Comparison of Blood Lactate Elimination in Individuals With Paraplegia and Able-Bodied Individuals During Active Recovery From Exhaustive Exercise

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Abstract

Background/Objective: The aim of the present study was to compare blood lactate elimination between individuals with paraplegia (P) and able-bodied (AB) individuals after strenuous arm exercise.

Methods: Eight P and 8 AB men (matched for age, height, and weight) participated in this study. Average weekly arm-training volume for P participants (eg, hand bike, wheelchair basketball) and AB participants (eg, swimming, rowing, cross-country skiing) was 4.1 ± 1.6 vs 2.8 ± 0.8 h. A maximal-arm-cranking intensity-graded exercise test to volitional exhaustion was performed by all test participants. Immediately after the exercise test, the participants performed arm cranking for another 30 minutes at a workload of one third of the maximally achieved power output. During this active recovery, mixed-capillary blood samples were taken for lactate analysis.

Results: The lactate accumulation constant was significantly higher for P individuals, whereas the lactate elimination constant showed no significant difference between the two groups.

Conclusions: Individuals with paraplegia seem to have no disadvantages in lactate elimination after exhaustive arm exercise compared with able-bodied individuals.

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Key Words: Paraplegia; Exercise; Spinal cord injuries; Ergometry; Exhaustion; Lactate metabolism; Training

INTRODUCTION

Strenuous exercise leads to lactate and hydrogen ion production in the exercising muscle and a concomitant decrease in intracellular pH, which compromises muscle contraction and glycolytic enzyme activity and, thus, exercise performance (1). In order to regain optimal performance as soon as possible, fast lactic acid elimination is crucial for athletes. Lactate oxidation takes place primarily in type-I fibers of working skeletal muscle, in the liver and the heart (2). However, there is some evidence that inactive skeletal muscle also plays a role in lactate metabolism. It was shown in able-bodied people that inactive skeletal muscle can store lactate (3,4) and retain 24% of the total lactate produced 25 minutes after cessation of strenuous exercise (3). Furthermore, 5% of the lactate produced during maximal exercise is metabolized in inactive skeletal muscle (4).

Adaptations after spinal cord injury (SCI) include a loss of muscle mass (5,6) in the paralyzed limbs. Olive et al (7) found a 38% reduction of muscle volume in paralyzed legs 10 years after an accident leading to SCI. Another adaptation to SCI is reduced oxidative capacity of paralyzed limbs, because no more type-I fibers can be found in the leg muscles of people with chronic paraplegia, although the proportion of these fibers in able-bodied people is up to 40% (8). As a consequence and in comparison with able-bodied individuals, the paralyzed leg muscles of individuals with paraplegia might have a reduced capacity of taking up and oxidizing lactate when performing upper body exercise.

Because the opportunities for people with paraplegia to participate in sports have increased markedly in recent years, it seems important to know whether training practices of able-bodied athletes can be adopted without any modifications. If one were to observe differences in lactate removal between paralyzed and able-bodied athletes, then training designs such as recovery duration between maximal bouts of interval training ought to be adapted. This seems to be of relevance in professional sport, in which peak performance is dependent on optimization of these kinds of details.

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Table 1. Study Participants' Characteristics

	Able-Bodied	Paraplegia	P-Value
Age [y]	33.5 ± 10.7	37.8 ± 9.8	0.420
Height [cm]	177.5 ± 7.1	179.5 ± 7.5	0.593
Weight [kg]	77.8 ± 8.0	76.0 ± 11.0	0.721
Arm training [h·wk ⁻¹]	2.8 ± 0.8	4.1 ± 1.6	0.061

The aim of the present study was therefore to investigate whether paralyzed (P) participants and able-bodied (AB) participants would show significant differences in blood lactate elimination after exhaustive arm exercise. Based on the above-mentioned differences between P and AB participants concerning leg muscle mass and fiber-type composition, we expected a slower lactate elimination rate for P individuals compared with AB individuals.

