ORIGINAL RESEARCH

Inter-sport variability of muscle volume distribution identified by segmental bioelectrical impedance analysis in four ball sports

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Abstract: The aim of this study was to evaluate and quantify differences in muscle distribution in athletes of various ball sports using segmental bioelectrical impedance analysis (SBIA). Participants were 115 male collegiate athletes from four ball sports (baseball, soccer, tennis, and lacrosse). Percent body fat (%BF) and lean body mass were measured, and SBIA was used to measure segmental muscle volume (MV) in bilateral upper arms, forearms, thighs, and lower legs. We calculated the MV ratios of dominant to nondominant, proximal to distal, and upper to lower limbs. The measurements consisted of a total of 31 variables. Cluster and factor analyses were applied to identify redundant variables. The muscle distribution was significantly different among groups, but the %BF was not. The classification procedures of the discriminant analysis could correctly distinguish 84.3% of the athletes. These results suggest that collegiate ball game athletes have adapted their physique to their sport movements very well, and the SBIA, which is an affordable, noninvasive, easy-to-operate, and fast alternative method in the field, can distinguish ball game athletes according to their specific muscle distribution within a 5-minute measurement. The SBIA could be a useful, affordable, and fast tool for identifying talents for specific sports.

Keywords: discriminant analysis, cluster and factor analysis, segmental bioelectrical impedance analysis, baseball, lacrosse

Introduction

Whole-body composition, such as percent body fat (%BF) and lean body mass (LBM), is critical to sports performance, especially in endurance sports (eg, long-distance running, swimming, and triathlon), acrobatic and artistic sports (eg, gymnastics and figure skating), and weight-limiting sports (eg, judo, wrestling, boxing, and weightlifting).[1] Furthermore, some ball sports tend to require more height (eg, basketball and volleyball), and certain team positions tend to require greater weight and LBM (eg, lineman in American football and prop in rugby).[1]

In contrast, specific whole-body composition may not be strictly required in many other ball sports.[1] Ball sports, however, require sport-specific movement patterns such as kicking, hitting, throwing, or shooting balls, with or without instruments. The repetitive movements required during participation in both practice and games promote changes in active muscles; thus, muscle mass distribution among the body segments would likely adapt after long-term practice in ball sports. Holzbaur et al[2] reported that the distribution of muscle volume in the upper limb is highly conserved across their subjects who did not participate in any special sports. In contrast, inter-sport variability of muscle volume distribution might exist in ball-sport athletes because of their long-term

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practice. However, to our knowledge, inter-sport differences in muscle distribution of ball-sport athletes have not been reported, but the assessment of these could be fundamental for further training and sport rehabilitation.

Bioelectrical impedance analysis (BIA) has gained recognition as an affordable, noninvasive, easy-to-operate, portable, and fast alternative for assessing body composition.[3–5] Traditionally, the impedance from wrist to ankle on one side of the body has been used to predict body composition (whole-body method); however, this method is most influenced by the composition of thin segments in the body such as the forearm and lower leg.[6] Therefore, researchers have proposed dividing the human body into different segments or regions to accurately assess body composition.[7,8] Segmental BIA (SBIA) can estimate not only whole-body composition,[9] but also segmental (upper arm, forearm, thigh, and lower-leg) muscle volumes (MVs).[3,10,11] Previous studies have validated the accuracy of segmental MV estimated by SBIA against magnetic resonance imaging, computed tomography, and dual energy X-ray absorptiometry.

The present study was designed to evaluate and quantify inter-sport differences in muscle distribution among athletes of different ball sports. The objective was to determine whether SBIA is effective in discriminating amongst athletes of different ball sports by identifying sport-specific MV distributions. If the normal MV distribution could be identified for particular sports, then SBIA might be helpful for developing sport-specific training strategies and assessing abnormal muscle distribution and the effectiveness of resistance training.

We selected collegiate athletes playing baseball, soccer, tennis, and lacrosse because representative movements of each seem to recruit different muscle groups. Tennis players use one dominant hand in their racket swing, while baseball and lacrosse players use both hands, and soccer players use only their legs to manipulate the ball. Furthermore, lacrosse requires catching, passing, and shooting with a "crosse" carried in both arms, but does not require directly hitting a high-speed ball, whereas doing so is required in tennis and baseball. This may cause inter-sport differences in the distribution of MV in the upper limbs.

Methods
Participants
We recruited 163 Japanese male college athletes from four ball sports (baseball, soccer, tennis, and lacrosse) after obtaining written informed consent. Of those, 115 athletes (baseball, n = 52; soccer, n = 19; tennis, n = 11; lacrosse, n = 33) aged 20.5 ± 1.2 (mean $\pm$ SD) years were selected for

the study based on the following eligibility criteria: (1) no orthopedic disorders within 6 months; (2) no acute disease at the time of the measurements; (3) had played a given ball sport continually for at least 30 months; (4) not a keeper, goalie, or pitcher (because the number of keepers, goalies, or pitchers is too small to apply statistical analysis, they could not be allocated as other groups); (5) right-pure or right-strong handedness according to the Edinburgh Handedness Inventory;[12] and (6) right-pure or right-strong footedness, meaning the preferential use of the right foot to act on and manipulate objects, such as to kick a ball, according to Chapman et al's foot preference test.[13,14] The study protocol was approved by the ethics committee of the Kyoto Prefectural University of Medicine.

