Lactate Production and Clearance During High Intensity Swimming Test in Elite Water-Polo Players

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Abstract

The aims of this study were to measure blood lactate levels before and after a high-intensity sprint swimming test and to estimate lactate production capacity and clearance. Twelve male water-polo players, who belonged to the Japanese National Water-Polo Team (24.6 ± 3.8 years of age), volunteered for this study. Players performed a 50-m × 3 times × 3 sets of maximum sprint using a normal diving start at 1-min intervals and with a 20-min rest period between sets. Capillary blood samples were drawn from the fingertips of the subjects 7 times; *i.e*., before and after each trial set as well as 20 min after finishing the third trial set. Mean swimming time showed little change as the trial sets proceeded. In contrast, variability in swimming times was significantly different between the first and the second sets as well as the first and the third sets (first > second, first > third, $p < 0.001$). Lactate production was highest after the first set, after which it decreased significantly during the second set and was maintained through the third set. Significant differences ($p < 0.001$) were observed between the first and the second sets as well as the first and the third sets. In contrast, lactate clearance showed little change. No significant correlation was found between swimming time and lactate values. The variability in swimming time during the second and the third sets showed a positive correlation with blood lactate levels, a negative correlation to lactate production during the second set, and a negative correlation to lactate clearance during the third set. Our results suggest that these international players could improve their glycolytic capacity, particularly lactate clearance. Thus, players lacking lactate clearance capacity should reconsider their training intensity.

Key words: water polo, lactic acid, glycolytic capacity, swimming performance

Introduction

The Fédération Internationale de Natation (FINA), which is the international governing body for swimming, introduced a number of rule changes about water polo in 2006 that mainly consist of shortening the playing time allowed for players to shoot at the goal (*i.e*., from 35 to 30 s) and have extended the quarter time by 1 min (*i.e*., from 7 to 8 min). Consequently, these changes may have altered demands during the game, resulting in higher physiological requirements than those reported previously (Rodrigues, 1994; Platanou and Geradas, 2006). Rodrıquez (1994) and Platanou and Geradas (2006) examined blood lactate levels in elite water-polo players during quarter breaks of actual games and found that the glycolytic demands are high (4–9 mM). They concluded that a high glycolytic capacity is required for successful participation in water polo.

In a recent study after the rule revision, Melchorrim (2010) reported that mean blood lactate level was 7.7 ± 1.0 mM (range 2.2–14.3 mM), and that blood lactate levels were 7.7 ± 1.2, 7.8 ± 0.6, 7.5 ± 0.9, and 7.2 ± 1.6 mM during the first, second, third, and fourth quarters, respectively. These values are almost the same as those of previous studies but it is noteworthy that blood lactate levels decreased in the fourth quarter. Such a decrease in blood lactate levels at the end of a game has been ob-

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served in a previous study (Platanou and Geradas, 2006), in which a tendency for lower blood lactate levels was observed as the game progressed toward the fourth quarter. In addition, not only in water polo but also in basketball, mean blood lactate levels after a game are significantly ($p < 0.001$) lower than those reported at halftime (Ben Abdelkrim, 2007).

Many water-polo coaches and players must accept that a high glycolytic capacity is required for successful participation, but it may be difficult for them to understand exactly what a high glycolytic capacity means. The observation that players are almost burned out but their blood lactate level decrease at the end of the game may alter the notion that blood lactate changes are caused by fatigue.

According to the latest scientific findings, lactic acid is not a waste material after anaerobic exercise but an important energetic substrate for oxidization (Hashimoto and Brooks, 2008). Thus, a high glycolytic capacity may mean that a player can produce more lactate to perform high-intensity exercise and can use the lactate for oxidation by continuing to exercise at a high level of intensity. Muscle cells have 2 major functions such as to production and clearance of lactate, and blood lactate levels change as a result of a balance between production and clearance.

Therefore, lactate production and clearance must be evaluated to improve glycolytic capacity in water-polo players. Thus, the aim of this study was to measure blood lactate levels before and after a high-intensity sprint swimming test and to estimate lactate production capacity and lactate clearance. These results could lead to improved training methods.

