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Original Article

Relationship between skeletal muscle mass and blood lactate level reduction after short squat jumps in healthy adult non-athletes

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Abstract. [Purpose] Blood lactate reduction helps in understanding muscle recovery. Although light exercise and stretching are known interventions to reduce its concentration, the impact of skeletal muscle mass on blood lactate clearance is unknown. This study aimed to determine the relationships between blood lactate reduction and skeletal muscle mass following exercise. [Participants and Methods] Healthy non-athletic males performed squat jumps for 1 minute and 30 seconds. Blood lactate level was measured before and immediately after the exercise and then every 2 minutes for a period of 20 minutes. The decrease in blood lactate level was estimated as the difference between the minimum and maximum values. The rate of decrease was calculated by dividing the decrease in blood lactate level by time. Blood lactate level was measured using Lactate Pro[TM] 2, while skeletal muscle mass was assessed using InBody 430. [Results] There was a significant positive correlation between skeletal muscle mass, the amount of blood lactate level reduction, and the rate of reduction of blood lactate level. [Conclusion] Our results demonstrated that greater skeletal muscle mass enabled a greater decrease in blood lactate level, suggesting that skeletal muscle mass may be involved in the reduction of blood lactate level after a squat jump. Interventions to increase skeletal muscle mass may promote more efficient lactate metabolism and muscle fatigue recovery.
Key words: Lactate reduction, Muscle fatigue, Skeletal muscle mass

INTRODUCTION

Blood lactate (BLa) has been widely used in the clinical and sports field of physiotherapy as an indicator of muscle fatigue. BLa has been considered to be related to the prevention of muscle overload and/or maintenance of exercise performance[1, 2], and is assumed as an index of recovery from muscle fatigue and performance[3, 4]. At present, specific factors affecting muscle fatigue have not been fully elucidated; however, in isolated muscle models, it has been reported that acidosis, phosphate ions, and calcium ions are associated with each other in a complex manner[5, 6]. Several recent studies show that lactate accumulation is not suggestive of muscle fatigue[6], but lactate is generally evaluated as one of the biomarkers for metabolism change in cases of muscle fatigue[7]. Lactate is produced when muscle glycogen is consumed during glycolysis, which is an energy supply system[8]. Lactic acid is an important energy substrate[9–11], that is reportedly produced by working muscle cells and circulated in the blood, and then metabolized in various tissues such as the brain, heart, liver, and skeletal muscles[9, 11]. In other words, efficient reduction of BLa indicates that the lactate carried to each tissue is metabolized and reused indirectly as an energy substrate. BLa is relatively easy to be measured at clinical settings compared to other muscle fatigue-related factors

as mentioned above, and is frequently used in various sports such as full squat exercise[2] swimming training[12] and 30-km running[13]. In recent years, several studies have focused on BLa reduction using various interventions and environmental settings[3, 14, 15], and demonstrated that active light exercises, massages, and oxygen supplements efficiently reduced BLa after performance[3, 14, 16]. In addition, Monedero & Donne reported that the higher the BLa reduction rate due to the intervention, the better the maintenance of performance[3]. However, few studies have investigated the relationships between individual biological factors and BLa reduction. Skeletal muscles have the ability to metabolize BLa as well as the ability to contract for physical exercise, and are often the target of therapeutic intervention in physical therapy. Lactate metabolism in the skeletal muscles occurs in the mitochondria[17]. Hambrecht et al. demonstrated that walking training for 6 months in patients with chronic heart failure increased mitochondrial activity by 41%, which was closely associated with improved aerobic capacity (r=0.66)[18]. Mitochondria in the skeletal muscles have an increased level of dehydrogenase activity, for which lactate[19] is used; this may promote the decrease in BLa levels. An individual with a large amount of skeletal muscle can be regarded as having a large amount of lactate-metabolizing tissue; thus, it can be hypothesized that a higher decrease in BLa may be observed with a greater amount of skeletal muscle mass. In this study, we performed a squat jump (SJ) exercise on healthy non-athletic males and measured BLa before and after SJ. SJ is used not only for the evaluation of sports performance[20], but also for athlete training[21] and assessment of anterior cruciate ligament injury[22]. We adopted SJ as an exercise task because it is not complex, and the load is sufficient even for healthy adults[20, 21]. The purpose of this study was to investigate whether BLa reduction increases as the amount of skeletal muscle increases.

