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Article

Relationships between bat swing speed and muscle thickness and asymmetry in collegiate baseball players

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Abstract: The purpose of the present study was to examine the relationships between bat swing speed (BSS) and muscle thickness and lateral asymmetry of the trunk and limbs in collegiate baseball players. Twenty-four collegiate baseball players participated in this study. The maximum BSS in hitting a teed ball was measured using a motion capture system. The muscle thicknesses of the trunk (upper abdominal rectus, central abdominal rectus, lower abdominal rectus, abdominal wall, and multifidus lumborum), upper limb, and lower limb were measured using a B-mode ultrasonography. Lateral asymmetry between each pair of muscles was determined as the ratio of the thickness of the dominant side to that of the non-dominant side. Significant positive correlations were observed between BSS and muscle thicknesses of the abdominal wall and multifidus lumborum on the dominant side (r = 0.426 and 0.431, respectively; $p < 0.05$), while nearly significant positive correlations were observed between BSS and muscle thicknesses on the non-dominant side. No significant correlations were found between BSS and lateral asymmetry of all muscles. These findings indicate the importance of the trunk muscles for bat swing, and the lack of association between BSS and lateral asymmetry of muscle size.

Keywords: hitting; ultrasonography; lateral dominance; abdominal muscle; back muscle

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1. Introduction

Bat swing speed (BSS) is one of the major determinants of baseball hitting performance because higher BSS can produce shorter swing time and higher batted ball velocity [1,2]. To develop a training program that effectively improves BSS, key components of bat swing have been investigated. Studies of high school and collegiate baseball players have revealed significant positive correlations between BSS and maximum muscle strength of the upper and lower limbs [3–5]. Therefore, because muscle volume and muscle strength are closely related, muscle volume also should be positively correlated with BSS [6]. Unlike muscle strength measured by dynamometers, muscle size can be measured precisely independent of synergistic muscles using a clinical imaging apparatus, such as ultrasonography, computed tomography, or magnetic resonance imaging. Measurement of individual trunk muscle size can be utilized to determine the prime mover muscle to generate higher BSS. However, to the best of our knowledge, there is no report on the relationship between muscle volume and BSS in baseball players.

Ultrasonography is a practical method to estimate muscle volume not only because muscle thickness measured using ultrasonography significantly correlates with muscle cross-sectional area and volume measured using computed tomography and magnetic resonance imaging [7,8], but also because its price and running cost are lower than other methods. In addition, the accessibility of ultrasonography allows frequent monitoring of muscle thickness, which can be useful for assessment of a training effect on target muscles. Therefore, ultrasonography is suitable for assessment of athletes' potential performance, once the relationship between muscle thickness and the performance variable is clarified.

The motion of baseball hitting consists of coordinative actions of multiple body segments, including trunk rotation [9]. A previous electromyographic study suggested the importance of trunk muscle activity to generate a large amount of force to accelerate the bat [10]. Furthermore, previous research showed that trunk muscle training with a medicine ball improved BSS in high school baseball players [11]. Therefore, trunk muscle size in baseball players should be related to maximum BSS. Shaffer et al. [10] reported a lateral difference in trunk muscle activity during baseball hitting. Lateral asymmetry of the trunk muscles exists in athletes of sports with unilateral dominance, such as soccer and tennis [12]. Because of dominant handedness and repeated unidirectional rotary movement during baseball hitting and throwing, lateral asymmetry of the trunk muscles also may exist in baseball players. However, the influence of such asymmetry on BSS is unknown. The purpose of the present study was to examine the relationship between BSS and muscle thickness and lateral asymmetry of the trunk and limbs in collegiate baseball players.

2. Materials and Method

2.1. Study Design

Maximal BSS of each subject during a teed ball hitting was adopted as their ability to produce BSS. Muscle thickness was measured as an indicative parameter for muscle volume and muscular strength. A cross-sectional design was employed to analyze the correlations between BSS and muscle thickness and lateral asymmetry of the trunk and limbs in order to examine the relationships between baseball hitting performance and muscle thickness and lateral asymmetry.