Materials and methods

Subjects

Twelve male water-polo players, who belonged to the Japanese National Water-Polo Team (24.6 ± 3.8 years of age), who belonged to the center forward, center back, and driver positions, volunteered for this study (Table 1). Height and body mass were 181.5 ± 4.5 cm and 83.8 ± 7.9 kg, respectively. The subjects had an average of 12.7 ± 4.2 years of competitive experience. The team placed third at the 2010 16th Asian Games and 11th at the 2011 14th FINA World Championships. Players were informed of the experimental procedure and of the potential risks and benefits of the study and gave written consent to participate.

Table 1 Subject characteristics

No	Subject	Height (cm)	Weight (kg)	Age (yrs.)	Career (yrs.)	Position
1	M▪S	178	75	20	14	D
2	A▪Y	190	93	23	13	CF
3	Y▪S	181	90	23	10	CF
4	K▪O	183	92	22	7	CB
5	Y▪S	178	87	29	13	D
6	K▪I	178	75	25	9	D
7	K▪T	177	77	21	11	D
8	S▪H	178	78	25	15	D
9	H▪W	187	85	24	14	CF
10	Y▪K	177	72	21	8	D
11	K▪A	185	92	31	23	D
12	S▪N	186	90	31	15	CB
Average		181.5	83.8	24.6	12.7	
±SD		4.5	7.9	3.8	4.2	

Position D: Driver, CB: Center Back, CF: Center Forward

Experimental procedures

Based on a pilot study to explore the sufficient exercise intensity which leads to maximum blood lactate production and the adequate rest period which ensures blood lactate clearance, with considering of a burden of players, we adopted the following protocol. Following a self-selected warm-up swim of about 1,000 m, players performed a 50-m maximum sprint test 3 times using a normal diving start at 1-min intervals. All tests were performed in a 50-m indoor pool, and each subject swam alone in a single lane to avoid a drafting effect. After a 20-min rest interval, players performed another 2 sets of the 50-m × 3 maximum sprint tests. Players swam 450 m in total (50-m × 3 times × 3 sets) and were asked to do their best during all trials (Fig. 1).

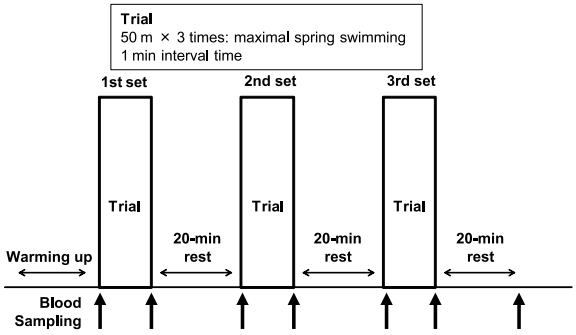

Fig. 1 Protocol of the experiment

Data collection

The swimming time of a player was obtained with an accuracy of 0.01 s with a manual stopwatch for each trial. Capillary blood samples were drawn from the fingertips of the subjects 7 times in total; that is, before (LA_Pre) and after (LA_Post) 1 trial set, and 20 min later (LA_Recov@20 min) after finishing the third set (Fig. 1). Blood

lactate levels were analyzed using the Lactate Pro™ 2 instrument (LT-1730, ARKREY Inc., Kyoto, Japan).

Data analysis

To investigate the relationships between swimming performance and blood lactate production/clearance capacity during maximum swimming efforts, a value of blood lactate production (LA_Production) and blood lactate clearance (LA_Clearance) were obtained using the formulas (1) and (2), respectively:

LA_production@n = LA_Pre@n – LA_Post@n (1)

LA_clearance@n = LA_Post@n – LA_Pre@n+1 (2)

where @n is the value of the n-th trial set.

The standard deviation (SD) of swimming time for each trial set (SD_T@n) was computed to evaluate swimming time variability.

