

# The gender-specific associations between body composition, countermovement jump performance and bone quality in a young Chinese population

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## Research article

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# Abstract

**Background:** Prophylactic interventions against osteoporosis require a determination of the factors that influence the bone status during adulthood. This study aimed to investigate the associations between body composition parameters (body height (BH), body weight (BW), fat free mass (FFM), fat mass (FM), lower limb muscle mass (LLMM), lower limb fat mass (LLFM)), countermovement jump (CMJ) performance, and calcaneal bone stiffness (SI) in a population of young adults. **Methods:** The study population included 560 Chinese adults (369 females), aged 20-40 years. Body composition was obtained by bioelectrical impedance analysis (BIA). The CMJ performance (CMJ height (CMJH), the impulse of CMJ phase (ICMJ) and potential energy in the CMJ phase (ECMJ)) was obtained by 3 maximal CMJ trials on ZTJ-II system. Bone quality was measured by quantitative ultrasound (QUS). **Results:** The present study found BW, FFM and LLMM had significant correlations with SI both in males ( $r=0.20-0.24$ ,  $p<0.05$ ) and females ( $r=0.12-0.20$ ,  $p<0.05$ ). However, FM and LLFM had positive correlations with SI only in females ( $p<0.05$ ). CMJ performances, including CMJH, ICMJ and ECMJ, had significant positive correlations with SI in men ( $r=0.415$ ,  $p<0.01$ ;  $r=0.32$ ,  $p<0.01$ ; and  $r=0.39$ ,  $p<0.01$ , respectively) and women ( $r=0.248$ ,  $p<0.01$ ;  $r=0.26$ ,  $p<0.01$ ;  $r=0.3$ ,  $p<0.01$ , respectively). **Conclusions:** This provides evidence that local muscle mass have greater positive associations with calcaneal bone quality than total FFM, and local muscle mass and power are the determinations of region bone quality in young adults. The bone–muscle relationship is more prominent in males than in females.

## Background

Osteoporosis has recently been recognized as a silent epidemic and much effort is being directed towards its prevention and management.<sup>[1]</sup> Bone quality in later life depends largely on the peak bone quality achieved in young adulthood, and the subsequent age- and hormone -related bone loss.<sup>[10,18]</sup> Several risk factors, such as advanced age, low body weight (BW), sarcopenia and life-style factors as well as decreased mobility, have been reported to be the important determinants of bone quality in the general population.

Body composition is one of the important determinants of bone quality.<sup>[11]</sup> However, the importance of fat-free mass (FFM) and fat mass (FM) for bone quality has been somewhat controversial. Greater FFM and FM may imposed a greater mechanical stress on bone, and would be beneficial for bone health.<sup>[3]</sup> On the other hand, both adipocytes and osteoblasts are derived from a common multipotential mesenchymal stem cell, and the secretion of adipocyte-derived hormones (e.g., estrogens, insulin, leptin, adiponectin, and interleukin-6) may affect the activation of osteoblasts and osteoclasts. Several cross-sectional study studies had found that FFM and FM, as well as both of them were determinants of bone quality.<sup>[5,8,30]</sup> Contrasting studies, however, suggest that excessive FM may have detrimental effects on bone quality. Moreover, these relationships were difference between men and women according to the recent reports.<sup>[32]</sup> Some studies found that FM was a more important determinant of bone quality in women than men,<sup>[2]</sup> while reports to the contrary exist.<sup>[24]</sup>

Meanwhile, regional muscle mass and strength has been shown to be related to local bone quality [14,23] [14,23].<sup>12, 13</sup> Muscle and bone form a functional unit, forces generated by muscle contraction induce changes in bone architecture.<sup>[6]</sup> However, recent reports found that the muscle-bone relationship is not necessarily site specific.<sup>[31,34]</sup> In addition, it is unknown whether gender alters the muscle-bone relationship. The correlation between muscle strength and bone characteristics has now been studied by previous studies using isokinetic dynamometer.<sup>[4,9]</sup> In our study, the countermovement jump (CMJ) was chosen because it had been found to be the most reliable and valid field tests for assessing the explosive power output of the lower limbs in physically active subjects.<sup>[25]</sup>

There is no large literature analyzing the association between body composition, muscle power and bone quality in the young adults, separately by gender. The objective of this cross-sectional study was (a) to determine the relationships among body composition parameters (body height (BH), BW, FFM, FM, lower limb muscle mass (LLMM), lower limb fat mass (LLFM)), CMJ performance and calcaneal bone stiffness (SI) in young Chinese adults, and (b) to assess the gender-specific contributions of regional muscle mass and power to local bone quality, so that if these are appropriately altered during adulthood, osteoporosis would be prevented.

