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## RESEARCH ARTICLE

# The Relationship Between muscle Damage and Activity Profiles During Team Handball Matches

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### Abstract:

#### Background:

Anaerobic activities often require explosive muscle power; it is therefore possible that players' skeletal muscles sustain damage during the game, which leads to a performance decrease as the game progresses.

#### Objective:

This study investigated the relationship between muscle damage and activity profiles during team handball matches.

#### Methods:

This study conducted two handball games to examine the relationship between muscle damage and impacts against the body during the games. We studied one handball match between members of the same university team (Game I: 12 male court players) and a practice match between a Japanese handball league team and the university student team (Game II: nine male court players and six controls).

#### Results:

Plasma myoglobin concentration and plasma creatine kinase activity, both of which are biomarkers for muscle damage, increased to above their normal ranges after both games. The magnitudes of the changes in both plasma myoglobin ( $p < .05$ ) and plasma creatine kinase activity ( $p < .05$ ) from before to after the game were significantly different between the players and controls in Game II. There were significant correlations between the number of shots taken in Game II and biomarkers for muscle damage; the changes in plasma myoglobin concentrations ( $p < .01$ ) and plasma creatine kinase ( $p < .01$ ) activity levels.

#### Conclusion:

These results suggest that team handball matches involve high-intensity exercise that is sufficient to cause muscle damage. Additionally, our findings suggest that the severity of muscle damage is related to the specific actions associated with taking shots, such as jumping and colliding with a defender.

**Keywords:** Body contact, Creatine kinase, Myoglobin, Aerobic, Shots, sprint, Handball matches.

### Article History

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## 1. INTRODUCTION

Playing handball requires both anaerobic activities (*e.g.*, sprinting, shooting, jumping, or high intensity body contact) and aerobic activities (*e.g.*, standing, walking, or jogging), which occur at random rates [1 - 3]. Handball is considered to be a high-intensity sport; the total distance covered in a match can be as much as 4500–7000 m, and heart rates of up to 170

beats per minute are often attained during games [1 - 3]. In addition, approximately 8.9% of the motions used during a handball match are anaerobic [3]. For example, Back players make as many as 20 jumping motions when attacking, and Pivot players make about 190 body contacts when attacking [3]. These anaerobic activities often require explosive muscle power, which may cause skeletal muscle damage during a game. This damage, in combination with the gradual decrease in the players' energy supplies, could lead to the decreases in the performance that are observed as a game progresses.

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The plasma myoglobin (Mb) concentration and plasma Creatine Kinase (CK) activity are biomarkers of muscle damage [4, 5]. Many studies have measured these indicators to evaluate the relationship between specific physical activities or changes in muscle strength and skeletal muscle damage [6 - 9]. Based on the levels of these biomarkers, researchers have concluded that playing in a soccer match causes damage to skeletal muscles [6]. It has also been reported that sprinting ability and lower limb strength are decreased for 72 hours after a game, and greater reductions in post-game sprinting ability have been associated with higher CK activities and Mb levels [6, 8]. Similarly, studies of rugby players have demonstrated that skeletal muscles are damaged during games, and the degree of muscle damage was correlated with the number of front tackles [10]. After real boxing matches and shadow boxing at the same physical intensity, Mb and CK levels have been reported to reflect the degree of skeletal muscle damage after real matches only; this indicates that muscle damage was caused by the direct impacts to the body that occurred during the real matches [9]. Overall, these studies have indicated that direct impacts on the body and explosive muscle power during sports result in skeletal muscle damage.

Skeletal muscle damage could also occur because of body contact in handball games, which might lead to impaired performance later on in a game. Although some researchers have reported that there is muscle damage after handball games [11, 12], to our knowledge, no studies have investigated the relationship between the extent of muscle damage and the activity profiles of handball players. Thus, the purpose of this study was to assess the damage to skeletal muscles during handball games by measuring post-game Mb and CK levels, and to examine the relationship between muscle damage and impacts to the body during the game.

## 2. METHODS

### 2.1. The Experimental Approach to the Problem

This study conducted two handball games (Game I and Game II) to examine the relationship between muscle damage and impacts against the body during the games. Muscle damage was analyzed using blood samples before and after the games [11, 12]. While there were many types of activity during the games, the focus of this study was the impact on the body. In addition, activity patterns have been reported to differ

between goalkeepers and court players [3], so goalkeepers were not included in this study.

The participants followed all the official rules of handball, apart from the member change rule, with no member changes being allowed during Game I. This was done to simulate those on-court players who play for the full 60 minutes in official games. However, in Game II, both teams made tactical and member changes as would be done in an official game. As all the members of the college team used the same training and warm up routine before Game II, the degree of skeletal muscle damage in Game II was only impacted by the division of the team into the experimental and control groups. The warm up routines used before both games were the same as what is usually done before an official game, including jogging, sprinting, dynamic stretching and jumping. The game consisted of two 30-minute periods, between which there was a 10-minute half-time break. The game was videotaped to analyze the activity patterns of each player fulfilling the inclusion criteria.

### 2.2. Participants

Game I was a practice game among members of the same team. The participants in this game were 12 male court players who had reached the top 16 teams in a national championship at the highest level of college handball in Japan (mean age:  $21.3 \pm 0.7$  years, mean height:  $178.3 \pm 4.2$  cm, mean weight:  $72.8 \pm 6.2$  kg). The participants were divided into three offensive positions as follows: wing players, pivot players, and back players (see Table 1 for participants' physical characteristics). These players were divided into two teams, which had the same competitive levels.

