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Plasma Volume Changes Related to Posture and Exercise (40952)

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Abstract. Plasma volume shifts were investigated in four male subjects who remained in either the upright or low-sit posture on a bicycle ergometer during 60 min of rest, 45 min of exercise, and 45 min of recovery. Rest in the upright and low-sit posture induced plasma volume decreases of 14 and 6.9%, respectively. When postural effects were partialed out, exercise in the upright posture resulted in minimal alterations in plasma volume. Work in the low-sit posture was characterized by hemoconcentration during the early phases of pedalling followed by a slight increase in plasma volume which remained stable for the duration of the exercise period. During recovery, plasma volumes returned rapidly to the pre-exercise levels associated with each seated posture. It is evident that when analyzing fluid shifts, posture and time should be rigorously controlled so as to differentiate between the effects of posture and exercise.

Both hemoconcentration and hemodilution have been reported to occur following submaximal (1–7) and maximal leg exercise (7–9). In several of these investigations (2, 4, 10) rest and exercise were in the same posture, while in others the posture and time of the blood sampling prior to and after exercise were neither controlled nor indicated (5, 9, 11). It has been demonstrated that rapid and progressive changes in the concentration of erythrocytes and plasma constituents occur with changes in posture of resting subjects (11–13). Since, in many instances, pre-exercise postures and the time interval in that position were not regulated or stated, it is possible that the confusion regarding the shifts in plasma volume associated with exercise may have been influenced by the prior posture and the duration in that position. Therefore, the present study was conducted to elucidate the influence of resting and exercising in two different postures on changes in plasma volume.

Materials and methods. Four healthy males participated as subjects[4] for the present investigation ($\bar{X}$ age = 31.5 ± 0.7 years, $\bar{X}$ height = 175.8 ± 1.3 cm, $\bar{X}$ weight = 67.8 ± 1.2 kg, $\bar{X}$ % fat = 11.6 ± 0.9). Each subject was given a resting 12-lead electrocardiogram and pulmonary function tests prior to beginning the series of submaximal exercise bouts. All tests were conducted in an environment of 23 ± 2°, RH = 50 ± 5% between 0800 and 1200 hr with the subject 12 to 15 hr post absorptive.

Each subject performed separate 45-min submaximal tests at 360 and 720 kpm·min^{-1} (60 rpm) in the low-sit and upright positions on a Monark bicycle ergometer. Two subjects also performed additional tests at 900 kpm·min^{-1}. Max $\dot{V}_{O_2}$ uptake was also determined in the upright and low-sit posture utilizing the progressive resistance technique of Taguchi *et al.* (15). In the low-sit position, the exercise was performed as previously described (16), the torso being

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[4] The nature and purpose of this study and the risks involved were explained verbally and given in written form to each subject prior to his voluntary consent to participate. The protocol and procedures for this study have been approved by the Committee on Activities Involving Human Subjects, University of California—Santa Barbara.

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upright and the legs extended horizontally; while in the upright position, the torso was also vertical but the legs dependent beneath the body. The order of the tests was presented randomly and at least 1 week elapsed between exercise bouts.

The subject rested on a bed in a recumbent position while a 20-gauge catheter was inserted into the median cubital or cephalic vein. After 30 min of bed rest the subject moved to the ergometer, where he sat for 60 min in either the low-sit or upright posture. The subject then exercised for 45 min which was followed by 45 min of recovery, all in the same posture as the ergometer rest period. Blood samples (5 ml) were obtained after 30 min of supine bed rest; at min 0, 15, 30, 45, and 60 of seated rest; after 5, 10, 15, 20, 30, and 45 min of exercise; and after 5, 15, 30, and 45 min of the recovery period. The two-syringe technique was employed to collect blood samples and the catheter was kept patent by injecting 2.5 ml of heparin–isotonic saline (5000 units/liter) after each sample.

During the three phases of each test, heart rate was obtained from ECG (V_4 lead) during the last 15 sec of each 5-min interval. Expired ventilatory volumes were collected in a 350-liter Collins chain-compensated gasometer during the last 5 min of seated rest and between minutes 15 and 20, 30 and 35, and 40 and 45 of exercise. Aliquots of the expired air were analyzed for $F_{E_{O_2}}$ and $F_{E_{CO_2}}$ by gas chromatography and checked via Haldane analysis. Resting and exercise oxygen uptakes were calculated from the data.

