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ORIGINAL RESEARCH

Whole-body and segmental muscle volume are associated with ball velocity in high school baseball pitchers

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Abstract: The aim of the study was to examine the relationship between pitching ball velocity and segmental (trunk, upper arm, forearm, upper leg, and lower leg) and whole-body muscle volume (MV) in high school baseball pitchers. Forty-seven male high school pitchers (40 right-handers and seven left-handers; age, 16.2 ± 0.7 years; stature, 173.6 ± 4.9 cm; mass, 65.0 ± 6.8 kg, years of baseball experience, 7.5 ± 1.8 years; maximum pitching ball velocity, 119.0 ± 9.0 km/hour) participated in the study. Segmental and whole-body MV were measured using segmental bioelectrical impedance analysis. Maximum ball velocity was measured with a sports radar gun. The MV of the dominant arm was significantly larger than the MV of the non-dominant arm ($P < 0.001$). There was no difference in MV between the dominant and non-dominant legs. Whole-body MV was significantly correlated with ball velocity ($r = 0.412$, $P < 0.01$). Trunk MV was not correlated with ball velocity, but the MV for both lower legs, and the dominant upper leg, upper arm, and forearm were significantly correlated with ball velocity ($P < 0.05$). The results were not affected by age or years of baseball experience. Whole-body and segmental MV are associated with ball velocity in high school baseball pitchers. However, the contribution of the muscle mass on pitching ball velocity is limited, thus other fundamental factors (ie, pitching skill) are also important.

Keywords: pitching, ball velocity, muscle volume, body composition, trunk, upper and lower extremities

Introduction

Baseball is one of the most popular sports in Japan and the US. In Japan, the number of registered high school baseball players has increased annually from 117,246 in 1982 to 169,449 in 2009,[1] with teams aiming to qualify for the national championship tournament called the "Koshien Baseball Tournament."[2] The ability to pitch at a high velocity is one of the important characteristics of a pitcher, as is the ability to control a variety of pitches. Although several studies have examined the relationship between pitching mechanics and ball speed,[3–5] research on this topic is limited.

Werner et al[4] examined collegiate baseball pitchers and found that body mass and nine temporal and kinematic parameters of pitching were related to ball velocity. Matsuo et al[5] investigated the differences between a group of 29 collegiate and professional pitchers who threw the ball at velocities above 85 mph, and a group of 23 college pitchers whose velocities were below 77 mph. They found that height, arm length, and six temporal and kinematic parameters were significantly different between the low- and high-velocity groups.[5]

Skeletal muscle mass is a determinant of power generation.[6,7] Body size is closely associated with muscle strength.[8] A clear example of this principle is demonstrated

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by the strong positive correlation (r = 0.97) between world records for power lifting and weight classes.[9] van den Tillar and Ettema[10] demonstrated that fat-free mass (FFM), estimated by the skinfold method, significantly correlated with maximal handball velocity in both male and female adult handball players (r = 0.62 and 0.69, respectively). However, these authors examined whole-body FFM and did not determine the contribution of muscle mass from the different segments of the body.[10] More recently, Sanchis-Moysi et al[11–14] reported the muscle volume (MV) of trunk and upper extremity MVs in professional and prepubescent tennis players, which also perform unilateral movements. However, no studies were conducted about baseball pitchers. The present study is the first to examine the relationship between segmental muscle mass and ball velocity.

In addition, previous studies have only examined collegiate or adult players.[4,5,10] The pitching skill of collegiate or adult players is mature compared to adolescents, and anthropometric aspects have been shown to be major determinants of ball velocity in more experienced players.[15] In contrast, it is unknown whether skeletal muscle mass is a determinant of ball velocity in adolescents.

The aim of the present study is to examine the relationship between ball velocity and segmental (trunk, upper arm, forearm, upper leg, and lower leg) and whole-body MV in high school baseball pitchers. The abdominal core muscles play an important role in baseball pitching. The contribution of the core is considered to be at least equal to and possibly greater than that of the limb muscles.[16] Therefore, we hypothesized that the correlation between trunk MV and ball velocity would be stronger than the correlation between limb MVs and ball velocity in baseball pitchers.