Basic theory of SBIA
Instruments for BIA introduce into the body a known amount of current (I), of about 800 μA, most often at a frequency of 50 kHz. The actual parameter measured with BIA is the voltage (V), which is produced between two electrodes located most often at sites near to, but different from, the sites at which current is introduced. The measurement is normally expressed as a ratio, V/I, which is also called impedance (Z). In BIA, reactance (Xc) is about 10% of the resistance (R), so the magnitude of Z is similar to that of R. In many BIA reports, Z and R are used as if they are interchangeable, although

$$Z = (R^2 + Xc^2)^{1/2}. \qquad (1)$$

Explanations of the BIA method often begin with a discussion of a special, simplified volume that has a uniform cross-section, such as a cylinder, and that is filled with a homogeneous conducting material of resistivity (ρ). It is then observed that the end-to-end R is the resistivity times the length (L), divided by the cross-sectional area (A):

$$R = \rho L/A. \qquad (2)$$

Multiplying the right side of the equation by L/L gives the following equation:

$$R = \rho L^2/\text{Vol}, \qquad (3)$$

where Vol is the volume. Rearranging gives

$$\text{Vol} = \rho L^2/R, \qquad (4)$$

an equation that allows one to determine the volume, for this special case, if ρ, L, and R are measured.[15] The limb can be

considered as three electrical conductors, low-resistance skeletal muscle, and high-resistance adipose tissue and bone. Previous studies indicate good correlations between limb R or closely-related Z, measured at 50 kHz, and limb skeletal muscle volume estimated by magnetic resonance imaging (MRI) or computed tomography (CT). This observation suggests that limb muscle volume can be predicted from measured R or Z by SBIA.[16]

Measurement of SBIA

SBIA measurement was conducted according to previous studies.[3,6,9,10,17] All measurements were done with the participants in a relaxed supine position on a padded wooden table, arms slightly abducted from the body, forearms pronated, and legs slightly apart. An eight-channel battery-operated impedance instrument (Muscle-α; Art Haven 9, Kyoto, Japan) was used to simultaneously measure and display values obtained from four electrode pairs.[9,10,17–19] This system applies a constant current of 500 μA at 50 kHz through the body. Before the test, a system calibration was conducted with precision resistors of 10, 100, and 1000 Ω, as well as several precision resistors provided by the manufacturer; errors were less than 1%. Participants were told to refrain from vigorous exercise and alcohol intake for 24 hours preceding the testing and to fast for at least 4 hours. All testing was done during the first month of the off-season of the respective sports. The room temperature was kept within a thermoneutral range (20°C–22°C). Impedance measurements were taken with 2×2 cm² pre-gelled electrocardiogram tab-type monitoring electrodes (Red Dot™; 3M™, St Paul, MN, USA) within 5 to 10 minutes after the participants were in the supine position. Current-injection electrodes were placed on both sides of the body and on the dorsal surfaces 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 at the middorsum of the wrist centered on a line joining the bony prominences of the radius and ulna, at the dorsal surface of both elbows between the lateral epicondyles of the humerus, at the articular cleft between the femoral and tibial condyles of both legs, and at the mid-anterior ankle centered on a line joining the malleolus lateralis and malleolus medialis (Figure 1).[6,17]

The anthropomorphic distinction between the trunk and upper or lower limb segments is difficult. Therefore, the principle of equipotential[7] was exploited. The detail of measuring the impedance of the upper arm and upper leg without shoulder and hip electrodes was described in a previous study.[6] When Z_1 was defined as the impedance with shoulder
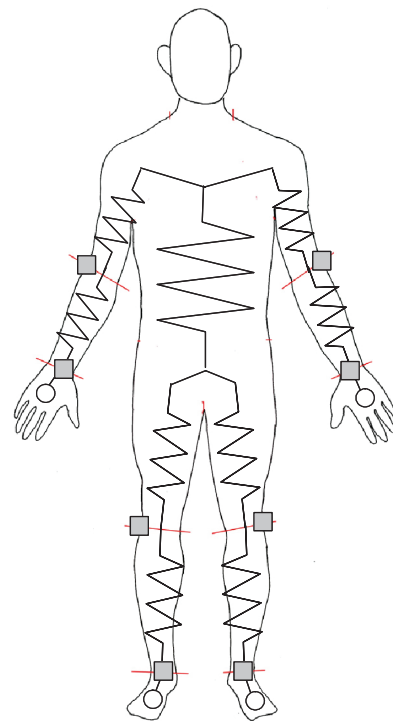
Figure 1 Schema of electrode locations.
Notes: ○, current-injection electrodes; □, voltage-measurement electrodes.

and hip electrodes and Z_2 was defined as the impedance without shoulder and hip electrodes using electrodes in the contralateral limbs, Z_2 was very strongly correlated with Z_1 (r = 0.977 to 0.981, $P < 0.001$); Z_1. Z_1 can be calculated using the following equations:

$$\text{for the upper arm, } Z_1 = 0.827 \times Z_2 \tag{5}$$

($R^2 = 0.962$, standard error of the mean [SEE] = 3.71 Ω);

$$\text{And, for the upper leg, } Z_1 = 0.876 \times Z_2 \tag{6}$$

($R^2 = 0.961$, SEM = 1.98 Ω). These results indicate that Z_1 and Z_2 are proportionate to each other and either value can be used. Therefore, Z_2 was used in the present study.

