Plasma Volume Response to Water Immersion: Implications for Space Flight

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A FREE WATER diuresis is seen during both head out[1,2] and complete water immersion[3] of human subjects. A similar diuresis during recumbency is also well known.[4] It has been suggested that the diuresis both of immersion and of recumbency is due in part to the reflex inhibition of the anti-diuretic hormone (ADH) by blood volume stimulation of cardiac atrial volume receptor mechanisms.[3,4,5] Such receptors have recently been described for the regulation of blood and body fluid volumes.[5,6] In recumbency plasma volume initially increases[7,8,0] and is redistributed cephalad[10] with an increase in the filling of the intrathoracic circulation. Such fluid shifts have been suggested[11] but not demonstrated in water immersion subjects. In the present study plasma volume change was measured in five subjects during six hours of complete water immersion and during six hours of office activity control by the determination of relative changes in hematocrit and hemoglobin concentration and by the dilution of radio-iodinated (I^{131}) serum albumin (RISA).

METHODS

The water immersion facility and the immersion procedures have been described in detail in other publications from this Laboratory.[3,11] Subjects were completely immersed in modified SCUBA gear in water at 33°C, with instructions to rest in any comfortable position. Five apparently normal young men between the ages of 18 and 28 were studied in periods of immersion of from one to six hours. The immersion tests began at 0800 after 12 hours of fasting. The six hour immersion and all control subjects were given one can of *Nutrament* (Meade Johnson food supplement 400 cal./375cc. can) at the end of the third hour. Blood was drawn by venepuncture just prior to immersion and after 25, 40, 60, 120 and 240 minutes of immersion. The subject partially emersed for each venepuncture. Control samples were drawn similarly, beginning at 0800, after zero, 25, 40, 60, 120, 240 and 360 minutes of routine office activity. Hemoglobins were performed in duplicate by the cyanmethemoglobin method and read on a spectrophotometer (Coleman Junior). Macro-hematocrits (Wintrobe) were also performed in duplicate. The means of the duplicate values are Reported (Table I).

TABLE I. HEMOGLOBIN AND HEMATOCRIT AND CHANGE IN HEMOGLOBIN AND HEMATOCRIT FROM ZERO TIME, DURING SIX HOURS OF WATER IMMERSION AND SIX HOURS OF OFFICE ACTIVITY CONTROL AT 0, 25, 40, 60, 120, 240, AND 360 MINUTES

