Blood Glucose and Lactate Kinetics during an Incremental Running Test in Endurance Runners

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Aim: We examined the difference in blood glucose and lactate kinetics between highly and moderately trained runners during an incremental running test, and to examine the relationship between GT and LT in different training states. **Methods:** Eight highly trained (25.9 ± 5.6 years, 167.6 ± 5.2 cm, 57.5 ± 6.0 kg) and eight moderately trained (23.8 ± 3.7 years, 173.6 ± 3.8 cm, 62.4 ± 4.6 kg) male runners performed the incremental running test. Each stage of the test consisted of running for 4 min on a treadmill. The velocity was increased by $0.6 \text{ km} \cdot \text{h}^{-1} \cdot \text{stage}^{-1}$ until exhaustion. Blood glucose and lactate were measured after each stage, and GT and LT were determined using the log-log method. **Results:** During the incremental running test, blood lactate increased significantly in both groups, whereas blood glucose increased significantly only in highly trained runners. In highly trained runners, LT and GT did not differ significantly (15.2 ± 1.0 and $15.7 \pm 1.3 \text{ km} \cdot \text{h}^{-1}$, respectively; $p = 0.08$), but were significantly correlated ($r = 0.906$, $p < 0.01$). In moderately trained runners, however, LT was significantly lower than GT (12.1 ± 0.8 and $13.7 \pm 1.6 \text{ km} \cdot \text{h}^{-1}$, respectively; $p = 0.02$), and no significant correlation was observed between LT and GT ($r = 0.596$, $p = 0.16$). **Conclusions:** The relationship between blood glucose and lactate kinetics differs according to training state, so that the relationship of blood glucose and lactate kinetics and appearance pattern of GT reflects a different exercise capacity than that of LT.

Keywords: Glucose threshold, lactate threshold, endurance capacity

1. Introduction

Blood lactate threshold (LT) is thought to reflect the transition point of aerobic and anaerobic energy supply, which is an important physiological determinant of endurance exercise performance (Stallknecht et al., 1998; Iwaoka et al., 1988). Simões *et al.* (1999, 2003) observed that the blood glucose (Glu) concentration also passed through a transition point during an incremental exercise test, and defined this as the blood glucose threshold (GT). The GT is reportedly significantly correlated with LT (Simões et al., 1999, 2003) and ventilation threshold (VT) (Simões et al., 2003), and as a physiological parameter is considered similar to LT. Nonetheless, Webster *et al.* (2013) have reported

that GT may be lower than VT, and could not be identified in two of 22 subjects.

Blood lactate (Lac) (Podolin et al., 1991; Mazzeo and Marshall, 1989) and Glu (Sigal et al., 1994; Marliss et al., 2000) increase as a result of sympathetic nervous system activity and epinephrine release during intense exercise. In addition, plasma epinephrine and Lac increase at identical rates during incremental exercise (Podolin et al., 1991; Schneider et al., 2000). However, Glu kinetics in trained and untrained subjects are different during high-intensity exercise (Coggan et al., 1995; Bloom et al., 1976). Coggan *et al.* (1995) investigated the Glu response during 30 min cycling at 80% of maximal oxygen uptake ($\dot{V}O_{2\text{max}}$) in trained cyclists and untrained subjects, and found that Glu increased

significantly in the trained cyclists but not in untrained subjects. Meanwhile, Bloom *et al.* (1976) compared the metabolic responses of trained cyclists and untrained subjects during an incremental cycling test (at 30%, 45%, 60% and 75% of maximal work capacity) and found that Glu increased in both groups, but to a greater extent in the trained cyclists. Together these studies strongly suggest that the increase in Glu during high-intensity exercise is greater in trained than untrained subjects. After endurance training, muscle glycogen and Glu utilization decrease during same absolute exercise intensity (Bergman *et al.*, 1999b; Coggan *et al.*, 1990), and the rate of decrease of Glu is greater than that of muscle glycogen (Coggan *et al.*, 1990). Furthermore, Coggan *et al.* (1995) reported that the utilization rate of Glu was lower in trained than untrained subjects during high-intensity exercise (at 80% $\dot{V}O_{2\max}$), and that the increase in Glu in trained subjects during intense exercise appeared to be due to a lower Glu utilization rate rather than higher glucose production. Consequently, Glu kinetics may not be consistent with Lac kinetics during the incremental exercise in different training states, and the relationship of GT and LT may become altered in training states; however, the relationship between GT and LT in different training states has not been examined.