METHODS

Study Participants

Eight P and 8 AB men participated in this study, which was approved by the local ethics committee. All participants gave their written informed consent and completed a detailed questionnaire about their health histories and dietary practices; training and especially arm-training status was assessed using a questionnaire about each person's sportive activities. P participants were mainly engaged in sports like hand biking or wheelchair basketball, whereas AB participants had performed sports like swimming, rowing, or cross-country skiing for several years. Activities of daily living were not considered arm-training exercise in P participants.

The P and AB groups did not differ in age, height, weight, and weekly arm-training volume (Table 1). In the P group, all participants had complete SCI (ASIA A). Those in the P group had been paralyzed for 17 ± 7 years (range: 9–28 years). Lesion levels ranged from T4 to T12.

Materials

All tests were performed by using an arm-cranking ergometer (Ergometrics 800 SH, Ergoline, Bitz, Germany). Test participants were placed on a chair that was connected to the ergometer. Before each test, the pedal axis was aligned with the participant's shoulder, and participants were positioned such that their elbows were slightly flexed at maximal reach. Their feet were placed on the floor such that the knees were bent at an angle of approximately 90°. Mixed-capillary blood was taken at the earlobe to determine lactate concentrations as measured by an enzymatic lactate analyzer (Super GL Ambulance, Ruhrtal Labor Technik, Möhnesee, Germany). For heart rate determination, a monitor watch (Polar S610, Polar, Kempele, Finland) was used. Oxygen consumption was determined by using an ergospiro-

metric device (Oxycon Pro, Jaeger, Würzburg, Germany), which was calibrated immediately before each test according to the manufacturer's recommendations.

Exercise Protocol

The test consisted of a maximal intensity-graded exercise test with a subsequent 30-minute active recovery period. The graded exercise test started at 20 W. Thereafter, the workload was increased 5 W every 20 seconds until the participant's volitional exhaustion. The load was then reduced to one third of the maximally achieved power output ($P_{\max}$) for active recovery. Immediately before starting the active recovery period, study participants rated their overall perceived exertion by means of the Borg Scale (9), with a rating of 6 indicating "no" and 20 "maximal" exhaustion. Further, they were asked to indicate the reason for exhaustion. Lactate was sampled at rest, immediately after cessation of the intensity-graded exercise test, as well as every minute up to the 10th minute of the active recovery period. For the remaining 20 minutes of recovery, blood sampling was performed every 4 minutes.

Data Evaluation and Statistical Analysis

Data points of the measured lactate concentrations were fitted to the following biexponential curve, as described in detail elsewhere (10):

$$La(t) = La(0) + A_1(1 - e^{\gamma_1 t}) + A_2(1 - e^{\gamma_2 t}).$$

$La(t)$ denotes the time-dependent lactate concentration, with $La(0)$ being the lactate concentration at the start of recovery. This equation suggests that the lactate kinetics during recovery can be described by two main processes, one with a high velocity constant (γ_1) describing the appearance ($A_1 > 0$) of lactate in the bloodstream and the other with a low velocity constant (γ_2) describing its disappearance ($A_2 < 0$). The parameters were calculated using SYSTAT (Version 10, SPSS Inc, Richmond, CA) with the regression method of least mean squares. The maximal lactate concentration ($Lac_{\max}$) was defined as the peak value of the fitted curve. All statistical analysis was conducted using SYSTAT. Variables were compared with an unpaired two-tailed t test for data with separate variances. Statistical significance was set at $P < 0.05$.

RESULTS

The velocity constant for lactate elimination (γ_2) showed no significant difference between P and AB participants. However, the velocity constant for lactate accumulation (γ_1) was significantly higher in P participants (Table 2).