Methods

Subjects

Forty-seven healthy male high school baseball pitchers from 47 high schools in Kyoto Prefecture, Japan, participated in the study. The inclusion criterion was that the high school baseball pitchers participated in a baseball workshop, which was held by the Kyoto High School Baseball Federation on a weekend in November 2010. The exclusion criterion was that the pitchers had a history of shoulder or elbow pain that involved time loss from competition in the previous 6 months. Forty of the athletes were right-hand dominant and seven were left-handed. The study protocol was approved by the ethics committee of Kyoto Prefectural University of Medicine. The participants provided informed consent. Barefoot stature was measured to the nearest 0.1 cm using a wall-mounted stadiometer. Body mass was measured to the nearest 0.1 kg, with the subjects dressed in light clothing without shoes. Anthropometric measurements were obtained in the morning, and the lengths of the limbs were measured to the nearest 0.5 cm using a flexible tape with the subjects in a standing position.

Segmental and whole-body muscle volume

Segmental and whole-body MV were measured by the segmental bioelectrical impedance analysis (SBIA) method that had been previously validated against magnetic resonance imaging (MRI) to estimate limb, trunk, and whole-body MV.[7,17,18] All measurements were performed on a padded wooden table with the participants in a relaxed supine position, arms slightly abducted from the body, forearms pronated, and legs slightly apart. An eight-channel battery-operated impedance instrument (Muscle-α, Art Haven 9 Co, Kyoto, Japan) was used because it was capable of measuring and displaying values obtained from four electrode pairs simultaneously.[7,17–22] This system applied a constant current of 500 μA at 50 kHz through the body and measured impedance (Z), not resistance. Before the test, the system was calibrated against 10, 100, and 1000 Ω and was checked against a series of precision resistors provided by the manufacturer. Errors were less than 1% across all measurements. The impedance measurements were taken once the subjects had been in the relaxed supine position for 5 to 10 minutes. Pregelled electrocardiogram tab-type monitoring electrodes (Red Dot™, 3M, St Paul, MN, USA) were used. Current injection electrodes were placed on both sides of the body on the dorsal surface of the hands and feet proximal to the metacarpal–phalangeal and metatarsal–phalangeal joints, respectively (Figure 1). Voltage measurement electrodes were placed on both sides of the body on the middorsum of the wrist centered on a line joining the bony prominences of the radius and ulna, the mid-anterior ankle centered on a line joining the malleolus lateralis and malleolus medialis, the lateral epicondyle of the humerus, the articular cleft between the femur and tibia-condyles, the greater trochanter of the femurs, and the head of the radius and the acromion process of the shoulders.[17,22]

The repeatability of the impedance measurements for each segment was assessed on two separate days in 14 young adult males. The intraclass correlation coefficients ($ICC_{[3,1]}$) for the test–retest ranged from 0.943 to 0.978 for the measurements.[22] There were no significant differences in any of the Z measurements between the two tests.

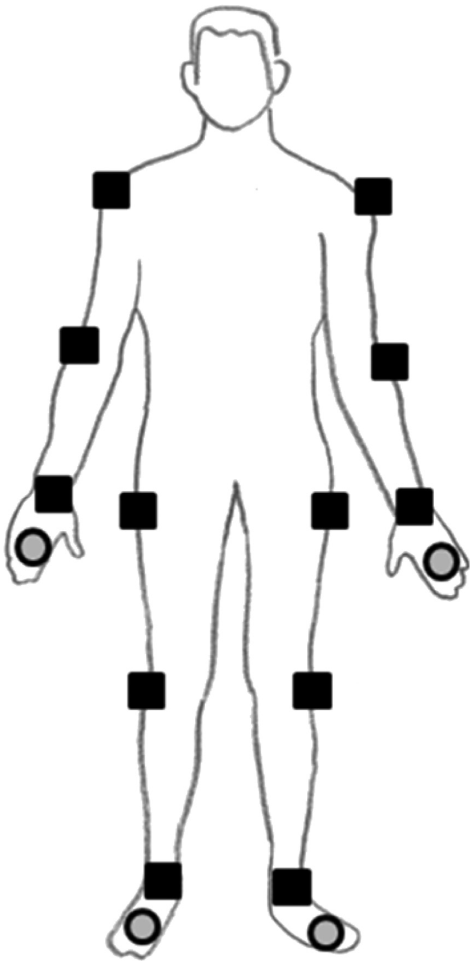

Figure 1 Schematic representation of electrode position for segmental bioelectrical impedance analysis.

Notes: Current injection electrodes were placed on both sides of the body on the dorsal surface of the hands and feet proximal to the metacarpal–phalangeal and metatarsal–phalangeal joints, respectively (◉). Voltage measurement electrodes were placed on both sides of the body on the middorsum of the wrist centered on a line joining the bony prominences of the radius and ulna, the midanterior ankle centered on a line joining the malleolus lateralis and malleolus medialis, the lateral epicondyle of the humerus, the articular cleft between the femur and tibiacondyles, the greater trochanter of the femurs, and the head of the radius and the acromion process of the shoulders (■).