## Methods

### Subjects

The study is a cross-sectional study in 963 independently living people, aged 20-40 years, who were randomly selected from Anhui, Hubei and Hunan province in the middle areas of China. They were initially selected to participate in this study carried out in Anhui National Physical Fitness Monitoring Center in Hefei, China, from February 2017 to May 2017. The age range was chosen for study based on the observation that CMJ test in the participants greater than 40 years of age would be hard to carry out.

Data on medical history and current medication use and psychiatric diagnoses were collected. Individuals with history of fractures in previous 24 months or significantly impaired renal or hepatic function, chronic kidney disease, type 1 diabetes, sustained periods of immobilization, amenorrhea (>6 months), use of hormone replacement therapy (>12 months), cortisone (>6 months) were excluded.

At last, 560 eligible participants (191 men and 369 premenopausal women, aged 20–40 years) remained for further study from May 2017 to December 2018. All participants provided informed consent and the rights of the subjects were protected. The study was approved by appropriate institutional research ethics committee. Likewise, the study methods met the ethical standards of the International Journal of Sports Medicine [12]

### Measurements of CMJ performance

Compared with squat jump (SJ) test, the CMJ test showed higher relationship with the explosive power factor.<sup>[25]</sup> In our study, CMJ was performed for the measurement of explosive impulse and the reuse of

elastic energy during inversion of eccentric to concentric movement. Subjects were asked to stand with both feet on the ZTJ-II (Jian Min Corporation, China) and lower their body towards the ground by moving into flexion position at the trunk and lower extremity while extending upper extremity. Then subjects were asked to jump as high as possible while extending their legs. The jump was repeated 3 times, and the countermovement jump height (CMJH) was displayed on the screen.

The impulse in the CMJ phase ( $I_{CMJ}$ ) was assessed by equation (4), which was derived by equations (1)-(3). The potential energy in the CMJ phase ( $E_{CMJ}$ ) was obtained by the equation (5). (See Equations in the Supplementary Files)

, where  $g$  = acceleration due to gravity,  $BW$  indicates body weight,  $CMJH$  indicates countermovement jump height,  $V_{top}$  indicates the velocity of body on the highest position, and  $V_{up}$  indicates the velocity of body leaving from the ground.

### Measurements of body composition

BH was measured to the nearest 0.1 cm by a stadiometer (GM-I, Jian Min Corporation, China). Body composition was measured using multi-frequency body composition analyzer MC-180MA (Tanita Corporation, Tokyo, Japan). Subjects stood on bare feet with the heel and toe of each foot in contact with the metal footpads, with arms hanging to each side, lightly holding the analyzer handgrips. Coefficient of variance (CV) of the impedance measure was 0.4%. The Tanita software (v1.7.0) generated values for  $BW$ ,  $FFM$ ,  $FM$  and lower limb tissue composition including left lower limb muscle mass (LLLMM), right lower limb muscle mass (RLLMM), left lower limb fat mass (LLLFM) and right lower limb fat mass (RLLFM). Values obtained from bioelectrical impedance analysis (BIA) were supported by skinfold measurement using Harpenden calipers. Previous work indicated that BIA method had advantages over anthropometry for measuring lower limb tissue composition in healthy individuals,<sup>[15]</sup> and there was a high correlation between dual-energy X-ray absorptiometry (DXA) and Tanita MC-180.<sup>[26]</sup>

### Measurements of bone quality

Quantitative ultrasound (QUS) measurements have been found to reflect strength and architecture of bone<sup>[16,33][16,33].<sup>22,23</sup></sup> In this study, QUS device (Achilles express; LUNAR, USA) was used to assess SI of the right calcaneus, which is a combination of speed of sound (m/s) (SOS) and broadband ultrasound attenuation (BUA) (dB/MHz) ( $SI = 0.67 \times BUA + 0.28 \times SOS - 420$ ).<sup>[27]</sup> This measurement was calibrated daily in accordance with the manufacturer's recommendations and before measurement. To examine the reliability of Achilles devices, short-term precision expressed as CV and standardized CV were calculated in another 25 individuals using duplicate measurement. The CV (%) were 2.2 (1.2–3.1) for BUA, 0.3 (0.2–0.5) for SOS, and 2.3 (1.5–4.1) for SI, respectively. The standardized CV (%) were 4.1 (2.7–9.7) for BUA, 3.4 (1.5–4.7) for SOS, and 2.9 (0.9–3.7) for SI, respectively.