SUBJECT	EXPERIMENT	0	25	40	60	120	240	360
		HEMOGLOBIN (GRAMS/100 ml.)						
	CONTROL							
1		15.2	14.9 - .3	15.2 0	14.9 - .3	15.2 0	14.3 - .9	14.4 - .8
2		13.2	13.4 + .2	13.3 + .1	13.5 + .3	13.4 + .2	13.5 + .3	13.7 + .5
3		15.6	15.7 + .1	15.7 + .1	15.6 0.0	15.5 - .1	15.4 - .2	14.4 - 1.2
4		15.0	14.6 - .4	15.0 0.0	14.8 - .2	14.8 - .2	15.0 0	15.3 + .3
5		14.6	14.5 - .1	14.9 + .3	14.8 + .2	15.1 + .5	14.8 + .2	14.7 + .1
$\bar{x}$		14.7	14.6 - .10	14.8 + .10	14.7 0	14.8 +.08	14.6 - .12	14.5 - .22
SE			± .11	± .05	± .11	± .12	± .21	± .29
	IMMERSION							
1		15.6	14.8 - .8	14.9 - .7	15.4 - .2			16.7 + 1.1
2		14.7	13.7 - 1.0	14.4 - .3	15.0 + .3	15.7 + 1.0	16.7 + 2.0	15.6 + 0.9
3		15.3	14.6 - .7	14.8 - .5	15.5 + .2	15.7 + .4	16.7 + 1.4	16.4 + 1.1
4		15.1	14.8 - .3	14.9 - .2	15.0 - .1			17.0 + 1.9
5		16.1	15.6 - .5	15.4 - .7	15.4 - .7			17.5 + 1.4
$\bar{x}$		15.4	14.7 - .66	14.9 - .48	15.2 - .1	15.7 + .7	16.7 + 1.7	16.6 + 1.28
SE			± .06	± .08	± .17	± .3	± .24	± .18
		HEMATOCRIT (Per Cent)						
	CONTROL							
1		50.0	50.0 0	50.3 + .3	49.3 - .7	48.0 - 2.0	47.3 - 2.7	47.5 - 2.5
2		44.5	44.3 - .2	45.0 + .5	45.5 + 1.0	44.5 0	44.8 + .3	44.5 0
3		52.0	51.0 - 1.6	51.5 - .5	50.3 - 1.7	50.3 - 1.7	50.0 - 2.0	47.8 - 4.2
4		46.3	44.5 - 1.8	45.0 - 1.3	45.8 - .5	46.5 + .2	46.5 + .2	46.0 - .3
5		47.0	47.3 + .3	47.5 + .5	48.0 + 1.0	48.3 + 1.3	48.0 + 1.0	47.3 + .3
$\bar{x}$		47.9	47.4	47.9	47.8	47.5	47.3	46.6
	IMMERSION							
1		46.5	46.0 - .5	47.0 + .5	47.8 + 1.3			49.5 + .3
2		45.0	42.0 - 3.0	43.5 - 1.5	45.0 0	47.0 + 2.0	47.0 + 1.8	46.8 + 1.8
3		45.0	41.4 - 3.6	41.4 - 3.6	42.6 - 2.4	44.5 - 0.5	47.0 + 2.0	47.0 + 2.0
4		48.0	46.6 - 1.4	47.1 - .9	47.8 - .2			50.0 + 2.0
5		47.8	46.4 - 1.4	46.6 - 1.2	46.8 - 1.0			50.8 + 3.0
$\bar{x}$		46.5	44.5	45.1	46.0	45.8	47.0	48.8

Plasma and whole blood volumes were determined by the dilution of RISA during two hours of immersion in five additional subjects. A stock solution of RISA (Abbott Laboratories) was diluted with normal saline to a concentration of 3-5 microcuries/cc. The non-protein bound radioactivity of this material was 5 per cent or less.

A 10 cc. sample for background or residual counting was drawn from the right antecubital vein, and a 1 cc. dose of RISA injected in the left antecubital vein 10 minutes before immersion and after 120 minutes of immersion. 10 cc. samples for counting were drawn from the right antecubital vein at zero, 25 and 120 mintues. Counts of plasma and whole blood were made in a deep well scintillation counter (Nuclear Chicago) and whole blood and plasma volumes calculated by methods similar to those of Berson et al.[9] Weighed syringes were not used. The determination of absolute or quantitative changes in plasma volume requires measurement with the dilution principle using a marker such as RISA. However, on the assumption that the total circulating hemoglobin remains unchanged during the measurement period, relative changes in plasma volume may be calculated from simultaneously observed changes in peripheral venous hematocrit and hemoglobin concentration.[12] Relative plasma volume changes are obtained as per cent change from the simple relationship:

$$\frac{Pv_2}{Pv_1} = \frac{1-Hct_2}{1-Hct_1} \times \frac{Hb_1}{Hb_2} \times 100$$

Pv = plasma volume
Hct = hematocrit
Hb = hemoglobin.

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RESULTS

In a series of pilot studies it was observed that the peripheral venous hemoglobin concentration decreased shortly after the onset of complete water immersion of human subjects, that this decrease was maximal after approximately 25 minutes of immersion and that progressive hemoconcentration ensued over the next 6 hours.