Statistical analysis

Mean and SD values were obtained for all descriptive variables. A 1-way repeated-measures analysis of variance (ANOVA) was used to compare parameters among the maximum sprint tests. When a significant *F*-value was observed, Bonferroni post hoc procedures were performed for blood lactate levels using pairwise differences between the averages. Pearson's correlation and partial correlation analyses were used to assess the relationships between variables in each trial set. A p value of <0.05 was considered significant.

Results

The mean values, 1-way ANOVA, and multiple comparison results for the main parameters are shown in Table 2. Changes in mean swimming time and its variability, mean blood lactate levels, and mean lactate production/clearance for each trial set are illustrated in Figs. 2–4, respectively.

As shown in Fig. 2, mean swimming time showed little

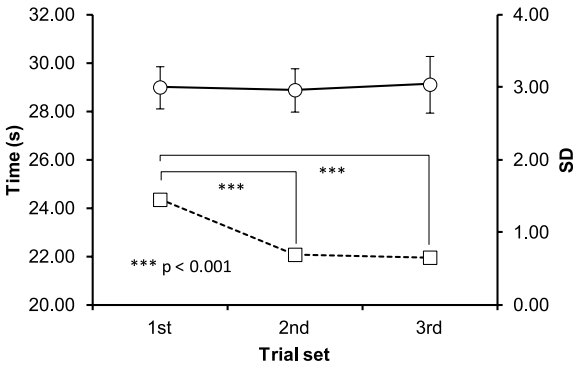

Fig. 2 Changes in mean swimming time results and the standard deviations for each trial set.

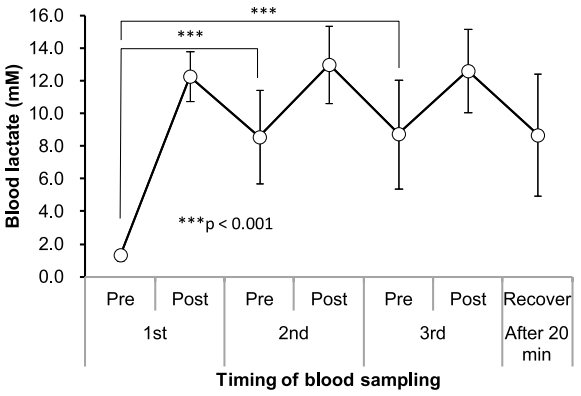

Fig. 3 Changes in the mean blood lactate level at each stage.

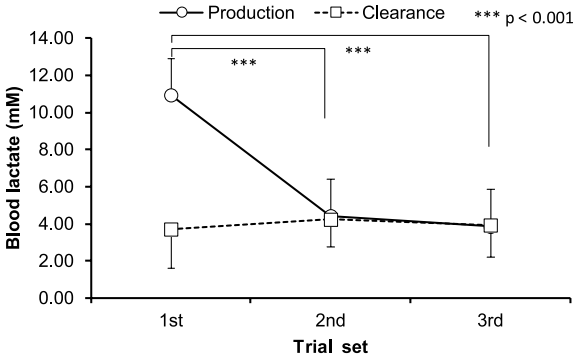

Fig. 4 Changes in the mean lactate production and lactate clearance for each trial set.

Table 2 Averages, 1-way analysis of variance, and multiple comparisons for the main parameters.

	Mean values			ANOVA		Multiple comparison
	1st	2nd	3rd	*p*	*F*-value	*Bonferroni*
Time (sec)	29.01	28.90	29.12	0.851	0.162	
SD_Time	1.46	0.70	0.66	< 0.001	13.262	1st > 2nd***, 1st > 3rd ***
LA_Pre (mM)	1.34	8.57	8.76	< 0.001	33.096	1st < 2nd ***, 1st < 3rd ***
LA_Post (mM)	12.28	13.00	12.62	0.727	0.322	
LA_Product (mM)	10.94	4.43	3.86	< 0.001	79.861	1st > 2nd ***, 1st > 3rd ***
LA_Clearence (mM)	3.72	4.24	3.93	0.767	0.268	

*** p < 0.001

change within the trial sets. In contrast, swimming-time-variability of the three 50-m sprint tests were significantly different between the first and the second and the first and the third sets respectively (first > second, first > third, $p < 0.001$).