### Statistical analysis

Subject characteristics, measurements including age, body composition parameters (BH, BW, FFM, FM, LLLMM, RLLMM, LLLFM, RLLFM) and CMJ performance were expressed as mean±standard deviation (SD). The level of significance was set at  $p<0.05$ . Student's *t*-test was used for comparison of means and quantitative data. Bivariate correlation analysis and multiple linear regression analysis were used to investigate the relations among the CMJ performance, body composition parameters (BH, BW, FFM, FM, LLMM, and LLFM) and calcaneal bone SI. The statistical analysis was done using SPSS for Windows, Version 22.0 (IBM Corp., Armonk, NY).

## Results

### Participant characteristics and age-related differences

The participant characteristics are summarized in **TABLE 1**. The mean ages of men and women were  $31.8\pm 4.1$  years and  $32.1\pm 4.1$  years. The BH, BW, FFM, LLLMM, RLLMM, CMJH and SI were significantly ( $p<0.001$ ) higher in men than in women. However, FM, LLLFM and RLLFM were higher in women than in men. Moreover, the CMJ performances ( $CMJH$ ,  $I_{CMJ}$ , and  $E_{CMJ}$ ) were higher in women than in men. Meanwhile, the calcaneal QUS parameters (SI) was also higher in men than in women.

The distributions of age-related difference in anthropometric characteristics, CMJH and SI are shown in **TABLE 2**. BH, BW, FFM, LLMM, CMJH and SI were higher in men than in women in all age groups. CMJH and SI reduced with age both in men and women.

### Influences of anthropometric parameters to QUS parameters

The bivariate correlation analysis of SI against age, anthropometric characteristics and CMJH is shown in **TABLE 3**. In both genders, age was a negative predictor of SI, and there were significant positive correlations between BW, FFM, LLLMM, RLLMM and SI in males and females, but the correlations were weaker in females than in males. Meanwhile, FM, LLLFM, RLLFM showed positive correlations with SI in females, which were not found in males. Moreover, CMJH had positive correlations with SI in males and females, but correlations were stronger in males than in females.

### Bone-Muscle Relationships

The correlations between  $I_{CMJ}$ ,  $E_{CMJ}$  and LLMM in males and females were showed in **FIGURE 1**. There was a high relationship between  $I_{CMJ}$  with LLMM ( $r=0.85$ ) in males and ( $r=0.68$ ) in females. There was a strong positive correlation ( $r=0.69$ ,  $P<0.001$ ) between  $E_{CMJ}$  and LLMM in males, and the correlation was weaker in females ( $r=0.52$ ,  $P<0.001$ ) than in males.

The correlations between  $I_{CMJ}$ ,  $E_{CMJ}$  and SI in males and females were showed in **FIGURE 2**. There was a positive correlation between  $I_{CMJ}$  and SI in the males ( $r=0.32$ ,  $P<0.01$ ) and in the females ( $r=0.26$ ,  $P<0.01$ ). There was a positive correlation ( $r=0.39$ ,  $P<0.01$ ) between  $E_{CMJ}$  and SI in males and females ( $r=0.30$ ,  $P<0.01$ ). These correlations were higher in males than in females.

**TABLE 4** shows the multivariate regression of SI against age, RLLMM and CMJH in males and females. Both in men and women, age was the negative determinant for SI, and CMJH and RLLMM was the positive predictors of SI.

## Discussion

This study was conducted to assess age, body composition, muscle power to bone quality in young men and women, and to assess the gender-specific contributions of regional muscle mass and power to local bone quality. We found that CMJ performances ( $CMJH$ ,  $I_{CMJ}$ , and  $E_{CMJ}$ ) and bone quality decreased with increasing age in men as well as in women. BW and FFM had positive associations with calcaneal bone quality, while FM had a positive correlation with bone quality only in women. Local muscle mass and power was the determinations of region bone quality in young adults. However, the bone–muscle relationship was more prominent in males than in females.