The repeatability of the Z measurements for each segment was assessed in a pilot study with 14 young adult athletes on two separate days, and no significant difference was detected in the intraclass correlation coefficients ($ICC_{[3,1]}$) for the test–retest (0.94–0.98). The %BF of the Japanese college athletes was calculated according to a previous study.[9] MVs were calculated from Z and segment L using the following equations provided by a previous study of Japanese college athletes:[10]

$$\text{upper arms, } (70.681[L^2/Z] - 72.71); \tag{7}$$

forearms, $(110.41[L^2/Z] + 54.238)$; (8)

thighs, $(131.19[L^2/Z] - 152.86)$; (9)

lower legs, $(126.35[L^2/Z] + 31.35)$. (10)

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.[10]

Measurements and procedures

The measurements were anthropometric characteristics (n = 13; Table 1), segmental MV (n = 8; Table 2), and ratio between muscle volumes (n = 10; Table 2). The measurements included 31 variables (Figure 2). Body mass was measured to the nearest 0.1 kg with the participants dressed in light clothing. Barefoot standing height was measured to the nearest 0.1 cm with a wall-mounted stadiometer. The lengths of the limbs were measured to the nearest 0.5 cm with a flexible tape (Flat rule; KDS Co, Ltd, Kyoto, Japan). The segment lengths were measured as following: for forearm, between the mid-dorsum of the wrist centered on a line joining the bony prominences of the radius and ulna and the lateral epicondyle of the humerus; for upper arm, between the lateral epicondyle of the humerus and the head of the radius and the acromion process of the shoulders; for lower leg, between the mid-anterior ankle centered on a line joining the malleolus

lateralis and malleolus medialis and the articular cleft between the femur and tibia-condyles; for upper leg, between the articular cleft between the femur and tibia-condyles and the greater trochanter of the femurs.

The ratio of the dominant-to-nondominant (D/N) limbs was calculated for the upper arms, forearms, thighs, and lower legs by:

D/N (%) = (MV of dominant limb)/
(MV of nondominant limb) × 100–100. (11)

The ratio of proximal-to-distal (P/D) limbs was calculated for the upper and lower limbs on both sides by:

P/D = (MV of proximal limb)/(MV of distal limb). (12)

The ratio of the upper-to-lower limb (U/L) was calculated for the right and left sides by:

U/L = (MV of upper limb)/(MV of lower limb). (13)

Data analysis

Results are presented as means ± SD. One-way analysis of variance (ANOVA) was carried out for group comparisons, and Tukey's b was used post hoc as the test of multiple comparisons to account for different sample sizes of the groups.[20] A single multivariate analysis of variance (MANOVA) was

Table 1 Physical characteristics of the analyzed participants (n = 115)

	Baseball (n = 52)	Soccer (n = 19)	Tennis (n = 11)	Lacrosse (n = 33)
Age (years)	20.5 ± 1.5	20.3 ± 1.2	19.8 ± 1.2	20.9 ± 0.9
Height (cm)	174.5 ± 5.3	172.7 ± 4.4	172.0 ± 6.4	173.5 ± 5.8
Weight (kg)	67.5 ± 6.9[a]	64.7 ± 6.1[a,b]	61.7 ± 6.1[b]	64.8 ± 4.7[a,b]
BMI (kg/m^2)	22.1 ± 1.6[a]	21.7 ± 1.7[a,b]	20.8 ± 1.1[b]	21.5 ± 1.5[a,b]
LBM (kg)	59.7 ± 4.7[a]	56.5 ± 4.1[a,b]	54.9 ± 3.9[b]	58.0 ± 3.4[a,b]
% BF	11.4 ± 2.9	12.5 ± 3.3	10.7 ± 3.4	10.4 ± 3.0
Segment length (cm)				
Upper arm				
Right	32.2 ± 1.2	32.0 ± 1.3	32.6 ± 2.0	32.1 ± 1.2
Left	32.1 ± 1.2	32.0 ± 1.3	32.6 ± 2.0	32.3 ± 1.1
Forearm				
Right	24.6 ± 1.3	24.2 ± 0.8	24.3 ± 1.4	23.8 ± 1.1
Left	24.6 ± 1.2	24.2 ± 0.9	24.2 ± 1.2	23.7 ± 1.1
Thigh				
Right	40.3 ± 1.7	40.6 ± 1.6	40.8 ± 2.3	40.7 ± 1.5
Left	40.4 ± 1.8	40.6 ± 1.6	40.8 ± 2.2	40.7 ± 1.5
Lower leg				
Right	40.2 ± 1.4	39.3 ± 1.7	39.0 ± 2.4	39.6 ± 1.8
Left	40.2 ± 1.4	39.4 ± 1.7	39.0 ± 2.4	39.7 ± 1.8

Notes: [a,b]Significantly different at post hoc multiple comparisons by Turkey's b (a>b). Right is dominant and left is non-dominant side in all participants.
Abbreviations: BMI, body mass index; LBM, lean body mass; %BF, percent body fat.

