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Relationships between bone mineral density, body composition, and isokinetic strength in postmenopausal women

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ABSTRACT

Objectives: The increase in body fat mass (BFM) and the loss of lean body mass (LBM) or muscle strength with age affects bone mineral (BMD). These factors increase the prevalence and incidence of obesity and sarcopenia, which have unclear effects on bone mineral density. The purpose of this study was to determine how the above selected factors affect BMD.

Methods: A cross-sectional study was conducted involving 58 women (aged 62.1 ± 4.8 years). Total body, left proximal femur, lumbar spine BMD, and body composition parameters were measured with dual-energy x-ray absorptiometry. Isokinetic flexion and extension strength of the dominant leg were measured at 60 deg./s. Grip strength was measured with the dominant upper extremity. To determine the volume of physical activity (PA), the PA level was monitored for seven consecutive days using an ActiGraph model GT1M accelerometer.

Results: BFM was positively associated with BMD of the proximal femur ($\beta = 0.31$; $P < 0.05$), whereas LBM or appendicular lean mass (ALM) did not relate to BMD at any sites. Dominant isokinetic strength also did not relate to BMD at any site. A/G (android/gynoid) fat ratio shows positive association with lumbar spine BMD after adjusting for YSM (years since menopause), height, smoking status, and steps per day.

Conclusion: We observed a positive association between proximal femur BMD and BFM, but not between LBM, ALM or isokinetic strength. A/G ratio and BMI showed a positive association with lumbar spine BMD or proximal femur BMD, respectively.

1. Introduction

A progressive decline in bone mineral density (BMD), muscle mass, and muscle strength, also known as sarcopenia, is a key feature of the ageing process. It predisposes older individuals to disability, falls, fractures, and frailty, thereby posing an increasing major clinical and public health burden (Verschueren et al., 2013; Ahedi et al., 2014).

Unni et al., 2010 state that years since menopause (YSM) is the strongest predictor of BMD in the first 10–15 years after the onset of menopause. Similarly, a lack of estrogen or a lack of physical activity (PA) in postmenopausal women results in reduced muscle strength and reduced BMD (Gaba et al., 2012; Zhou et al., 2013), altering the relationships between BMD, muscle strength, and body composition (Melton 3rd et al., 2006).

A recent Cochrane review about the effectiveness of exercise in postmenopausal women showed a relatively small but statistically significant effect of physical activity (non-weight bearing – resistance strength training) on proximal femur BMD or combination exercise programs (aerobics, weight bearing, and resistance exercises) on lumbar spine BMD (Howe et al., 2011). Seco et al. (2013) state that it is important to perform a long-term physical activity training program (aerobic exercise such as slow running/brisk walking) that increases strength and flexibility and improves balance in older adults.

There are many disagreements in the literature about the effect of body fat mass (BFM) or lean body mass (LBM) on bone mineral density. Some studies have shown that body fat mass in postmenopausal women is a better predictor of BMD than lean body mass or fat-free mass (FFM) (Gonnelli et al., 2013; Kapuš et al., 2014) but other studies (Ho-Pham et al., 2014; Leslie et al., 2014; Ilesanmi-Oyelere et al., 2018) have shown the opposite results.

Dramatic body composition changes, including an increase in total body and central adiposity (android region), and decrease in gynoid fat

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proportion, appear just after menopause (Fu et al., 2011) and influence its relationship with BMD. In addition, carrying too much fat in the wrong areas can increase the chance of serious health problems. It is reported that regional fat mass such as android is associated with cardio-metabolic risks, while android-to-gynoid fat ratio (A/G ratio) reflecting visceral fat accumulation is associated with insulin resistance (Bouchi et al., 2016).

There is also conflicting evidence pertaining to the relationship between muscular strength and BMD (Bayramoglu et al., 2005; Pasco et al., 2015; Rikkonen et al., 2012). Bayramoglu et al. (2005) and Pasco et al. (2015) found little or no association between muscular strength and BMD. However, there are studies that point to positive association between the above factors (Li et al., 2018; Marin et al., 2010). Ahedi et al. (2014) states that some muscles did not show any associations with bone density or strength. For instance, no association was found between gluteus maximus size, muscle strength, and bone density.