PARTICIPANTS AND METHODS

A total of 15 healthy non-athletic males were included in this study (Table 1). Their consent for participation in this study was taken through written and oral explanations. Each participant performed SJ for 1 minute and 30 seconds at a pitch of 46 beats per minute. SJ was defined in this study as follows: For squatting, the legs were opened up till the shoulder width, the knees were bent at 90°, and the trunk and lower legs were set in parallel. For jumping, the participants were instructed to jump upwards as high as possible while swinging their upper limbs upwards. In order to draw out maximum effort from each participant, the examiner did not inform the participants of the exercise time in advance and instructed them to continue SJ until the examiner's signal. BLa was measured before exercise (pre), immediately after exercise (post), and then at 2-minute intervals until 20 minutes later (2, 4, 6, 8, 10, 12, 14, 16, 18, 20), from the fingertips of the dominant hand using a simplified device, Lactate Pro™ 2[23] (ARKRAY, Inc., Kyoto, Japan). After the examiner disinfected the blood collection site and dried it sufficiently, the examinee performed a puncture using a medical puncturing device (Naturalette Petit, ARKRAY, Inc.). A small amount of blood was collected, and the Lactate Pro™ 2 sensor (ARKRAY, Inc.) was directly attached to the blood to measure the lactate concentration. Heart rate (HR) and Borg scale were recorded at the same time as BLa measurement. HR was measured with Polar M200 (polar Electro Japan, Tokyo, Japan). InBody430 (Inbody Japan, Tokyo, Japan) was used for skeletal muscle mass measurements. For data analyses, the amount of BLa reduction was calculated by subtracting the minimum value of BLa from its maximum value. The amount of decrease in BLa depends on its peak value, which is influenced by the physical characteristics of each participant. The BLa reduction rate was determined by dividing the amount of BLa reduction by time. The reason for using the rate of decrease in addition to the amount of decrease in BLa was to evaluate the metabolic rate per minute since the peak value of BLa varied among participants. Skeletal muscle mass index (SMI) was calculated by dividing the total muscle mass of the extremities by square of the height (m). The normality test was performed using the Shapiro-Wilk test. To examine the exercise load, repeated-measures analysis of variance or the Friedman test was performed using mean values to compare the pre values of BLa, HR, and the Borg scale with the post values and those taken at each measurement point. The relationships among BLa, skeletal muscle mass, and SMI were examined by Pearson's product moment correlation coefficient or Spearman's rank correlation coefficient. The significance threshold was set at p<0.05. All statistical analyses were performed with EZR software (Saitama Medical Center, Jichi Medical University, Saitama, Japan), a graphical user interface for R software (The R Foundation for Statistical Computing, Vienna, Austria). More precisely, EZR is a modified version of R commander designed to add statistical functions frequently used in biostatistics[24]. Sample size calculation was performed using G*Power[25] based on the data from a prior study, and the calculated minimum requirement was 11. Effect size, statistical power, and p-value were set at 0.70, 0.80, and 0.05, respectively, by conducting a pilot study. All authors performed in accordance with the ethical standards of the Helsinki Declaration and the participants signed an informed consent form. This study was approved by the Medical Ethics Committee (approval no. 4520).

Table 1. Characteristics of the participants (n=15)

	Age (years)	Height (cm)	Body weight (kg)	Skeletal muscle mass (kg)	SMI (kg/m^2)
Mean (SD)	21.5 (1.41)	172.3 (5.59)	61.1 (6.73)	29.7 (2.86)	7.57 (0.42)

SD: standard deviation; SMI: skeletal muscle mass index.

