The measurement of peripheral blood volume reactions to tilt test by the electrical impedance technique after exercise in athletes

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Abstract. We have investigated the distribution of peripheral blood volumes in different regions of the body in response to the tilt-test in endurance trained athletes after aerobic exercise. Distribution of peripheral blood volumes (ml/beat) simultaneously in six regions of the body (two legs, two hands, abdomen, neck and ECG) was assessed in response to the tilt-test using the impedance method (the impedance change rate (dZ/dT)). Before and after exercise session cardiac stroke (CSV) and blood volumes in legs, arms and neck were higher in athletes both in lying and standing positions. Before exercise the increase of heart rate and the decrease of a neck blood volume in response to tilting was lower (p <0.05) but the decrease of leg blood volumes was higher (p<0.001) in athletes. The reactions in arms and abdomen blood volumes were similar. Also, the neck blood volumes as percentage of CSV (%/CSV) did not change in the control but increased in athletes (p <0.05) in response to the tilt test. After (10 min recovery) the aerobic bicycle exercise (mean HR=156±8 beat/min, duration 30 min) blood volumes in neck and arms in response to the tilting were reduced equally, but abdomen (p<0.05) and leg blood volumes (p <0.001) were lowered more significantly in athletes. The neck blood flow (%/CSV) did not change in athletes but decreased in control (p<0.01), which was offset by higher tachycardia in response to tilt-test in controls after exercise. The data demonstrate greater orthostatic tolerance in athletes both before and after exercise during fatigue which is due to effective distribution of blood flows aimed at maintaining cerebral blood flow.

1. Introduction

The assessment of blood volumes simultaneously entering main peripheral regions of the human body is important for the orthostatic instability understanding and presents a rather difficult task. Peripheral blood volumes can be measured by non-invasive technique of electrical impedance on a beat by beat basis in various peripheral regions of the body. This impedance technique has been successfully used for analysis of cardiac stroke volume [1] and lower limb blood flow [2]. We suggest that the impedance method can be applied for assessment of peripheral blood volume reactions in response to orthostasis. The aim of our study was to evaluate blood volume reactions in the peripheral regions of the body in response to the tilt test in endurance-trained male athletes prior and after exercise. We hypothesized that in athletes with high aerobic fitness blood volume reactions will be decreased in the neck vessels and increased in the lower limbs and/or in the abdomen region and that these reactions in athletes after exercise will be less deteriorated.
2. Subjects and methods
Twelve healthy young (22.4±5.5 years) male racing skiers composed the athlete group. All athletes had 4-8 years of total sport experience and 10-15 hours exercise per week for last 2 months. The control group included healthy aged-matched (19.4±1.6) sedentary men (n=23).

2.1. Impedance measures of blood volumes
Measures were made using “Medass” (Russia) impedance analyzer. In this analyzer a current generated with a frequency of 1000 Hz is distributed into 8 channels at 125 Hz. It allows simultaneous monitoring of impedance change rates (dZ/dT) in six regions of the body: two legs, two hands, abdomen, neck, and ECG. For analysis of impedance changes in these peripheral regions five pairs of ECG-electrodes (one is outer current and other is inner potential) are applied to the wrists of both hands, to the ankles of lower limbs and to the temples of head. To assess dZ/dT in proper leads the current and potential electrodes were automatically switched in desired combination, thereby providing required work leads. For example, to measure the impedance of the right hand a current circuit was created where current electrodes are located on the right wrist and the right temple of head, and the potential electrodes are located on the right arm and right leg. Thus, a common part for both circuits is the right hand. The ECG is monitored using seventh channel of the analyzer from a first lead. Cardiac stroke volume was measured by the standard impedance cardiographic method [1]. For calculation of blood volume (in ml) values in neck (BVneck), abdomen (BVabdomen), arms (BVarm), legs (BVleg) and cardiac stroke volume (CSV) additional anthropometric measurements (cm) were used: circumferences of neck, trunk at the levels of the xyphoid process, groin, waist, wrist (minimum) and shoulder (maximum), ankle (minimum) and hip (maximum); the lengths from jugular notch of the neck to the temple and the xyphoid process; shoulder width; the lengths of hands from wrist to clavicle, the lengths of legs from ankle to pelvis. The left and right measurements in legs and arms were averaged. Every calculations were made as an average over 60 heart beats. Blood volumes (BV) in all regions were calculated using Kubicek's equation [1]. We used absolute values of blood volumes in cardiac and peripheral regions because the total anthropometric characteristics and statistical significance of differences of indexed BV between the groups did not change.

2.2. Protocol
All measures of blood volume reactions in response to the head up tilt test (hand-made tilt table with a footboard) were made twice at baseline state before and 10 min after aerobic exercise session. The measurements were performed after a 5 min rest period in a lying position and after 3 min standing period in an orthostatic position. Brachial arterial blood pressure was measured using the Omron 907 sphygmomanometer. After baseline measurements were completed subjects performed an exercise session on a bicycle ergometer (Kettler FX-1). The initial 25 Wt exercise load (70 rev/min) increased stepwise by 25 Wt every 1 min until the heart rate was 140 beat/min. Then operating power remained constant for 30 min. The postexercise measurements were performed in 10 minutes after end of exercise.