Table 2 The muscle volumes and muscle volume ratios between segments

	Baseball	Soccer	Tennis	Lacrosse
Segmental muscle volume (cm³)				
Upper arm				
Right	806 ± 110[a,b,***]	727 ± 100[b]	745 ± 105[a,b,***]	813 ± 95[a,***]
Left	770 ± 95[a]	719 ± 88[a,b]	663 ± 99[b]	788 ± 87[a]
Forearm				
Right	634 ± 84[a]	544 ± 70[b]	573 ± 82[b,***]	558 ± 55[b]
Left	638 ± 87[a]	535 ± 72[b]	519 ± 66[b]	556 ± 54[b]
Thigh				
Right	4270 ± 563	4092 ± 412[***]	3909 ± 560	4164 ± 383
Left	4259 ± 538[a]	3923 ± 470[a,b]	3839 ± 539[b]	4106 ± 398[a,b]
Lower leg				
Right	1484 ± 188[a]	1398 ± 158[a,b]	1321 ± 161[b,**]	1494 ± 159[a]
Left	1474 ± 183[a]	1402 ± 159[a,b]	1287 ± 162[b]	1491 ± 156[a]
Muscle volume ratio				
Ratio of dominant-to-nondominant limbs (%)				
Upper arms	4.68 ± 5.47[b]	0.89 ± 4.71[b]	12.54 ± 5.88[a]	3.20 ± 4.81[b]
Forearms	−0.44 ± 5.49[b]	1.69 ± 4.58[b]	10.38 ± 4.35[a]	0.30 ± 3.56[b]
Thighs	0.24 ± 3.80[b]	4.57 ± 3.93[a]	1.81 ± 3.07[a,b]	1.56 ± 4.73[a,b]
Lower legs	0.74 ± 4.39	−0.18 ± 4.27	2.68 ± 2.33	0.30 ± 4.58
Ratio of proximal-to-distal limbs				
Right arm	1.28 ± 0.13[b]	1.34 ± 0.15[b]	1.31 ± 0.18[b]	1.46 ± 0.13[a]
Left arm	1.22 ± 0.13[c]	1.35 ± 0.11[a,b]	1.29 ± 0.20[b,c]	1.42 ± 0.12[a]
Right leg	2.89 ± 0.28	2.94 ± 0.26	2.96 ± 0.27	2.80 ± 0.28
Left leg	2.90 ± 0.27	2.81 ± 0.28	2.99 ± 0.29	2.77 ± 0.30
Ratio of upper-to-lower limbs				
Right side	0.251 ± 0.018[a]	0.232 ± 0.020[b]	0.253 ± 0.017[a]	0.242 ± 0.014[a,b]
Left side	0.247 ± 0.022	0.236 ± 0.024	0.232 ± 0.019	0.240 ± 0.015

Notes: [a,b,c]Significantly different (a>b>c). [*****]Significantly larger than nondominant side by paired *t* test (**$P < 0.01$, ***$P < 0.001$). Right is dominant and left is non-dominant side in all participants.

conducted before ANOVA to avoid type I error. A correlation matrix among the ratios of the 31 variables was calculated and submitted to cluster and factor analyses to identify possible redundant variables. Ten suitable dependent variables were selected from these results for the discriminant analysis. Discriminant analysis was employed to identify the nature of the discovered differences and to provide a scaling model with functions that maximized group differences. Classification procedures were used to determine if groups could be accurately described by their muscle characteristics.[21] All analyses were performed using SPSS 12.0 for Windows (SPSS, Inc, Chicago, IL, USA), with an alpha of 0.05 used to denote statistical significance.

Results

The single MANOVA shows a significant main effect for group ($P < 0.001$).

Physical characteristics

There were no significant differences amongst groups for age, height, %BF, and all segmental lengths (Table 1).

Baseball players had greater weight, body mass index (BMI), and LBM compared to tennis players.

Segmental MV characteristics

There was no significant difference amongst groups for the MV of the right thigh, but there were significant group differences in the other segments ($P < 0.05$; Table 2). Baseball players had greater MVs of the right and left forearms than other players and greater MVs of the left upper arm, left thigh, and right and left lower legs compared to tennis players. Lacrosse players had a greater MV of the right upper arm than soccer players and greater MVs of the left upper arm and right and left lower legs compared to tennis players.