The bioelectrical impedance index for each segment was calculated using the equation:

$$\text{Bioelectrical impedance index} = \text{Segment length}^2/Z. \quad (1)$$

We assumed that the segment lengths (L) were reflected by the distance between the two detector electrodes. The estimated MV was calculated using previously validated equations,[7,17,18] as follows.

Upper arms:

$$MV = 70.681[L^2/Z] - 72.71; \quad (2)$$

forearms:

$$MV = 110.41[L^2/Z] + 54.238; \quad (3)$$

thighs:

$$MV = 131.19[L^2/Z] - 152.86; \quad (4)$$

lower legs:

$$MV = 126.35[L^2/Z] + 31.35. \quad (5)$$

The standard errors of the estimates against the MVs measured by MRI were as follows: forearm, 38.4 cm^3; upper arm, 40.9 cm^3; lower leg, 107.2 cm^3; and thigh, 362.3 cm^3.[7] Trunk and whole-body MVs were also calculated using previously validated equations that are described in detail elsewhere.[17,18]

Ball velocity

After performing a normal warm-up routine that included stretching of the upper and lower extremities, pitching drills, and a number of throws and pitches, three maximal effort pitching trials were performed. Ball speed was measured using a high performance sports radar gun (Stalker Pro II, Applied Concepts, Inc, Plano, TX, USA),[23–25] which has an accuracy of 0.16 km h^{-1}, a speed range of 1.6–1432 km h^{-1}, and a target acquisition time of 0.01 seconds. The maximal ball velocity achieved across the three trials was recorded.

Statistical analyses

All analyses were performed using PASW 18.0 for Windows (SPSS, Inc, Chicago, IL, USA). Results are presented as mean ± standard deviation and range. For all of the analyses, an alpha of 0.05 was used to denote statistical significance. A statistical power calculation (based on a correlation of $r = 0.35$, power $1 - \beta = 0.80$, and type 1 error probability of $\alpha = 0.05$) determined that the appropriate subject number for the study was 46. Paired *t*-tests were performed to compare the MV between dominant and nondominant limbs. Independent *t*-tests were used to compare the physical characteristics between right-handed and left-handed athletes. Pearson product moment correlation coefficients were calculated. Because ball velocity was significantly correlated with age and years of baseball experiences, partial correlation coefficients were also calculated using age as a control variable.

Results

Table 1 displays the maximum ball velocity and MV for the subjects. The range of the maximum ball velocity was 92 to 134 km/hour (57 to 83 mph). The MV of the dominant arm was significantly larger than the MV of the nondominant arm ($P < 0.001$). In contrast, there was no significant difference in MV between the dominant and nondominant leg.

Table 1 Physical characteristics of the subjects (n = 47)

	Mean ± SD	Range
Age (years)	16.2 ± 0.7	15–17
Height (cm)	173.6 ± 4.9	164.0–183.0
Weight (kg)	65.0 ± 6.8	54.0–82.0
BMI (kg/m²)	21.5 ± 1.6	18.4–25.2
Percent body fat (%)	14.5 ± 5.3	2.6–30.3
Maximum ball velocity (km/hour)	7.5 ± 1.8	3.0–11.0
Muscle volume (cm³)	119.0 ± 9.0	92–134
Whole-body	25647 ± 2927	20299–32490
Trunk	10168 ± 1180	6704–12538
Dominant upper arm	715 ± 100	514–919***
Nondominant upper arm	671 ± 101	474–952
Dominant forearm	530 ± 72	395–718***
Nondominant forearm	516 ± 68	376–704
Dominant upper leg	4513 ± 593	3614–6012
Nondominant upper leg	4548 ± 544	3409–5873
Dominant lower leg	1425 ± 181	1048–1828
Nondominant lower leg	1409 ± 193	1070–1829

Note: ***Significantly larger muscle volume than nondominant side ($P < 0.001$).
Abbreviations: n, number; SD, standard deviation; BMI, body mass index.

Table 2 compares the physical characteristics between right- and left-handed pitchers. There were no significant differences in any variables between right- and left-handed pitchers. Therefore, all 47 pitchers were included in the correlation analysis.

Table 3 displays the correlations between physical characteristics and maximum ball velocity of the pitchers.

