Volume 5, No. 2, 2026, pp. 853-866

HJSE
Holistic Journal of Sport Education
E-ISSN: 2809-9974
https://journal.uniga.ac.id/index.php/penjas
DOI:10.52434/penjas.v5i2.44375

ANTHROPOMETRIC AND BODY COMPOSITION DETERMINANTS OF PHYSICAL PERFORMANCE IN ADOLESCENT VOLLEYBALL ATHLETES: A CROSS-SECTIONAL STUDY

Muchamad Rizki Sentani[1-ABCDE], Syifa F. Syihab[1-ABD], Isti Kumalasari[1-BCD], Muhammad Ivan Muftahul Aziz[2-BC], Hung-Chin Huang[3-BC]
[1]Faculty of Sports and Health Education, Universitas Pendidikan Indonesia, Bandung, Indonesia
[2]Universitas Negeri Makassar, Makassar, Indonesia
[3]National Kaohsiung University of Science and Technology, Kaohsiung, Taiwan

Keywords:
anthropometry, body composition, fat-free mass, physical fitness, adolescent athletes, volleyball,

Abstract
Volleyball performance depends on a complex interaction between anthropometric characteristics, body composition, and physical fitness qualities. Identifying which characteristics most strongly predict physical performance can support talent identification and training prescription in youth volleyball. This study examined which anthropometric and body composition variables most strongly and consistently predict physical performance in adolescent volleyball athletes. A cross-sectional correlational design was used with 69 volleyball athletes (47 boys, 22 girls; age 13–19 years). Anthropometric variables (height, weight, BMI, body fat percentage, muscle mass percentage, fat-free mass) and body composition variables (five skinfolds, two bone breadths, arm and calf circumference) were measured alongside ten physical performance tests spanning balance, strength, power, speed, agility, and cardiorespiratory endurance. Data were analyzed with Spearman correlation and backward-elimination multiple linear regression. Fat-free mass (FFM) and body fat percentage (BF%) were the most consistent significant predictors, appearing in eight of ten regression models ($R^2 = 0.217$–0.648, $p<0.001$ for all but stand-stroke balance and push-up). FFM was positively associated with strength, power, agility, and cardiorespiratory endurance, whereas BF% was negatively associated with power, speed, agility, and endurance. Muscle mass percentage predicted sprint speed and change-of-direction ability. Localized skinfold thickness and bone breadth showed weak, mostly non-significant associations with performance. Male athletes outperformed female athletes on nearly all fitness tests except push-up. Global body composition indices particularly fat-free mass and body fat percentage rather than raw anthropometric size or localized skinfold/bone measures, are key determinants of physical performance in adolescent volleyball athletes, offering practical, low-cost targets for talent identification and training prescription.

Received: April 7, 2026 **Accepted:** June 20, 2026 **Published:** June 29, 20266

Authors' contribution:
A - Conception and design of the study; B - Acquisition of data; C - Analysis and interpretation of data; D - Manuscript preparation; E - Obtaining funding

Correspondence:
Muchamad Rizki Sentani

Email: rsentani@upi.edu

INTRODUCTION

Volleyball is a fast, intermittent team sport combining short bursts of maximal effort jumping, spiking, and blocking with brief recovery periods, requiring a well-developed combination of muscular power, speed, agility, and anaerobic-aerobic conditioning (Podstawski et al., 2025). Because the sport places simultaneous demands on strength, explosive power, and coordinated movement, coaches and sport scientists have long sought the anthropometric and body composition profile that best distinguishes higher- from lower-performing players, both for early talent identification and for guiding individualized training prescription (Albaladejo-Saura, Vaquero-Cristóbal, García-Roca, & Esparza-Ros, 2023; Milić et al., 2017).

Accumulating evidence indicates that anthropometric and body composition characteristics are closely linked to volleyball-specific motor performance. Milić et al. (2017) reported that playing position and competitive level in young female volleyball players could be differentiated by body height, body mass, and body composition profile. Similarly, Tessutti et al. (2019) found that height and bone mass distinguished players by age group and position, although fitness test performance itself did not differ strongly by position within the same age category. Body composition also appears trainable in the short term: Podstawski et al. (2025) showed that a one-week intensive training camp reduced body fat mass and increased fat-free mass in adolescent volleyball players, even though most motor test results were unchanged over that short period, suggesting body composition and motor performance do not always change in lockstep.