The time course of average blood lactate and corresponding biexponential correlation curves for P and AB participants are presented in Figure 1. The correlation coefficients of the individual curves ranged from 0.98 to 0.99. Significantly lower values for P participants compared with AB participants were found

Table 2. Results of Comparisons of Able-Bodied Men vs Men With Paraplegia

	Able-Bodied	Paraplegic	P-Value
γ_1 (min^{-1})	0.257 ± 0.064	0.419 ± 0.133	0.008
γ_2 (min^{-1})	0.054 ± 0.030	0.062 ± 0.036	0.632
P_{max} (W)	158.8 ± 15.1	136.3 ± 17.3	0.015
Lac_{max} ($\text{mmol}\cdot\text{l}^{-1}$)	9.7 ± 1.1	8.6 ± 0.4	0.014
$\dot{V}_{\text{O}_{2\text{peak}}}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	36.6 ± 2.9	29.5 ± 4.4	0.002
HR_{max} (min^{-1})	180.0 ± 12.9	174.8 ± 13.4	0.437
Borg value	19.8 ± 0.5	19.5 ± 0.9	0.506

in P_{max} , Lac_{max} , and peak oxygen consumption ($\dot{V}_{\text{O}_{2\text{peak}}}$), whereas no statistical difference was found in maximal heart rate (HR_{max}). Corresponding data are presented in Table 2. All participants indicated exhaustion of the arm muscles as the exercise-limiting factor. Rating of overall perceived exertion ranged from 18 to 20 and showed no significant difference between groups (Table 2).

DISCUSSION

Blood Lactate Elimination

The expected difference in γ_2 between P and AB participants was not confirmed by our findings. With regard to the wide statistical spread of γ_2 in our groups (P: $0.008\text{--}0.114 \text{ min}^{-1}$, AB: $0.011\text{--}0.095 \text{ min}^{-1}$), the individual fitness level and genetic predisposition might have a much higher influence on blood lactate elimination than being either P or AB status. A wide range of lactate elimination constants (expressed as half-life period: $9.2\text{--}18.2 \text{ min}$) had already been found in cyclists after exhaustive exercise (11), which supports the hypothesis of interindividual differences in lactate kinetics. Moreover, it has to be taken into account that the mechanisms for production and clearance of lactate may

differ between P and AB individuals and that the specific source of lactate elimination can not be determined in the present study. Thus, it remains unknown whether lactate is cleared by muscle above or below the level of lesion in P individuals. Further studies are needed to clarify this issue.

However, considering the similar range of γ_2 in our groups, P participants seem not to be disadvantaged compared with AB participants concerning the trainability of lactate removal: a well-directed training program probably leads to improved blood lactate elimination in both groups. However, the trained P individuals in our study do not represent the general population with thoracic SCI. Our findings may be applicable to paralyzed athletes but not to the large segment of the paralyzed population that is not performing sports regularly. Further investigations are needed to elucidate this issue.

Blood Lactate Accumulation Participants

γ_1 was significantly higher in the paralyzed men, and, thus, the slope of the P group's curve rises more rapidly in the early stage of recovery than that of the AB group. Although it is not definitely known, one could speculate about a negligible potential for lactate oxidation (7) and a reduced potential for lactate storage (5,6) in the leg muscles of our P participants, because all these men were paralyzed for more than 9 years. Reduced oxidative and lactate storage capacities in our P participants' paralyzed limb muscles could have contributed to the finding of faster blood lactate accumulation in the present study. However, follow-up confirmation is needed to prove our assumptions.

In the late stage of exercise and in the early stage of recovery, AB participants were able to eliminate more lactate from the bloodstream than P participants, resulting in a slower increase of the lactate concentration after cessation of exhaustive arm exercise. The lower gradient of lactate accumulation in AB participants compared with P participants makes the regression lines of the lactate curves converge (Figure 1). However, it is important to note that our P participants' lactate concentrations are lower throughout the whole recovery period. The difference in γ_1 is therefore not big enough to evoke higher Lac_{max} in P participants. If this were the case, one could argue that even though γ_2 is not

Figure 1. Comparison of blood lactate elimination between P and AB participants during active recovery after exhaustive arm exercise (means and standard deviations). The point of origin of the time scale indicates the beginning of active recovery.

significantly different between groups, P participants have to handle higher lactate concentrations and are therefore disadvantaged when compared with AB participants. Regarding the lower Lac_{max} in P participants, we conclude that they are not disadvantaged concerning lactate elimination, despite a higher γ_1 .