Mean blood lactate levels rose sharply from an initial level of 1.34 ± 0.35 mM before the first set to 12.28 ± 1.55 mM after the first set. Then, lactate levels fell before rising again after the sets (Fig. 3). According to ANOVA, significant differences in blood lactate levels were observed before the first and the second and between the first and the third sets (first > second, first > third, $p < 0.001$).

The highest blood lactate levels were observed after the first trial set. Afterward, blood lactate levels decreased significantly toward the second set and was maintained after the third set. Significant differences ($p < 0.001$) were observed between the first and the second sets as well as between the first and the third sets. In contrast, lactate clearance showed little change.

The correlation analysis results for selected parameters are shown in Table 3. Only correlation coefficients with absolutes values of >0.5 and that were statistically significant ($p < 0.05$) are indicated in Table 3. Swimming times for each trial set were strongly correlated ($r > 0.87$) with each other. However, no significant correlations were observed between the swimming times and lactate levels. Swimming-time-variabilities of the second (T_SD@2nd) and third (T_SD@3rd) sets were positively correlated with most of blood lactate levels except for T_SD@3rd vs LA_Pre@1st and T_SD@3rd vs LA_Post@3rd, whereas a negative correlation was observed with lactate clearance at the second set (LA_Clearance@2nd), with lactate production at the third set (LA_Production@3rd) and with lactate clearance at the third set (LA_Clearance@3rd) except for T_SD@3rd vs LA_Clearance@3rd.

The capacity of lactate production/clearance affected swimming performance. All records for the 9 swimming tests (3 times × 3 sets), and their average time and SD values by each subject are indicated in Table 4. As typical examples, the swimming results of subject H·W, who had the largest SD value, and those of subject M·S, who had the smallest SD, are shown in Fig. 5. The subject M·S is a player called as “Driver”, who plays a role in carrying the ball to the front court by swimming as fast as possible and making an opportunity to shot. While H·W is a center forward player, who is mainly located in front of the opponent's goal and plays a role in scoring the goal with pushing a defender off. The first swimming time of H·W in each set was almost the same as that of M·S. However, as the trials progressed, H·W could not maintain his swimming speed and his swimming times lengthened.

A difference in the changes in blood lactate levels was also observed between the 2 players. As shown in Fig. 6, blood lactate levels in H·W rose sharply after the first trial but did not decrease during the rest period, similar to those in M·S, and baseline blood lactate levels tended to increase gradually in H·W. In contrast, blood lactate levels of M·S rose similar to those of H·W after the first trial, but fell faster than those of H·W, and then went up and down with an unchanged baseline.

These differences may have been caused by differenc-

Table 3 Correlation matrix for the tested parameters

	Height	Weight	T@1st	T_SD@1st	T@2nd	T_SD@2nd	T@3rd	T_SD@3rd
Height	1	0.775						
Weight	0.775	1						
T@1st			1		0.910		0.875	
SD_T@1st				1				
T@2nd			0.910		1		0.947	
SD_T@2nd						1		
T@3rd			0.875		0.947		1	
SD_T@3rd						0.833		1
LA_Pre@1st								
LA_Post@1st						0.673		0.654
LA_Pre@2nd						0.568		
LA_Post@2nd						0.645		0.515
LA_Pre@3rd						0.717		0.697
LA_Post@3rd						0.570		
LA_Recov@20min						0.673		0.521
LA_Production@1st						0.572		0.560
LA_Clearance@1st			0.659					
LA_Production@2nd								
LA_Clearance@2nd						-0.591		-0.754
LA_Production@3rd						-0.647		-0.792
LA_Clearance@3rd						-0.638		

Table 4 All records for the 9 swimming tests, mean and SD values by each subject in ascending order of SD value