Body fat, in particular, has repeatedly been implicated as a negative correlate of volleyball performance. A recent systematic review and meta-analysis pooling data from 63 studies and more than 2,600 players established sex-specific normative body fat values for competitive volleyball players and highlighted body fat as a variable of practical interest for monitoring athlete readiness (Matłosz et al., 2023). Sex-specific analyses in elite adolescent players further showed that fat mass index correlated positively with the time cost of change-of-direction and agility tasks in male athletes, meaning greater fatness was associated with poorer agility performance (Koźlenia, Popowczak, Horička, Šimonek, & Domaradzki, 2024). Consistent with this, Oliveira, Marinho, Jacinto, Sampaio, and Morais (2025) reported that although anthropometric size and sprint speed increased with age across youth female volleyball groups, lower-limb strength, power, and dynamic balance did not automatically improve in parallel, and change-of-direction deficit was best predicted by reactive strength (drop-jump height) rather than by size alone underscoring that raw body size is an incomplete predictor of performance without considering body composition and neuromuscular qualities together.

Fat-free mass and lean tissue, conversely, have been positively linked to explosive and high-velocity actions. In elite male volleyball players, Challoumas and Artemiou (2018) found that a higher percentage of lean mass was associated with faster spike speed alongside vertical jump height, underscoring the role of lean body mass in attacking performance. Maturity status compounds these relationships: Akinci and İnce (2025) showed that more biologically mature female volleyball players produced greater force but lower velocity in force-velocity profiling, yet the correlation between force-velocity parameters and spike-jump height remained weak, indicating that spike-jump performance is multifactorial and not explained by force or maturation status alone. Biological maturation and skeletal robustness similarly influence selection for representative volleyball teams: adolescent boys with more advanced bone-related anthropometric values and better power-related fitness scores were more likely to be selected for national-level competition, although fitness performance itself was the more universal predictor across both sexes (Albaladejo-Saura, González-Gálvez, Vaquero-Cristóbal, García-Roca, & Esparza-Ros, 2024; Albaladejo-Saura, Vaquero-Cristóbal, García-Roca, & Esparza-Ros, 2022). Likewise, when comparing more- and less-successful adolescent players, Albaladejo-Saura, Vaquero-Cristóbal, García-Roca, and Esparza-Ros (2023) found that more successful U14 and U16 players showed more advanced biological maturation, higher bone- and muscle-related anthropometric values, lower adiposity, and superior strength/power test results again pointing toward body composition, rather than height or mass alone, as the more discriminating characteristic.

Training studies reinforce the causal plausibility of this relationship. Plyometric training performed alongside regular volleyball training has been shown to improve physical qualities such as jump height, sprint speed, and stretch-shortening cycle function in youth players, with the magnitude of benefit sometimes moderated by maturity status or training frequency (Hernandez-Martinez et al., 2023; Sylvester, Lehnert, Hanzlíková, & Krejčí, 2024). Comparable conditioning research in junior female players found that a 3-month skill-based or plyometric program improved multiple fitness parameters concurrently (Idrizovic et al., 2018), while in youth male players, lower-body power measured under laboratory conditions correlated strongly with field measures of jump, sprint, and change-of-direction performance (Ben Ayed, Hammami, Latiri, & Ben Saad, 2026), reinforcing that muscular power a quality closely tied to fat-free mass underlies several performance components simultaneously. External and health-related disruptions can also affect the performance–body composition relationship: Orscelik, Kaya, Karaaslan, Agiragac, and Ceyhan (2022) observed that adolescent and young-adult volleyball players' vertical jump performance did not necessarily worsen after COVID-19 infection, suggesting that performance can be resilient to short-term physiological insult, possibly buffered by training status and body composition maintained prior to illness. Nutritional practices, which directly shape body composition, are also a relevant background factor, as supplement use is not uncommon even among adolescent-aged competitive athletes (Sousa, Fernandes, Moreira, & Teixeira, 2013).

Despite this body of evidence, most existing studies have examined anthropometry, body composition, and physical performance as separate pairwise relationships, or have focused on a narrow age band, a single sex, or a single performance quality. Comprehensive studies simultaneously modelling a wide anthropometric and body composition profile against a full physical fitness battery spanning balance, strength, power, speed, agility, and cardiorespiratory endurance in a single sample of adolescent volleyball athletes of both sexes remain comparatively scarce. In addition, the age boundaries of "adolescence" used across the literature are not fully consistent; contemporary definitions place early adolescence at approximately 10–14 years, with later stages extending toward the early twenties (Sawyer, Azzopardi, Wickremarathne, & Patton, 2018), a distinction that matters when interpreting studies, like the present one, that include a broad age range of youth athletes.

The present study therefore aimed to (1) describe the anthropometric, body composition, and physical performance profile of a sample of adolescent volleyball athletes, and (2) identify, through correlation and multiple regression analysis, which anthropometric and body composition variables most strongly and consistently predict performance across ten physical fitness components. It was hypothesized that global body composition indices fat-free mass and body fat percentage would emerge as more consistent predictors of performance than raw anthropometric size (height, weight) or localized skinfold and bone-breadth measures.