Game II was a practice game between the same college team and a professional team.

The subjects in this game were 15 male court players in the college team (mean age:  $21.3 \pm 1.0$  years, mean height:  $176.6 \pm 7.3$  cm, mean weight:  $72.3 \pm 7.8$  kg). Nine participants who were the most qualified members of the college team served as the experimental group. The other six members of the college team, who did not play in Game II, served as the control group. The members of the professional team were not subjects in this study. The members of the college team in Game II were divided into three offensive position groups, as follows: wing players, pivot players, and back players (see Table 2 for participants' physical characteristics).

**Table 1. Physical characteristics of the participants in Game I.**

-	Back Player	Pivot Player	Wing Player
	n=5	n=3	n=4
Height(cm)	$179.2 \pm 4.6$	$179.0 \pm 5.7$	$176.5 \pm 0.5$
Body mass(kg)	$74.0 \pm 3.6$	$77.3 \pm 3.2$	$71.0 \pm 0.6$
Age(y)	$21.4 \pm 5.9$	$21.7 \pm 3.2$	$21.0 \pm 1.2$

values are means  $\pm$  SD.

**Table 2. Physical characteristics of the participants in Game II.**

–	Back Player	Pivot Player	Wing Player	Controls
	n=5	n=2	n=2	n=6
Height(cm)	180.5 ± 4.3	186.5 ± 4.9	172.0 ± 1.4	172.3 ± 7.3
Body mass(kg)	75.6 ± 6.5	79.0 ± 4.2	64.5 ± 3.5	69.8 ± 8.8
Age(y)	21.6 ± 0.4	22.5 ± 0.7	21.5 ± 0.7	20.8 ± 1.3

values are means ± SD.

**Table 3. Activity profiles in the attack during Game I.**

–	Back Player	Pivot Player	Wing Player	Mean	–
Body contact	–	–	–	–	–
Weak	9.4 ± 3.3	37.7 ± 4.6	8.0 ± 5.2	16.0 ± 13.7	* #
Hard	4.0 ± 2.2	19.3 ± 2.5	10.5 ± 6.5	10.0 ± 7.4	*
Shot	10.2 ± 3.2	8.0 ± 6.2	11.3 ± 5.6	10.0 ± 4.6	–
Hit the floor	2.8 ± 1.9	5.0 ± 1.0	5.0 ± 2.1	4.1 ± 2.0	–

values are means ± SD. Difference between Back player and Pivot player □\* : p<0.01, Difference between Pivot player and Wing player □# : p<0.01.

To conform with the recommendations of the Declaration of Helsinki, a full explanation of the purpose of the study and the blood sampling methods was provided to the participants, and informed consent was obtained. This study was approved by the ethics committee of Fukuoka University.

### 2.3. Data Collection

Video data of activities, including direct body impacts such as weak and hard body contacts, shots, and hits on the floor, were analyzed by an experienced handball coach. This coach had been in charge of a college handball team for over 10 years and had a handball coach license from the Japan Sports Association. The distinction between hard and weak body contacts was agreed upon by another handball coach, who had coached a college handball team for over 30 years and had a handball master coach license from the Japan Sport Association. A collision between high-speed players was regarded as hard body contact, while push out and block plays about space between players were regarded as weak body contacts [13, 14].

### 2.4. Blood Collection and Analysis

Resting blood samples were collected from the antebachial vein before and after each game, and the Mb and CK levels were measured [11, 15]. For Game I, blood samples were drawn directly before (Baseline) and after (Post) the game, and 45 minutes (Post 45 m) and 24 hours (Post 24 h) after the game. For Game II, Baseline, Post, and Post 45 m samples were collected as for Game I; in addition, a sample was also collected 20 hours (Post 20 h) after the game. The blood samples were taken using blood collection kits (Japan BD, Tokyo, Japan), were centrifuged (4°C, 3000 rpm, 10 minutes), and the plasma components were then separated from the blood cells [13, 14]. The plasma components of each sample were analyzed by SRL Co Ltd (Tokyo, Japan).

### 2.5. Statistical Analyses

All values are presented as the mean ± standard deviation. A one-way analysis of variance (ANOVA) with post hoc

Bonferroni tests was used to detect significant differences in direct body impacts between offensive player positions in both games and in changes over time in Mb and CK levels. Differences in Mb and CK levels between the offensive player positions, between the controls and players in Game II, and their interactions, were investigated using a two-way ANOVA. Correlation coefficients were calculated using Pearson's product-moment correlation analysis. For all statistical analyses,  $p < 0.05$  was considered significant.

## 3. RESULTS

### 3.1. Practice Game (Game I)

#### 3.1.1. Game Results

Game I included 80 offensive phases for team A and 79 for team B. Team B won the game by a score of 32 to 23. The shooting rate was 43% for team A and 56% for team B. The misplay rates were 31% and 28% for teams A and B, respectively. While team A used a 2-4 offensive system, team B used a 3-3 offensive system. Both teams used a 6-0 defensive system.

#### 3.1.2. Player Activities During Game I

The activities of each offensive player position during the game are presented in Table 3. A significant main effect for weak body contacts was found ( $F [2, 9] = 50.45, p < 0.01$ ), with Pivot players experiencing significantly more weak body contacts than players in the other positions ( $p < 0.01$ ). There was also a significant main effect for hard body contacts ( $F [2, 9] = 12.62, p < 0.01$ ), with Pivot players experiencing more hard body contacts than Back players ( $p < 0.01$ ) significantly.