In view of the above disagreements, this study was designed to examine the relationship between body composition, hip muscle strength, grip strength and BMD of selected regions in postmenopausal women. We wanted to point out the link and complexity of the relationships between body composition, muscle strength and BMD.

2. Materials and methods

2.1. Subjects and methods

The assessment of selected body composition, isokinetic parameters and BMD was conducted in 58 postmenopausal women aged 50–74 years. The research involved women who regularly attend education programs at the University of the Third Age of Palacký University in Olomouc, Czech Republic. The main exclusion criteria were the following: (1) rheumatologic, orthopedic or cardiac diseases, (2) hormone replacement therapy, (3) use of medication significantly affecting bone metabolism (e.g., corticosteroids) in the last two years, (4) a bilateral ovariectomy, and (5) metallic implants inserted during a surgery. Furthermore, women who had undergone densitometric examinations within the last 12 months were also excluded from this study. Women involved in the research were predominantly non-smokers ($n = 38$) and mainly active ($n = 54$).

Ethical approval for the study was obtained in accordance with the local institutional requirements. All subjects provided written informed consent prior to the actual procedure. The research was conducted in 2012 at a specialized clinic with the participation of professionally trained staff and a radiology assistant.

2.2. Bone tissue and body composition assessments

The lumbar region of the spine (L_1–L_4), the proximal part of the left femur, and the total body BMD were measured using the DXA Lunar Prodigy Primo™ device (GE Healthcare, United Kingdom) with Encore™ software version 12.20.023. T-score was also used to diagnose osteopenia or osteoporosis using the World Health Organization (WHO) recommendations (Kanis, 1994). The device was regularly calibrated every morning before each diagnostic block using a Lunar phantom. The DXA measured the BMD of lumbar spine and proximal femur with a precision (coefficient of variation) of 1.6% and 2.8%, respectively. The precision of the lean body mass, body fat mass and fat percentage in vivo was ~1.0%, 0.8%, and 2.7%, respectively (Toombs et al., 2012). Appendicular lean mass (ALM, in kg) was determined by summing lean mass measures for the arms and legs. Fat distribution was assessed by android to gynoid fat mass (kg) ratio (Android/waist to Gynoid/hip Ratio).

2.3. Isokinetic muscle strength determination

The measurement of dominant leg muscle strength alone was preceded by a five-minute warm-up on a bicycle ergometer. Unilateral concentric force of hip flexors and extensors was measured using isokinetic dynamometer IsoMed 2000 (D. & R. Ferstl GmbH, Hemau, Germany). The participating women were tested lying down with their hands on the handles along the deck chair. They were fixed in the pelvis area, and the axis of rotation of the dynamometer was identical to the hip axis (trochanter major).

The range of motion was 70° and was measured at 60°/*sec* (Brown, 2000; Dvir, 2004). Several series were made to familiarize the movement. After a short pause (1 min), proper measurements (6 contractions) were followed with maximum effort. There was a 2-min rest period between left and right leg measurements.

For the measurement of dominant hand grip strength, participants underwent 3 trials with a maximum effort using a hand grip dynamometer. For the statistical analysis, we used the mean of 3 performed trials. Grip strength was measured using a Jamar Analogue Hand Dynamometer with participants seated, their elbows by their side and flexed to right angles, and in a neutral wrist position, the dynamometer handle in standard position and provision of support underneath the dynamometer. This position, followed by calculation of the mean of three trials of grip strength for each hand, has been well-documented as reliable (Mac Dermin et al., 2015).

2.4. Physical activity

To determine the daily volume of physical activity, the PA level was monitored for seven consecutive days using an ActiGraph model GT1M accelerometer (ActiGraph; LLC, Pensacola, FL, USA) that registered vertical acceleration in units of counts. Before testing, each accelerometer was calibrated according to the manufacturer's recommendations. The time sampling interval was set at 60s using the manufacturer's software (ActiLife version 5.8) and step mode was activated. Each accelerometer was securely positioned near the right iliac crest. Participants were instructed to wear the accelerometer while awake and to remove it for water activities. They were considered sedentary ($N = 4$) if they accumulated fewer than 5000 steps per day (Tudor-Locke and Bassett, 2004).