2.2. Participants

Twenty-four collegiate baseball players (11 right-handed and 13 left-handed hitters) participated in this study. Participants' mean age, height, body mass, and duration of baseball experience were 20.5 ± 0.7 years, 1.739 ± 0.039 m, 71.4 ± 5.9 kg, and 13.5 ± 1.4 years, respectively. This research protocol was approved by the university institutional ethical review board, and was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants after explaining the experimental procedures, risks, and benefits.

2.3. Procedures

After sufficient warm-up and practice hitting of a teed ball, participants completed 5 hits of a teed ball toward the center field direction using their maximum effort. Sixteen 500-Hz infrared cameras (Raptor; nac Image Technology Inc., Tokyo, Japan) were utilized to capture the movement of a reflective marker attached on the barrel end of a wood bat. The length and weight of the bat were 0.84 m and 0.9 kg, respectively. Motion analysis software (Cortex 4.0; Motion Analysis, Santa Rosa, CA, USA) was used to track and analyze each trial. The measurement space in which bat swing was performed was calibrated using a dynamic wand calibration method with a wand kit. BSS was the magnitude of the resultant velocity during the 10 ms immediately prior to the moment of ball-bat contact, which was detected using a sound-to-electrical transducer trigger unit (ATRG-100; Nihon Fastec Imaging Co. Ltd., Tokyo, Japan). The mean of the 3 highest BSSs of the 5 trials represented each participant's BSS. The mean (± standard deviation, SD) value of the coefficient of variation for the 3 highest BSSs of each participant was less than 1.2 (± 0.8) %.

A B-mode ultrasonographic device (SSD-3500SV; Aloka, Tokyo, Japan) using a linear scanner with a sampling rate of 7.5 MHz was utilized to measure thickness of the muscles of the trunk (upper abdominal rectus, central abdominal rectus, lower abdominal rectus, abdominal wall, and multifidus lumborum), upper limbs (elbow extensors, elbow flexors, and forearm muscles), and lower limbs (knee extensors, knee flexors, ankle dorsiflexors, and ankle plantarflexors) on both sides. Lateral asymmetry of muscle thickness for each participant was calculated as below:

$$\text{Asymmetry (\%)} = \frac{\text{dominant side thickness}}{\text{non} - \text{dominant side thickness}} \times 100$$

in which, for a right-handed hitter, the dominant side was the right side and the non-dominant side was the left side. Although reliability of thicknesses of the limb muscles has been frequently examined [7], reliability of thicknesses of the trunk muscles has been poorly examined. Therefore, in a recent study [Wachi et al. Unpublished data], we examined the intraclass correlation coefficients in thicknesses of the trunk muscles on 2 separate days in 12 healthy men (age: 22.5 ± 1.6 years, height: 169.5 ± 3.3 cm, weight: 63.8 ± 6.4 kg). Accordingly, the intraclass correlation coefficients for the right and left sides were 0.960 for right side and 0.965 for left side in the upper abdominal rectus, 0.963 for right side and 0.959 for left side in the central abdominal rectus, 0.959 for right side and 0.946 for left side in the lower abdominal rectus, 0.970 for right side and 0.921 for left side in the abdominal wall, and 0.919 for right side and 0.965 for left side in the multifidus lumborum.

2.4. Statistical Analyses

Data were expressed as mean ± SD. The Pearson product-moment correlation (r) between BSS and muscle thickness of each part and lateral asymmetry of each pair were calculated and used to analyze the relationship. All statistical analyses were conducted using SPSS version 19.0 (IBM Corp., Armonk, NY, USA), with the alpha level for significance set at $p < 0.05$.