In our previous research, we have found that BW and FFM positively correlate with bone quality in young adults [7]. In this research, we have further discover that local muscle mass (RLLMM) have a stronger relationship with region bone quality (right calcaneus) comparing with LLLMM and FFM. Our study suggests that the greater local muscle mass may be an important factor in achieving peak bone density. We also observed that FM and LLFM had positive correlations with bone quality only in women. IR Reid et al. found that bone density was closely related to FM in premenopausal women, but less so in men,<sup>[29]</sup> and similar results were found by others studies.<sup>4,8</sup> In contrast, other studies used QUS to study the effect of body composition on bone quality with differing results. Our finding supports the point of view that FM has a positive relationship with bone quality in young women. FM contributes to skeletal load in the same way as lean mass, so this simple mechanical effect may contribute to the fat-bone relationship to some extent. In our study, female samples had less BW and more FM and LLFM than male samples, and this would contributes to the gender discrepancy. A further possible link between the two tissues is the common stromal cell origin of both osteoblasts and adipocytes, and a number of hormones may link the two tissues. The secretion of estrogens from the adipocyte in women may be involved in bone metabolism. This may probably contribute to this gender discrepancy.

CMJ performance depends on the muscle power (muscle force and muscle velocity),<sup>[13]</sup> and CMJ test had been found to be the most reliable and valid field tests for assessing the explosive power output of the lower limbs in physically active subjects.<sup>15</sup> In our study, we found LLMM and CMJ performance showed positive relationships with SI in males and females. This indicated that local muscle mass and muscle strength were the determinations of region bone quality in young adults. Our results were consistent with those findings by others, which human regional muscle mass was related with bone mass<sup>[8]</sup> and bone mineral density (BMD).<sup>[19]</sup> Zudin Puthuchearly et al. found that training-related increases in rectus femoris volumes and bone volumes were related ( $R^2=0.21-0.31$ ).<sup>[28]</sup> Regional muscle plays a vital role in bone biomechanics, especially with exercise, which is most likely producing osteocyte viability factors that protect osteocytes against glucocorticoid induced apoptosis.<sup>[17,20]</sup> Muscle strength is

associated with total osteocalcin levels which was reported by Fernandez-Real JM et al.,<sup>[12]</sup> and osteocalcin levels have a direct effect on bone formation.<sup>[22]</sup>

In addition, we observed that bone–muscle relationship was more prominent in males than in females. A cross-sectional study in including 2264 older men and women in Korea, found that the positive correlations between muscle and BMD were stronger in older men than in older women.<sup>34</sup> Our results further proves this point of view in a young adult population by measuring the local body composition and muscle performance. To our knowledge, testosterone in men increases both muscle mass–muscle strength and bone quality, while estrogen in women only affects the bone through inhibiting bone resorption by binding to its estrogen receptor.<sup>[21]</sup><sup>5</sup> This may partly explain this gender discrepancy.

### **Strength and limitations**

Compared with previous studies, the strengths of our study are that body composition, CMJ performance and calcaneal bone quality were simultaneously measured in the subjects, which included different genders and ages within a single group in certain areas in a certain age range, and these people were not receiving medication or suffering from diseases affecting bone metabolism. There are several limitations to our studies. First, we did not consider further variables that might impact bone quality, such as physical activity, dietary calcium and vitamin D intake, genetic, serum hormone levels in our study. Second, we did not include measurements of bone quality at other sites or use additional techniques such as DXA. But as we know, QUS measurement has become an important modality for the assessment of osteoporosis status and the estimate of osteoporotic fracture risk, and the general consensus is that QUS seems to provide structural information in addition to density.<sup>[27]</sup>

## **Conclusion**

In conclusion, we observed that local muscle mass have greater positive associations with calcaneal bone quality than total FFM, and local muscle mass and strength are the determinations of region bone quality in young adults, with the bone–muscle relationship being more prominent in males than in females. To increase or preserve the bone quality of specific site, maintaining or increasing regional muscle mass and muscle power would appear to be an appropriate strategy, especially in men.

## **Abbreviations**

BMI: Body Mass Index; FFM: Fat-free mass; FM: Fat Mass; BH :Body height; BW: Body weight; LLMM: Lower limb muscle mass; LLFM: Lower limb fat mass; CMJ: countermovement jump (CMJ); SI: Calcaneal bone stiffness; CMJH : countermovement jump height; ICMJ: the impulse of CMJ phase; ECMJ: Potential energy in the CMJ phase; QUS: quantitative ultrasound; BMD: bone mineral density.