Hematocrit (Hct) was determined in quadruplicate by the microhematocrit method corrected for 4% trapped plasma. Hemoglobin (Hb) was measured in triplicate using the cyanmethemoglobin method. Mean corpuscular hemoglobin concentration (MCHC) was calculated from the Hct and Hb values. Plasma protein concentration (PP) was assessed by Goldberg refractometer. Percentage changes in blood, red cell, and plasma volumes were computed from the Hct (17), Hct-Hb (18), and Hct-PP (19) methods using supine bed rest as a zero reference point for the seated rest interval and the 60th minute of seated rest for the exercise period. A comparison of the percentage changes in plasma volume calculated by the three methods indicated no significant differences, concurring with previous observations (12). Therefore, only the Hct-Hb method (18) was utilized to present the data. Neither this method nor the others utilized require knowledge of the initial plasma volume and utilize the concept that pre-plasma volume is taken as 100 and that shifts from this base value are represented by concurrent alterations in hemoglobin and hematocrit values. The percentage change in PB can be derived from the basic percentage change equation, $\% \Delta PV = 100 (PV_A - PV_B) / PV_B$, and the blood volume (BV) and hemoglobin equation, $BV_A = BV_B (BV_B / Hb_A)$, when A is after and B is before interval of time, Hb in g/100 ml, and Hct as a percentage:

$$\% \Delta PV = 100 \left[\frac{Hb_B}{Hb_A} \times \frac{(1 - Hct_A \times 10^{-2})}{(1 - Hct_B \times 10^{-2})} \right] - 100.$$

Rectal temperature was measured prior to and immediately after the exercise period. Nude body weight was recorded prior to and after the 3-hr test period. Statistical analysis of the data for all conditions was completed utilizing a nonparametric Walsh test (20).

Results. Rest. Movement from the supine resting posture to either the low-sit or upright posture was accompanied by significant alterations in plasma volume ($P < 0.05$) which stabilized after 15 min of resting in the low-sit or 30 min in the upright postures (Fig. 1). Thirty minutes of upright rest resulted in a 14.1% decrement in plasma volume, which did not significantly change throughout the remaining 30 min of the rest period. Fifteen minutes of rest in the low-sit posture produced a decrease in plasma volume of 6.0%. The additional 45 min of rest in the low-sit posture produced no further statistically significant changes. After 60 min of low-sit rest, the mean plasma volume loss was 6.9%.

Exercise. No significant differences in oxygen uptake, heart rate, change in rectal

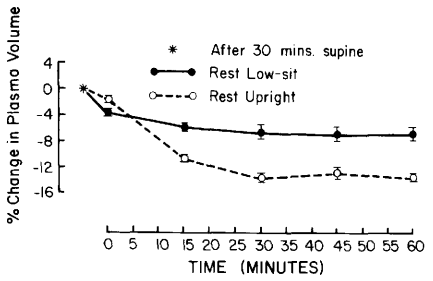

FIG. 1. Changes in plasma volume during 60 min of rest in the upright or low-sit posture using a supine posture as reference. (n = 4.)

temperature, and percentage change in body weight occurred when comparing similar workloads for exercise in the low-sit and upright position (Table 1). Oxygen uptakes and heart rates indicated that the subjects were exercising at approximately 31, 51, and 69% of their bicycle maximal aerobic capacities. Rectal temperatures increased 0.6, 1.3, and 1.6°, respectively, and body weight was reduced by 0.45, 0.75, and 1.05%. Oxygen uptakes and heart rates were not measured during the recovery period, since recovery from these levels of exercise (31–69% of maximum) is rapid and is essentially complete within 5 to 10 min.

All calculations were made based on identical postures from rest to exercise to recovery. When using the supine rest as the base reference, exercise in the upright posture at 31% $\dot{V}_{O_2\ max}$ produced a 10.1% reduction in plasma volume, while with the 60th minute of seated rest as the base reference a 4% increase in plasma volume was calculated.

Regardless of workload, exercise in the low-sit posture was characterized by a rapid decrease in plasma volume during the first 10 min of exercise, after which there was a tendency for the plasma volume to increase by approximately 2% and then remain stable for the duration of the work (Fig. 2). The percentage change in plasma volume at the end of exercise, calculated from the supine rest posture, indicated reductions of 10.9, 11.5, and 15.7% for the 31, 51, and 69% $\dot{V}_{O_2\ max}$ workloads, respectively. When the plasma volume shifts were calculated from the 60th minute of low-sit rest to the end of exercise, the changes were only −4.0, −4.6, and −8.8%, respectively.