METHODS

Study Design

This study used a cross-sectional, correlational-explanatory design, in which anthropometric, body composition, and physical performance variables were measured concurrently in a single testing session per athlete, without experimental manipulation of any variable.

Participants

Sixty-nine volleyball athletes (47 boys, 22 girls) participated using a total sampling technique from sekolah bola voli generasi Indonesia terpadu. Age ranged from 13 to 19 years (M = 15.6, SD = 2.0 years). Using WHO-consistent adolescent age-band conventions (Sawyer et al., 2018), 26 athletes (37.7%) fell within the early-adolescent band (10–14 years) matching the study's original target population, while the remainder were in middle adolescence (15–17 years, n = 31) or late adolescence (18–19 years, n = 12). Mean playing experience was 4.2 ± 2.4 years. All procedures complied with the ethical standards for research involving human participants; in Komisi Etik Penelitian Kesehatan (KEPK) FK UMS with No. 6410/B.2/KEPK-FKUMS/VI/2026.

Measures

Anthropometry and body composition. Height (cm) and body mass (kg) were measured with a stadiometer and digital scale, respectively, and used to calculate body mass index (BMI, kg/m²). Body fat percentage (BF%), muscle mass percentage (MM%), and fat-free mass (FFM, kg) were estimated using bioelectrical impedance analysis, a field method whose accuracy in youth populations has been cross-validated against skinfold and dual-energy X-ray absorptiometry reference methods (González-Ruíz et al., 2018). Body composition was further characterized using five skinfold thicknesses (triceps, biceps, subscapular, suprailiac, medial calf; skinfold caliper), two bone breadths (humerus, femur; sliding caliper), and two circumferences (relaxed upper arm and calf; measuring tape).

Physical performance. Ten physical performance tests were administered, representing six components of physical fitness: balance (stork-stand test), muscular strength (back-leg dynamometer), lower-body power (vertical jump, standing broad jump), upper-body power (medicine-ball throw), muscular endurance (push-up), speed (sprint), agility/change of direction (hurdle jump, side-step test), and cardiorespiratory endurance (multistage fitness/beep test, estimated VO_2max).

Statistical Analysis

Data were screened for normality using the Shapiro-Wilk test. Because the majority of variables (56.0%) departed from a normal distribution, Spearman's rank-order correlation was used to screen for significant bivariate associations ($p<0.05$) between each anthropometric/body composition variable and each performance variable. Variables significantly correlated with a given performance outcome were then entered as candidate predictors into a multiple linear regression model using backward elimination, in which the least-significant predictor was removed iteratively until only significant predictors ($p<0.05$) remained. Standardized regression coefficients (β) were used to identify the dominant predictor within each final model, and variance inflation factors (VIF) were inspected to rule out problematic multicollinearity (VIF > 10). Independent-samples t-tests (for normally distributed variables) or Mann-Whitney U tests (for non-normally distributed variables) compared male and female athletes on all measures. Analyses were performed in Python (SciPy and statsmodels libraries), reproducing the descriptive, correlation, and general linear model output conventionally obtained from SPSS; statistical significance was set at $p<0.05$.

RESULTS

Sample Characteristics

Table 1 summarizes the age-category and sex distribution of the 69 athletes.

Table 1.
Sample characteristics (N = 69)

Characteristic	n	%
Sex		
Male	47	68.1
Female	22	31.9
Age category (WHO)		
Early adolescence (10–14 y)	26	37.7
Middle adolescence (15–17 y)	31	44.9
Late adolescence (18–19 y)	12	17.4

Note. Age category boundaries follow adolescent age-band conventions consistent with Sawyer et al. (2018). Mean age = 15.6 ± 2.0 years; mean playing experience = 4.2 ± 2.4 years.

Descriptive Statistics

Mean height was 161.9 ± 9.1 cm and mean body mass 55.6 ± 10.8 kg, yielding a mean BMI of 21.2 ± 3.7 kg/m². Mean body fat percentage was 19.0 ± 7.7%, mean muscle mass percentage was 33.5 ± 5.6%, and mean fat-free mass was 44.7 ± 7.7 kg (Table 2).

Physical performance scores showed considerable spread (e.g., vertical jump 25–82 cm, M = 52.8 ± 12.2 cm; estimated VO_2max 19–50 $mL \cdot kg^{-1} \cdot min^{-1}$, M = 33.3 ± 8.1), consistent with the broad age and competitive range of the sample.