2.5. Statistical analysis

The descriptive statistics of the outcome measures are presented as the mean and standard deviation. All variables had normal distribution according to the Shapiro-Wilk test. The associations of body composition and isokinetic strength with lumbar spine BMD or proximal femur BMD were examined using a multiple linear regression analysis adjusted for potential confounding variables. Model 1 represents an explorative (unadjusted) model that does not consider the possible influence of confounders depending on body composition. Model 2 was adjusted for model 1 and years since menopause, smoking status, and body height or body weight. Model 3 was adjusted for model 2 and steps per day to determine whether the associations between BMD indicators and predictors (e.g., body composition and strength variables) are independent of the volume of physical activity. Statistical significance was assumed when $P < 0.05$. Statistica version 13.4 software was used to complete all analyses.

3. Results

Table 1 presents descriptive characteristics of the entire cohort (aged 62.1 ± 4.8 years). The mean time after menopause (YSM) was 10.7 ± 6.2 years and the mean body weight was 68.9 ± 10.7 kg. Women older than 70 years reported the highest BMI values (29.62 kg/m^2). According to *T*-score, 53 women were osteopenic and 5 women suffered from osteoporosis.

We can also observe higher values for extension than for flexion in the hip isokinetic muscle strength in Table 1.

Table 1
Descriptive statistics ($N = 58$).

	Mean	SD
Age (years)	62.1	4.8
Age of menopause (years)	51.3	3.5
Years since menopause (YSM)	10.7	6.2
Height (cm)	162.3	5.7
Body composition		
Weight (kg)	68.9	10.7
BMI (kg/m^2)	26.1	4.0
BFM (kg)	25.5	9.0
BFM (%)	36.0	8.1
LBM (kg)	41.1	4.0
LBM (%)	60.6	7.9
ALM (kg)	17.44	1.9
A/G ratio	0.5	0.2
T-score		
Femoral neck	−1.24	0.80
Ward's triangle	−1.76	0.96
Proximal femur	−0.72	0.96
L_1–L_4	−1.08	1.23
Total body	−0.20	1.13
BMD (g/cm^2)		
Femoral neck	0.86	0.11
Ward's triangle	0.68	0.13
Proximal femur	0.92	0.12
L_1–L_4	1.05	0.15
Total body	1.11	0.09
Muscle strength (dominant extremity)		
Flexion PT (Nm)	72.2	18.9
Extension PT (Nm)	125.6	42.8
Grip strength (kg)	21.9	4.0
Physical activity		
Steps per day	10,149	3338

BMI body mass index, BFM body fat mass, LBM lean body mass, ALM appendicular lean body mass, A/G ratio android/gynoid fat mass ratio, BMD bone mineral density, PT peak torque, Nm Newton-meters.

The raw and adjusted associations of different sites of BMD with selected parameters of body composition are shown in Table 2. No significant associations ($\beta = -0.23$ to 0.18) were found between BMD and lean body mass or appendicular lean mass in the unadjusted model 1 (as well as in adjusted models 2 and 3). On the contrary, positive associations were found between BMD of proximal femur and body fat mass ($\beta = 0.31$; $CI = 0.06$ to 0.57) in unadjusted model. This association strengthened after adjusting for YSM, smoking status, and height ($\beta = 0.35$; $CI = 0.07$ to 0.62), and was independent of steps per day ($\beta = 0.40$; $CI = 0.07$ to 0.73). Furthermore, there was a strengthening of association between the lumbar spine BMD and the A/G ratio or between proximal femur and BMI in adjusted model 2 and model 3 compared to the unadjusted model 1.

Table 3 represents raw and adjusted associations of different BMD sites with muscular strength. There was no significant association between BMD and muscle strength of the hip in flexion or extension. Dominant grip strength was significantly positively associated with BMD, represented by the femoral neck, Ward's triangle, and total body ($\beta = 0.29$ to 0.34); this association became non-significant after the model was adjusted for all confounding factors.

4. Discussion and conclusion

In this study, we evaluated the relationships between body composition, muscular strength, and bone density in postmenopausal women. Our results indicate that BFM is a significant ($P < 0.05$) predictor of proximal femur BMD. In contrast, lean body mass and hip flexion or extension were not found to be predictors of BMD in participating postmenopausal women.