Peak Values

Compared with AB participants, P participants showed significantly lower values for $\dot{V}_{\text{O}_{2\text{peak}}}$, P_{max} , and Lac_{max} , whereas no differences were found in HR_{max} between groups (Table 2). Previous studies found similar results (12,13), with reduced $\dot{V}_{\text{O}_{2\text{peak}}}$ values and lower Lac_{max} in paralyzed individuals compared with able-bodied individuals (14). However, Borg values at the end of the intensity-graded exercise test indicate a high level of physical exhaustion, which was not different between groups (Table 2). Thus, the lower values for $\dot{V}_{\text{O}_{2\text{peak}}}$, P_{max} , and Lac_{max} in paralyzed individuals may not be explained by incomplete exhaustion of this group, particularly because no differences in Borg values and HR_{max} were found between groups.

Van Loan et al (15) observed reduced cardiorespiratory capacity in paralyzed individuals with higher-level lesions. Because the lesion level was limited in our P participants to those lower than T4 and no differences in heart rate or rating of perceived exertion were found between the P and the AB group, neither the respiratory nor the cardiovascular system seemed to be an exercise limiting factor in the present study, and may not explain the differences in performance between the groups.

Because all of our test participants ate food rich in carbohydrates prior to the exercise test and abstained from exercise for at least 24 hours before the test, the smaller Lac_{max} in P participants cannot be explained by incompletely filled glycogen stores. However, some trunk and leg muscle contraction in AB participants cannot be absolutely excluded. Thus, the resulting larger volume of muscle mass eventually recruited in our AB participants could have led to higher $\dot{V}_{\text{O}_{2\text{peak}}}$, P_{max} , and Lac_{max} . This speculation contrasts with the results of Theisen et al (16), who found no differences in P_{max} between paralyzed and able-bodied individuals.

Active Recovery

Moderate active recovery was performed to enhance lactate extraction of inactive muscles (17), which otherwise stops soon after the cessation of exercise (3,4,18). Moreover, active recovery is a widespread technique in sports and more applicable than passive recovery.

Study Participant Recruitment

In the present study, participants' characteristics with respect to age, height, weight, and arm-training status did not differ between groups (Table 1). This is of importance because age-related differences in muscle

fiber composition and enzyme activity exist, with younger people having more type-II fibers and increased anaerobic enzyme capacity (19–21). Furthermore, muscle fiber composition is plastic and trainable: endurance training leads to an increased ability to lower blood lactate concentrations and an increased proportion of type-I fibers and aerobic enzymes (22,23), and resistance training is followed by hypertrophy of type-II fibers and enhanced muscle buffer capacity (24,25). People with SCI are known to have a higher proportion of arm muscle type-I fibers compared with untrained able-bodied individuals (22). This was an important point to consider during participant recruitment. Thus, all our AB participants had to perform sports in which the arms are used, such as rowing, swimming, or cross-country skiing. Activities of daily living of P participants were not considered training because intensities of such activities are markedly lower than intensities experienced during sport activities and are not known to improve physical fitness (26). Although no muscle biopsies were performed in the present study, no or only small differences in arm muscle fiber composition were expected between the groups due to careful study participant recruitment.

CONCLUSIONS

Participants with paraplegia do not seem to be disadvantaged compared with AB participants concerning blood lactate elimination, even though lactate concentrations after cessation of heavy exercise rose faster in P participants. For both P and AB test participants, the individual fitness level and genetic predisposition might be of greater importance for lactate elimination than their group status. Thus, the time of recovery after maximal bouts of physical arm activity does not have to be prolonged in trained paralyzed individuals to reach lactate recovery levels comparable with those of able-bodied individuals.

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