Table 2 Comparison of physical characteristics between right- and left-handers

	Right-handers (n = 40) Mean ± SD	Left-handers (n = 7) Mean ± SD
Age (years)	16.2 ± 0.7	16.0 ± 0.8
Height (cm)	174.0 ± 4.9	171.4 ± 4.9
Weight (kg)	65.5 ± 6.7	62.0 ± 6.8
BMI (kg/m²)	21.6 ± 1.6	21.0 ± 1.3
Percent body fat (%)	14.8 ± 5.2	12.6 ± 5.9
Maximum ball velocity (km/hour)	7.6 ± 1.9	7.3 ± 1.1
Muscle volume (cm³)	119.6 ± 9.0	115.3 ± 8.8
Whole-body	25785 ± 2710	24858 ± 4133
Trunk	10224 ± 1193	9847 ± 1129
Dominant upper arm	719 ± 93	696 ± 141
Nondominant upper arm	672 ± 90	669 ± 162
Dominant forearm	534 ± 65	507 ± 108
Nondominant forearm	522 ± 64	484 ± 86
Dominant upper leg	4523 ± 578	4460 ± 722
Nondominant upper leg	4540 ± 532	4592 ± 652
Dominant lower leg	1437 ± 181	1357 ± 181
Nondominant lower leg	1414 ± 187	1384 ± 236

Note: There is no significant difference between the two groups.
Abbreviations: n, number; SD, standard deviation; BMI, body mass index.

Table 3 Correlation coefficients with maximum ball velocity (n = 47)

	r	Partial r
Age (years)	0.293*	
BMI (kg/m²)	0.443**	
Percent body fat (%)	0.248	0.252
Muscle volume (cm³)	0.036	0.033
Whole-body	0.412**	0.397**
Trunk	0.284	0.213
Dominant upper arm	0.358*	0.303*
Nondominant upper arm	0.307*	0.245
Dominant forearm	0.341	0.351*
Nondominant forearm	0.333*	0.348*
Dominant upper leg	0.311*	0.370*
Nondominant upper leg	0.139	0.215
Dominant lower leg	0.398**	0.380*
Nondominant lower leg	0.453**	0.424**

Notes: Since ball velocity was significantly correlated with age and years of baseball experience, partial correlation coefficients were also calculated using age as control variables. *$P < 0.05$; **$P < 0.01$.
Abbreviations: n, number; BMI, body mass index.

Whole-body MV was significantly correlated with maximum ball velocity ($P < 0.01$). Because maximum ball velocity was significantly correlated with age and years of baseball experience, partial correlation coefficients were calculated with age and years of baseball experience as control variables. However, whole-body MV remained significantly correlated with ball velocity ($P < 0.01$). The MVs for all four segments on the dominant side were significantly correlated with ball velocity. On the nondominant side, the MV of the forearm and lower leg were significantly correlated with ball velocity. In contrast, the MV of the trunk, nondominant upper arm, and upper leg were not correlated with ball velocity. Body mass index and percent body fat were not correlated with maximum ball velocity.

Discussion

The main finding of this study was that maximum ball velocity during pitching in high school baseball pitchers was significantly correlated with whole-body and limb segment MV. There was no correlation between trunk MV and ball velocity.

Although several studies have examined the relationship between bat swing velocity and FFM,[26] no previous studies have examined the relationship between MV and maximum ball velocity during baseball pitching. A reason for the lack of studies examining pitchers may be because it is difficult to recruit an appropriate number of pitchers compared to batters. Bat swing velocity was significantly correlated with FFM.[26] van den Tillaar and Ettema[10] examined the relationship between overarm throwing velocity and FFM in adult handball players. They found a moderate correlation between handball velocity and FFM in men and women (r = 0.62 and r = 0.69, respectively).[10] In the present study, the correlation between whole-body MV and ball velocity was weaker (r = 0.412) than in the handball study. Two possible reasons may account for the differences between the two studies. Firstly, the weight of a baseball is 145 g, while the weight of a handball is 450 g for men. Throwing a heavy and large ball requires greater muscle strength than throwing a light ball. Therefore, the contribution of FFM to ball velocity may be higher in handball compared to baseball. Secondly, youth athletes have more immature skills compared to adults, and therefore pitching skill is more varied between athletes.[15] The result is that whole-body MV may only make a limited contribution to ball velocity. Despite this reasoning, our study demonstrated that whole-body MV was significantly correlated with ball velocity in high school pitchers.