The effect of different tissues on BMD in postmenopausal women is unclear. Genaro et al. (2010) and Ho-Pham et al. (2014) suggest that lean body mass has a relevant role in BMD measurements in postmenopausal women. Gonnelli et al. (2013) found that the role of body fat mass in BMD seems more important than lean body mass. Kapuš et al. (2014) states that lean body mass was a stronger predictor of the proximal femur BMD than body fat mass in 1–10 YSM category, whereas body fat mass was a stronger predictor of the proximal femur BMD than lean body mass in 11–20 and 21–30 YSM categories. The study by Leslie et al. (2014), which examined over 40,000 women (age ≥ 50 years), found that skeletal adaptation to lean body mass was associated with greater femoral neck BMD, whereas increasing body fat mass had neutral effects on femoral neck BMD. Our findings are in agreement with the work of Gonnelli et al. (2013) and partly with Kapuš et al. (2014). Only the proximal femur BMD was positively associated with body fat mass in postmenopausal women, while lean body mass was not associated with BMD at any sites.

Menopause is accompanied by dramatic body composition changes, and a significant decrease in total and regional BMD. Therefore, postmenopausal women with more years since menopause are more likely to experience rapid bone loss and develop osteoporosis (Chen et al., 2015). The results of correlation indicate that YSM (all $P < 0.05$; $r = -0.28$ to -0.47) were negatively correlated with selected BMD, as demonstrated by the robust data or by Kapuš et al. (2014).

Furthermore, the lumbar spine BMD showed positive association with A/G fat ratio after adjusting confounding variables ($\beta = 0.29$–0.32; $P < 0.05$). Positive associations of A/G ratio were also found in Maisnam et al. (2014) at proximal femur and lumbar spine of the body in premenopausal women (mean age of 42.3 ± 5.2). Namwongprom et al. (2019) state significant ($P < 0.001$) positive association between A/G fat ratio and measured BMD (femoral neck, proximal femur, lumbar spine). Their study also shows that the strongest association ($\beta = 0.156$; $P \leq 0.001$) was found between A/G fat ratio and lumbar spine BMD in Thai postmenopausal women. After menopause, android fat and A/G ratio increase, as Hodson et al. (2015) noted. We suggest that this is probably the reason why A/G ratio affects BMD (independently of YSM), especially in lumbar spine. It can be also attributed to biomechanics where higher A/G ratio (and higher regional fat) loads the spine and thus increases the BMD of the spine.

There is much discrepancy in the literature concerning relationships between muscle strength and bone mass. Various reports have noted significant correlations between hip flexor or extension torque and BMD of the proximal femur and lumbar spine in postmenopausal women (Pasco et al., 2015; Zhou et al., 2013). We have not found an association between hip flexor or extensor strength with selected BMD because we did not find an association between lean body mass (or appendicular lean mass) and BMD either.

Associations between grip strength and bone density at distant sites such as the spine and hip have also been reported (Dixon et al., 2005). We have found positive but non-significant associations (in unadjusted model) between grip strength and proximal femur, Ward, and total body BMD. Muscle hip strength in flexion or extension, on the other hand, does not show any association with BMD. Grip strength as well as hip muscle strength correlated with lean body mass (all $P < 0.05$; all $r = 0.32$ to 0.40). Li et al. (2018) and Kim et al. (2012) illustrate that low grip strength is associated with low BMD of the lumbar spine and proximal femur, and was an independent factor affecting BMD. Furthermore, Li et al. (2018) notes that grip strength is a reliable indicator of muscle strength. We suggest that handgrip is a better predictor of proximal femur BMD than isokinetic muscle strength because handgrip strength assessment is an objective measure of overall body muscle strength and physical function, as stated by Selakovic et al. (2019). Bohannon (2015) also identified grip strength as an important measure for frailty or sarcopenia, which can be used as an important predictor of future mortality.

We also concede that this study had several limitations. We did not measure plasma and hormone levels, vitamin D or any bone turnover markers. Small sample size could be seen as limiting our study. In addition, this was a cross-sectional study, which means that our ability to

Table 2
Associations between bone mineral density and body composition (N = 58).