Our aim was to investigate the relationship of Glu and Lac kinetics in highly and moderately trained runners during an incremental running test, and to examine the relationship between GT and LT in different training states. We hypothesized that Glu and Lac kinetics are similar only in highly trained runners, and that the GT may be a different parameter than LT.

2. Materials and methods

2.1. Participants, equipment and measurements

Eight highly trained and eight moderately trained male runners participated in this study; their characteristics are shown in **Table 1**. Highly trained runners had competed in endurance running races (5 km–42.195 km) for ≥ 5 years and ran ≥ 5 days per week. Moderately trained runners had run ≤ 3 days per week for the preceding 3 months, mainly jogging for 5–10 km. The Ethics Committee for Human Experiments of the University of Tsukuba approved

Table 1 Subject characteristics.

	Highly trained group (<i>n</i> = 8) Mean $\pm$ SD	Moderately trained group (<i>n</i> = 8) Mean $\pm$ SD	<i>p</i> value
Height (cm)	167.6 $\pm$ 5.2	173.6 $\pm$ 3.8	0.02
Weight (kg)	57.5 $\pm$ 6.0	62.4 $\pm$ 4.6	0.09
BMI (kg $\cdot$ m ⁻²)	20.4 $\pm$ 1.1	20.7 $\pm$ 0.9	0.64
Age (years)	25.9 $\pm$ 5.6	23.8 $\pm$ 3.7	0.38
Stage in exhaustion	8.6 $\pm$ 0.7	8.6 $\pm$ 1.3	1.00
$\dot{V}O_2$ peak (ml $\cdot$ kg ⁻¹ $\cdot$ min ⁻¹)	64.6 $\pm$ 4.7	54.7 $\pm$ 2.7	<0.01
HR peak (beats $\cdot$ min ⁻¹)	190.5 $\pm$ 8.0	190.7 $\pm$ 5.4	0.96
Vmax (km $\cdot$ h ⁻¹)	18.6 $\pm$ 0.8	15.2 $\pm$ 1.0	<0.01

Abbreviations: BMI, body mass index; $\dot{V}O_2$ peak, peak oxygen uptake; HR peak, heart rate peak; Vmax, maximal velocity.

the study, and all participants provided informed consent.

All participants performed the incremental running test. They were instructed to refrain from strenuous exercise for 1 day before the tests and were provided with two identical meals (758 kcal per meal; 17% protein, 18% fat, 65% carbohydrates) before testing on the day of the trials. Testing began 3 h after the second meal.

We measured Glu and Lac using an automatic analyzer (Glu, Antsens III, HORIBA, Kyoto, Japan; Lac, 1500 Sports, YSI Inc., Yellow Springs, OH, USA). Respiratory gas exchange during testing was measured breath-by-breath using an automatic gas analyzer (Oxycon Alpha, Jaeger, Wurzburg, Germany). Heart rate (HR) was also measured continuously at 5-s intervals using a wireless HR monitor (RS800, Polar, Kempele, Finland).

2.2. Experimental methods

Before the incremental running test, the participants performed a warm-up consisting of lower body stretching followed by running for 10 min at 0.6 km $\cdot$ h⁻¹ lower than their first-stage velocity. The treadmill (ORK-700, Ohtake-Root Kogyo, Iwate, Japan) incline was set at 1% during running. Each stage of the test consisted of running for 4 min followed by a 2 min rest. The eighth-stage velocity was set according to the mean of each runner's 5 km performance. The velocity was increased by 0.6 km $\cdot$ h⁻¹ $\cdot$ stage⁻¹ until exhaustion (Nakamura *et al.*, 2015).