3. Results

The mean BSS was 34.3 ± 2.4 m/s. Muscle thickness of the dominant and non-dominant sides and the rate of lateral asymmetry are presented in Table 1. A matrix for the correlation coefficients between BSS and muscle thickness of the dominant and non-dominant sides and the rate of lateral asymmetry is presented in Table 2. Significant positive correlations were found between BSS and muscle thickness of the abdominal wall and multifidus lumborum on the dominant side (Figure 1A and B), while nearly significant positive correlations were obtained in the abdominal wall and multifidus lumborum on the non-dominant side (Figure 1C and D) and elbow flexors on the dominant side. In contrast, no significant correlations were found between BSS and lateral asymmetry of all muscles.

4. Discussion

The aim of the present study was to examine the relationships between BSS and muscle thickness and lateral asymmetry of the trunk and limbs in collegiate baseball players. BSS significantly correlated with only muscle thickness of the abdominal wall and multifidus lumborum on the dominant side; muscle thickness of the other parts and lateral asymmetry were not significantly correlated. These results suggest that the trunk muscles, especially the abdominal wall and multifidus lumborum on the dominant side, may be important for higher BSS in baseball players.

In the present study, muscle thickness of the abdominal wall and multifidus lumborum on the dominant side positively correlated with BSS. The abdominal wall plays a major role in trunk rotation [13]. High electromyographic activity of the abdominal wall is present from the "pre-swing," or "loading," phase to the "follow-through" phase of hitting motion [10]. In a similar way, the multifidus lumborum serves as a trunk rotator [14,15]. Therefore, the size of the abdominal wall and multifidus lumborum relate to rotational force of the trunk, thereby contributing to generation of higher BSS. On the other hand, muscle thickness of the abdominal wall and multifidus lumborum on the non-dominant side demonstrated a smaller correlation with BSS. Similarly, Shaffer and colleagues [10] reported that electromyographic activity of the abdominal wall on the non-dominant side was lower than that on the dominant side. However, further investigation of the kinetic and kinematic aspects of the trunk muscles during hitting motion is necessary to clarify any causal associations.

Muscle thickness of the upper and lower limbs did not significantly correlate with BSS in the present study. However, the relationship between BSS and muscle strength of the upper and lower limbs seems to vary depending on age. Previous studies have found significant correlations between bat swing velocity and muscle strength of the upper and lower limbs in high school baseball players [3,11], whereas collegiate baseball players have shown inconsistent results regarding the correlation between BSS and upper and lower limb muscle strength [2]. The findings of the present study suggest that muscle thickness of the upper and lower limbs does not correlate with BSS. In previous studies, resistance training emphasizing the upper and lower limbs effectively increased BSS in high school baseball players but not in collegiate baseball players [11,16]. Such difference between high school and collegiate players can be explained by the higher trainability of high school players because of their less developed muscle strength and BSS. In a previous study of high school baseball players, Miyaguchi and colleagues [3] reported a significant correlation between bat swing velocity and maximum load for bench press with one repetition in a group of players with relatively high bat swing velocity; however, they found no correlation between bat swing velocity and maximum load for bench press with one repetition in another group of players with relatively low bat swing velocity. Based on these studies, improvement in muscle strength of the whole body, including the upper and lower limbs, may be crucial to improve swing mechanics and BSS in not well-trained hitters. On the other hand, improvement in only the trunk muscles, which are responsible for trunk rotation, could effectively increase BSS in well-trained hitters. In fact, in a previous study, a training protocol including maximum trunk rotation with a bat swing–like posture successfully increased bat swing velocity in collegiate baseball players [17]. Therefore, the amount of training for muscle strength of the upper and lower limbs should be controlled based on the hitter's level of strength and BSS in order to establish an effective training program.