There were no significant differences amongst groups for the ratio of the dominant-to-nondominant MV in the lower legs, the ratio of the proximal-to-distal MV in the right and left legs, and the ratio of the upper-to-lower MV in the left limbs (Table 2). In contrast, tennis players had remarkably greater ratio of the dominant-to-nondominant MV in the upper arms (12.54% ± 5.88%) and forearms (10.38% ± 4.35%) compared to other players. Tennis and
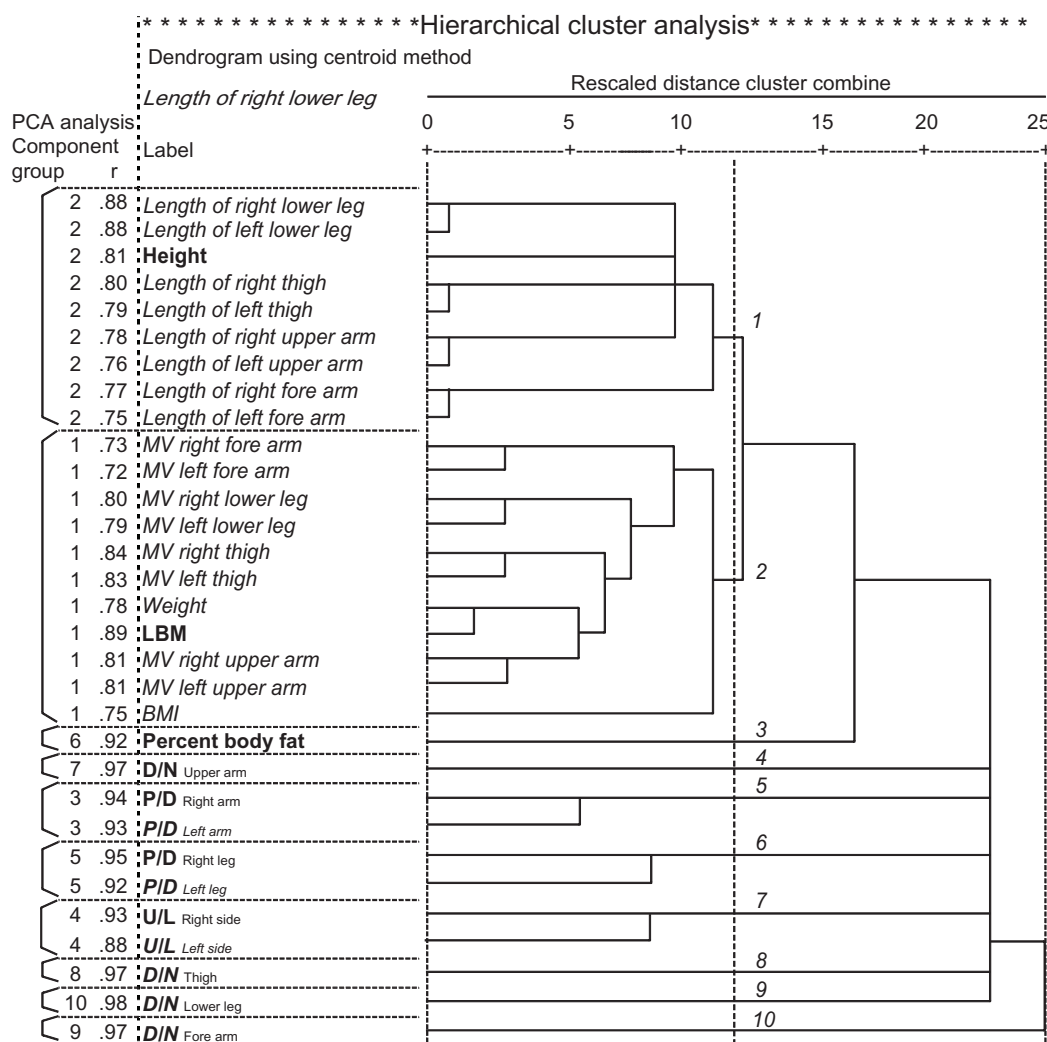
Figure 2 Dendrogram of the cluster analysis.

Notes: The dendrogram does not plot actual distances but rescales them to numbers between 0 and 25. The left side of the figure shows factor numbers and the factor loading obtained from the factor analysis. All variables in the same cluster have high factor loading for the same factor. The variables in bold were used for the discriminant analysis.

Abbreviations: BMI, body mass index; D/N, the ratio of dominant-to-nondominant limbs in the upper arms, forearms, thighs, and lower legs; L, length; LBM, lean body mass; MV, muscle volume; PCA, principal component analysis; P/D, the ratio of proximal-to-distal limbs in the right and left arms and legs; U/L, the ratio of upper-to-lower limbs in the right and left sides.

baseball players had a greater ratio of the upper-to-lower MV in the right limbs than soccer players. Soccer players had a greater ratio of the D/N MV in the thighs (4.57% ± 3.93%) compared to baseball players, and lacrosse players had a greater ratio of the P/D limbs MV in their right and left arms compared to all other players.

Reducing redundancy by cluster analysis

The correlation matrix among the 31 variables was submitted to cluster analysis to measure the similarity among variables or clusters based on the squared Euclidean distance after normalization using Z scores, and the variables were clustered based on the centroid method (Figure 2). The data suggested that rescaled distances of more than 12.5 (r = 0.5) indicate no

similarity among variables; there were two major and three minor clusters and five independent variables. The first major cluster contained height and all of the segment lengths. The second major cluster contained weight, BMI, LBM, and all of the segment MVs. The P/D of the right and left arms were combined into a cluster, the P/D of the right and left legs were combined into one cluster, and the U/L of the right and left limbs were combined into another cluster. D/N and %BF in each segment were separated from the other clusters.

When the same correlation matrix was submitted to factor analysis, ten factors were identified with eigenvalues greater than 0.65, and 95.5% of the total variance was accounted for by these ten factors. These ten factors were rotated using the varimax criterion to make the structure easier to understand

(Figure 2). The results indicate that the variables have very high factor loading for each of the ten factors, and that all variables in the same cluster have high factor loading for the same factor.

Height, LBM, %BF, D/N in the upper arms, forearms, thighs, and lower legs, P/D in the right arm and leg, and U/L in the right limbs were selected as representatives of the 31 measurement variables based on the following criteria: (1) one variable was selected from each cluster; (2) one variable was selected among those with high factor loading for the same factor; and (3) one variable was selected among those related to the same physiological system.