Blood samples were collected by fingertip prick at rest, at the start of the incremental running test,

Figure 1 Blood glucose and lactate kinetics during incremental running test for a single participant (highly trained group)
 A: Blood glucose and lactate kinetics
 B: VGT and VLT were evaluated using log-log transformation
 C: Blood glucose and lactate kinetics of coefficient of determination

Abbreviations: VLT, velocity at lactate threshold; VGT, velocity at glucose threshold; Lac, blood lactate; Glu, blood glucose.

immediately after each stage and at exhaustion. Glucose and lactate thresholds were evaluated using log-log transformation (**Figure 1B**) (Beaver et al., 1985).

2.3. Data analysis

All data are expressed as mean $\pm$ standard deviation (SD). Pearson correlation coefficients of Glu and Lac kinetics were calculated in each participant, and the Glu and Lac kinetics of coefficient of determination (R^2) was determined (**Figure 1C**). The exhaustion stage, peak oxygen uptake ($\dot{V}O_{2peak}$), HR peak, and maximal velocity (V_{max}) were compared between groups using Student's *t*-test. The

parameters of Glu and Lac, including rest value (Glu rest and Lac rest), peak value (Glu peak and Lac peak), threshold velocity (VGT and VLT), Glu at GT and Lac at LT, and the Glu and Lac kinetics of R^2 were compared between groups using Student's *t*-test. In each group, Pearson correlation coefficients between GT and LT (velocity and $\% \dot{V}O_{2peak}$) were calculated, and the extent of differences between GT and LT was determined using the paired *t*-test. Pearson correlation coefficients between $\dot{V}O_{2peak}$ and VLT, $\dot{V}O_{2peak}$ and VGT were calculated in all participants. Data from rest to exhaustion (the last stage at completed four minutes) recorded in all participants were included in the statistical analysis.

The time courses of Glu and Lac kinetics were compared between groups by two-way repeated-measures (i.e., group $\times$ stage) analysis of variance. The number of stages completed by the participants during the incremental running test ranged from seven to 11. Therefore, the data of each participant during the last seven stages (the seventh from the last stage; L7~the last stage at completed four minutes; L1) were analyzed. Similarly, respiratory exchange ratio (RER), $\%HR$ peak and $\% \dot{V}O_{2peak}$ during the last seven stages were compared in training states. When a significant difference was observed, a Bonferroni *post hoc* test was used to identify where the difference was observed. The level of statistical significance was set at $p < 0.05$. All analyses were performed using SPSS software (version 20, IBM, Tokyo, Japan).

3. Results

During the last seven stages of incremental running test, significant Group $\times$ Stage interactions were not observed for RER ($p = 0.63$), $\%HR$ peak ($p = 0.46$) and $\% \dot{V}O_{2peak}$ ($p = 0.20$), and no significant group differences were found in RER ($p = 0.65$), $\%HR$ peak ($p = 0.29$) and $\% \dot{V}O_{2peak}$ ($p = 0.08$). The stage at which exhaustion occurred did not differ significantly between highly trained and moderately trained groups ($p = 1.00$; **Table 1**).

Significant differences in Glu were evident between the groups and stages during the incremental running test. Blood glucose concentration increased significantly from L6 stage in the highly trained group ($p < 0.05$), and was significantly higher in the highly trained group compared with the moderately trained group after L6 stage ($p < 0.05$; **Figure 2**).

Figure 2 Differences in blood glucose response between highly and moderately trained runners in the incremental running test

○: moderately trained group ($n=8$)

●: highly trained group ($n=8$)

The data collected in the last seven stages (the seventh from the last stage; L7~the last stage at completed four minutes; L1) of the incremental running test were analyzed for all subjects.

The velocity of moderately trained group was $11.6 \pm 0.9 \sim 15.2 \pm 1.0 \text{ km} \cdot \text{h}^{-1}$.

The velocity of highly trained group was $15.0 \pm 0.7 \sim 18.6 \pm 0.8 \text{ km} \cdot \text{h}^{-1}$.

Group $p < 0.01$, Stage $p < 0.01$, Group $\times$ Stage $p < 0.01$.

+ Significantly different between highly and moderately trained runners.

#Significantly different from L7 stage in highly trained runners.