Recovery. After 45 min of recovery in the upright posture, the plasma volume expanded above the level of the 60th minute of seated rest (Fig. 2), 2.0, 2.2, and 5.8% increases being observed for the 31, 51, and 69% $\dot{V}_{O_2\ max}$ workbouts, respectively. The shift in plasma volume from the end of exercise (45 min) to the end of the 45-min recovery period was −2% for the 31% $\dot{V}_{O_2\ max}$ workload and +3.5 and +6.0% for the 51 and 69% $\dot{V}_{O_2\ max}$ work intensities, respectively. The change in plasma volume from the end of exercise to 5 min of recovery indicated no alterations for the 51 and 69% workloads and an insignificant 1.2% increase for the 31% work.

Forty-five minutes of recovery in the low-sit posture resulted in a return of the plasma volume to the pre-exercise (60th minute of rest) level following the 31% $\dot{V}_{O_2\ max}$ exercise and an increase of 3.2% above the pre-exercise levels for the 51 and 69% $\dot{V}_{O_2\ max}$ trials. Compared to the 45th minute of exercise, plasma volume increased 4.4, 8.6, and 10.4% for the workloads, respectively, during the 45-min recovery period.

TABLE I. MEAN (±SEM) HEART RATES AND OXYGEN UPTAKES AT 360, 720, AND 900 kpm·min^{-1} PERFORMED IN THE UPRIGHT AND LOW-SIT POSTURE

	360 kpm·min^{-1}		720 kpm·min^{-1}		920 kpm·min^{-1}	
	Upright	Low-sit	Upright	Low-sit	Upright	Low-sit
$\dot{V}_{O_2}$ (liters/min)	1.16 ± 0.10	1.03 ± 0.05	1.83 ± 0.12	1.83 ± 0.12	2.21 ± 0.03	2.28 ± 0.07
Percentage $\dot{V}_{O_2\ max}$	32.8 ± 0.6	29.2 ± 0.4	50.0 ± 0.7	51.8 ± 0.8	67.9 ± 1.8	70.0 ± 1.6
Heart rate (beats/min)	102.7 ± 7.5	88.4 ± 6.6	135.1 ± 7.4	134.4 ± 10.5	167.5 ± 4.2	163.9 ± 8.3

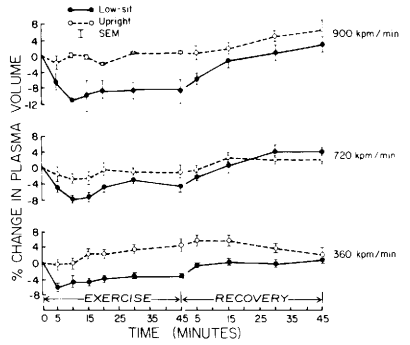

FIG. 2. Alterations in plasma volume during exercise in the upright and low-sit postures calculated as percentage changes from blood samples obtained after 60 min of seated rest in that posture. (n = 4, except for the highest workload, where n = 2.)

The first 5 min of recovery produced a 3.2, 3.4, and 2.7% increase in plasma volume for the three workloads.

During rest, exercise, and recovery, for either posture, the percentage red cell water, plasma osmolality, and MCHC remained constant, 64.4 ± 0.2, 273 ± 2.0 m*Osm*/kg H_2O, and 36.0 ± 1.0, respectively.

Discussion. The change in plasma volume recorded after 60 min of upright seated rest was twice as great as that in the low-sit position (14.1 vs 6.9%). The reduction of plasma volume during the upright seated rest is comparable to a previous study (12) in which movement from a supine to an erect posture was accompanied by a 16.0% decrease in plasma volume. Tan *et al.* (13) reported that movement from standing to chair-sitting was accompanied by a decrement in hematocrit of 3.7%, while a shift from standing to recumbency produced a 7.1% decrease. These changes in posture would approximate a 5.9 and 11.8% increase in plasma volume, respectively, and further demonstrate the effects of posture on plasma volume. The patterns of fluid shifts observed during seated rest may involve the development of varying magnitudes of hydrostatic pressures inside the capillaries. Presumably, fluid transudation between the plasma and interstitium is related to capillary and tissue hydrostatic pressures (21). Thus, these pressures become elevated to a greater extent in the upright posture than in the low-sit, producing a greater reduction in plasma volume.