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RESULTS

None of the participants opted out of the study, and data from all 15 participants were used for the analysis. The mean values of BLa, HR and Borg scale for each measurement time (pre, post, 2, …. 20) are shown in Table 2. In the results of the Shapiro-Wilk test, BLa showed no normality at 10 and 12 minutes ($p<0.05$) and HR showed normality at all times ($p>0.05$). The Borg scale displayed no normality only for the post value ($p<0.05$). BLa levels were significantly increased at each time point as compared with the pre value ($p<0.05$). Similarly, the HR at each measurement was significantly higher than the pre value ($p<0.01$), and the Borg scale was significantly higher for up to 12 minutes than the pre value ($p<0.05$). The mean $\pm$ standard deviation values for the amount of BLa reduction (mmol/l), BLa reduction rate (mmol/l/min), skeletal muscle mass (kg), and SMI (kg/m^2) of the participants were 6.47 ± 1.36, 0.54 ± 0.32, 29.7 ± 2.86 and 7.57 ± 0.42, respectively. The normality of the BLa reduction ($p>0.05$), BLa reduction rate ($p<0.05$), skeletal muscle mass ($p>0.05$), and SMI ($p>0.05$) were also determined using the Shapiro-Wilk test. The relationships between the amount of decrease in BLa, the rate of decrease in BLa, skeletal muscle mass and SMI are shown in Table 3. There was a significant positive correlation between decrease in BLa and skeletal muscle mass ($r=0.71$, $p<0.01$, $R^2=0.50$). There was also a significant positive correlation between the rate of decrease in BLa and skeletal muscle mass ($\rho=0.63$, $p<0.05$, $R^2=0.40$). The relationships between the amount of decrease in BLa, the rate of decrease in BLa, and SMI are shown in Table 3. A significant positive correlation was found between the decrease in BLa and SMI ($r=0.71$, $p<0.01$, $R^2=0.50$) and the rate of decrease in BLa and SMI ($\rho=0.59$, $p<0.05$, $R^2=0.35$), respectively.

DISCUSSION

This study aimed to investigate the relationships between skeletal muscle mass and BLa reduction. Compared with the pre-measurement, BLa, HR and Borg scale increased significantly after SJ. It was inferred from the HR and the Borg scale that the SJ provided a sufficient load for a muscle fatigue task. Petrovsky recorded surface electromyography (EMG) from the quadriceps muscle during the bicycle ergometer. Compared with 20% and 40% of the maximal oxygen uptake (VO_2max), it was reported that muscle fatigue accompanied by an increase in EMG amplitude and a decrease in frequency was observed

Table 2. BLa and HR values measured at each time points (n=15)

	Mean $\pm$ SD					
	BLa (mmol/l)	HR (beats/min)	Borg scale	vs. pre[a] (BLa)	vs. pre[b] (HR)	vs. pre[a] (Borg scale)
Pre	1.51 ± 0.25	72.8 ± 8.78	6.00	-	-	-
Post	6.23 ± 2.02	129.6 ± 14.2	16.6 ± 1.66	**	**	*
2	11.94 ± 2.11	115.2 ± 15.3	13.7 ± 1.67	**	**	*
4	12.05 ± 2.05	108.9 ± 11.2	12.3 ± 1.62	**	**	*
6	11.55 ± 1.98	104.9 ± 10.4	11.5 ± 1.59	**	**	*
8	11.20 ± 1.82	103.3 ± 10.3	10.5 ± 1.59	**	**	*
10	10.25 ± 2.21	101.7 ± 11.8	9.87 ± 1.89	*	**	*
12	9.93 ± 2.18	100.2 ± 8.21	9.20 ± 1.60	*	**	*
14	8.92 ± 2.08	98.5 ± 9.81	8.73 ± 1.69	**	**	ns
16	8.61 ± 1.88	97.6 ± 9.87	8.00 ± 1.63	*	**	ns
18	7.62 ± 1.63	97.1 ± 9.50	7.67 ± 1.49	**	**	ns
20	7.39 ± 1.87	96.7 ± 8.50	7.20 ± 1.38	*	**	ns

[a] Friedman test, [b] Repeated measure analysis of variance, *$p<0.05$, **$p<0.01$.
ns: not significant; SD: standard deviation; BLa: blood lactate; HR: heart rate.

