RELATIVE PLASMA VOLUME DECREASE DURING ALL-OUT LABORATORY EXERCISE IN VARIOUSLY ACTIVE MALES

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Abstract

Relative plasma volume decrease has mostly been studied in exercises of long duration and without respect to habitual physical activity. Anthropometric characteristics and peak exercise plasma volume decrease were compared in adult male non-athletic subjects (n=20), PE students (n=25) and League I soccer players (n=25). Height, body mass, Conrad (1963) indices, muscle and fat body mass were compared. The all-out exercise was performed on the treadmill. Haematology studied by the QBC AUTOREADER technique at rest and immediately after exercise was carried out in 30 μl arterialized blood samples. Relative plasma volume decrease was estimated by Greenleaf and Hinghofer-Szalkay's (1985) method. Except for mononuclear cell percentage, the initial haematology was similar in all the groups. Peak-exercise plasma volume decrease was significantly smaller, mononuclear percentage was significantly larger in the physically active groups. The greater mononuclear cell percentage is likely to be one of the indicators of such regulatory processes that play an important role in the smaller peak-exercise plasma volume decrease in the physically active groups.

Keywords: plasma volume decrease, physical activity, body composition, all-out exercise

Zusammenfassung

Relative Senkung der Plasmamasse unter maximaler labordurchgeführten Belastung der unterschiedlich aktiven Männer

Die relative Senkung der Plasmamasse wurde bisher nur bei länger dauernden und nicht bei den üblichen körperlichen Aktivitäten untersucht. Verglichen wurden antropometrische Charakteristiken der Senkung von Plasmamasse unter maximaler Belastung bei den nicht-sportbetreibenden Männern (n=20), bei den Sporthochschulstudenten (n=25) und Fussballspielern der Ersten Liga (n=25). Verglichen wurden Körpergröße, -gewicht, Conrad-Indexe (1963.), Muskelmasse und Masse der fetten Unterhautgewebe. Die Untersuchten wurden auf dem Fliessband getestet. Hämatologische Untersuchungen wurden im 30 mikroliter sauerstoffgesättigten Blut durch QBC-AUTOREADER-Technik im Ruhestand und gleich nach der Belastung unternommen. Die relative Senkung der Plasmamasse wurde nach der Methode Greenleaf und Hinghofer-Szalkayj (1985.) gemessen. Der hämatologische Anfangsbefund, die Mononukleozellenrate ausgenommen, war in allen Gruppen ähnlich. Unter den körperlich aktiven Gruppen kam es unter der maximalen Belastung zur wesentlich kleineren Senkung der Plasmamasse, und bedeutender Vergrösserung der Monozellenrate. Die erhöhte Monozellenrate ist ja wahrscheinlich eins der Anzeichen jener regulativen Körperprozesse, die eine bedeutende Rolle bei der Erscheinung von Senkung der Plasmamasse unter der maximalen Belastung bei den körperlich aktiven Gruppen spielt.

Schlüsselwörter: Senkung der Plasmamasse, körperliche Aktivitäten, Körperstruktur, maximale Belastung

Introduction

Increased resting blood and/or plasma volumes induced by regular physical training have been reported by several authors in the last two decades (Convertino et al., 1980; Collins et al., 1986; Schmidt et al., 1988). Since this increase in blood/plasma volume can develop even after some weeks of the regular endurance training, it may be considered to be an early sign of cardio-respiratory and metabolic adaptation to exercise. Experimentally increased resting plasma/blood volume (within the range of 400-700 ml) has been found favourable by allowing a larger stroke volume and cardiac output (Hopper et al., 1988).

Fortney and associates (1983) made the physiologically intriguing statement that the exercise decrease of blood or plasma volume was directly proportionate to the stroke volume, and in this way to cardiac output, measurable during submaximum exercise. Thus, cardially very fit athletes having exceptionally high aerobic power, i.e. maximum stroke volume and cardiac output, would be in a less advantageous position than non-athletes since in this way haemoconcentration would be more marked in them and so impair their physiological performance.

The purpose of the present study was to compare peak-exercise plasma volume decrease in young adult males of different habitual physical activity.

Our research hypothesis was as follows. Cardially well-trained athletes have larger stroke volume and cardiac output during exercise (Blomqvist and Saltin, 1983). If plasma volume decrease were directly related to cardiac output or stroke volume, plasma volume decrease during exercise should be smaller in non-athletic subjects.

Subjects and methods

The investigated subjects were volunteers:

1. Adult, male, League I soccer players (n = 25) having 11 intensive trainings and at least one competition per week.

2. Students of the Hungarian University of Physical Education (n = 25) having five practical sessions (of 90 min. each) and 3-5 event trainings of high intensity per week.

3. Non-athletes (n = 20) having a maximum of two hours a week of non-regular fitness activity.

The members of Groups 1 and 2 had sport medical license for competitions, the non-athletic subjects underwent a detailed internal medical and cardio-respiratory screening before the data collection.

For comparability's sake, the subjects' relative body linearity and skeleto-muscular robustness were described by Conrad's (1963) metric and plastic indices. The metric index is the ratio of chest breadth to chest depth, corrected for height. The plastic index is the sum of shoulder width, lower arm girth and hand circumference.