	Lean body mass (kg)			Body fat mass (kg)			A/G fat ratio			ALM (kg)			BMI[a] (kg/m^2)		
	β	(95% CI)	*P*-value	*β*	(95% CI)	*P*-value	*β*	(95% CI)	*P*-value	*β*	(95% CI)	*P*-value	*β*	(95% CI)	*P*-value
BMD neck (g/cm^2)															
Model 1	0.07	(−0.20, 0.34)	0.60	0.20	(−0.06, 0.46)	0.14	−0.01	(−0.28, 0.25)	0.91	0.15	(−0.12; 0.44)	0.27	0.07	(−0.20; 0.34)	0.60
Model 2	−0.14	(−0.44, 0.16)	0.35	0.22	(−0.04, 0.49)	0.09	0.08	(−0.18, 0.35)	0.52	−0.07	(−0.38; 0.24)	0.65	0.16	(−0.11; 0.43)	0.23
Model 3	−0.15	(−0.48, 0.18)	0.36	0.31	(−0.01, 0.62)	0.05	0.10	(−0.18, 0.37)	0.48	−0.07	(−0.41; 0.26)	0.66	0.28	(−0.05; 0.60)	0.10
BMD ward (g/cm^2)															
Model 1	−0.06	(−0.32, 0.21)	0.67	0.14	(−0.13, 0.40)	0.30	−0.06	(−0.33, 0.21)	0.66	0.02	(−0.24; 0.29)	0.85	0.03	(−0.24; 0.30)	0.83
Model 2	−0.21	(−0.51, 0.09)	0.17	0.18	(−0.09, 0.45)	0.18	0.02	(−0.25, 0.28)	0.90	−0.14	(−0.45; 0.18)	0.39	0.13	(−0.13; 0.40)	0.32
Model 3	−0.23	(−0.55, 0.10)	0.17	0.16	(−0.10, 0.55)	0.17	0.03	(−0.24, 0.30)	0.83	−0.16	(−0.50; 0.18)	0.34	0.17	(−0.16; 0.49)	0.31
BMD proximal femur (g/cm^2)															
Model 1	0.05	(−0.22, 0.32)	0.72	0.31	(0.06, 0.57)	0.02	0.14	(−0.12, 0.41)	0.28	0.11	(−0.15; 0.38)	0.40	0.24	(−0.02; 0.50)	0.07
Model 2	−0.06	(−0.38, 0.27)	0.73	0.35	(0.07, 0.62)	0.01	0.20	(−0.07, 0.48)	0.14	0.02	(−0.31; 0.35)	0.90	0.31	(0.04; 0.58)	0.03
Model 3	−0.08	(−0.44, 0.27)	0.64	0.40	(0.07, 0.73)	0.02	0.21	(−0.07, 0.50)	0.14	−0.01	(−0.36; 0.35)	0.97	0.38	(0.05; 0.71)	0.03
BMD L_1-L_4 (g/cm^2)															
Model 1	0.12	(−0.15, 0.39)	0.38	0.13	(−0.14, 0.40)	0.35	0.20	(−0.07, 0.46)	0.15	0.15	(−0.12; 0.42)	0.27	0.12	(−0.15; 0.39)	0.39
Model 2	0.07	(−0.27, 0.41)	0.68	0.19	(−0.10, 0.48)	0.19	0.29	(0.01, 0.56)	0.04	0.08	(−0.27; 0.43)	0.64	0.19	(−0.08; 0.47)	0.17
Model 3	0.09	(−0.27, 0.46)	0.61	0.14	(−0.20, 0.49)	0.41	0.32	(0.04, 0.59)	0.02	0.06	(−0.31; 0.44)	0.73	0.19	(−0.15; 0.53)	0.28
BMD total body (g/cm^2)															
Model 1	0.18	(−0.08, 0.44)	0.18	0.17	(−0.09, 0.43)	0.20	0.02	(−0.25, 0.29)	0.88	0.24	(−0.02; 0.50)	0.07	0.13	(−0.14; 0.39)	0.35
Model 2	0.07	(−0.24, 0.39)	0.64	0.22	(−0.05, 0.50)	0.11	0.11	(−0.16, 0.39)	0.40	0.13	(−0.19; 0.44)	0.43	0.21	(−0.06; 0.48)	0.13
Model 3	0.08	(−0.26, 0.42)	0.64	0.23	(−0.10, 0.56)	0.16	0.13	(−0.15, 0.41)	0.36	0.12	(−0.22; 0.47)	0.47	0.27	(−0.06; 0.60)	0.10

Model 1 – unadjusted (raw) model.
Model 2 – adjusted for YSM, smoking status, height.
Model 3 – adjusted for Model 2 and steps per day.
β standardized regression coefficient, CI confidence interval, BMD bone mineral density, A/G android/gynoid fat mass ratio, ALM appendicular lean mass.
[a] BMI –Model 2 adjusted only for YSM and smoking status.