Table 3. Correlations between BLa decrease and skeletal muscle mass, SMI (n=15)

	Correlation (r)		Coefficient of determination (R^2)	
	BLa reduction (mmol/l)	BLa reduction rate (mmol/l/min)	BLa reduction (mmol/l)	BLa reduction rate (mmol/l/min)
Skeletal muscle mass	0.71[a]**	0.63[b]*	0.50*	0.40*
SMI	0.71[a]**	0.59[b]*	0.50*	0.35*

[a] Pearson's product moment correlation coefficient, [b] Spearman's rank correlation coefficient, *$p<0.05$, **$p<0.01$.
BLa: blood lactate; SMI: skeletal muscle mass index.

when exercise intensity exceeded 60% VO_2max[26]. %VO_2max is expressed as relative exercise intensity, and exercise intensity is sometimes defined from HRmax[27]. The mean value of HR immediately after SJ, 129.6 (beats/min), in this study was calculated as a percentage of HRmax based on the formula reported by Tanaka et al.[28] and converted to exercise intensity, which was 67% VO_2max. In addition, the mean value of the Borg scale immediately after SJ was 16.6, which was calculated to be 71% VO_2max from the conversion table for %VO_2max, based on the Borg scale[29]. These were higher than the 60% VO_2max reportedly causing muscle fatigue; therefore, SJ provided a sufficient load to cause muscle fatigue. We checked the relationships between BLa decrease, BLa decrease rate, skeletal muscle mass, and SMI. Our results showed a significant positive correlation between BLa reduction and skeletal muscle mass. Furthermore, since the BLa reduction rate also had a positive correlation with skeletal muscle mass, it may be possible to metabolize more lactate in a short time as the skeletal mass increases. Moreover, the decrease in BLa and the rate of decrease in BLa showed a significant positive correlation with SMI. This indicates that greater the skeletal muscle mass, better is the BLa clearance when compared at the same height. The limitation of our study was that we did not examine muscle fatigue using the change in physical performance. The SJ required a large amount of load; thus, it was necessary to consider its burden on the participants. In addition to HR and the Borg scale, performance tests such as vertical jumps are also important to confirm that the muscles are fatigued.

In conclusion, our results demonstrated that increased skeletal muscle mass was associated with a greater decrease in BLa after a high-intensity, short-term SJ task.

Funding

Conflicts of interest

None.

REFERENCES

1) Di Martino S, Tramonti C, Unti E, et al.: Aerobic rehabilitation program for improving muscle function in Parkinson's disease. Restor Neurol Neurosci, 2018, 36: 13–20. [Medline]

2) Mora-Custodio R, Rodríguez-Rosell D, Yáñez-García JM, et al.: Effect of different inter-repetition rest intervals across four load intensities on velocity loss and blood lactate concentration during full squat exercise. J Sports Sci, 2018, 36: 2856–2864. [Medline] [CrossRef]

3) Monedero J, Donne B: Effect of recovery interventions on lactate removal and subsequent performance. Int J Sports Med, 2000, 21: 593–597. [Medline] [CrossRef]

4) Seo B, Kim D, Choi D, et al.: The effect of electrical stimulation on blood lactate after anaerobic muscle fatigue induced in Taekwondo athletes. J Phys Ther Sci, 2011, 23: 271–275. [CrossRef]

5) Debold EP, Fitts RH, Sundberg CW, et al.: Muscle fatigue from the perspective of a single crossbridge. Med Sci Sports Exerc, 2016, 48: 2270–2280. [Medline] [CrossRef]

6) Brooks GA: The science and translation of lactate shuttle theory. Cell Metab, 2018, 27: 757–785. [Medline] [CrossRef]

7) Wan JJ, Qin Z, Wang PY, et al.: Muscle fatigue: general understanding and treatment. Exp Mol Med, 2017, 49: e384 [CrossRef]. [Medline]

8) Ament W, Verkerke GJ: Exercise and fatigue. Sports Med, 2009, 39: 389–422. [Medline] [CrossRef]

9) Adeva-Andany M, López-Ojén M, Funcasta-Calderón R, et al.: Comprehensive review on lactate metabolism in human health. Mitochondrion, 2014, 17: 76–100. [Medline] [CrossRef]

10) van Hall G: Lactate kinetics in human tissues at rest and during exercise. Acta Physiol (Oxf), 2010, 199: 499–508. [Medline] [CrossRef]