## **Declarations**

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## Availability of data and materials

The raw data is available upon reasonable request from the corresponding authors.

## Author contributions

Zenghui Ding was responsible study concept and design and drafting of the manuscript. Yubing Xu led on the statistical analyses and manuscript revise. Yanyan Chen contributed to data collection. Yue Xia played a key role in service user engagement. Yining Sun wrote sections of the paper, with input from Xianjun Yang. All authors contributed to the design of the study and approved the final draft of the manuscript.

## Ethics approval and consent to participate

The study was approved by the local Institutional Review Board. All study participants were given written informed consent after the study was explained to them.

## Consent for publication

Not applicable

## Competing interests

The authors declare that they have no competing interests

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## Tables

**TABLE 1.** Characteristics of the Participants

	Men	Women	P
Age (years)	31.8±4.1	32.1±4.1	0.122
BH (cm)	170.8±5.8	159.0±5.2	<0.001
BW (kg)	69.7±9.3	53.4±5.3	<0.001
FFM (kg)	55.6±5.3	38.6±2.9	<0.001
FM (kg)	13.9±3.5	14.9±4.4	<0.001
BMI (kg/m <sup>2</sup> )	23.9±2.8	21.2±2.5	0.047
LLLMM (kg)	9.9±1.1	6.69±0.50	<0.001
RLLMM (kg)	10.0±1.1	6.76±0.48	<0.001
LLLFM (kg)	2.63±0.81	3.18±0.61	<0.001
RLLFM (kg)	2.66±0.83	3.23±0.62	<0.001
CMJH(cm)	39.6±6.7	25.0±4.1	<0.001
I <sub>CMJ</sub>	193.2±29.8	117.5±16.4	<0.001
E <sub>CMJ</sub>	270.2±57.7	130.2±25.3	<0.001
SI	105.0±16.9	93.4±12.1	<0.001

The data are shown as mean ± standard deviation;

BH indicates body height; BW, body weight; FFM, fat free mass; FM, fat mass; LLLMM, Left lower limb muscle mass; RLLMM, Right lower limb muscle mass; LLLFM, Left lower limb fat mass; RLLFM, Right lower limb fat mass; CMJH, Countermovement jump height; I<sub>cmj</sub>, Impulse of CMJ phase (I<sub>cmj</sub>= ); E<sub>cmj</sub>, the potential energy in the CMJ phase (E<sub>cmj</sub>=BW\*g\*CMJH); SI, calcaneal bone stiffness;

P value determined by Student's t-test for differences in the basic characteristics of women and men.

**TABLE 2.** Distribution of age-related change in anthropometric characteristics, CMJH and SI

	BH (cm)	BW (kg)	FFM (kg)	FM (kg)	LLMM (kg)	LLFM (kg)	CMJH (cm)	SI
Men (n=191)								
20-25(n=16)	172.5±5.9	67.0±10.9	55.6±7.0	11.3±5.5	20.2±0.9	4.5±1.7	45.6±5.3	118±18
26-30(n=56)	171.6±3.5	70.9±5.0	56.5±5.7	14.5±4.4	19.7±0.8	5.4±1.1	40.5±5.2	105±22
31-35(n=77)	170.8±6.4	69.9±9.4	56.7±5.7	14.1±5.1	19.9±2.2	6.2±1.1	39.5±5.8	102±15
36-40(n=42)	168.6±4.5	68.2±5.5	52.6±5.1	13.9±4.3	18.9±1.9	5.2±1.4	35.6±6.5	100±16
Women (n=369)								
20-25(n=32)	158.8±5.8	52.0±7.6	37.6±3.1	14.0±5.0	13.8±1.1	6.3±1.5	26.7±1.5	98±16
26-30(n=88)	158.8±5.6	52.6±6.8	38.1±3.0	14.6±4.7	13.5±1.0	6.4±1.3	25.8±3.7	97±13
31-35(n=174)	159.0±5.1	53.4±6.1	38.6±2.9	14.9±4.2	13.4±1.0	6.4±1.2	24.9±4.1	92±12
36-40(n=75)	159.0±4.9	54.9±6.0	39.4±2.7	15.6±4.2	13.4±0.9	6.5±1.1	23.5±3.9	90±10

BH indicates body height; BW, body weight; FFM, fat free mass; FM, fat mass; LLLMM, lower limb muscle mass; LLLFM, lower limb fat mass; CMJH, Countermovement jump height; SI, calcaneal bone stiffness.