The hematocrit and hemoglobin concentration immediately before immersion and after 25, 40, 60, 120 and 360 minutes of complete water immersion are presented in Table I. After 25 minutes of immersion the mean decrease in hemoglobin concentration for the five subjects is 0.66 grams ± 0.06 (standard error). The mean change in hemoglobin concentration for the five subjects after 25 minutes of office activity control is a decrease of 0.10 ± 0.11 grams. The difference between the control and immersion changes is significant ($p<.025>.010$). After 240 and 360 minutes of immersion the mean hemoglobin concentration has increased above both baseline (zero time) and control levels (Figure 1). At 240 minutes the mean immersion

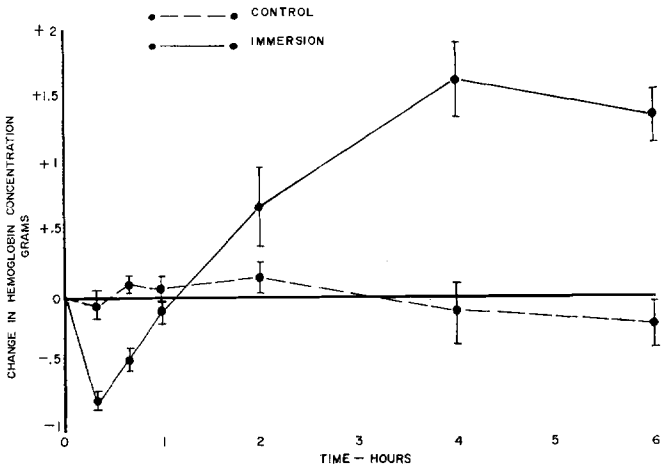

Fig. 1. Change in hemoglobin concentration in grams ± standard error for five subjects after 0, 25, 40, 60, 120, 240 and 360 minutes of complete water immersion and office activity control.

hemoglobin has increased 1.7 ± 0.24 grams compared to a control decrease of 0.12 ± 0.21 grams ($p<.1>.05$). Similarly, after 360 minutes of immersion the mean hemoglobin concentration is increased 1.28 ± 0.18 grams compared to a control decrease of 0.22 ± 0.29 grams ($p<.15>.10$).

Per cent changes in plasma volume were calculated from the hematocrit and hemoglobin concentration by the relationship given above and are presented in Figure 2. After 25 minutes of water immersion the mean plasma volume has increased 9 per cent relative to the baseline or zero time while the 25 minute control valve has increased 2 per cent. After 360 minutes of immersion the plasma volume has decreased 11 per cent from the baseline or zerotime value compared to a control increase of 4 per cent.

An attempt was made to confirm and quanitate these results using plasma volume measurements with RISA.

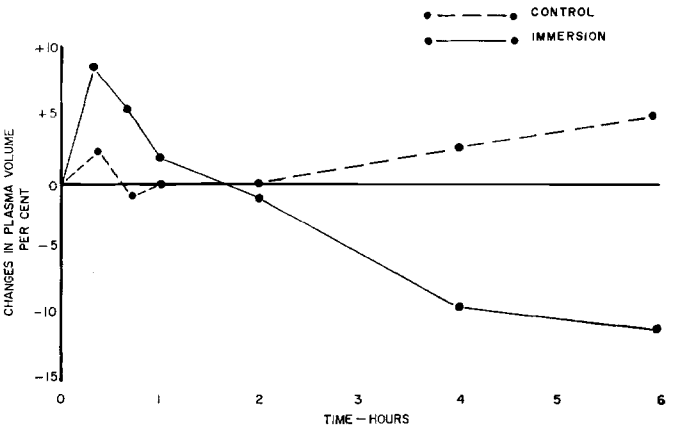

Fig. 2. Change in plasma volume in per cent estimated from changes in hematocrit and hemoglobin concentration for five subjects after 0, 25, 40, 60, 120, 240 and 360 minutes of complete water immersion and office activity control.