#### 3.1.3. Changes in Mb and CK Levels

The overall and player position mean changes in the Mb and CK levels over time are presented in Fig. (1). The ANOVA revealed a significant main effect on the overall mean Mb level ( $F [3,33] = 31.74, p < 0.01$ ). In the Post (148.8±61.8 ng/ml) and Post 45 m (241.6±127.0 ng/ml) blood samples, the Mb

level was significantly greater than at the Baseline ( $p < 0.05$ ). The main effect of time was also found to be significant for the means of each player position ( $F [3, 27] = 34.05, p < 0.01$ ); however, the main effect of position was not significant ( $F [2, 9] = 2.76, p = 0.11$ ). There was no significant interaction between time and position ( $F [6, 27] = 2.01, p = 0.09$ ). There was a significant difference in the Post Mb levels between the Pivot players ( $101.6 \pm 7.6$  ng/ml) and the Wing players ( $194.7 \pm 73.7$  ng/ml;  $p < 0.05$ ). The Post 45 m samples differed significantly between all the positions (Back:  $220.0 \pm 110.2$  ng/ml; Pivot:  $153.3 \pm 40.4$  ng/ml; Wing:  $335.0 \pm 147.3$  ng/ml;  $p < 0.05$ ).

The ANOVA revealed a main effect of the overall mean CK level ( $F [3,33] = 6.21, p < 0.01$ ). Furthermore, the overall mean CK was significantly increased at all measurement time points after the game compared with the Baseline (Baseline:  $287.7 \pm 160.0$  IU/l; Post:  $371.0 \pm 192.8$  IU/l; Post 45 m:  $378.5 \pm 193.5$  IU/l; Post 24 h:  $384.1 \pm 245.2$  IU/l;  $p < 0.05$ ). A statistically significant main effect for time was found for each mean position value ( $F [3, 27] = 8.25, p < 0.01$ ), but no such effect was found for position ( $F [2, 9] = 1.13, p = 0.36$ ). There was a significant interaction between time and position ( $F [6, 27] = 3.28, p = 0.01$ ), and the post-game CK values of the Wing players were significantly greater than their Baseline

levels (Post:  $467.0 \pm 278.2$  IU/l; Post 45 m:  $487.7 \pm 276.8$  IU/l; Post 24 h:  $579.5 \pm 327.7$  IU/l;  $p < 0.05$ ). The mean CK values of the Back and Pivot players were significantly increased in the Post (Back:  $317.6 \pm 147.5$  IU/l; Pivot:  $332.0 \pm 130.9$  IU/l) and Post 45 m (Back:  $322.6 \pm 141.3$  IU/l; Pivot:  $326.3 \pm 124.3$  IU/l) measurements, compared with the Baseline (Back:  $246.2 \pm 116.4$  IU/l; Pivot:  $268.3 \pm 115.0$  IU/l;  $p < 0.05$ ). At Post 24 h, the Wing players had a significantly higher CK concentration than the samples from the other two positions ( $p < 0.05$ ).

Fig. (2) shows the changes in the Mb and CK levels from the Baseline values for each position. For the Mb measurements, a statistically significant main effect of time was found ( $F [3, 27] = 34.05, p < 0.01$ ), but no such effect was found for position ( $F [2, 9] = 2.19, p = 0.17$ ). There was no significant interaction between time and position ( $F [6, 27] = 2.0, p = 0.1$ ). In the Post (Back:  $91.6 \pm 38.2$  ng/ml; Pivot:  $63.67 \pm 3.7$  ng/ml; Wing:  $136.5 \pm 38.2$  ng/ml) and Post 45 m (Back:  $171.2 \pm 101.3$  ng/ml; Pivot:  $115.3 \pm 29.9$  ng/ml; Wing:  $276.7 \pm 144.1$  ng/ml) samples, the Mb level was significantly greater than the Baseline levels for every position ( $p < 0.05$ ). Wing players had significantly greater Post values than Pivot players ( $p < 0.05$ ). The Post 45 m values differed significantly between the positions ( $p < 0.05$ ).