11) Proia P, Di Liegro CM, Schiera G, et al.: Lactate as a metabolite and a regulator in the central nervous system. Int J Mol Sci, 2016, 17: 1450. [Medline] [CrossRef]

12) Feijen S, Tate A, Kuppens K, et al.: Monitoring the swimmer's training load: a narrative review of monitoring strategies applied in research. Scand J Med Sci Sports, 2020, 30: 2037–2043. [Medline] [CrossRef]

13) Santos RV, Almeida AL, Caperuto EC, et al.: Effects of a 30-km race upon salivary lactate correlation with blood lactate. Comp Biochem Physiol B Biochem Mol Biol, 2006, 145: 114–117. [Medline] [CrossRef]

14) Fleming N, Vaughan J, Feeback M: Ingestion of oxygenated water enhances lactate clearance kinetics in trained runners. J Int Soc Sports Nutr, 2017, 14: 9. [Medline] [CrossRef]

15) Lucertini F, Gervasi M, D'Amen G, et al.: Effect of water-based recovery on blood lactate removal after high-intensity exercise. PLoS One, 2017, 12: e0184240 [CrossRef]. [Medline]

16) Akinci B, Zenginler Yazgan Y, Altinoluk T: The effectiveness of three different recovery methods on blood lactate, acute muscle performance, and delayed-onset muscle soreness: a randomized comparative study. J Sports Med Phys Fitness, 2020, 60: 345–354. [Medline] [CrossRef]

17) Brooks GA: Lactate as a fulcrum of metabolism. Redox Biol, 2020, 35: 101454. [Medline] [CrossRef]

18) Hambrecht R, Fiehn E, Yu J, et al.: Effects of endurance training on mitochondrial ultrastructure and fiber type distribution in skeletal muscle of patients with stable chronic heart failure. J Am Coll Cardiol, 1997, 29: 1067–1073. [Medline] [CrossRef]

19) Glancy B, Kane DA, Kavazis AN, et al.: Mitochondrial lactate metabolism: history and implications for exercise and disease. J Physiol, 2021, 599: 863–888. [Medline] [CrossRef]

20) Loturco I, Kobal R, Maldonado T, et al.: Jump squat is more related to sprinting and jumping abilities than Olympic push press. Int J Sports Med, 2017, 38:

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604–612. [Medline] [CrossRef]

21) Gołaś A, Wilk M, Stastny P, et al.: Optimizing half squat postactivation potential load in squat jump training for eliciting relative maximal power in ski jumpers. J Strength Cond Res, 2017, 31: 3010–3017. [Medline] [CrossRef]

22) van Melick N, van Cingel RE, Brooijmans F, et al.: Evidence-based clinical practice update: practice guidelines for anterior cruciate ligament rehabilitation based on a systematic review and multidisciplinary consensus. Br J Sports Med, 2016, 50: 1506–1515. [Medline] [CrossRef]

23) Raa A, Sunde GA, Bolann B, et al.: Validation of a point-of-care capillary lactate measuring device (Lactate Pro 2). Scand J Trauma Resusc Emerg Med, 2020, 28: 83. [Medline] [CrossRef]

24) Kanda Y: Investigation of the freely available easy-to-use software 'EZR' for medical statistics. Bone Marrow Transplant, 2013, 48: 452–458. [Medline] [CrossRef]

25) Faul F, Erdfelder E, Buchner A, et al.: Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. Behav Res Methods, 2009, 41: 1149–1160. [Medline] [CrossRef]

26) Petrofsky JS: Frequency and amplitude analysis of the EMG during exercise on the bicycle ergometer. Eur J Appl Physiol Occup Physiol, 1979, 41: 1–15. [Medline] [CrossRef]

27) Mann T, Lamberts RP, Lambert MI: Methods of prescribing relative exercise intensity: physiological and practical considerations. Sports Med, 2013, 43: 613–625. [Medline] [CrossRef]

28) Tanaka H, Monahan KD, Seals DR: Age-predicted maximal heart rate revisited. J Am Coll Cardiol, 2001, 37: 153–156. [Medline] [CrossRef]

29) Borg GA: Psychophysical bases of perceived exertion. Med Sci Sports Exerc, 1982, 14: 377–381. [Medline] [CrossRef]