Table 2.
Descriptive statistics for anthropometric, body composition, and physical performance variables

Variable	N	Mean ± SD	Min–Max	Unit
Height	69	161.9 ± 9.1	143.5–182.0	cm
Body mass	69	55.6 ± 10.8	30.8–81.3	kg
BMI	69	21.2 ± 3.7	14.2–33.3	kg/m²
Body fat (BF%)	69	19.0 ± 7.7	7.0–38.5	%
Muscle mass (MM%)	68	33.5 ± 5.6	21.6–41.6	%
Fat-free mass (FFM)	69	44.7 ± 7.7	23.8–61.7	kg
Triceps skinfold	65	8.6 ± 3.6	3.0–28.0	mm
Biceps skinfold	65	6.6 ± 3.8	3.0–22.0	mm
Subscapular skinfold	65	8.1 ± 3.4	3.0–23.0	mm
Suprailiac skinfold	65	8.2 ± 3.5	4.0–21.0	mm
Medial calf skinfold	65	10.6 ± 4.4	3.9–24.0	mm
Humerus breadth	65	5.4 ± 0.6	4.3–6.7	cm
Femur breadth	65	7.8 ± 1.2	3.2–10.4	cm
Arm circumference	65	26.8 ± 3.3	19.0–36.0	cm
Calf circumference	65	33.0 ± 4.3	21.0–41.0	cm
Stork-stand balance	57	9.4 ± 7.1	3.0–40.5	s
Back-leg dynamometer	57	67.0 ± 24.9	22.5–120.0	kg
Vertical jump	57	52.8 ± 12.2	25.0–82.0	cm
Medicine-ball throw	57	432.3 ± 101.2	237.0–703.0	cm
Standing broad jump	57	201.5 ± 33.1	128.0–260.0	cm
Push-up	57	39.8 ± 8.6	26.0–62.0	reps
Sprint	57	4.1 ± 0.6	3.0–5.4	s
Hurdle jump	57	41.1 ± 12.3	9.0–66.0	reps
Side-step	57	31.8 ± 4.9	12.0–40.0	reps
Beep test (VO_2max, est.)	57	33.3 ± 8.1	19.0–50.0	mL/kg/min

Note. N varies because 12 athletes did not complete the full fitness battery and one athlete had a missing MM% reading.

Correlation Analysis

Height, body fat percentage, muscle mass percentage, and fat-free mass showed significant correlations ($p<0.05$) with most performance variables (Table 3). Body fat percentage was consistently and negatively correlated with power, speed, agility, and cardiorespiratory endurance (r = -0.34 to -0.62), while fat-free mass, height, and muscle mass percentage were positively correlated with the same qualities (r = 0.30 to 0.72). In contrast, localized skinfold thickness and bone-breadth variables were largely uncorrelated with performance; only arm and calf circumference showed significant associations, with strength and upper-body power (back-leg dynamometer and medicine-ball throw, r = 0.34–0.45).

Table 3.
Spearman correlation coefficients (r) between anthropometric/body composition variables and physical performance

Predictor	Stand-stroke	Back-leg dyn.	Vertical jump	Medicine ball	Broad jump
Height	0.09	0.68**	0.61**	0.71**	0.68**
Body mass	-0.05	0.49**	0.22	0.54**	0.32*
BMI	-0.10	0.16	-0.15	0.18	-0.07
Body fat (BF%)	-0.34*	-0.41**	-0.62**	-0.40**	-0.55**
Muscle mass (MM%)	0.31*	0.24	0.45**	0.22	0.46**
Fat-free mass (FFM)	0.07	0.70**	0.53**	0.72**	0.61**
Skinfolds (5 sites)[a]	ns	ns	ns	ns	ns
Bone breadths (2 sites)[b]	ns	ns	ns	ns	ns
Arm circumference	-0.10	0.45**	0.18	0.45**	0.23
Calf circumference	-0.04	0.42**	0.05	0.34*	0.12

Predictor	Push-up	Sprint	Hurdle jump	Side-step	Beep test
Height	-0.07	-0.43**	0.36**	0.37**	0.45**
Body mass	0.10	-0.16	0.11	0.04	0.10
BMI	0.23	0.09	-0.05	-0.17	-0.16
Body fat (BF%)	0.07	0.54**	-0.45**	-0.40**	-0.58**
Muscle mass (MM%)	-0.12	-0.49**	0.32*	0.36**	0.43**
Fat-free mass (FFM)	0.04	-0.39**	0.32*	0.24	0.40**
Skinfolds (5 sites)[a]	0.30* (suprail.)	ns	ns	ns	ns
Bone breadths (2 sites)[b]	ns	ns	ns	ns	ns
Arm circumference	0.12	0.05	0.05	-0.02	0.05
Calf circumference	0.07	0.08	-0.06	0.00	0.07

*Note. *p<0.05, **p<0.01. [a]Triceps, biceps, subscapular, suprailiac, medial-calf skinfolds (individual r values in text where significant). [b]Humerus and femur breadth. "ns" = no significant correlation (p≥0.05) for any test in that row unless otherwise noted. Full correlation matrix available from the corresponding author.*