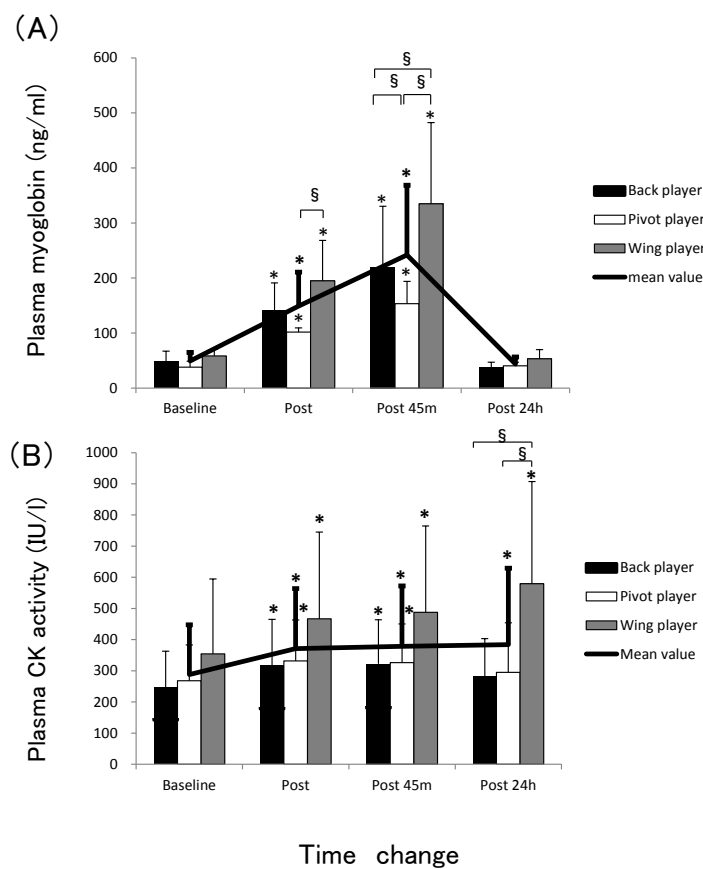
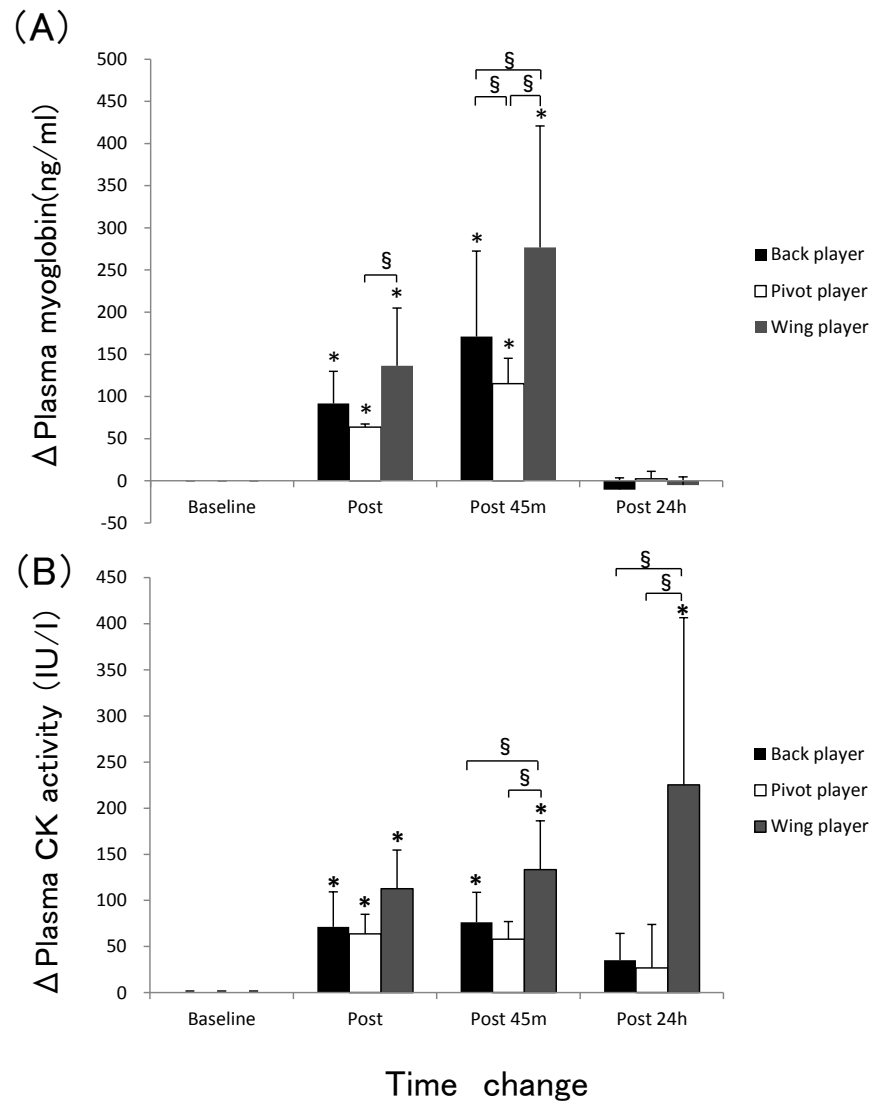


Fig. (1). Change in mean value and different play position before and after the Game I. (A) plasma myoglobin concentration, (B) plasma CK activity. Difference versus Baseline indicate \*: $p < 0.05$ , Difference between each play position indicate §: $p < 0.05$ .



**Fig. (2).** Amount of changes in plasma myoglobin concentration (A) and plasma CK activity (B) in different play position before and after the Game I. Difference *versus* Baseline indicate \*: $p < 0.05$ , Difference between each play position indicate §: $p < 0.05$ .

There were significant main effects of time ( $F [3, 27] = 8.25, p < 0.01$ ) and position ( $F [2, 9] = 4.93, p < 0.05$ ) on the CK measurements. There was also a significant interaction between time and position ( $F [6, 27] = 3.28, p < 0.05$ ). The CK levels in the Post samples from the Wing players increased significantly over time (Post:  $112.7 \pm 41.7$  IU/l; Post 45 m:  $133.5 \pm 52.8$  IU/l; Post 24 h:  $225.2 \pm 181.3$  IU/l). Back players showed a significant increase in their CK activity levels from the Baseline to the Post ( $71.4 \pm 37.9$  IU/l) and Post 45 m ( $76.4 \pm 32.4$  IU/l) measurements. Pivot players also had significantly higher CK levels immediately after the game (Post:  $63.6 \pm 21.2$  IU/l) than at the Baseline. Wing players continued to have significantly higher CK levels than players in the other positions at the Post 45 m and Post 24 h measurements.

Correlations between the target activities in the game and plasma values

No correlations were found between any of the direct body impacts and Mb and CK levels.