Multiple discriminant analysis to quantify variable contributions

Multiple discriminant analysis revealed three significant functions ($P < 0.001$; Table 3). Based on Wilks' lambda values, discriminant function 1 accounted for 43.3% of the variance, discriminant function 2 accounted for 42.1%, and discriminant function 3 accounted for 14.6%. Standardized coefficients represent the relative importance of the variables by quantifying the potential of each variable to discriminate among athletes according to their sport. Unstandardized coefficients allow for the derivation of discriminant scores for each individual. Based on these scores, group membership could be predicted according to the proximity of the respective group centroid values (mean group values).

The first discriminant function described the differences between tennis players and the other groups (group centroids of discriminant function 1: tennis, 2.916; soccer, 0.0095; baseball, −0.3620; lacrosse, −0.4071; Figure 3, Table 3). The

D/N in the upper arms and forearms, and LBM had relatively large standardized coefficients. The second discriminant function described the differences between baseball players and soccer or lacrosse players (group centroids of discriminant function 2: baseball, −0.9767; soccer, 1.003; lacrosse, 1.013; tennis −0.1545). The P/D in the right arm, D/N in the thighs, and U/L in the right limbs had relatively large standardized coefficients. The third discriminant function described the differences between soccer and lacrosse players (group centroids of discriminant function 3: soccer, −1.102; baseball, −0.0278; lacrosse, 0.5985; tennis, 0.2405), and %BF and P/D in the right arm had relatively large standardized coefficients. Approximately 84% of the athletes could be discriminated correctly in this model (Table 4).

When we used four physique variables (height, LBM, BMI, and %BF) in the discriminant analysis, only 49.6% of athletes could be correctly discriminated, and only the first function was significant. However, when we used four muscle-distribution variables (D/N in the upper arm, D/N in the thigh, P/D in the right upper limb, and U/L in the right limb), 66.1% athletes could be correctly discriminated, and all three functions were significant ($P < 0.001$).

Discussion

The %BF was not different among athletes who participated in baseball, soccer, tennis, and lacrosse (10.4%–12.5%). This result agrees with the review by Sinning,[1] who cited studies with similar results (baseball, 12.6%; soccer, 9.5%; tennis, 11.3%; lacrosse, 12.3%), and the %BF was intermediate when compared to long-distance runners (4.7%), gymnasts (6.5%), and defensive linemen of American football (18.2%).

Table 3 Statistical significance and standardized and unstandardized coefficients for the three discriminant functions

	Standardized coefficients			**Unstandardized coefficients**		
	Function 1	**Function 2**	**Function 3**	**Function 1**	**Function 2**	**Function 3**
Height	−0.070	−0.442	0.066	−0.013	−0.082	0.012
LBM	−0.547	0.010	0.338	−0.130	0.002	0.080
Percent body fat	0.076	−0.169	−0.757	0.025	−0.056	−0.251
D/N$_{Upper arm}$	0.579	−0.316	0.216	0.111	−0.061	0.042
D/N$_{Forearm}$	0.651	0.359	0.123	0.137	0.075	0.026
D/N$_{Thigh}$	0.178	0.578	−0.375	0.044	0.143	−0.092
D/N$_{Lower leg}$	0.338	−0.064	−0.108	0.079	−0.015	−0.025
P/D$_{Right arm}$	−0.067	0.900	0.550	−0.476	6.439	3.934
P/D$_{Right leg}$	0.262	−0.354	−0.210	0.946	−1.279	−0.758
U/L$_{Right side}$	0.089	−0.475	0.235	5.155	−27.527	13.607
Constant				5.428	16.436	−10.489

Notes: Function 1: Wilk's Lambda 0.201, Chi-square 171.6, df 30, $P < 0.001$; Function 2: Wilk's Lambda 0.393, Chi-square 99.9, df 18, $P < 0.001$; Function 3: Wilk's Lambda 0.757, Chi-square 29.8, df 8, $P < 0.001$.
Abbreviations: LBM, lean body mass; D/N, the ratio of dominant-to-nondominant limbs in the upper arms, forearms, thighs, and lower legs; P/D, the ratio of proximal-to-distal limbs in the right arms and legs; U/L, the ratio of upper-to-lower limbs on the right sides.
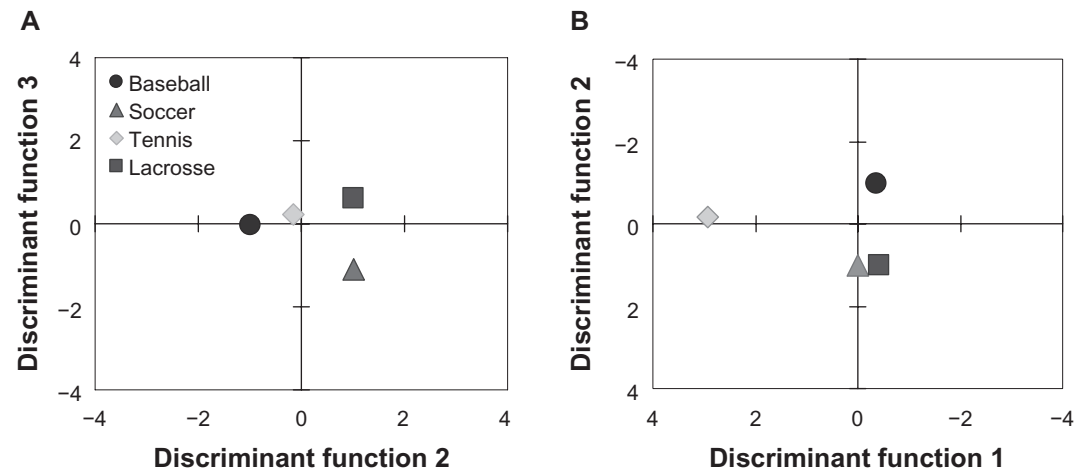
Figure 3 The two-dimensional projection plots of the group centroids.
Notes: The two-dimensional projection plots of the group centroids. (**A**) the two-dimensional projection of discriminant function 2 and 3. (**B**) the two-dimensional projection of discriminant function 1 and 2. ○, baseball; △, soccer; ◇, tennis; □, lacrosse.