Figure 3 Blood lactate responses of highly and moderately trained runners during the incremental running test

○: moderately trained group ($n=8$)

●: highly trained group ($n=8$)

The data collected in the last seven stages (the seventh from the last stage; L7~the last stage at completed four minutes; L1) of the incremental running test were analyzed for all subjects.

The velocity of moderately trained group was $11.6 \pm 0.9 \sim 15.2 \pm 1.0 \text{ km} \cdot \text{h}^{-1}$.

The velocity of highly trained group was $15.0 \pm 0.7 \sim 18.6 \pm 0.8 \text{ km} \cdot \text{h}^{-1}$.

Group $p = 0.03$, Stage $p < 0.01$, Group $\times$ Stage $p = 0.65$.

+ Significantly different between highly and moderately trained runners.

#Significantly different from L7 stage in highly trained runners.

*Significantly different from L7 stage in moderately trained runners.

Table 2 Blood glucose and lactate parameters.

	Highly trained group (<i>n</i> = 8) Mean ± SD	Moderately trained group (<i>n</i> = 8) Mean ± SD	<i>p</i> value
Lac rest (mmol·l ⁻¹)	1.07 ± 0.42	1.12 ± 0.24	0.78
Lac peak (mmol·l ⁻¹)	7.09 ± 1.43	8.07 ± 1.34	0.18
Glu rest (mmol·l ⁻¹)	5.30 ± 0.64	5.51 ± 1.07	0.64
Glu peak (mmol·l ⁻¹)	8.53 ± 1.16	5.88 ± 0.94	<0.01
VLT (km·h ⁻¹)	15.2 ± 1.0	12.2 ± 0.8	<0.01
Lac at LT (mmol·l ⁻¹)	1.66 ± 0.47	2.89 ± 1.08	0.01
VGT (km·h ⁻¹)	15.7 ± 1.3	13.7 ± 1.6	0.02
Glu at GT (mmol·l ⁻¹)	5.66 ± 0.65	4.97 ± 1.37	0.26
Glu × Lac (R ²) (%)	94.1 ± 3.7	60.9 ± 31.3	0.02

One moderately trained runner failed to measure Lac at rest. Thus, in the moderately trained group, Lac rest was analyzed in seven subjects. GT was not observed in one moderately trained runner. Therefore, in the moderately trained group, VGT and Glu at GT were analyzed in seven subjects.

Abbreviations: Lac, blood lactate; Glu, blood glucose; VLT, velocity at lactate threshold; VGT, velocity at glucose threshold; Glu × Lac (R²), Glu and Lac kinetics of coefficient of determination (R²).

There was no significant increase in Glu in the moderately trained group at any stage of the test (**Figure 2**). Training status and stage also significantly influenced Lac, which increased significantly from L6 stage in both groups ($p < 0.05$), but remained significantly lower in the highly trained group than the moderately trained group during L7 to L3 stages ($p < 0.05$; **Figure 3**). Furthermore, Glu peak ($p < 0.01$) was significantly greater in the highly trained group, whereas Lac peak ($p = 0.18$) did not differ significantly between the groups. Training status was also significant influence in the Glu and Lac kinetics of coefficient of determination (R²), which was significantly higher in the highly trained group than the moderately trained group ($p = 0.02$; **Table 2**).

A LT was observed in all participants, and VLT was significantly higher in the highly trained group ($p < 0.01$). A VGT was not evident in one moderately trained runner in whom Glu was stable during the incremental running test. Threshold velocity for Glu was significantly higher in the highly trained group ($p = 0.02$; **Table 2**). In the highly trained group there was no significant difference between LT and GT (Velocity, $p = 0.08$; % $\dot{V}O_{2peak}$, $p = 0.13$), and the two parameters were significantly correlated (Velocity, $r = 0.906$, $p < 0.01$; % $\dot{V}O_{2peak}$, $r = 0.883$, $p < 0.01$; **Figure 4A, 5A**). In contrast, in the moderately trained group, LT was significantly lower than GT

Figure 4 Correlations between VLT and VGT

Highly trained group (A): VLT and VGT were not significantly different ($p = 0.08$).