## 3.2. Practice Match Between the Professional team and the University Student Team (Game II)

### 3.2.1. Game II Results

Sixty-two offensive phases for each team were included in Game II. The professional team won the game by a score of 23 to 22. The shooting rates for the university team and the professional team were 47% and 50%, respectively. The misplay rates were 24% and 27% for the university team and the professional team, respectively. The teams used either a 2-4 or 3-3 offensive system. The university student team used a 6-0 defensive system, while the professional team used either a 3-2-1 or a 4-2 defensive system.

### 3.2.2. Activities During Game II

The activities of each position during Game II are presented in Table 4. The number of body contacts, shots, and hits on the floor were lower than those in Game I. Pivot players experienced significantly more weak body contacts than Wing

**Table 4. Activity profiles in the attack during Game II.**

	Back Player	Pivot Player	Wing Player	Mean	
Body contact	–	–	–	–	–
Weak	8.0 ± 2.3	12.0 ± 2.8	3.5 ± 0.7	7.9 ± 3.6	†
Hard	1.8 ± 0.4	4.5 ± 0.7	0.5 ± 0.7	2.1 ± 1.5	* #
Shot	6.6 ± 5.0	3.5 ± 0.7	6.0 ± 2.8	5.8 ± 3.9	–
Hit the floor	2.2 ± 1.3	4.0 ± 0.0	1.0 ± 0.0	2.3 ± 1.4	–

values are means ± SD. Difference between Back player and Pivot player \* : p<0.01, Difference between Pivot player and Wing player # : p<0.01, †: p<0.05.

players (F [2, 6] = 7.12, p < 0.05), and significantly more hard body contacts than players in the other positions (F [2, 6] = 28.48, p < 0.01).

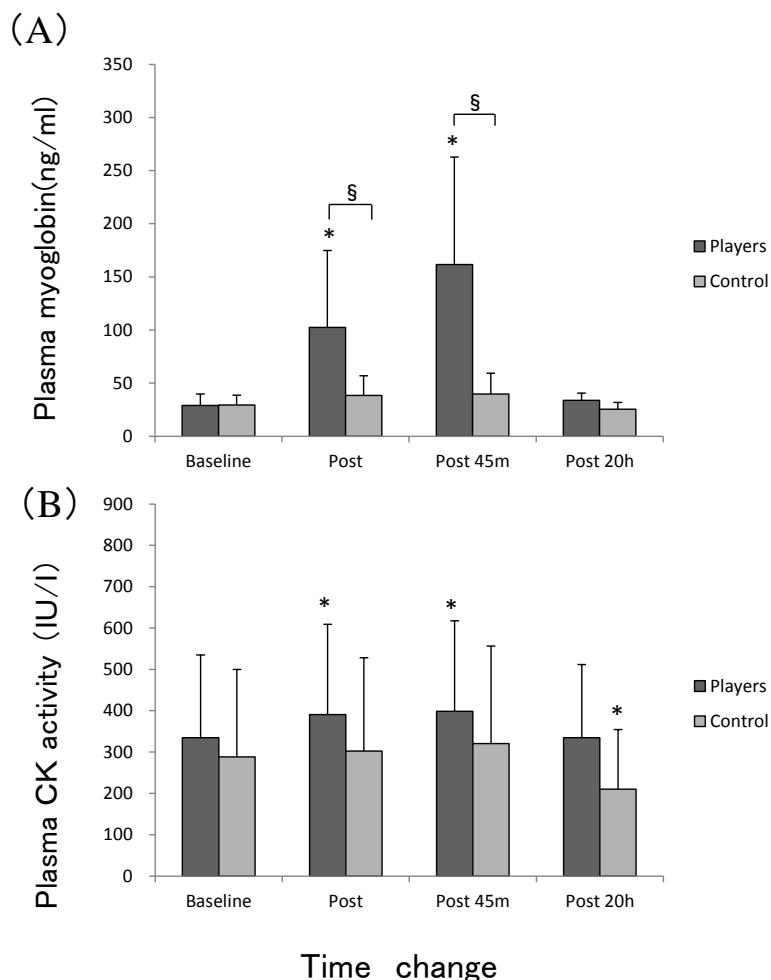
**3.2.3. Changes in Mb and CK**

The changes in the mean Mb and CK levels of each group over time are presented in Fig. (3).

For the Mb measurements, there were significant main effects of time (F [3,39] = 11.57, p < 0.01) and group (F [1, 13] = 6.2, p = 0.02). There was a significant interaction between time and group (F [3,39] = 7.74, p < 0.01). There was a significant increase in the mean Mb level of the college team

experimental group in the Post (102.3±72.4 ng/ml) and Post 45 m (161.6±101.1 ng/ml) measurements. There were significant differences in the Mb values between the control and experimental groups in the Post 45 m and Post 24 h measurements.

For the CK measurements, there was a significant main effect of time (F [3,36] = 6.8, p < 0.01), but no main effect of group (F [1, 12] = 0.35, p = 0.56). There was no significant interaction between time and group (F [3,36] = 1.43, p = 0.25). The mean CK in the experimental group increased significantly from the Baseline to the Post (390.6±218.5 IU/l) and Post 45 m (398.4±218.9 IU/l) measurements.



**Fig. (3).** Changes in plasma myoglobin concentration (A) and plasma CK activity (B) before and after the Game II. Difference versus Baseline indicate \*:p<0.05, Difference between each play position indicate §:p<0.05.