Utilizing the 60th minute of rest, upright exercise at 31, 51, and 69% $\dot{V}_{O_2\ max}$ produced no significant fluctuations in plasma volume during the first 20 min of exercise. A tendency toward dilution occurred during the 31% $\dot{V}_{O_2\ max}$ as activity continued for an additional 25 to 35 min and supports the findings of previous studies (3, 5, 11, 21). Youmans *et al.* (21) reported that after 30 min of upright seated exercise of unknown resistance, plasma protein concentration and osmotic pressure were lower in the pedalling leg compared to the non-working leg, indicating a hemodilution in the exercising leg. Drinkwater *et al.* (3), Macek *et al.* (5), and Novosadova (11) also found an expansion of the plasma volume during exertion of 30 to 40% $\dot{V}_{O_2\ max}$. In the present study, exercise of 51 to 69% $\dot{V}_{O_2\ max}$ produced no further change in plasma volume after 20 min of exertion. Macek *et al.* (5) also reported no change in plasma volume during bicycle ergometry of 60% $\dot{V}_{O_2\ max}$.

Alterations in plasma volume during recovery from muscular exercise have not been sufficiently described. Cullumbine and Koch (1) reported that decreases in plasma volume produced by stair-stepping required between 25 and 75 min to return to pre-exercise levels. The fact that their subjects were supine during the pre- and post-exercise periods suggests that the long recovery times were related to a shift in postural position than to muscular exercise. In a previous study (12) the plasma volume changes that occurred when moving from an erect to a supine position required at least 20 min to reach equilibrium. In the present study, in which exercise and recovery posture were the same, approximately 15 min were required for the plasma volume to return to ±2% of the pre-exercise levels associated with each position. The next 30 min of recovery produced no significant changes in plasma volume, indicating that equilibrium was attained.

Wilkerson *et al.* (22) and Lundvall *et al.* (23) have suggested that a decrease in

plasma volume with exercise is related to the intensity of the work. The findings of a slight hemodilution in the upright posture observed in this and other studies do not support their results. One explanation might be the change in the subject's posture from the time that the pre and post blood samples are obtained. Any change in posture from rest to exercise will affect the percentage change in plasma volume associated with the exercise. Discrepancies in comparisons with past investigations may be attributed, in part, to the lack of appreciation of the importance of posture. A 15.3% reduction in plasma volume occurring after 45 min of upright cycling at 720 kpm·min^{-1} may be attributed to the subject being supine at the time of the pre-exercise blood sample, while if the subject were seated on the bike for 5 or 15 min before the initial sample was obtained, the reduction in plasma volume would be approximately 11.2 and 5.2%, respectively. Therefore, any study involving changes in plasma volume or constituents should take posture and position pre- and post-exercise into account.

During rest, the Starling–Landis equilibrium of capillary exchange is influenced by posture. In the upright posture, long hydrostatic columns of blood are present (23), blood accumulates in the capacitance vessels (24), and plasma volume is reduced to a constant size. In the low-sit posture the capillary pressures are less severe, resulting in a smaller reduction of plasma volume. When exercise is performed in the upright posture, the Starling–Landis equilibrium of capillary exchange is different from work performed in the low-sit position. The onset of exercise produces an increase in cardiac output and mean blood pressure, and a decrease in resistance for muscle blood flow, which raises capillary pressure and forces fluid to leave the vascular bed. However, the increased interstitial fluid pressure and total tissue pressure oppose an additional efflux of fluid from the capillaries (26). During the initial phases of exercise in the low-sit position there is an outward flux of fluid from the capillary to the interstitial space. The efflux is completed after approximately 15 min of work (27, 28) and a new transudation equilibrium is reached when the increased interstitial fluid pressure and the total tissue pressure begin to oppose the outward flux of fluid (26). Thus, submaximal exercise of light to moderate intensity may produce optimum venous and lymphatic return and capillary fluid transudation in an attempt to maintain a constant plasma and blood volume.

It is possible that only a certain amount of plasma can be removed from the blood. The shift in plasma volume can be due to exercise and/or posture. In the upright posture approximately 14% of the plasma volume was shunted into the interstitial space before exercise began, and no further change occurred during exercise. In the low-sit posture, approximately 7% of the plasma volume was lost during rest and an additional 5 to 6% decrement occurred as a result of exercise. Thus, the total plasma volume shift associated with low-sit rest and exercise approximates that seen with rest and/or work in the upright position. The combined effect of exercise and posture creates pressures in the capillaries and interstitium which balances fluid transudation in order to maintain an adequate plasma volume.

Whenever plasma volume shifts are to be examined, consideration should be given to the resting body posture and the capillary dynamics that result from that posture. The specific time of blood sampling and the position in which the subject has his initial blood sample taken determine the magnitude and direction of plasma volume shifts that will be observed. Appropriate control of these factors will result in a more adequate understanding of the alterations in plasma volume associated with various modes of exertion and/or environmental stressors which have also been associated with plasma volume shifts.

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