Lateral asymmetry, which can be harmful because of mechanical strain on the body, is common for athletes in sports with repetitive throwing and striking [18]. For example, lateral asymmetry is a well-known consequence of playing soccer and tennis [12]. In baseball, the unilateral dominance of throwing and hitting motions is considered to be the cause of apparent lateral asymmetry of muscle size, strength, and flexibility [19]. However, there has been no study on the relationship between baseball hitting performance and lateral asymmetry. The present study found no correlation between BSS and lateral asymmetry of muscle thickness. The results in the present study suggest that muscle size rather than lateral asymmetry is more important to achieve high BSS. Because lateral asymmetry of trunk muscle volume can be associated with injury and back pain [20], equalizing such asymmetry is beneficial for hitters by preventing or alleviating related injuries without compromising the potential to produce high BSS.

The positive correlation between the BSS and muscle volume of trunk muscle groups which was found in the present study is limited to collegiate baseball players. Therefore, further investigation of the relationship in younger baseball players will clarify the contribution of trunk muscle development to baseball hitting performance in a longer time span. In addition, influence of trunk muscle volume on the kinematics of bat swing needs to be clarified to elucidate the mechanism for higher BSS in hitters with greater trunk muscle volume. In the present study, muscle thickness measured with ultrasonography was utilized to estimate muscle volume. Although ultrasonography is much more affordable method to estimate muscle volume than computed tomography or magnetic resonance imaging, standardization and familiarization to measurement procedure is necessary to assure intrarater and interrater reliability.

Baseball hitting requires both power and biomechanical skill. Assessment of a hitter's BSS and trunk muscle thickness may be useful for allocation of hitting practice and strength training because such assessment can effectively estimate a hitter's potential to produce the highest BSS. Moreover, for well-trained hitters, such as collegiate baseball players, strength training should emphasize the trunk muscles rather than the limbs. Although lateral asymmetry is common in athletes of sports with repetitive throwing and striking, equalizing lateral asymmetry for injury prevention will not compromise a hitter's potential to produce the highest BSS.

In conclusion, the relationships between BSS and muscle thickness and lateral asymmetry of the trunk and limbs in collegiate baseball players were examined in the present study. BSS significantly correlated with only muscle thickness of the abdominal wall and multifidus lumborum on the dominant side. These findings indicate, in accordance with previous studies [10], the importance of the trunk muscles for producing high BSS. The present study is the first to find the correlation between BSS and trunk muscle volume which supports the importance of trunk muscle training.

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Table 1. Muscle thickness (mean ± s) in dominant and non-dominant sides and asymmetry

	Dominant (mm)	Non-dominant (mm)	Asymmetry (%)
Trunk muscles			
Upper abdominal rectus	16.2 ± 2.4	16.2 ± 2.4	100.0 ± 6.0
Central abdominal rectus	17.4 ± 2.5	17.2 ± 2.6	101.9 ± 7.0
Lower abdominal rectus	19.5 ± 3.3	19.8 ± 3.5	99.4 ± 9.9
Abdominal wall	30.9 ± 5.2	33.7 ± 5.9 *	92.5 ± 8.6
Multifidus lumborum	27.3 ± 3.5	27.9 ± 3.1 *	97.8 ± 4.5
Upper limb muscles			
Elbow flexors	32.3 ± 2.9	32.1 ± 2.9	101.0 ± 6.1
Elbow extensors	35.1 ± 5.5	35.3 ± 5.6	100.1 ± 11.2
Forearm flexors	24.5 ± 2.7	24.5 ± 2.5	100.6 ± 10.1
Lower limb muscles			
Knee extensors	61.7 ± 5.2	60.2 ± 5.4	102.7 ± 5.9
Knee flexors	76.6 ± 6.6	76.6 ± 5.9	100.1 ± 3.3
Dorsiflexors	29.5 ± 2.3	29.2 ± 2.3	101.3 ± 4.0
Plantar flexors	69.4 ± 4.9	69.6 ± 4.5	99.7 ± 4.5

* Significant difference between dominant and non-dominant sides ($p < 0.05$)

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Table 2. Correlation coefficients (r) between bat swing speed and muscle thickness of the dominant and non-dominant sides and rate of lateral asymmetr