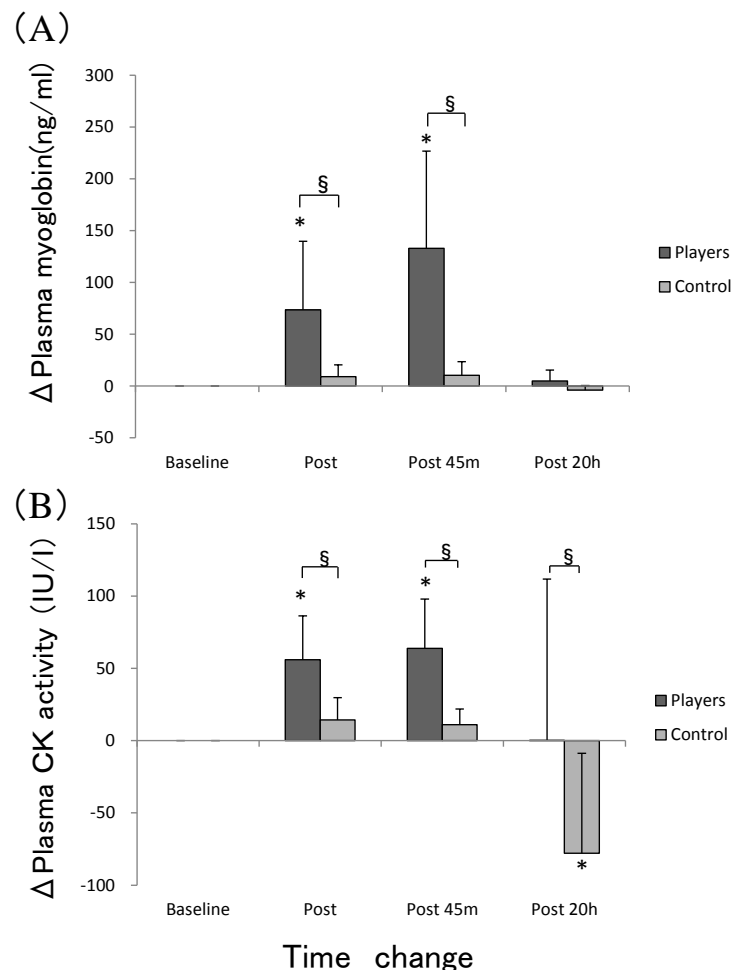
Fig. (4) shows the changes in the Mb and CK levels over time relative to the Baseline values. For the Mb measurements, there were significant main effects of time ( $F [3,39] = 11.57, p < 0.01$ ) and group ( $F [1, 13] = 9.02, p = 0.01$ ). There was also a significant interaction between time and group ( $F [3,39] = 7.74, p < 0.01$ ). For the CK measurements, there were significant main effects of time ( $F [3,36] = 6.81, p < 0.01$ ) and group ( $F [1, 12] = 6.15, p = 0.02$ ). However, there was no significant interaction between time and group ( $F [3,36] = 1.44, p = 0.25$ ). In the experimental group, both the Mb and the CK levels were significantly higher at the Post (Mb:  $73.4 \pm 66.1$  ng/ml; CK:  $56.0 \pm 30.3$  IU/l) and Post 45 m (Mb:  $132.7 \pm 93.9$  ng/ml; CK:  $63.7 \pm 34.1$  IU/l) measurements than at Baseline. At Post and Post 45 m, significant differences in the plasma Mb levels were seen between the experimental and control group. Likewise, all the CK levels after the game differed significantly between the experimental group and the control group.

Fig. (5) shows the changes in the Mb and CK levels relative to their baseline values for the positions. For the Mb

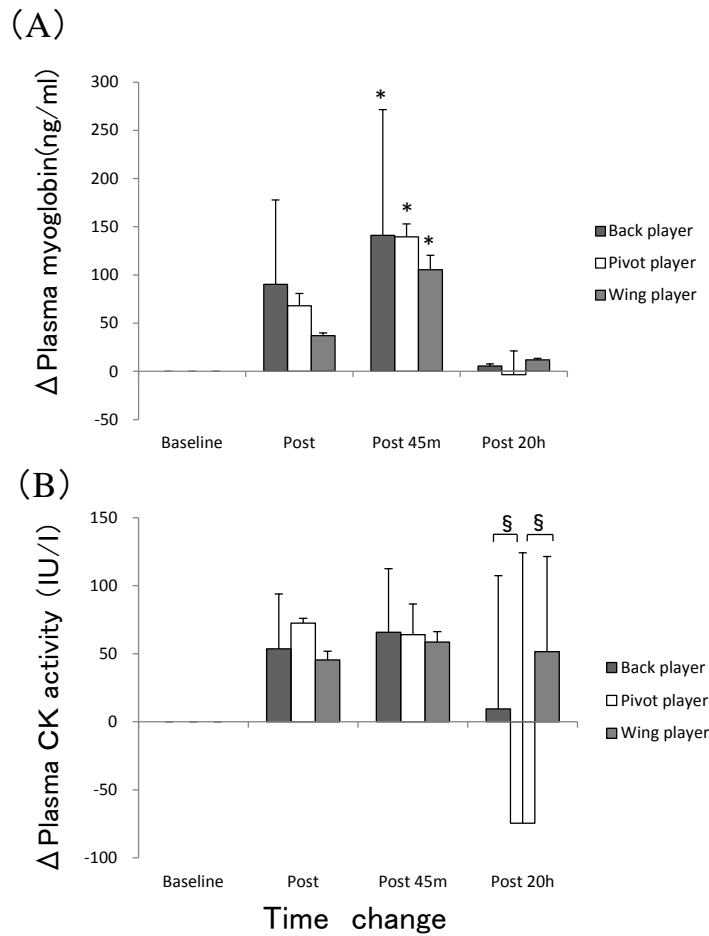
measurements, there was a significant main effect of time ( $F [3, 18] = 4.92, p = 0.02$ ), but no main effect of position ( $F [2, 6] = 0.16, p = 0.85$ ). There was no significant interaction between time and position ( $F [6, 18] = 0.11, p = 0.99$ ). For the CK measurements, there were no significant main effects of time ( $F [3, 18] = 0.77, p = 0.18$ ) or position ( $F [2, 6] = 0.17, p = 0.84$ ). There was no significant interaction between time and position ( $F [6, 18] = 0.40, p = 0.82$ ). The Mb at Post 45 m (Back:  $141.0 \pm 130.6$  ng/ml; Pivot:  $139.5 \pm 13.4$  ng/ml; Wing:  $105.4 \pm 14.8$  ng/ml) was significantly greater than the Mb at Baseline for all the positions ( $p < 0.05$ ). The CK was significantly lower in the Pivot players ( $-74.5 \pm 198.7$  IU/l) than the other players at Post 20 h, but otherwise did not differ between the positions.