Lean and fat body masses were estimated by the Drinkwater and Ross (1980) body mass fractionation technique and expressed as percentages. In taking the necessary body dimensions the IBP suggestions (Weiner and Lourie 1969) were observed.

The all-out laboratory exercise was performed on the treadmill. The test exercise began at a 12 km/h treadmill speed and zero level of inclination after individual warming up. (The soccer players and university students warmed up independently, for the non-athletes the warming up was directed by a PE teacher and contained callisthenics, skipping, jogging and stretching exercises). Treadmill inclination was increased by 3% every second minute until exhaustion. The treadmill was stopped by the subjects.

Peak exercise serum lactate was measured by an LP-20 model miniphotometer (Dr. Lange, Germany) in 10 microlitre capillary blood samples. Haematology (haematocrit, haemoglobin level, white blood cell count, granulocyte and lymphocyte + monocyte percentage) was determined by the QBC AUTOREADER (USA) technique, using 30 µl of arterialized blood samples. Blood was sampled at rest (before the anthropometric data collection) and immediately after stopping the exercise, from the fingertip when sitting.

Post-exercise relative plasma volume was calculated by the equation of Greenleaf and Szalkay-Hinghofer (1985):

$$PV\%\ \ 100 \times [HGB_b \times HGB_a^{-1} \times (1-HCT_a) \times (1-HCT_b^{-1})]$$

where: PV% = relative plasma volume as a percentage of the initial volume, HGB = haemoglobin concentration (g x 100 ml^{-1}), HCT = haematocrit (%), b = before exercise, a = after exercise.

Means and standard deviations of the anthropometric and haematological parameters were computed by standard statistical procedures, while the differences were tested by F-test at the 5% level of random error after one-way ANOVA. Differences between the resting and post-exercise variable means were analyzed by t-tests for respective samples.

Results and discussion

The first part of this section contains the results of the studied anthropometric variables, and in the second one the haematological and plasma volume changes are reported.

Statistical means and standard deviations of the anthropometric variables are shown in Table 1. The mean calendar age of the non-athletes was significantly greater than that of the university students and soccer players, but in this young adult range of age no particular importance was attributed to a difference of 2-4 years.

The non-athletes were significantly shorter and heavier than the university students and soccer players termed *active groups* hereafter. Both active groups had significantly greater muscle and markedly lower fat percentage means. The growth type of the non-athletes was metromorphic and normoplastic by Conrad's (1963) categories. The active groups could be qualified as hyperplastic and slightly leptomorphic. Leptomorphy was rather "athletic" and not extremely linear, as one of the consequences of sports selection effects (Mészáros and Mohácsi, 1982a, 1982b; Mohácsi and Mészáros, 1982). The well developed musculo-skeletal system was attributed to their regular physical activity. All the studied anthropometric characteristics of the PE students and soccer players were statistically the same.

Table 1. Basic statistics of the compared anthropometric variables.

Group	Non-athletes		University students		Soccer players		
Variable	Mean	SD	Mean	SD	Mean	SD	P
CA(yr.)	27.20	2.53	23.14	2.27	25.47	3.50	5%
BH (cm)	175.89	6.23	180.84	6.09	181.73	4.84	5%
BM (kg)	77.43	6.46	74.21	5.95	73.04	4.87	5%
M (%)	45.01	1.11	48.79	1.06	49.25	1.14	5%
F (%)	15.55	2.83	9.23	1.58	9.03	1.20	5%
MIX (cm)	-0.85	0.29	-1.14	0.28	-1.27	0.24	5%
PLX (cm)	86.08	3.12	88.96	3.26	91.41	2.25	5%

Abbreviations: CA = chronological age expressed in decimal years, BH = height, BM = body mass, M = lean body mass percentage, F = fat body mass percentage, MIX = metric index, PLX = plastic index, 5% = the difference between the compared means is statistically significant.

Table 2. Means and standard deviations of the physiological parameters.

Group	Non-athletes		University students		Soccer players		
Variable	Mean	SD	Mean	SD	Mean	SD	P_F
HCT_b	46.00	0.89	46.16	1.00	46.24	0.81	NS
HCT_a	49.68	1.58	48.79	1.79	49.01	1.52	NS
P_t	5%		5%		5%		
HGB_b	15.05	0.59	15.21	0.61	15.11	0.52	NS
HGB_a	16.68	0.61	16.38	0.76	16.15	0.78	NS
P_t	5%		5%		5%		
WBC_b	5.10	0.58	5.39	0.60	5.05	0.45	NS
WBC_a	8.58	1.39	8.85	1.35	9.21	1.19	NS
P_t	5%		5%		5%		
$L+M\%_b$	41.30	5.35	39.16	5.07	35.71	4.97	5%
$L+M\%_a$	45.30	6.60	53.40	6.39	54.45	6.31	5%
P_t	5%		5%		5%		
LA	15.06	2.94	15.60	2.86	14.82	2.17	NS
RD	1665.55	328.99	2362.76	281.55	1881.12	214.23	5%
$PV\%_a$	84.08	2.55	88.32	2.19	88.57	2.03	5%

Abbreviations: HCT = haematocrit (%), HGB = haemoglobin ($g \times 100\ ml^{-1}$), WBC = white blood cell count ($1000 \times l^{-1}$), L:M% = ratio of lymphocytes and monocytes in the measured WBC (%), LA = blood lactate concentration ($mmol \times L^{-1}$), RD = running distance (m), PV% = peak exercise plasma volume as a percentage of the initial value, P_F 0.05 = the difference between the group means is significant at 5% level of random error, P_t 0.05 = difference significant before and after the exercise, NS = non-significant.