It was hypothesized that the trunk MV would be more strongly correlated with ball velocity compared to limb MV in baseball pitchers. However, trunk MV was not correlated with ball speed, while limb MVs were significantly correlated. The reason that the hypothesis was disproven may be the limitation of estimating trunk MV by SBIA. Ishiguro et al[18] demonstrated that trunk SBIA can estimate trunk MV, but the agreement of trunk SBIA against MRI was less than whole-body or appendicular MVs. This is because the trunk has too complex a morphology to assume a cylindrical shape. The lack of accuracy in estimating trunk MV by SBIA may affect the results of the present study. Sanchis-Moysi et al[11–14] reported trunk and upper extremity MVs in professional and prepubescent tennis players, who also perform unilateral movements. These studies indicated that the professional tennis players had larger trunk muscles (iliopsoas, gluteal, and rectus abdominis muscles) compared with controls. They showed that the significant asymmetries of these muscles were observed in the tennis players. In the present study, because the specific and unilateral MVs cannot be assessed by the trunk SBIA, further studies are needed.

The dominant leg, which is called the trail leg during pitching, supports the pitcher's mass during the phase from wind-up to stride foot contact. The pitcher should push off the pitching rubber and control his or her fall towards the home plate with the trail leg during this phase.[27] Campbell et al[27] demonstrated that the electromyography (EMG) values for triceps surae and quadriceps contractions in the trail and stride leg, during the phase from stride foot contact to ball release, were greater than the maximum voluntary isometric contraction EMG values for these muscles. The authors concluded that pitching requires a high level of lower extremity strength.[27] Oliver and Keeley[28] demonstrated that gluteal EMG values during pitching were greater than gluteal maximum voluntary isometric contraction EMG values. Guido and Werner[29] examined the kinematics and the lower-extremity ground reaction forces in baseball pitchers, and indicated a significant correlation between braking force of the stride leg and ball velocity. The results of the previous and present studies suggest the importance of lower limb MV and strength for ball velocity during pitching. The resistance training of lower limbs may be effective in increasing ball velocity in the baseball pitcher.

Significant correlations were also observed between ball velocity and MVs of the dominant upper extremity. Werner et al[4] found that maximum elbow extension angular velocity was a significant contributor to ball velocity. Pugh et al[30] reported that arm and wrist strength were significantly correlated with throwing speed in experienced pitchers. Therefore, MV and strength of the dominant upper extremity may also be important for achieving high ball velocity.

There are several limitations in the present study. We estimated MV by SBIA, which is a secondary method to estimate MV and inferior to MRI or computerized tomography. The previous studies that have examined the validity of SBIA in estimating MV against MRI had important limitations.[7,17,18] Some of them include: (1) that the accuracy estimations of MV would vary depending on subject samples; (2) that the method used to analyze the MRI scans for regional areas was a bit primitive and did not exploit more advanced segmentation software being used in this research field;[31] and that as a consequence, (3) smaller islands of adipose tissue within the skeletal muscle bundle were not fully excluded, and so the skeletal volume might be overestimated.[32] Therefore, further study to clarify the influences in the subject samples and especially the method used to analyze the MRI scans to estimate skeletal MV is needed to generalize the findings obtained in the previous studies.[7,17,18] However, we would like to note that SBIA is an affordable, noninvasive, easy to operate, portable, and fast (within 5–10 minutes) alternative for assessing segmental or whole-body MV. Thus, SBIA can be a practical method for assessing MV as a primary physical checkup. The present results should be reexamined by MRI or computerized tomography.

One of the strengths of the SBIA used in the present study is that it can estimate the MV of nine segments (trunk, upper arms, forearms, upper legs, and lower legs) as well as whole-body MV, and it has been validated against MRI. Dual-energy X-ray absorptiometry or other bioimpedance analysis devices cannot measure upper arms and forearms, or upper and lower legs separately. The SBIA used in this study estimates the MV from raw impedance data without additional variables such as age, weight, and sex, while other commercially available BIA uses such additional variables.

In conclusion, whole-body muscle mass was correlated with pitching ball velocity in experienced high school pitchers. The novel finding of this study was that the MV of the dominant and nondominant legs and dominant arm were significantly correlated with ball velocity. These results were not affected by age or years of baseball experience. The results suggest that strength training to increase pitching-specific MV in the lower extremities and dominant arm may be effective for increasing ball velocity. However, the contribution of muscle mass on pitching ball velocity is limited; thus, the other fundamental factors (eg, pitching skill) are also important.

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Disclosure

The authors report no conflicts of interest in this work.

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