Regression Analysis

Multiple regression models were significant ($p<0.05$) for eight of the ten performance variables (Table 4); models for stand-stroke balance and push-up were not statistically significant. Across the eight significant models, fat-free mass was retained as a significant predictor in seven models and was the dominant predictor (largest standardized β) in three (back-leg dynamometer, medicine-ball throw, broad jump); body fat percentage was retained in five models and was dominant in three (vertical jump, hurdle jump, beep test/VO_2max); and muscle mass percentage was dominant in two models (sprint, side-step). Explained variance (R^2) ranged from 0.217 (side-step) to 0.648

(broad jump). Body mass entered two models (back-leg dynamometer, broad jump) with a negative coefficient once fat-free mass was accounted for; variance inflation factors of 4.95–5.75 in these two models indicated moderate collinearity between body mass and fat-free mass, warranting joint rather than separate interpretation of these two coefficients.

Table 4.
Final backward-elimination multiple regression models predicting physical performance

Outcome	Predictor	B (SE)	β	p	R^2	F	Model p
Back-leg dynamometer (kg)	Body mass	-1.68 (0.55)	-0.68	0.003	.568	34.15	<.001
	Fat-free mass	4.03 (0.67)	1.31	<.001			
Vertical jump (cm)	Body fat %	-1.14 (0.17)	-0.61	<.001	.568	34.88	<.001
	Fat-free mass	0.57 (0.14)	0.37	<.001			
Medicine-ball throw (cm)	Body fat %	-3.22 (1.38)	-0.20	.024	.634	44.98	<.001
	Fat-free mass	9.07 (1.06)	0.73	<.001			
Broad jump (cm)	Body mass	-4.06 (0.58)	-1.27	<.001	.648	48.83	<.001
	Fat-free mass	7.03 (0.75)	1.70	<.001			
Sprint (s)	Muscle mass %	-0.06 (0.01)	-0.56	<.001	.440	20.82	<.001
	Fat-free mass	-0.02 (0.01)	-0.27	.013			
Hurdle jump (reps)	Body fat %	-0.89 (0.22)	-0.47	<.001	.303	11.53	<.001
	Fat-free mass	0.37 (0.18)	0.24	.044			
Side-step (reps)	Muscle mass %	0.46 (0.12)	0.47	<.001	.217	14.99	<.001
Beep test (VO_2max, est.)	Body fat %	-0.67 (0.13)	-0.54	<.001	.421	19.28	<.001
	Fat-free mass	0.31 (0.11)	0.30	.006			
Stand-stroke balance (s)[a]	Body fat %	-0.23 (0.15)	-0.21	.117	.045	2.54	.117
Push-up (reps)[a]	Suprailiac skinfold	0.47 (0.34)	0.19	.167	.036	1.96	.167

Note. B (SE) = unstandardized coefficient (standard error); β = standardized coefficient. [a]Model not statistically significant. VIF = 4.95–5.75 for body mass/fat-free mass in the back-leg dynamometer and broad-jump models (all other models VIF ≤ 1.04).

Sex Differences

Male athletes scored significantly higher than female athletes on nearly all physical performance tests ($p<0.05$; Table 5), including back-leg dynamometer, vertical jump, medicine-ball throw, broad jump, sprint (lower time = better), hurdle jump, side-step, and beep test; only push-up did not differ significantly between sexes. These differences paralleled significantly higher fat-free mass and muscle mass percentage, and significantly lower body fat percentage, in male athletes.

Table 5.
Sex differences in body composition and physical performance

Variable	**Male (n=47)**	**Female (n=22)**	**p**
Body fat (%)	14.6 ± 3.9	28.5 ± 4.6	**<.001**
Muscle mass (%)	37.1 ± 2.3	26.1 ± 2.1	**<.001**
Fat-free mass (kg)	46.0 ± 8.2	41.8 ± 5.8	**.033**
Back-leg dynamometer (kg)	72.9 ± 24.4	44.6 ± 9.5	**<.001**
Vertical jump (cm)	56.5 ± 10.6	38.9 ± 6.3	**<.001**
Medicine-ball throw (cm)	453.4 ± 100.5	353.1 ± 54.9	**<.001**
Broad jump (cm)	212.1 ± 26.9	161.8 ± 21.9	**<.001**
Push-up (reps)	39.4 ± 9.4	41.0 ± 3.8	.199
Sprint (s)	3.9 ± 0.4	4.8 ± 0.4	**<.001**
Hurdle jump (reps)	44.1 ± 11.3	29.8 ± 9.3	**<.001**
Side-step (reps)	33.0 ± 3.3	27.2 ± 7.0	**.015**
Beep test (VO_2max, est.)	35.8 ± 6.9	23.8 ± 4.3	**<.001**

Note. Values are M ± SD. p values from independent-samples t-test or Mann-Whitney U test as appropriate to each variable's distribution.