	Dominant		Non-dominant		% Asymmetry	
	r	p values	r	p values	r	p values
Trunk						
Upper abdominal rectus	0.229	0.283	0.151	0.480	0.160	0.456
Central abdominal rectus	0.236	0.267	0.184	0.390	0.077	0.722
Lower abdominal rectus	0.097	0.651	0.098	0.650	0.006	0.978
Abdominal wall	**0.426**	**0.038**	0.386	0.062	0.008	0.972
Multifidus lumborum	**0.432**	**0.035**	0.379	0.068	0.261	0.218
Upper limb						
Elbow flexors	0.378	0.069	0.223	0.295	0.183	0.393
Elbow extensors	–0.149	0.487	–0.015	0.945	–0.201	0.346
Forearm flexors	0.003	0.989	–0.143	0.505	0.167	0.436
Lower limb						
Knee extensors	0.194	0.364	0.245	0.249	–0.105	0.624
Knee flexors	0.081	0.706	0.028	0.898	0.136	0.528
Dorsiflexors	–0.110	0.609	0.005	0.980	–0.237	0.265
Plantar flexors	–0.044	0.837	0.152	0.478	–0.286	0.176

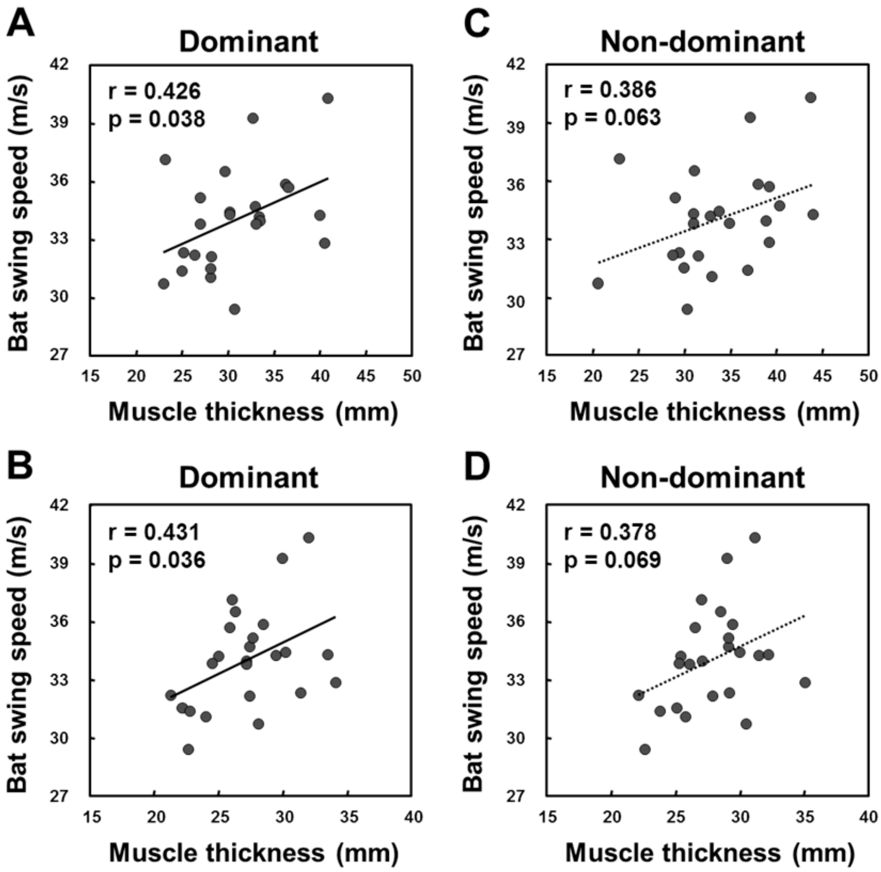

Figure 1. Scatterplots with regression lines for bat swing speed (m/s) and muscle thickness (mm) of the abdominal wall on the dominant side (A), the multifidus lumborum on the dominant side (B), the abdominal wall on the non-dominant side (C), and the multifidus lumborum on the non-dominant side (D).