Moderately trained group (B): VLT was significantly lower than VGT ($p = 0.02$).

GT was not observed in one moderately trained runner. Thus, in the moderately trained group, VGT and VLT were compared in seven subjects.

Abbreviations: VLT, velocity at lactate threshold; VGT, velocity at glucose threshold.

(Velocity, $p = 0.02$; % $\dot{V}O_{2peak}$, $p = 0.02$), but no significant correlation was observed between the two variables (Velocity, $r = 0.596$, $p = 0.16$; % $\dot{V}O_{2peak}$, $r = 0.420$, $p = 0.35$; **Figure 4B, 5B**).

$\dot{V}O_{2peak}$ and VLT were significantly correlated ($r = 0.765$, $p < 0.01$; **Figure 6A**), but no significant correlation was observed between $\dot{V}O_{2peak}$ and VGT ($r = 0.491$, $p = 0.06$; **Figure 6B**).

4. Discussion

We found that Lac increased significantly in both groups, whereas Glu increased significantly only in highly trained group, and that the Glu and Lac kinetics of R² was significantly higher in the highly trained group than the moderately trained group. Furthermore, although GT was consistent with LT in highly trained runners, GT was significantly higher than LT in moderately trained runners, a

Figure 5 Correlations between GT and LT ($\% \dot{V}O_{2peak}$) Highly trained group (A): LT and GT were not significantly different ($p = 0.13$). Moderately trained group (B): LT was significantly lower than GT ($p = 0.02$). GT was not observed in one moderately trained runner. Thus, in the moderately trained group, GT and LT were compared in seven subjects. Abbreviations: LT, lactate threshold; GT, glucose threshold.

finding that contrasts with previous reports (Simões et al., 1999, 2003; Webster et al., 2013). These results suggested that Glu kinetics might be closely related Lac kinetics after continued endurance training, and that GT might be a different parameter than LT.

A GT has been observed not only in endurance runners (Simões et al., 1999), but also in physically active men (Simões et al., 2003; Webster et al., 2013). Furthermore, GT is reported to be closely associated with LT, although a GT may not be identifiable in approximately 10% of physically active men (Webster et al., 2013). We were able to identify a GT in all eight highly trained runners, but a GT was absent in one of the eight moderately trained runners (12.5%). It appears, therefore, that GT is influenced by training state. In contrast to previous studies of active men (Simões et al., 2003; Webster et al., 2013), we found that GT was broadly comparable

Figure 6 Correlations between $\dot{V}O_{2peak}$ and VLT (A), $\dot{V}O_{2peak}$ and VGT (B) ○: moderately trained group ●: highly trained group (A): $\dot{V}O_{2peak}$ and VLT were significantly correlated ($r = 0.765$, $p < 0.01$) (B): $\dot{V}O_{2peak}$ and VGT were not significantly correlated ($r = 0.491$, $p = 0.06$) GT was not observed in one moderately trained runner. Thus, the correlation between $\dot{V}O_{2peak}$ and VGT were analyzed in fifteen subjects. Abbreviations: VLT, velocity at lactate threshold; VGT, velocity at glucose threshold; $\dot{V}O_{2peak}$, peak oxygen consumption.

with LT in highly trained runners, but was significantly higher than LT in the moderately trained group.

In a previous study mean Glu at exhaustion during an incremental running test in a group of physically active men was 5.9 ± 1.1 mmol·l⁻¹ (Simões et al., 2003), which is similar to Glu peak in the moderately trained runners in our study (5.88 ± 0.94 mmol·l⁻¹). Thus, the differences in the finding between our study and those of other investigators (Simões et al., 2003; Webster et al., 2013) may be in part due to the method of evaluating GT and LT. GT and LT were evaluated by a similar method in a study of endurance runners (Simões et al., 1999), and in our study. However, other methods have been used to establish GT and LT in active men (Simões et al., 2003; Webster et al., 2013). These