DISCUSSION

This study examined which anthropometric and body composition variables best predict physical performance across a comprehensive fitness battery in adolescent volleyball athletes. The central finding that fat-free mass and body fat percentage, rather than raw body size or localized skinfold/bone measures, were the most consistent predictors both extends and is consistent with prior volleyball research.

The dominance of fat-free mass as a positive predictor of strength, power, agility, and cardiorespiratory endurance aligns with Challoumas and Artemiou (2018), who linked a higher percentage of lean mass to faster spike speed in elite male volleyball players, and with training studies in which plyometric conditioning which preferentially builds fat-free mass and neuromuscular power improved jump, sprint, and stretch-shortening cycle performance in youth players (Hernandez-Martinez et al., 2023; Idrizovic et al., 2018; Sylvester et al., 2024). It is also consistent with Ben Ayed et al. (2026), who found that laboratory-measured lower-body power correlated strongly with field tests of jump, sprint, and change-of-direction performance in youth volleyball players, since fat-free mass is the tissue substrate for muscular power production.

The negative association between body fat percentage and power, speed, agility, and cardiorespiratory performance mirrors Koźlenia et al. (2024), who reported that a higher fat mass index was associated with slower change-of-direction and agility performance in male adolescent volleyball players, and is consistent with the broader normative pattern described by Matłosz et al. (2023), whose meta-analysis of more than 2,600 competitive volleyball players established that body fat differs meaningfully by sex and competitive level and is a variable worth monitoring in athlete development.

Mechanistically, excess adiposity increases the mass that must be accelerated or decelerated during jumping, sprinting, and directional changes without contributing to force production, which plausibly explains why BF% rather than BMI or body mass, which do not distinguish fat from lean tissue emerged as the more informative predictor in the present study. Indeed, BMI was not a significant correlate of any performance variable in this sample, reinforcing the point made by Oliveira et al. (2025) that raw anthropometric size is an incomplete predictor of performance without accounting for body composition and neuromuscular qualities.

The role of muscle mass percentage as the dominant predictor of sprint speed and side-step agility is broadly consistent with the literature linking lean tissue to speed and change-of-direction performance (Challoumas & Artemiou, 2018; Koźlenia et al., 2024) and suggests that, beyond overall fat-free mass, the specific proportion of muscle may be relevant to velocity-dependent qualities. That body mass entered two models (back-leg dynamometer, broad jump) with a negative coefficient once fat-free mass was controlled is readily interpretable: for a given fat-free mass, a higher body mass implies a higher fat mass, which consistent with the BF% findings above would be expected to impair relative power output. The accompanying moderate variance inflation factors (4.95–5.75) reflect the mathematical relationship between body mass and fat-free mass (the latter being a component of the former) and indicate these two coefficients should be interpreted jointly rather than in isolation.

That localized skinfold thickness and bone breadth measures were largely unrelated to performance in contrast to the global indices FFM and BF% echoes Tessutti et al. (2019), who found playing-position and age-group differences in bone mass and height but not in fitness-test performance within the same age category, and is broadly consistent with the idea that composite, whole-body indices capture performance-relevant variance that single-site anthropometric measures do not. The exception in the present data arm and calf circumference predicting strength and upper-body power may reflect these circumferences partly indexing appendicular muscle mass, a plausible proxy for the muscular tissue directly engaged in the back-leg dynamometer and medicine-ball throw tasks.

Two performance measures stand-stroke balance and push-up were not significantly predicted by any anthropometric or body composition variable. This is consistent with Akinci and İnce (2025), who found only weak correlations between force-velocity profile parameters and spike-jump height in female volleyball players, concluding that spike-jump performance is multifactorial and not fully explained by force- or maturation-related variables alone; balance and local muscular endurance likely depend similarly on neuromuscular coordination, technique, and motor-learning factors not captured by anthropometry or body composition.

The pronounced sex differences observed here male athletes outperforming female athletes on nearly all fitness tests except push-up, paralleling sex differences in fat-free mass, muscle mass percentage, and body fat percentage are consistent with well-established sex-related differences in body composition and neuromuscular performance in youth and adult volleyball populations (Idrizovic et al., 2018; Tessutti et al., 2019) and reinforce that sex should be treated as an important covariate, rather than ignored, in future modelling of anthropometry-performance relationships in mixed-sex youth samples.

