Percentage changes in blood volume (BV), red cell volume (CV), and plasma volume (PV) were calculated from values for Hb and Hct in each of the six men before and after losing 4% of body weight using the relations that follow. The subscripts B and A refer to before dehydration and after dehydration, respectively, and BV_B was taken as 100.

$$BV_A = BV_B\ (Hb_B/Hb_A)$$
$$CV_A = BV_A\ (Hct_A)$$
$$PV_A = BV_A - CV_A$$

$$\Delta\ BV,\ \% = 100\ (BV_A - BV_B)/BV_B$$
$$\Delta\ CV,\ \% = 100\ (CV_A - CV_B)/CV_B$$
$$\Delta\ PV,\ \% = 100\ (PV_A - PV_B)/PV_B$$

The results for each man and the means are shown in Table 1. The following explanation will make the method clear, using the mean values of the table.

After dehydration what volume of blood contains 15.1 g Hb?

$$16.7:100 = 15.1:x \text{ and } x = 90.4\text{ ml}$$

Hence, the decrease in blood volume is 9.6%.

After dehydration Hct_A is 0.453 and the volume of cells in 90.4 ml of blood is 0.453 × 90.4 = 41.0 ml. Hence the hemoglobin in the original 43.7 ml is now contained in 41.0, a decrease of 6.3% (Fig. 1). The concentration of hemoglobin in red cells in g·100

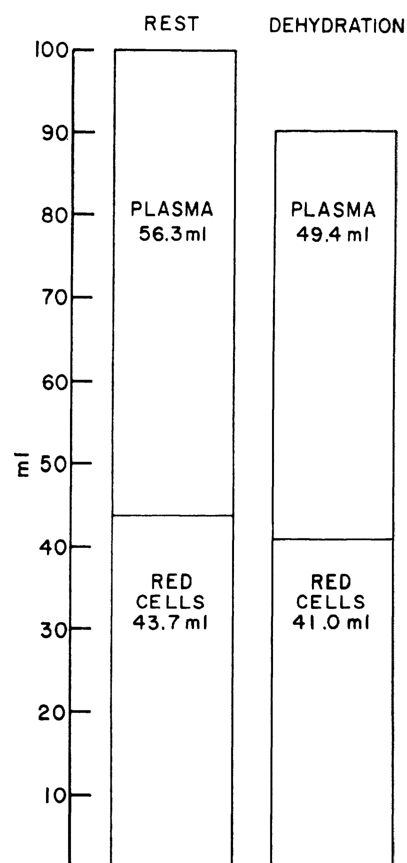

FIG. 1. Mean relative changes in plasma and red cell volumes in acute dehydration. Six men lost 4% of their body weight during 2.5- to 3-h exercise in a hot room. See text for explanation of the method of calculation based on determination of hemoglobin and hematocrit before and after dehydration.

TABLE 1. *Observations on the blood of six runners before (B) and after (A) a 4% reduction in body weight*

Subj	Hct, %		Hb, g·100 ml⁻¹		Δ BV, %	Δ PV, %	Δ CV, %	Plasma Protein, g·100 ml⁻¹	
	B	A	B	A				B	A
1	43.5	43.7	14.8	16.5	−10.3	−10.6	−9.9	7.60	7.82
2	43.1	44.4	15.0	16.2	−7.4	−9.5	−4.6	7.13	7.71
3	43.1	44.8	14.9	17.1	−12.9	−15.5	−9.4	7.27	7.93
4	45.7	48.9	15.9	18.1	−12.2	−17.3	−6.0	7.36	8.23
5	45.2	45.3	15.6	16.4	−4.9	−5.1	−4.7	7.48	7.62
6	41.7	44.6	14.6	16.1	−9.3	−13.8	−3.0	6.82	7.92
$\bar{X}$	43.7	45.3	15.1	16.7	−9.6	−12.2	−6.3	7.28	7.87
±SE	1.0	0.8	0.2	0.3	1.2	1.8	1.1	0.16	0.23

ml^{-1} (MCHC) is obtained by dividing Hb by Hct:

$$MCHC_B = 15.1/0.437 = 34.6$$
$$MCHC_A = 16.7/0.453 = 36.8$$

Thus there has been an increase in concentration of hemoglobin in red cells of 2.2 g·100 ml^{-1} or 6.3%. This checks with the 6.3% decrease in CV shown in Table 1.