studies (Simoes et al., 2003; Webster et al., 2013) evaluated GT in physically active men on the basis of lowest Glu, which is an analytical procedure for the lactate minimum test, although supramaximal exercise was not performed initially. Previously, we investigated the relationship between LT and GT during the incremental exercise and lactate minimum tests in highly trained endurance runners, and evaluated LT and GT according to log-log method in the incremental test and by the lowest Lac (LM) and Glu (GM) in the lactate minimum test (Nakamura et al., 2015). We found that GM was significant lower than LM, although GT was consistent with LT. Furthermore, LM and LT were not significant different, but GM was significantly lower than GT in our previous study (Nakamura et al., 2015). These results suggested that the concept of lactate minimum test might not be serves as a standard method to evaluate GT. Because the supramaximal exercise was not performed initially, it is suspicious whether lowest Glu is reflected by the Glu transition point during the incremental exercise test. Thus, we evaluated LT and GT according to log-log method in this study.

Glucose is a critical energy source in exercising humans, particularly endurance athletes; Glu utilization increases as exercise intensity and duration increase (Coggan, 1991). The maintenance of Glu homeostasis depends on the insulin/glucagon ratio during low- and moderate-intensity exercise (Jenkins et al., 1986). Meanwhile, during intense exercise ($\geq 80\% \dot{V}O_{2\max}$), high catecholamine stimulation causes hepatic glucose production to exceed muscle glucose uptake and hence Glu rises (Sigal et al., 1994; Marliss et al., 2000). Few studies have investigated the hormonal mechanisms underlying GT. Webster *et al.* (2013) reported that GT can be identified at the same power output as the glucagon transition point, while insulin and cortisol remain unchanged, and proposed that the GT arises due to increases in glucagon and reductions in insulin release, although they did not measure blood catecholamine concentrations. Júnior *et al.* (2001) examined the relationship between Lac and Glu during an incremental cycling test in trained men under normal conditions and acute β -adrenergic blockade, and found that Lac and Glu exhibit similar response patterns in normal conditions, while Glu decreases with β -adrenergic blockade. Furthermore, they reported that GT was not observed under acute β -

adrenergic blockade, although LT and GT were not different in normal condition. These results suggested that Glu kinetics during incremental exercise may be more influenced on catecholamine stimulation rather than other hormones.

Blood lactate (Podolin et al., 1991; Mazzeo and Marshall, 1989) and Glu (Sigal et al., 1994; Marliss et al., 2000) increase as a result of sympathetic nervous system activity and epinephrine release during intense exercise. In addition, plasma epinephrine and Lac increase at identical rates during incremental exercise (Podolin et al., 1991; Schneider et al., 2000). However, previous studies have shown that the rise in plasma epinephrine concentration is not accompanied by a concomitant increase in Glu during high-intensity exercise in untrained subjects (Coggan et al., 1995; Kjaer et al., 1986; Cooper et al., 1989). Thus, response of Glu to catecholamine was different in training states, which might alter relations between Glu and Lac kinetics during incremental exercise.

After endurance training, the muscle content of glycogen increases (Bergman et al., 1999b; Coggan et al., 1990; Richter and Hargreaves, 2013), which might be associated with carbohydrate oxidation during incremental exercise. Coggan *et al.* (1995) reported that the utilization rate of Glu was lower in trained than untrained subjects during high-intensity exercise (at $80\% \dot{V}O_{2\max}$), and that the increase in Glu in trained subjects during intense exercise appeared to be due to a lower Glu utilization rate rather than higher glucose production. Thus, muscle Glu uptake might be lower in the highly trained group, meaning that Glu increased significantly only in our highly trained cohort. This suggests that the physiological mechanisms underpinning the increase in Glu during high-intensity exercise may only occur after long-term strenuous training, and are not manifested during moderate-intensity exercise. We have previously shown that during an incremental running test, GT was higher in low glycogen conditions compared with normal glycogen conditions in endurance runners, even though there was no difference in LT in either condition (Nakamura et al., 2011). In our study, the rules for physical activity and meal were same as previous our study in normal glycogen conditions (Nakamura et al., 2011), which suggested that the both groups glycogen conditions might be normal in our study. Thus, we found a different relationship between GT and LT in highly

trained and moderately trained runners, which may be a consequence of different muscle glycogen storage in each training state.