Correlation between target activities during the game and blood parameters

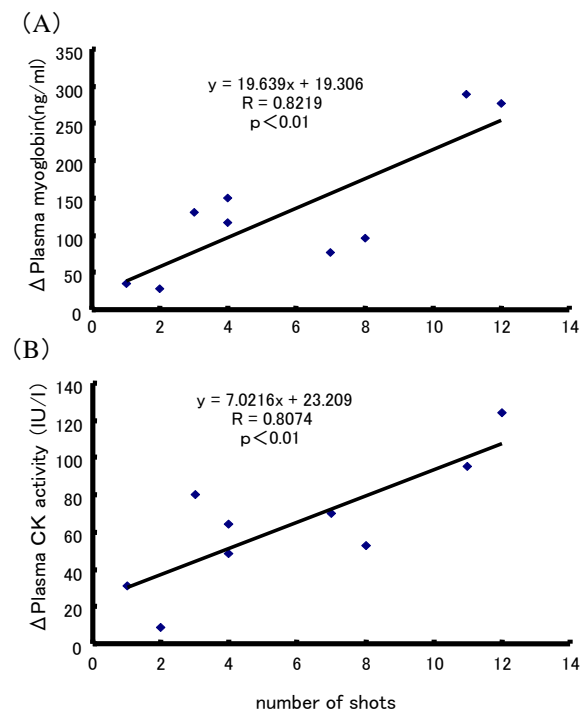
There was a significant positive correlation between the shot counts and both plasma biomarkers at Post 45 m (Mb:  $r = 0.821$ , CK:  $r = 0.807$ ;  $p < 0.01$ ; Fig. (6).



**Fig. (4).** Amount of changes in plasma myoglobin concentration (A) and plasma CK activity (B) before and after the Game II. Difference versus Baseline indicate \*:  $p < 0.05$ , Difference between each play position indicate §:  $p < 0.05$ .



**Fig. (5).** Amount of changes in plasma myoglobin concentration (A) and plasma CK activity (B) in different play position before and after the Game II. Difference *versus* Baseline indicate \*:p<0.05, Difference between each play position indicate §:p<0.05.



**Fig. (6).** Relation between number of shots and amount of changes plasma myoglobin concentration in Post 45m (A) and amount of changes plasma CK activity in Post 45m (B) of Game II.



#### 4. DISCUSSION

Ball games that include hard body contacts also involve repeated and explosive exertions of muscle power. It is thought that fatigue from these anaerobic muscle exertions accumulates throughout the game, which results in decreased performance levels towards the end of the game. Therefore, we investigated the relationship between muscle damage and player activity profiles during a practice match of a university team (Game I) and during a game between a professional team and a university team (Game II). The levels of Mb and CK, which are biomarkers for muscle damage, were increased to above their normal ranges after both games.

##### 4.1. Practice Game between Members of the Same Team (Game I)

Although the score gap in Game I, which had a final result of 32 to 23, was relatively large, it was typical of what is commonly seen in official games. An official game of handball generally includes 60 offensive phases [16]. In Game I, there were 80 offensive phases, meaning that there were more offensive situations than in a general game. In addition, the misplay rate was nearly 30% for each side, which indicates that there were more fast break situations resulting from misplays than would occur in a regular game. Pivot players experienced a significantly higher number of body contacts than players in any other position. The 6-0 defensive system, for which the space between the defensive players is narrower than for other systems, was used by both teams. The Pivot players attacking against this defensive system tended to receive body contacts from the defenders more often [13, 14].

A normal Mb level is less than or equal to 96 ng/ml [17], while a normal CK level is less than or equal to 130 IU/l [18]. Values between 130 IU/l and 200 IU/l are considered to be due to training-induced physiological changes, whereas values between 200 and 1000 IU/l are usually considered to result from skeletal muscle damage due to strenuous muscular exertion [18]. The Mb level reached its maximum value of  $241.67 \pm 127.05$  ng/ml 45 minutes after the game. CK reached its maximum of  $384.17 \pm 245.21$  IU/l, which is out of the normal range, 4 hours after the game. Post-game Mb and CK levels exceeded the levels considered to be indicative of skeletal muscle damage, which indicates that some of the movements performed during the game caused muscle damage. In addition, the CK level reported was similar to the levels observed in previous research, and seems to be indicative of the intensity of a standard game [11, 19].