DISCUSSION

What are the constraints that determine the sources of water used for body cooling? One constraint involves protein concentration: less water is surrendered by intracellular spaces with their high protein concentration than by extracellular spaces. This constraint and others have been pictured by the Henderson alignment charts relating the physicochemical properties of blood to CO_2 and O_2 movements in the respiratory cycle. For example, in work involving a sevenfold increase in oxygen consumption the Hct changed from 44.0 in arterial blood to 44.7 in venous blood (2). Or if the pH of arterial blood were increased by hyperventilation from 7.35 to 7.45, Fig. 6 of that reference indicates that the Hct would decrease from 44.0 to 43.5.

While the most obvious event in dehydration is loss of water in sweat, the accompanying loss of electrolytes also must be considered. The osmotic pressure of sweat is about one-fourth that of blood plasma but it varies greatly. The mean chloride concentration in the sweat of 12 men was found to be 32.9 meq·l^{-1} but the range was from 18.2 to 65.4, a ratio of nearly 1 to 4 (3). It is likely that the large range in responses seen in Table 1 is due in part to differences in salt loss in sweat.

Still another variable on which the physicochemical equilibrium in blood depends is body temperature: change of temperature modifies the base-binding of protein. This was not a factor under our conditions since the body temperature had returned to the control level when the second blood was drawn.

Table 1 includes observations on plasma protein concentrations before and after dehydration. Values for Δ PV calculated from these concentrations are considerably smaller than Δ PV calculated from Hb and Hct except for *subject 6* whose values were equal. The order of differences for the two methods of estimating Δ PV was roughly the same from subject to subject; the highest values were in *subjects 3, 5,* and *6*. The mean Δ PV's were −7.5% by the plasma protein method vs. −12.2% by our method. This difference suggests considerable loss of protein from the circulation. Had none of the proteins left the circulating plasma then the 12.2% loss of plasma water would have resulted in a plasma protein concentration of 8.29 g·100 ml^{-1}. Since plasma protein concentration was only 7.87 g·100 ml^{-1}, then the loss of protein from plasma was 8.29 − 7.87 or 0.42 g·100 ml^{-1}, equivalent to about 6% of the initial concentration.

Based on the preceding discussion it is apparent that the changes in blood volume, cell volume, and plasma volume can be calculated from measurements of hemoglobin and hematocrit. Unlike computation of % Δ PV based solely on changes in Hct (4), the equations illustrated here are not distorted by alterations in the volume of the red blood cells.

This study was supported by National Science Foundation Grant GB-35281 and National Institutes of Health Grant HD-05625.

Received for publication 18 December 1973.

REFERENCES

1. ADOLPH, E. F., AND ASSOCIATES. *Physiology of Man in the Desert.* New York: Interscience, 1947, Fig. 10-2.
2. BOCK, A. V., D. B. DILL, L. M. HURXTHAL, J. S. LAWRENCE, T. C. COOLIDGE, M. E. DAILEY, AND L. J. HENDERSON. Blood as a physicochemical system. V. The composition and respiratory exchanges of normal human blood during work. *J. Biol. Chem.* 73: 749–766, 1927.
3. DILL, D. B., S. M. HORVATH, W. VAN BEAUMONT, G. GEHLSEN, AND K. BURRUS. Sweat electrolytes in desert walks. *J. Appl. Physiol.* 23: 746–751, 1967.
4. VAN BEAUMONT, W. Evaluation of hemoconcentration from hematocrit measurements. *J. Appl. Physiol.* 31: 712–713, 1972.