No	Subject	Position	1st set (s)			2nd set (s)			3rd set (s)			Mean	SD
			#1	#2	#3	#1	#2	#3	#1	#2	#3		
1	M•S	D	27.12	28.55	28.16	27.13	28.14	28.43	27.90	28.26	27.88	27.95	0.52
2	Y•S	D	28.05	29.84	29.53	28.60	29.56	29.72	29.00	30.30	29.97	29.40	0.72
3	S•H	D	26.47	28.28	29.28	27.94	28.55	29.08	27.95	28.70	28.36	28.29	0.82
4	K•T	D	27.74	29.58	30.07	28.68	28.33	28.81	28.88	30.22	29.62	29.10	0.83
5	S•N	CB	27.10	27.90	29.20	27.40	27.50	29.30	28.00	27.30	28.80	28.06	0.84
6	A•Y	CF	27.01	29.29	29.58	27.96	28.84	29.25	28.13	29.11	29.63	28.76	0.88
7	Y•K	D	27.90	30.70	30.60	28.80	28.90	28.90	28.70	29.00	29.10	29.18	0.90
8	K•A	D	27.10	28.90	30.60	28.20	28.70	28.70	28.50	28.30	28.10	28.57	0.93
9	K•O	CB	27.18	29.41	30.60	28.20	28.55	29.27	27.90	28.32	28.44	28.65	0.99
10	Y•S	CF	29.34	31.75	32.18	30.40	31.70	32.08	31.58	31.73	32.96	31.52	1.06
11	K•I	D	27.57	29.60	31.39	28.03	29.27	30.86	28.60	29.72	31.38	29.60	1.40
12	H•W	CF	26.73	29.09	30.98	27.36	29.14	29.98	27.70	29.56	30.87	29.05	1.51

Position: D: Driver, CB: Center Back, CF: Center Forward

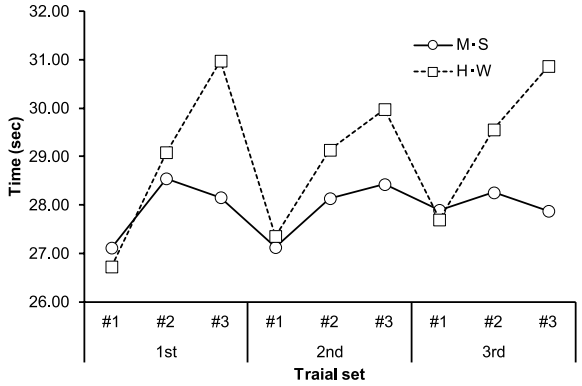

Fig. 5 Typical examples of swimming result changes for subject H·W (□), who had the largest standard deviation (SD) value from the 9 swimming sets (3 times × 3 sets), and subject M·S (○), who had the smallest SD value for the trials.

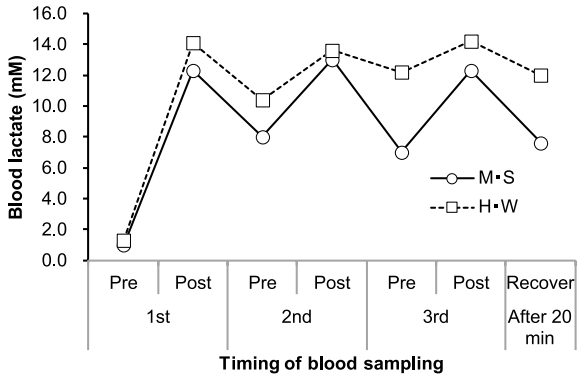

Fig. 6 Typical examples of blood lactate changes in subjects H·W (□) and M·S (○).

es in lactate production/clearance capacity, and the changes in the 2 players' blood lactate production/clearance are shown in Fig. 7. Lactate production of H·W (□) was considerably higher compared with that of M·S (○) after the first set, but that of H·W fell abruptly after the second set and was maintained at a low level during the

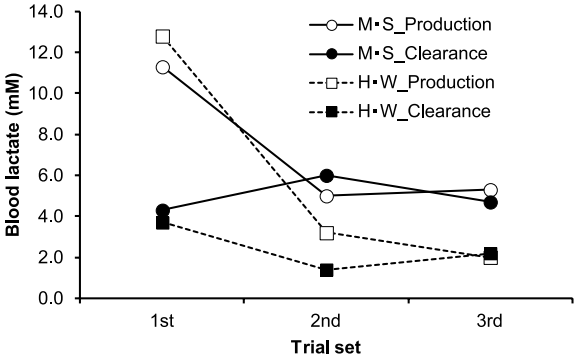

Fig. 7 Typical examples of lactate production changes and lactate clearance changes for subjects H•W (□, ■) and M•S (○, ●).