When whole-body composition and physical characteristics were used, only 49.6% of the athletes could be discriminated by a significant function. In contrast, when muscle distribution and physique were included, we could correctly discriminate 84.3% of the athletes with three significant functions (Table 4). This was particularly true when the four muscle-distribution variables (D/N in the upper arms, D/N in the thighs, P/D in the right arm, and U/L in the right limbs) were used. With that model, 66.1% of the athletes could be correctly discriminated, and all three functions were significant ($P < 0.001$). The results suggest that the athletes of the four sports have different muscle distributions.

There are several advantages in using the ratio of MV between segments. One strength is the dramatic reduction of multicollinearity in the multivariate analysis. The skeletal muscles of the human body are well adapted for erect bipedalism in a gravity environment and are highly correlated with body weight or size. That body weight, BMI, LBM, and MV of all segments were classified into one cluster indicates that they had high multicollinearity in our study population (Figure 2). In contrast, the MV ratios between segments were distinct from body weight and from each other and were thus identified in the discriminant analysis. Another

strength is related to the sensitivity of SBIA to interindividual differences in muscle structure (eg, muscle shape, pennation angle, fiber composition, and intra- and extracellular water distribution). The MV ratio probably reduces errors arising from these characteristics as they are likely to be similar in the numerator and denominator.

The ratio of the distal to proximal muscle mass in the upper arms has not been well examined. Recently, Holzbaur et al analyzed upper-limb MV in ten young participants with varied body size and indicated that the MV of each limb strongly correlated with total MV. They stated that the mean volume fraction was sufficient to scale all upper limb muscles of a typical individual with a different total MV. In contrast, we found significant differences in the ratio of the distal to proximal muscle mass among athletes from the different ball sports. We examined well trained athletes in ball sports, whereas Holzbaur et al examined only healthy men and women who did not participate in any special sports. These results suggest that sports-specific repetition during practice produces a body-specific muscle distribution that differs from the normal muscle distribution. It is well known that the molecular composition including muscle changes with respect to the type and duration of exercise.[22–24] Sanchis-Moysi et al[25–28] reported that tennis participation is associated with increased muscle volumes in dominant compared to the nondominant arm, likely due to selectively hypertrophy of the loaded muscles. Sports-specific repetition produces selectively hypertrophy as well as selective adaptation of molecular composition in skeletal muscles.

Lacrosse players had significant D/N differences in the upper arm, but no differences in the forearm, thigh, and lower leg. Lacrosse players also had greater ratio of the P/D

Table 4 Classification for all significant discriminant functions

Groups	n	Predicted group membership, n (%)			
		1	2	3	4
1. Baseball	52	48 (92.3)	0 (0.0)	1 (1.9)	3 (5.8)
2. Soccer	19	3 (15.8)	12 (63.2)	1 (5.3)	3 (15.8)
3. Tennis	11	0 (0.0)	0 (0.0)	11 (100.0)	0 (0.0)
4. Lacrosse	33	4 (12.1)	3 (9.1)	0 (0.0)	26 (78.8)

Note: Percent of correctly classified cases: 84.3% ($P < 0.05$).

MV in the arms compared to baseball and tennis players. Despite the dramatic worldwide increase in lacrosse, only a few studies have examined the physical characteristics of male lacrosse players.[29,30] Although recommendations concerning resistance training for male lacrosse players have been reported,[31] there is a lack of objective experimental data about their muscle mass and strength characteristics. Lacrosse requires catching, passing, and shooting with a crosse carried in both arms, but does not require directly hitting a high-speed ball. Therefore, compared to the upper arms, the hypertrophy of muscles in the forearms developed during practice is predicted to be relatively smaller; however, it is unknown if greater forearm strength is necessary for accuracy and velocity during passing and shooting. Further studies are required to establish objective recommendations about strength training for male lacrosse players.

Baseball players had significant D/N characteristics in their upper arms. They, however, did not have significant D/N characteristics in volumes of their forearm, thigh, or lower leg muscles. A previous study also reported a significantly larger MV of the deltoid muscle on the dominant side of baseball players,[32] but another study reported no significant difference in forearm muscle strength.[33] A possible explanation for the difference may be that batting uses both hands, and the large impact and high-power output of muscle contraction is evoked in both forearm muscles.