Table 3
Associations between bone mineral density and muscle strength (N = 58).

	Dominant leg muscle strength in flexion – peak torque (Nm)			Dominant leg muscle strength in extension – peak torque (Nm)			Dominant arm grip strength (kg)		
	β	(95% CI)	*P*-value	*β*	(95% CI)	*P*-value	*β*	(95% CI)	*P*-value
BMD neck (g/cm^2)									
Model 1	0.15	(−0.11, 0.42)	0.25	0.10	(−0.17, 0.37)	0.45	0.29	(0.03, 0.55)	0.03
Model 2	0.11	(−0.15, 0.36)	0.40	0.01	(−0.25, 0.28)	0.92	0.17	(−0.10, 0.45)	0.22
Model 3	0.02	(−0.25, 0.29)	0.86	−0.10	(−0.39, 0.18)	0.46	0.08	(−0.21, 0.37)	0.57
BMD ward (g/cm^2)									
Model 1	0.15	(−0.12, 0.41)	0.27	0.11	(−0.16, 0.38)	0.41	0.34	(0.08, 0.59)	0.01
Model 2	0.11	(−0.15, 0.36)	0.41	0.03	(−0.24, 0.29)	0.84	0.22	(−0.05, 0.49)	0.11
Model 3	0.06	(−0.22, 0.33)	0.69	−0.08	(−0.36, 0.21)	0.60	0.12	(−0.18, 0.41)	0.42
BMD proximal femur (g/cm^2)									
Model 1	0.12	(−0.15, 0.38)	0.37	0.03	(−0.24, 0.29)	0.86	0.15	(−0.12, 0.41)	0.27
Model 2	0.08	(−0.18, 0.34)	0.55	−0.04	(−0.31, 0.23)	0.75	0.06	(−0.23, 0.34)	0.69
Model 3	0.03	(−0.25, 0.31)	0.83	−0.13	(−0.42, 0.16)	0.34	−0.03	(−0.33, 0.27)	0.82
BMD L_1-L_4 (g/cm^2)									
Model 1	0.04	(−0.23, 0.31)	0.77	−0.17	(−0.46, 0.13)	0.25	0.24	(−0.03, 0.50)	0.08
Model 2	0.001	(−0.27, 0.27)	0.99	−0.06	(−0.34, 0.21)	0.64	0.15	(−0.14, 0.44)	0.31
Model 3	−0.04	(−0.33, 0.24)	0.76	0.02	(−0.26, 0.29)	0.90	0.03	(−0.28, 0.34)	0.85
BMD total body (g/cm^2)									
Model 1	0.17	(−0.10, 0.43)	0.21	−0.002	(−0.27, 0.27)	0.99	0.31	(0.06, 0.57)	0.02
Model 2	0.12	(−0.14, 0.38)	0.35	−0.10	(−0.37, 0.16)	0.44	0.22	(−0.05, 0.50)	0.11
Model 3	0.06	(−0.22, 0.33)	0.67	−0.24	(−0.51, 0.04)	0.10	0.13	(−0.16, 0.43)	0.36

Model 1 – unadjusted (raw) model.
Model 2 – adjusted for YSM, smoking status, weight (except BMI).
Model 3 – adjusted for model 2 and steps per day.
β standardized regression coefficient, CI confidence interval, BMD (bone mineral density), Nm (newton-meter).

assign causality was limited.

It is important to understand the roles of body composition and muscular strength in the maintenance of bone health in post-menopausal women, as this information has clinical implications for the development of interventions benefitting muscle and bone function.

In conclusion, we found an association between body fat mass and BMD of the proximal femur but not in lean body mass or appendicular lean mass. We also observed positive association between the lumbar spine BMD and the A/G ratio or between the proximal femur BMD and BMI. The obtained results also suggest that isokinetic muscle strength or grip strength has no significant role in the monitored bone density parameters. Further research with more participants is required to clarify these results.

Contributors

None.

Declaration of competing interest

There is no conflict of interest

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