**TABLE 3.** Bivariate correlation analysis of SI against age, body composition parameters and CMJ performances

	SI of males	SI of females
	N=193	N=375
Age	-0.341**	-0.211**
BH	0.129	0.035
BW	0.203*	0.123*
FFM	0.210**	0.127*
FM	-0.059	0.121*
LLLMM	0.226**	0.190**
RLLMM	0.243**	0.202**
LLLFM	-0.017	0.111**
RLLFM	-0.030	0.113**
CMJH	0.415**	0.248**
I <sub>CMJ</sub>	0.328**	0.261**
E <sub>CMJ</sub>	0.397**	0.302**

BH indicates body height; BW, body weight; FFM, fat free mass; FM, fat mass; LLLMM, Left lower limb muscle mass; and RLLMM, Right lower limb muscle mass; LLLFM, Left lower limb fat mass; RLLFM, Right lower limb fat mass; CMJH , Countermovement jump height ;SI, calcaneal bone stiffness.

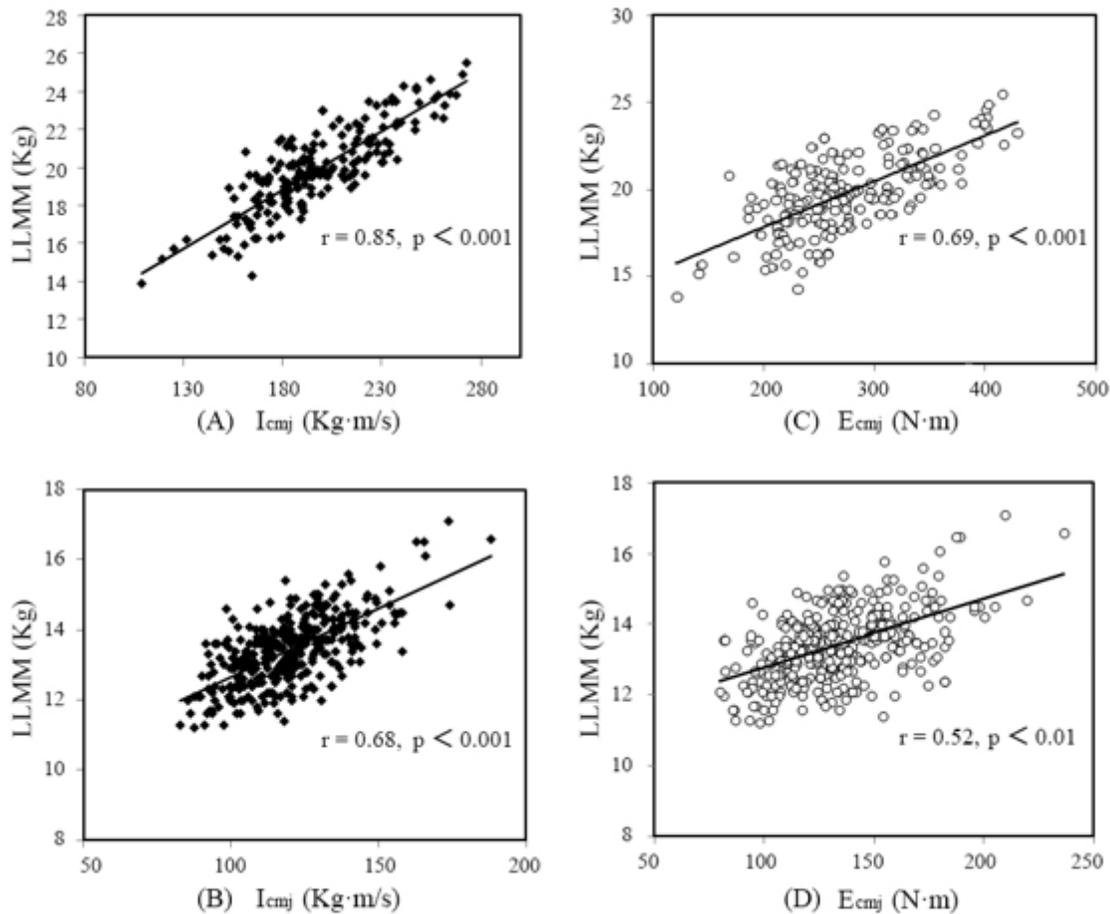
\* p<0.05, \*\* p<0.001

**TABLE 4.** Multivariate regression of SI against RLLMM and CMJH

Dependent Variable	Independent Variable	Standard $\beta$	p
Males (age<=40)			
SI:			
	Age	-0.183	0.000
	CMJH	0.318	0.002
	RLLMM	0.120	0.006
	R=0.471		
Females			
SI:			
	Age	-0.152	0.000
	CMJH	0.200	0.000
	RLLMM	0.161	0.001
	R=0.335		