The present findings also intersect with the broader talent-identification literature. Albaladejo-Saura and colleagues, across several studies of adolescent Spanish volleyball players, showed that bone-related anthropometric variables and physical fitness performance particularly power predicted selection for national-level competition (Albaladejo-Saura et al., 2024), that more successful U14/U16 players showed more advanced maturation, greater bone/muscle mass, and lower adiposity together with superior strength/power performance (Albaladejo-Saura, Vaquero-Cristóbal, García-Roca, & Esparza-Ros, 2023), and that biological maturation itself was associated with several anthropometric and fitness variables in adolescent male players (Albaladejo-Saura, Vaquero-Cristóbal, García-Roca, & Esparza-Ros, 2022). Taken together with the present results, this suggests that coaches seeking to identify or develop volleyball talent in early- to late-adolescent athletes may obtain more actionable information from body composition assessment (e.g., low-cost bioelectrical impedance to estimate FFM and BF%) than from height or weight alone, while remaining mindful that maturity status is a potential confounder of any single cross-sectional snapshot (Akinci & İnce, 2025; Podstawski et al., 2025).

Limitations

Several limitations should be considered. First, the wide age range of the sample (13–19 years, spanning WHO-consistent early through late adolescence; Sawyer et al., 2018) means biological maturation which was not directly assessed in this study could partly confound the anthropometry-performance associations reported here; studies using maturity-offset estimation (e.g., Akinci & İnce, 2025) would be a valuable extension. Second, effective sample sizes for the regression analyses ($n = 55–56$) were smaller than the full sample due to missing performance data for a subset of athletes, and the moderate collinearity between body mass and fat-free mass in two models warrants cautious, joint interpretation of those coefficients. Third, this cross-sectional design cannot establish causal or training-related directionality between body composition and performance; controlled training studies (e.g., Hernandez-Martinez et al., 2023; Sylvester et al., 2024) remain necessary to determine whether deliberately altering body composition produces the performance changes implied by the present associations. Finally, nutritional status a further potential determinant of both body composition and performance, and one relevant given that supplement use is not uncommon even among adolescent athletes (Sousa et al., 2013) was not captured in the present dataset and represents a priority for future data collection.

CONCLUSION

In this cross-sectional study of 69 adolescent volleyball athletes, fat-free mass and body fat percentage rather than height, weight, BMI, or localized skinfold/bone measures emerged as the most consistent anthropometric and body composition predictors of physical performance, explaining 21.7–64.8% of variance across eight of ten fitness components. Fat-free mass was positively associated with strength, power, agility, and cardiorespiratory endurance, while body fat percentage was negatively associated with power, speed, agility, and endurance; muscle mass percentage additionally predicted sprint speed and change-of-direction ability. These findings suggest that body composition assessment not simply height and weight should be prioritized in talent-identification and monitoring programs for adolescent volleyball athletes, and that training interventions targeting fat-free mass accrual and body fat reduction may be a productive avenue for performance development in this population. Future research should incorporate biological maturity assessment and longitudinal or training-intervention designs to clarify the directionality of the relationships identified here.

Conflict of Interest

The authors declare no conflict of interest.

Funding

No external funding information was provided for this revision. If funding was received, the authors should replace this statement with the appropriate grant details before submission.

REFERENCES

Akinci, İ., & İnce, İ. (2025). Maturation-dependent variations in force-velocity profiles and relationship with spike jump performance in female volleyball players. *Journal of Musculoskeletal & Neuronal Interactions, 25*(1), 47–55. https://doi.org/10.22540/JMNI-25-047

Albaladejo-Saura, M., González-Gálvez, N., Vaquero-Cristóbal, R., García-Roca, J. A., & Esparza-Ros, F. (2024). Influence of anthropometric and fitness variables on the probability of being selected for competing in the national championship in adolescent volleyball players. *Acta Gymnica, 54*, e2024.003. https://doi.org/10.5507/ag.2024.003

Albaladejo-Saura, M., Vaquero-Cristóbal, R., García-Roca, J. A., & Esparza-Ros, F. (2022). Influence of biological maturation status on selected anthropometric and physical fitness variables in adolescent male volleyball players. *PeerJ, 10*, e13216. https://doi.org/10.7717/peerj.13216

Albaladejo-Saura, M., Vaquero-Cristóbal, R., García-Roca, J. A., & Esparza-Ros, F. (2023). What variables allow the differentiation between more and less successful adolescent volleyball players? *Journal of Human Kinetics, 88*, 229–242. https://doi.org/10.5114/jhk/166107

Ben Ayed, K., Hammami, M. A., Latiri, I., & Ben Saad, H. (2026). The relationship between power, speed and agility in youth volleyball players. *La Tunisie Médicale, 103*(11), 1631–1641. https://doi.org/10.62438/tunismed.v103i11.6149

Challoumas, D., & Artemiou, A. (2018). Predictors of attack performance in high-level male volleyball players. *International Journal of Sports Physiology and Performance, 13*(9), 1230–1236. https://doi.org/10.1123/ijspp.2018-0125