third set, rather than the milder change observed for M·S. In contrast, lactate clearance of H·W (■) was almost the same as that of M·S (●) after the first trial set, but the gap between H·W and M·S became wider after the second and third sets until the level of M·S exceeded that of H·W.

Discussion

The subjects in this study were elite water-polo players, and the data were collected immediately before the Asian Olympic qualifications for the 2012 London Olympics. Therefore, these are valuable data to evaluate lactate production and clearance capacity in highly trained water-polo players. All the players completed the swimming task to the best of their ability. Although swimming times were not much different among the players and did not correlate with blood lactate parameters, we found a positive relationship between swimming-time-variabilities after the second and third trial sets and blood lactate levels at Post@1st to Recov@20 min. A negative correlation was observed between swimming-time-variabilities after

the second and third trial sets and lactate production after the second trial set and lactate clearance after the third trial set. These results suggest that players who had higher blood lactate levels throughout all trial sets showed more variation in swimming time. Conversely, players who had higher variations in swimming time showed lower lactate production and clearance capacity in later trial sets. The subject H·W –a representative example of higher swimming-time-variations and lower lactate clearance– produced high lactate levels after the first trial set, but could not produce sufficient lactate after the next trial set because of insufficient lactate clearance during the rest period, because of which their swimming times decreased. Whereas M·S repeated and appropriate lactate production and clearance levels and could maintain a high swimming velocity. Unlike football, a water-polo game allows for an unlimited number of player substitutions similar to basketball; therefore, a key physical characteristic for a successful water-polo player is to perform intense exercise and to recover rapidly from periods of high-intensity exercise. However, a player who has a limited lactate clearance capacity like H·W could not demonstrate his innate ability late in a game even though his position is a center forward not required endurance capacity.

The latest scientific findings seem to be useful to improve lactate clearance. Hashimoto and Brooks (2008) reported that lactate is produced as a result of glycolysis and is balanced by oxidative removal in mitochondria. Lactate production during exercise represents a physiological signal for the activation of a vast transcription network affecting monocarboxylate transporter (MCT1) protein expression and mitochondrial biogenesis, thereby explaining how training increases lactate clearance capacity via oxidation.

It has been demonstrated that MCT1 content is positively correlated with the percentage of type I fibers in humans (Pilegaard et al. 1999) and that MCT1 expression is lower in glycolytic muscle preparations obtained from rodents (McCullagh et al. 1996; Wilson et al. 1998). MCT1 adaptation has been investigated in human subjects undertaking lower intensity endurance exercise (Bonen et al. 1998; DuBouchaud et al. 2000), and these studies reported high MCT1 levels.

Taken together, players lacking sufficient lactate clearance capacity should reconsider their training intensity. Most water-polo coaches are proponents of high-intensity training for players, particularly for those who become exhausted at the later stages of a game, but this strategy could backfire. Therefore, it may be more efficient for a player lacking lactate clearance capacity to activate the MCT1 protein by considering lower intensity endurance training. However, this is just a hypothesis, and requires testing in a future study.

Conclusion

We conducted an experiment to estimate lactate production and lactate clearance capacity during a high-intensity sprint swimming test in highly trained water-polo players.

In conclusion,

1) The highest blood lactate levels were observed after the first trial set, they decreased significantly toward the second trial set, and were maintained at the same level after the third trial set ($p < 0.001$). In contrast, lactate clearance showed little change.
2) No significant correlation was observed between the mean swimming time and any of the blood lactate parameters.
3) Players who had higher blood lactate levels throughout all trial sets showed larger swimming-time-variations on the second and third trial sets.
4) Even top players could improve glycolytic capacity, particularly their lactate clearance capacity.

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