2.3. Statistics
In figures data are expressed as mean ±0.95 confidence interval and as M±Std Dev in the text. The analysis of variance for repeated measures was used to compare the cardiovascular reactions to orthostatic stress between controls and athletes and for determination of exercise effects on BV. Post-hoc comparisons were made using the Newman-Keuls criterion. Comparisons of blood volumes between groups in corresponding positions were made using unpaired t-test.

3. Results
Athletes had a higher working load at 140 b/s heart rate (205.4±24.7 Wt vs 117.0±18.2 Wt, p<0.001) and performed a higher total work (1907±344 kJ vs 979±176 kJ, p<0.001) compared to controls. But subjective exercise intensities as indicated mean HR (156±7 b/min in controls and 156±8 b/min in
athletes, p=0.98) during exercise session were equal in both groups. As a result of a higher absolute intensity body weight decrease was higher in athletes (p<0.001). Thus during postexercise tilt-testing athletes were more dehydrated.

**Figure 1.** Blood volume reactions to orthostatic stress in groups before and after exercise. The p-values are indicated a difference in reactions to the tilt-testing between controls and athletes. *, **, *** - p<0.05; 0.01; 0.001 between athletes and controls in the corresponding positions. S, SS, SSS - p<0.05; 0.01; 0.001 compared to supine in the corresponding groups according; ns – nonsignificant Solid lines – controls, dotted line – athletes.
3.1. Cardiovascular reactions to orthostatic stress before exercise session
In the supine baseline state athletes had lower HR (p<0.001. Figure 1-A), higher values of CSV (p<0.001. Figure 1-B), BVAabdomen (p<0.001. Fig. 1-C), BVLeg (p<0.001. Figure 1-D), BVArm (4.08±0.67 ml vs 3.06±0.49 ml, p<0.001) andBVneck (p<0.001. Figure 1-E). Before exercise session HR increment in response to orthostatic stress was significantly lower in athletes (р=0.017. Figure 1-A), but falls of CSV (p=0.027. Figure 1-B) and cardiac output (-0.68±0.75 l in athletes and +0.30±1.20 l, p=0.015) were significantly higher than in controls. Athletes had higher reduction of BVLeg (p=0.002. Figure 1-D) and lower fall of BVneck (p=0.017. Figure 1-E). Though the BVneck expressed as a percentage of CSV was significantly lower in supine in athletes (p<0.05) but increased in response to tilting in athletes (p<0.05) and did not change in controls (figure 1-F). Reactions of mean arterial pressure were not different in the groups (results are not shown).

3.2. Cardiovascular reactions to orthostatic stress after exercise session
Ten minute after exercise session in the supine state HR was higher in both groups compared to before exercise (p<0.001), mean arterial pressures and cardiac outputs did not change, and the values of CSV, BVAabdomen, BVLeg, BVArm andBVneck were all lower (all p<0.01) than those before exercise session. As well as before exercise in the supine position athletes had lower HR (p<0.001. Figure 1-A) and higher peripheral and cardiac blood volumes (p<0.001. Figure 1-B,C,D,E), but cardiac output and mean arterial pressure were the same in the groups. HR rise during the tilting was lower (p=0.011. Figure 1-A), but reductions of cardiac stroke volume (p<0.001. Figure 1-B), BVAabdomen (p=0.029. Figure 1-C) and BVLeg (p=0.0001. Figure 1-D) were higher in athletes than in controls. Cardiac output increased in controls (from 5.16±1.38 l lying to 5.99±1.78 l standing, p<0.05), but it did not change in athletes (from 6.0±0.89 l lying to 5.57±0.92 l standing, p<0.1). Although BVneck decreased equally in both groups during the orthostatic test (p=ns. Figure 1-E), the percentage of CSV entering into the neck did not change in athletes and decreased in controls (figure 1-F). As a result the difference between these reactions of neck blood volumes was significant (p=0.008. Figure 1-F).

4. Conclusion.
In general, our results indicate an increased orthostatic tolerance in athletes, which is contrary to some studies [3]. The study of the blood volume distribution in the peripheral regions by our impedance method indicates an increased ability to maintain cerebral blood flow during tilt testing in athletes in baseline state. This peculiarity of blood flow regulation in athletes was determined despite the increased fall of stroke volumes that may induce cerebral hypoperfusion [3]. These results are consistent with other authors [4], who noted improved mechanisms of cerebral autoregulation in physically active adults. In fatigue state after exercise session maintenance of blood volumes in the neck vessels was deteriorated, but it remained more favourable in athletes compared with controls. Thus we can conclude that endurance trained athletes have a more effective distribution of blood volumes aimed at maintaining cerebral blood flow. This may be due to higher vasoconstriction of leg and abdomen vascular beds.

Reference
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