Tennis, baseball, and lacrosse athletes had a significantly larger MV in their dominant upper arm than in their nondominant upper arm; however, tennis athletes had the largest difference (12.5%) between their dominant and nondominant upper-arm MVs compared to the other athletes. Furthermore, only tennis athletes had a significantly larger difference (10.4%) between their dominant and nondominant forearm MVs.[34–38] In soccer, upper body dominance may not be expected due to the demands of the sport, because upper body muscles are just required during running in the soccer match. However, in baseball and lacrosse, the upper body is used extensively; in the two sports, the bat or stick, respectively, is held with both hands. Tennis players could be discriminated from the other athletes mainly by the larger ratio of D/N MV in the upper arm and forearm.

Soccer athletes had significantly larger MV (4.57%) in the dominant thigh than in the nondominant thigh in the present study. Although we are unaware of a study that has examined MV differences between dominant and nondominant thigh muscles, various studies have examined their strength differences.[9,39–43] Some of these studies reported a significant strength difference between dominant and nondominant thigh

muscles,[39–41] whereas others reported no difference.[42,43] One reason for the discrepancy may be the selection criteria for footedness, because footedness is not as easy to distinguish as handedness.[13,14] We used Chapman's multi-item foot-preference test to select only right-pure or right-strong footed athletes.[14,15] Some previous studies[44,45] defined the dominant leg as just the kicking leg, which could have influenced the results of those previous studies. Another possible reason may be the relatively small ($<$5%) difference between dominant and nondominant thigh MVs compared to the larger ($>$10%) difference between dominant and nondominant arm MVs in tennis players. In the previous studies[44,45] that reported no significant differences, small tendencies for differences were observed (2%–7%) that could easily be masked by measurement error or a small sample size. This is particularly true with muscle strength, which can be affected by psychological factors or measurement order. Our results suggest that soccer players, who had strong footedness, had a moderate but significant difference between dominant and nondominant thigh MVs.

SBIA can be used to estimate segmental MV as well as whole-body composition.[3,8–10] However, BIA depends on several assumptions to estimate body composition or regional MV, and the accuracy of BIA remains a subject of debate, especially the frequently used single-frequency BIA (50 kHz), which is subject to error due to changes in extracellular water (ECW) balance.[44] Therefore, measurement conditions are vitally important. In our research, we minimized the effect of altered fluid balance, exercise, food, temperature, postural change, orthopedic disorders, acute disease, and competitive season. In addition, we used equations validated for college athletes to estimate whole-body composition and segmental MV,[9,10] thus maximizing the reliability of %BF, LBM, and segmental MV measurements.

A limitation of our study is that we did not examine kinetics (eg, using electromyography or inverse dynamics based on motion analysis) regarding how the athletes use their muscles during sports-specific movements. In addition, it remains uncertain whether motor-skill training or strength training influences sports-specific muscle distribution. Previous studies suggest that regular participation in competitive sports programs during early adolescence contributes to increased muscularity and strength capability.[45–47] If we consider strength training as a practice component of a particular sport, we could conclude that muscle distribution is induced by practice and games. Furthermore, studies comparing expertise and career as well as longitudinal studies are among the necessary future investigations. Since this study

only involved Japanese subjects, the results in this study may be only generalizable to Japanese or general Asian populations. Thus, further studies on other ethnicities are needed.

For error analysis, although the potential measurement error of impedance is relatively small (up to 1%), the potential measurement error of segment length is large (up to 2%). The impact of measurement error of segment length on calculating muscle volume is up to 4%, and the impact on calculating MV ratio is up to 5.7%. It should be noted that the measuring accuracy of segmental length is fundamental to calculate MV and MV ratio.

Whole-body BIA is affected by %BF.[6] In contrast, the effect of the distribution of fat on the estimation of segmental MV by SBIA is unknown.[11,48] The distribution of body fat may vary depending on sports participation.[49] It is important to examine fat and muscle distribution simultaneously. Further studies are needed.

We estimated muscle volume by SBIA, which is a secondary method to estimate MV and inferior to MRI or CT. The previous studies that examined the validity of SBIA to estimate MV with MRI[10,17,50] had important limitations, including (1) the accuracy estimations of MV would vary depending on subject samples; and (2) smaller islands of adipose tissue within the skeletal muscle bundle were not fully excluded, and so the skeletal volume might be overestimated.[51] 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 present study. Sanchis-Moysi et al[25–28] examined the segmental MVs in professional and prepubescent tennis players and soccer players recently. 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 show its feasibility in telling the difference among baseball, soccer, tennis and lacrosse players, and further suggest that these players have adapted their physique to their specific sports. The SBIA could be a useful, affordable, and fast tool for identifying talents for specific sports.

Conclusion

We identified inter-sport differences in muscle distribution in baseball, soccer, lacrosse, and tennis players using SBIA. When comparing lacrosse, baseball, and tennis players, it was evident that the impact of ball hitting during practice and games promotes muscle hypertrophy in the forearm.

We also demonstrated that the use of the MV ratio between segments can prevent the multicollinearity problem encountered in multivariate analysis. The SBIA, a simple and rapid assessment instrument, can be applied to distinguish ball game athletes based on their specific muscle distribution and might be useful for assessment and target-setting in training and sport rehabilitation.

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