However, it was readily apparent that the error introduced by the frequent administration and sampling of RISA was as large or larger than the plasma volume changes produced by water immersion. Berson, et al.,[9] in 1952 suggested that the repeated venepuncture injection of RISA would not be a suitable method for the study of acute blood volume changes over short periods of time and suggested the use of the hemoglobin and hematocrit dilution or the biologic decay curve of P^{32} tagged erythrocytes.[9]

DISCUSSION

The physiologic responses to bed rest or recumbency and water immersion are presently being reinvestigated as it is felt that these states may bear some analogy to the weightlessness of space flight.[1, 2, 11, 13] Body fluid distribution during recumbency and water immersion, has received particular attention.[3, 11] On assuming the recumbent position plasma volume is initially increased [7, 8, 9] shifts cephalad [10] and then decreases over the next two days [7] reaching a maximal decrease after two to three weeks of bed rest [10, 14] Similarly, the present study demonstrates hemodilution and an approximately 9 per cent plasma volume expansion within 30 minutes of complete water immersion followed by progressive hemoconcentration. The demonstration that the plasma volume is initially increased by water immersion suggests but does not establish that the simultaneous water diuresis may be mediated by volume receptor mechanisms.

In a weightless environment hydrostatic pressure effects of the cardiovascular system due to gravity will be absent and a redistribution of body fluids similar to that seen in recumbency and water immersion may be postulated.[11] Biomedical information is currently available from American and Russian astronauts exposed to considerable periods of weightlessness. At this early stage of manned space flight these data lack sufficient definition and control to permit firm conclusions. However, general responses may be recognized. At least three major physiological alterations have been identified to date which may reflect alterations in fluid

balance, possibly due to weightlessness. First, the astronaut of the second United States manned orbital space flight experienced substantial loss of body weight, hemoconcentration and relative dehydration.[15] Several known factors contributed to this response including a recurrent suit inlet temperature problem with overheating and sweating; but the physiologically intriguing observation is that during the flight a large amount of dilute urine (2300 cc. with specific gravity of 1.003) was excreted. This apparently inappropriate urinary response is compatible with significant and protracted ADH suppression. A similar trend seems to be evident in the first United States manned orbital flight but is much less striking.[16] The urine from the third flight was inadvertantly lost.[17] A second observation of interest is that the post-flight medical examinations of all three United States orbital astronauts revealed apparent hemoconcentration in all cases.[15, 16, 17] Similarly, a recent Russian report noted "a significant tendency for reduction in the fluid compartment of the blood" in the postflight examination of cosmonaut Titov.[18] Factors such as thermal imbalance, fluid intake and emotion are obviously involved in the observed hemoconcentration but fluid shifts due to weightlessness itself must be considered. A third alteration which may be in part a reflection of shifts in body fluid distribution due to weightlessness is the impaired post-flight orthostatic tolerance of the third United States orbital astronaut.[17] This intolerance was evidenced by a moderate increase in heart rate and a decrease in systolic blood pressure during quiet standing as compared to his preflight responses. Cosmonaut Titov is reported to have had orthostatic tachycardia during a tilt table test done 23 hours post-flight.[18] The possibility of such post-flight orthostatic intolerance has been predicted from bed rest and water immersion studies and related to decreased circulating blood volume.[13] Further definition of these biomedical observations and their relationship to weightlessness will require detailed physiological studies during future manned space flight.

SUMMARY

Change in plasma volume of five subjects was measured during six hours of complete water immersion and during six hours of office activity control by hemoglobin and hematocrit dilution and with radio-iodinated serum albumin (RISA) techniques. The mean plasma volume increased 9 per cent during the first 25 minutes of immersion and then decreased over the next 4 to 6 hours to approximately 11 per cent less than the zero time value. The repeated injection and sampling of RISA is not a suitable technique for the measurement of acute changes in plasma volume. The mechanisms of the water immersion diuresis and post-immersion orthostatic intolerance are discussed and inferences made to human exposure to weightlessness.

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