González-Ruíz, K., Medrano, M., Correa-Bautista, J. E., García-Hermoso, A., Prieto-Benavides, D. H., Tordecilla-Sanders, A., Agostinis-Sobrinho, C., Correa-Rodríguez, M., Schmidt Rio-Valle, J., González-Jiménez, E., & Ramírez-Vélez, R. (2018). Comparison of bioelectrical impedance analysis, Slaughter skinfold-thickness equations, and dual-energy X-ray absorptiometry for estimating body fat percentage in Colombian children and adolescents with excess of adiposity. *Nutrients, 10*(8), 1086. https://doi.org/10.3390/nu10081086

Hernandez-Martinez, J., Guzman-Muñoz, E., Ramirez-Campillo, R., Herrera-Valenzuela, T., Magnani Branco, B. H., Avila-Valencia, S., Luis Carter-Beltran, J., Aravena-Sagardia, P., Méndez-Cornejo, J., & Valdés-Badilla, P. (2023). Effects of different plyometric training frequencies on physical performance in youth male volleyball players: A randomized trial. *Frontiers in Physiology, 14*, 1270512. https://doi.org/10.3389/fphys.2023.1270512

Idrizovic, K., Gjinovci, B., Sekulic, D., Uljevic, O., João, P. V., Spasic, M., & Sattler, T. (2018). The effects of 3-month skill-based and plyometric conditioning on fitness parameters in junior female volleyball players. *Pediatric Exercise Science, 30*(3), 353–363. https://doi.org/10.1123/pes.2017-0178

Koźlenia, D., Popowczak, M., Horička, P., Šimonek, J., & Domaradzki, J. (2024). Sex-specific relationship patterns between body morphology and maturity status with change of direction and agility in elite adolescent volleyball players. *Scientific Reports, 14*, 13170. https://doi.org/10.1038/s41598-024-64190-6

Matłosz, P., Makivic, B., Csapo, R., Hume, P., Mitter, B., Martínez-Rodríguez, A., & Bauer, P. (2023). Body fat of competitive volleyball players: A systematic review with meta-analysis. *Journal of the International Society of Sports Nutrition, 20*(1), 2246414. https://doi.org/10.1080/15502783.2023.2246414

Milić, M., Grgantov, Z., Chamari, K., Ardigò, L. P., Bianco, A., & Padulo, J. (2017). Anthropometric and physical characteristics allow differentiation of young female volleyball players according to playing position and level of expertise. *Biology of Sport, 34*(1), 19–26. https://doi.org/10.5114/biolsport.2017.63382

Oliveira, J. P., Marinho, D. A., Jacinto, P., Sampaio, T., & Morais, J. E. (2025). Characterization of physical performance and change of direction deficit across age groups in young female volleyball players. *BMC Sports Science, Medicine and Rehabilitation, 17*, 209. https://doi.org/10.1186/s13102-025-01264-6

Orscelik, A., Kaya, I., Karaaslan, B., Agiragac, B., & Ceyhan, C. (2022). Is COVID-19 infection decreasing the sports performance of the volleyball players? A pilot study. *Journal of Men's Health, 18*(4), 1–6. https://doi.org/10.31083/jomh.2021.143

Podstawski, R., Bukowska, J. M., Borysławski, K., Biernat, E., Grodź, D., Ihasz, F., & Wąsik, J. (2025). Anthropometric but not motor characteristics of young volleyball players were improved after a one-week-long intense training sports camp. *Scientific Reports, 15*(1), 2835. https://doi.org/10.1038/s41598-025-85441-0

Sawyer, S. M., Azzopardi, P. S., Wickremarathne, D., & Patton, G. C. (2018). The age of adolescence. *The Lancet Child & Adolescent Health, 2*(3), 223–228. https://doi.org/10.1016/S2352-4642(18)30022-1

Sousa, M., Fernandes, M. J., Moreira, P., & Teixeira, V. H. (2013). Nutritional supplements usage by Portuguese athletes. *International Journal for Vitamin and Nutrition Research, 83*(1), 48–58. https://doi.org/10.1024/0300-9831/a000144

Sylvester, R., Lehnert, M., Hanzlíková, I., & Krejčí, J. (2024). The effect of plyometric training and moderating variables on stretch-shortening cycle function and physical qualities in female post peak height velocity volleyball players. *Frontiers in Physiology, 15*, 1346624. https://doi.org/10.3389/fphys.2024.1346624

Tessutti, L. S., Aguiar, S. da S., Costa, G. D. C. T., Clemente, F. M., Lima, R. F., Neves, R. V. P., Praça, G. M., & Castro, H. de O. (2019). Body composition and performance variables differences in female volleyball players by age-group and playing position. *Revista Brasileira de Cineantropometria & Desempenho Humano, 21*, e60131. https://doi.org/10.1590/1980-0037.2019v21e60131