To investigate how much of an effect the activity during the game had on skeletal muscle damage, we analyzed the changes in plasma biomarker values for each position. The Mb and CK levels immediately after the game were significantly increased for all positions, and Wing players exhibited the largest change compared with the Baseline. This is likely due to the increased number of fast break situations resulting from the higher misplay rate, as has been previously reported [3]. Indeed, Wing players performed considerably more fast breaks than the other positions [13, 14]. In addition, because no player changes were allowed during Game I, the Wing players were required to sprint repeatedly for 60 minutes. The lower limb

muscles repeatedly contract both concentrically and eccentrically during sprinting [20, 21], and eccentric muscle contractions result in more severe muscle damage than concentric contractions [22 - 25]. Furthermore, the decelerations that occur after every sprint may also have an influence, and increase the muscle damage.

One previous study found a significant correlation between the number of tackles during a rugby game and blood biomarker levels after the game [10]. In the current study, however, there was no significant association between plays that involved a direct body impact and Mb or CK levels. The performance of the Pivot players, whose direct body contact counts were the highest in this game, included blocking or pushing the defensive players and being pushed while in possession of the ball [13, 14]. These types of contacts are different in quality to tackling or being punched, which are types of body contact that occur during rugby or boxing. Thus, the lack of any significant relationship between body contacts and changes in plasma biomarker levels maybe because of the less severe nature of the contact that occurs during a handball game than during a rugby game or boxing match.

##### 4.2. Practice Match between the Professional Team and the University Student Team (Game II)

Game II was a neck-and-neck game because the attack achievement rate, shooting rate, and misplay rate were approximately equal for the two teams. The body contact counts of the Pivot players were significantly higher than for any other players. This was assumed to be due to the close positioning of the defensive players. However, the body contact counts during Game II were lower than in Game I and lower than those reported by previous studies [13, 14]. This could have been because the professional team used either the 3-2-1 or the 4-2 defensive systems, in which there is more space between each defensive player than in the 6-0 defensive system.

The mean Mb and CK levels reached their maximum of 45 minutes after the game. This rise in CK was similar to that reported by previous research and seems to reflect the intensity of a standard game [11, 19]. The magnitude of the change in the Mb level from the Baseline differed significantly between the experimental group and the control group directly after the game and 45 minutes after the game, and for the CK level at every measurement point after the game. This change was great enough to indicate skeletal muscle damage, and the magnitudes of the changes in these values were significantly different between the experimental and control groups. These results indicate that activities during the game led to muscle damage.

Furthermore, the changes in the CK levels of the Pivot players 20 hours after the game were significantly lower than for the other positions. This result was also assumed to be due to the defensive system used by the professional team. The different defensive systems change the playing style in a handball game [14]. We believe that the Pivot players, who received less body contact than those in Game I, experienced less skeletal muscle damage than the other players.

A positive correlation was found between the shooting counts and the Mb and CK levels at 45 minutes after the game.

As with other ball sports, the role of the offensive positions in handball is to score goals. A jump shot in handball consists of running-up, taking-off, throwing, and landing, and each of these activities requires the exertion of muscular power [26, 27]. In addition, the shooter often experiences hard body contacts from defensive players, who intend to block the shot, or experiences a full-body impact with the floor when landing after a shot [13, 14, 28]. It has been previously shown that the degree of muscle damage is more severe when eccentric stress is placed on an already stretched muscle [24, 25]. Thus, skeletal muscle damage in offensive players is due not only to the eccentric muscle contractions necessary for shooting but also to the hard impacts from the defensive players and whole-body impacts with the floor. Additionally, these impacts can cause extrinsic muscle damage [9, 29]. Therefore, we consider the activities associated with shooting, such as powerful muscular exertion and direct body impacts, to be closely related to the degree of muscle damage experienced by the offensive players.

In Game I, however, there was no significant correlation between the shot count and the changes in the plasma levels of the biomarkers. This could be because there was a wide scoring margin between each defensive player, and that more fast break situations occurred. More shots were unblocked, resulting in fewer body contacts.

## CONCLUSION

The results of this study indicate that handball is a high-intensity sport in which players are likely to sustain skeletal muscle damage. The degree of muscle damage sustained by Wing players is correlated with the amount of sprinting performed. Moreover, from the positive relationship between the shot counts and changes in CK and Mb levels, it seems that activities associated with the shooting, such as the muscular exertion of power and direct body impacts from defensive players or the floor, account for much of the muscle damage. To reduce the extent of the skeletal muscle damage that occurs during games, it is important to replace and rest the players who perform the highest number of sprints and shots. This is important for the coach's technique and the team tactics. Furthermore, it is extremely important to develop a strong body to protect against skeletal muscle damage caused by repeated shots, body contacts and sprints. The muscles used during a bench press are important because they prevent the decrease in the intermittent sprint power that is caused by body contacts [30].

In this study, we investigated the relationships between muscle damage and offensive actions during handball games, including direct body impacts. However, we did not investigate the muscle damage due to body contacts during defensive phases. Therefore, more research is needed for further analysis of additional offensive and defensive actions that occur during handball games. These factors should be considered in future studies.

## ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was approved by the Institutional Review Board

of Fukuoka University, Japan (approval number: 11-02-01).

## HUMAN AND ANIMAL RIGHTS

No animals were used for this study. All humans research procedures performed in the current study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

## CONSENT FOR PUBLICATION

All participants were informed about the protocol and gave their written informed consent before participating in the study.

## AVAILABILITY OF DATA AND MATERIALS

The datasets analysed during the current study available from the corresponding author [KA] on reasonable request.

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None.

## CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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