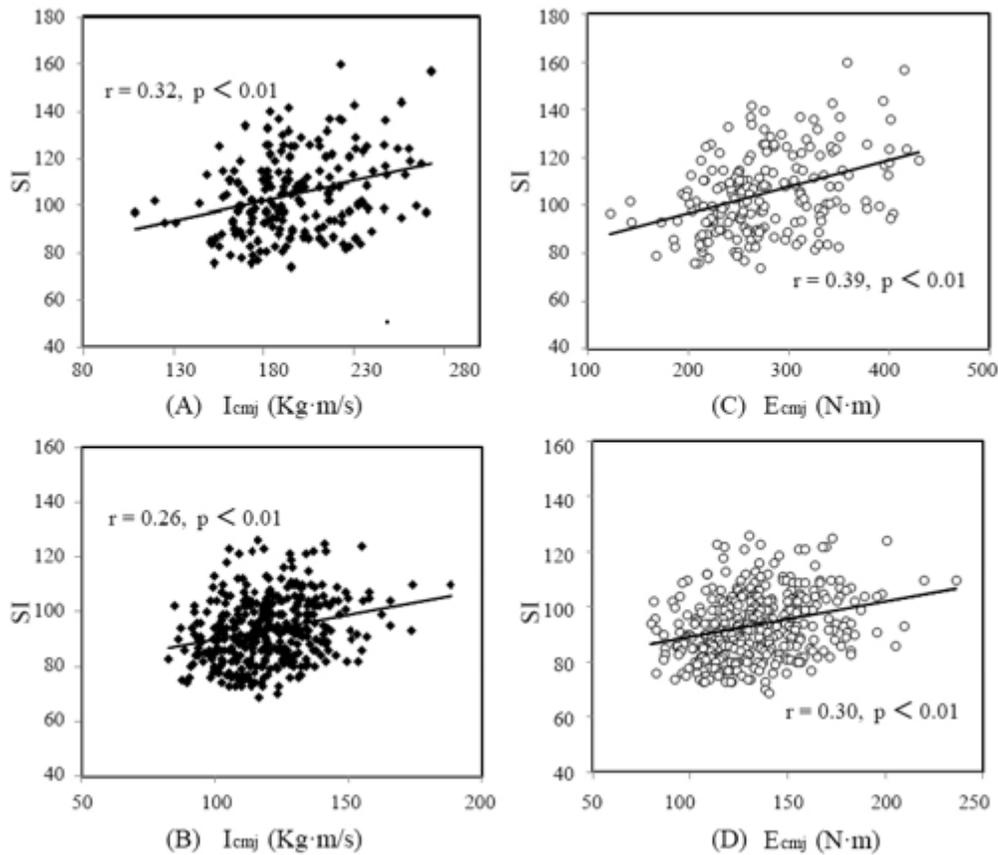
LLMM indicates Right lower limb muscle mass; and CMJH, Countermovement jump height; SI, calcaneal bone stiffness.

## Figures



**Figure 1**

Relationship between the impulse of CMJ phase ( $I_{cmj}$ ) ( $I_{cmj} = BW \times \sqrt{2g \times CMJH}$ ) and lower limb muscle mass (LLMM) in males (A) and in females (B); Relationship between the potential energy in the CMJ phase ( $E_{cmj}$ ) ( $E_{cmj} = BW \times g \times CMJH$ ) and lower limb muscle mass (LLMM) in males (C) and in females (D), BW indicates body weight, g = acceleration due to gravity.



**Figure 2**

Relationship between the impulse of CMJ phase ( $I_{cmj}$ ) ( $I_{cmj} = BW \times \sqrt{(2g \times CMJH)}$ ) and calcaneal bone stiffness index (SI) in males (A) and in females (B); Relationship between the potential energy in the CMJ phase ( $E_{cmj}$ ) ( $E_{cmj} = BW \times g \times CMJH$ ) and SI in males (C) and in females (D); BW indicates body weight, g = acceleration due to gravity.

## Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Equations.pdf](#)