The basic statistics of the physiological variables is summarized in Table 2. By an evaluation of the statistically different running distances (all the three means were different from each other) and the really high blood lactates (no essential differences were found between the means) it is easy to recognize that the investigated subjects performed at (or very near to) their momentary maximum. In absolute terms the groups' physical performance was naturally different, but all the three groups worked at their physiological maximum which is the basis of the present comparison.

No significant differences were found in the resting haematological group means. (The observed means were very near to the centre of the physiological ranges.) The only exception among the studied haematological parameters was the lower resting mononuclear percentage of the non-athletes. In other words, the two active groups had greater resting lymphocyte- and monocyte counts at rest. This finding is congruent with the observations of Keast and associates (1988) and Mackinnon (1989): Regular physical activity has positive effects on the immune functions manifested in the increased lymphocyte count and also in the increased activity of lymphocytes and other parts of the lymphatic immune system.

Initial haemoglobin and haematocrit levels and total white blood cell count increased significantly in all groups during the applied all-out exercise, a well-known consequence of long- or short-term (but intensive) physical exercise (Senay and Pivarnik, 1985; Schmidt et al., 1989; Ng et al., 1996). Although there were no statistical differences between the exercise-induced haemoglobin and haematocrit increases, the differences between the calculated mean plasma volume decreases were significant. In both active groups the relative plasma volume decrease was of a similar extent and significantly smaller than in non-athletes.

The post-exercise mononuclear cell percentages in the increased white blood cell count were also different in the active and non-active groups. This exercise-induced response was significantly greater in the university students and soccer players.

From international literature and the present results it is evident that the plasma volume decrease during any physical activity is one of the consequences of the activity itself. The mechanisms of this decrease have not yet been clarified in all detail.

Senay and Pivarnik (1985), and Nieman (1995) say that during a graded exercise 10 to 20 % of plasma volume leaves the blood and enters the active muscle tissue. This plasma volume shift, combined with the fluid loss caused by sweating, would lead to an increase in the blood viscosity called haemoconcentration. Wilmore and Costill (1994) have explained plasma volume decrease to appear because of the increased blood pressure and because of the changed metabolism of the working muscle. Contrary to these interpretations, Ng and associates (1996), Mészáros and associates (1996) have found that under laboratory conditions peak-exercise plasma volume decrease failed to correlate with the extent of fluid loss (either during an exercise or sitting in a sauna), with an increased systolic blood pressure and with an increase in running distance. Instead, they reported a slight but significant relationship between peak-exercise plasma volume decrease and an anthropometrically estimated muscle mass expressed as a percentage.

In the Wilmore and Costill (1994) interpretation the fluid shift from the circulation to the working muscle is favourable in respect to its metabolism. However, the plasma volume decrease is unfavourable for the cardiac functions during high-intensity exercise (Hopper et al., 1988).

Theoretically, circulating plasma volume at or around peak-intensity exercise is the joint effect of system redistribution of the circulatory system (Blomqvist and Saltin, 1983; Gisolfi, 1983), the fluid shift into the working muscle (Stephenson and Kolka, 1988; Schmidt et al., 1989; Ng et al., 1996) and resting blood/plasma volume, increased in well-trained subjects (Convertino et al., 1980; Collins et al., 1986; Schmidt et al., 1988).

Though the effects of intracirculatory redistribution are measurable and cannot be neglected, they seem to be less important in respect to this specific kind of plasma volume decrease. Redistribution *per se* cannot compensate completely for the fluid loss, because some exercise-induced plasma volume decrease occurs consistently in everybody. In respect to the mentioned cardiac functions (stroke volume, cardiac output) and blood viscosity, within the physiological range a larger initial blood or plasma volume and a smaller plasma volume decrease would be favourable for any physical effort.

The present results have shown that the plasma volume decrease was significantly smaller in the physically active students and endurance-trained soccer players. Taking all the studied effects into consideration, it is the healthy but untrained organism that turned out to be in a worse condition, because its initial blood volume was smaller and its plasma volume decrease during exercise was larger than in the physically more active subjects.

The greater mononuclear cell percentage is likely to be one of the indicators of such regulatory processes that play an important role in the appearance of smaller peak-exercise plasma volume decrease in the physically active groups.

To conclude: our hypothesis had to be abandoned, because the relative plasma volume decrease was significantly larger in non-athletic subjects than in the two investigated active groups. In respect to physical performance the latter represent the more preferable state.

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