It is also recognized that endurance training is increased fat oxidation but decreased carbohydrate oxidation in absolute exercise intensity (Bergman et al., 1999a, 1999b; Coggan et al., 1990; Friedlander et al., 2007; Phillips et al., 1996). However, some studies (Bergman et al., 1999a, 1999b; Friedlander et al., 2007) established that fat and carbohydrate oxidation rate did not alter in relative exercise intensity between before and after endurance training, and that carbohydrate was main energy source in moderate and greater intensity exercise. In our study, significant differences were not observed between groups for RER and relative exercise intensity (i.e., %HR peak and % $\dot{V}O_{2\text{peak}}$) at the last seven stages. Thus, fat oxidation might small effects on Glu kinetics and GT during incremental exercise in different training states.

In our study, GT was not evident in one moderately trained runner in whom Glu was stable during the incremental running test. Other investigators have also failed to identify a GT in some subjects (Webster et al., 2013; Sengoku et al., 2011). These results indicate that only in GT might not reflect parameter for endurance athlete physical capabilities. In a longitudinal study, Sengoku *et al.* (2011) investigated Glu and Lac kinetics during an incremental running test in elite Japanese soccer players in different training periods, and evaluated GT and LT using similar method to ours. They found that the proportion of occasions upon which a GT could be identified varied between training periods, and that a GT could be identified more frequently during the most intense training period even though LT and $\dot{V}O_{2\text{max}}$ were unchanged. In our study, $\dot{V}O_{2\text{peak}}$ and VLT were significantly correlated, but no significant correlation was observed between $\dot{V}O_{2\text{peak}}$ and VGT. Hence, these results suggest that GT may reflect a different physiological parameter than LT. Sengoku et al. (2011) did not demonstrate regarding the contents of soccer players training, and we did not also investigate the detailed training contents in both groups. Thereby, further research is required to identify what kind of training changes Glu kinetics during incremental exercise.

In our study, Glu increased significantly only in highly trained group, whereas Lac increased significantly in both groups, so that the Glu and Lac

kinetics of R^2 was significantly higher in the highly trained group than the moderately trained group. Furthermore, previous studies (Webster et al., 2013; Sengoku et al., 2011) and our studies were not able to identify GT at some subjects. These results suggested that after continued endurance training, Glu kinetics might be a close relationship of Lac kinetics during incremental exercise, and that GT might be consistent with LT only in highly trained subjects. Thus, the relationship of Glu and Lac kinetics and appearance pattern of GT might be more important parameter than intensity of GT for endurance athlete physical capabilities.

We did not measure muscle glycogen, hormone concentrations or the detailed training contents (i.e., volume, intensity), so cannot illuminate the relationship between these responses and Glu kinetics in the incremental running test. In addition, the velocity of each groups were different in this study, because there is difference in endurance capacity in both groups, the number of the stages of the highly trained group increases when both groups performed the same velocity. However, energy demand was higher in the highly trained group compared with the moderately trained group during same relative exercise intensity, which might be influenced Glu kinetics during incremental exercise. Further research is required to identify the physiological characteristics of the GT and the factors that change Glu kinetics during exercise before introducing this parameter to the training schedules of endurance athletes.

5. Conclusions

We found that Glu and Lac kinetics during incremental exercise differ according to training state, suggesting that Glu kinetics may be closely related Lac kinetics and GT may be consistent with LT after continued endurance training. Thus, the relationship of Glu and Lac kinetics and appearance pattern of GT reflects a different parameter than that of LT. Blood glucose utilization increases with increasing exercise intensity and exercise duration, highlighting the importance of glucose production as a determinant of performance in endurance athletes. The pattern of Glu kinetics that we observed in highly and moderately trained runners may reflect the effect of training on the ability to mobilize and use glucose during endurance exercise.

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- Japan Society of Physical Education, Health and Sport Sciences
 - Japanese Society of Physical Fitness and Sports Medicine
 - Japan Society of Exercise and Sports Physiology
 - Society for Running
 - Japanese Society of Nutrition and Dietetics
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