



# Stages of sarcopenia, bone mineral density, and the prevalence of osteoporosis in older women

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## Abstract

**Summary** A better understanding of the relationship between osteoporosis and sarcopenia may help to develop effective preventive and therapeutic strategies. In the present study, the association between different stages of sarcopenia, BMD, and osteoporosis was examined. The salient findings indicate that a dose–response relationship exists between sarcopenia stages and bone-related phenotypes.

**Purpose** To assess the association between sarcopenia stages, bone mineral density (BMD), and the prevalence of osteoporosis in older women.

**Methods** Two hundred thirty-four women ( $68.3 \pm 6.3$  years) underwent body composition and BMD measurements using dual-energy X-ray absorptiometry. Quadriceps isokinetic torque was evaluated, and the timed up-and-go test was conducted as a measure of function. Sarcopenia stages were classified according to European Working Group on Sarcopenia in Older People (EWGSOP): nonsarcopenia, presarcopenia, sarcopenia, and severe sarcopenia. Osteoporosis was defined as BMD value (hip or spine) 2.5 standard deviations below a young-adult reference population. Between-group differences were examined using ANOVA for continuous variables and chi-squared for categorical variables. Logistic regression was performed to evaluate the association between sarcopenia stages and osteoporosis.

**Results** Rates of osteoporosis were 15.8%, 19.2%, 35.3%, and 46.2% for nonsarcopenia, presarcopenia, sarcopenia, and severe sarcopenia, respectively ( $P = 0.002$ ). Whole-body and femoral neck BMD values were significantly lower among all sarcopenia stages when compared to nonsarcopenia (all  $P$  values  $< 0.05$ ,  $\eta^2_p$  0.113 to 0.109). The severe sarcopenia group also showed significantly lower lumbar spine BMD values and T-scores (both  $P$  values  $< 0.05$ ;  $\eta^2_p$  0.035 and 0.037, respectively). When clustered, sarcopenia and severe sarcopenia exhibited lower BMD values for all sites (all  $P$  values  $< 0.01$ ), and presented a significantly higher risk for osteoporosis (odds ratio 3.445; 95% CI 1.521–7.844).

**Conclusion** The observed results provide support for the concept that a dose–response relationship exists between sarcopenia stages, BMD, and the presence of osteoporosis. These findings strengthen the clinical significance of the EWGSOP sarcopenia definition and indicate that severe sarcopenia should be viewed with attention by healthcare professionals.

**Keywords** Aging · Sarcopenia · Osteoporosis · Osteosarcopenia

## Introduction

Osteoporosis is defined as a chronic disease characterized by reduced bone mass, deterioration of bone tissue microarchitecture, and a consequent increase in bone fragility and susceptibility to fracture [1]. Osteoporotic fractures impose a significant burden on healthcare costs, and increase the risk for disability and mortality [2]. Recent estimates indicate a prevalence of more than 50% of low bone mineral density (BMD) at the femoral neck and lumbar spine among women aged  $\geq 50$  years in the US

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[1, 3–5]. In absolute terms, it is important to note that the prevalence of osteoporosis and its related complications are expected to increase as the aging populations increase worldwide [6]. Thus, osteoporosis is widely recognized as a major public health problem that warrants further research for an effective screening of more susceptible sections of the older women population.

Due to interactions between bone and skeletal muscle tissues, individuals suffering from osteoporosis usually present reduction in both fat-free mass (FFM) and muscle strength [7, 8]. In 1989, Roseberg [9] introduced the term “sarcopenia” to refer to the age-related decline in skeletal muscle mass. Currently, sarcopenia has been defined as a progressive decline in muscle mass, strength, and physical function, increasing the risk for a variety of adverse outcomes, including osteoporosis [7, 8, 10–12]. Even though muscle and bone tissues are morphologically different, their functioning is closely interconnected. It has been shown that FFM, muscle strength, and sarcopenia are related to BMD in postmenopausal women [7, 11]. Lee et al. [11] recognized sarcopenia as an independent risk factor for decreased BMD and osteoporosis condition (OR = 6.952, 95% CI = 3.418–14.139,  $P < 0.001$ ) among older people. More recently, a study in the ROAD cohort supported that the prevalence of coexisting sarcopenia and osteoporosis is high, and suggested that older people with sarcopenia should also be screened for osteoporosis [13]. A better understanding of the synchronic relationship between osteoporosis and sarcopenia may help in the development of more effective diagnostic, preventive, and therapeutic strategies.

Despite the notable growing research attention sarcopenia has received, a consensual definition is still lacking. As an attempt to address this shortfall, the European Working Group on Sarcopenia in Older People (EWGSOP) was created to develop a consensual operational definition [8]. Moreover, the EWGSOP document introduced the concept of different sarcopenia stages, including presarcopenia, sarcopenia, and severe sarcopenia, being the latter a combination of low muscle mass, muscle strength, and functional performance. Intuitively, it could be postulated that severe sarcopenia might impose an even higher risk for osteoporosis and reduced BMD; however, no previous studies have addressed this question. Therefore, the aim of the present study was to assess the association between different stages of sarcopenia, BMD, and the prevalence of osteoporosis in older women. Based on previous evidences of an association between both FFM and strength with bone health, we hypothesized that severe sarcopenia would be associated to a greater extent with reduced BMD and increased prevalence osteoporosis.

## Materials and methods

### Subjects

Approximately 500 volunteers were invited to take part in this cross-sectional study through flyers, phone calls, e-marketing, and visits to senior centers. A total of 335 individuals agreed to participate in this project developed at the University of Brasilia between 2015 and 2018, and were then assessed for eligibility. Eligibility criteria included women between 60 and 85 years, of which 307 participants were identified. Exclusion criteria were as follows: incapacity to walk without assistance, lower limb prosthesis, musculoskeletal or neurological disorders (such as fibromyalgia syndrome, Parkinson disease, chronic myalgia, multiple sclerosis, severe rheumatoid arthritis, or uncontrolled epilepsy), and a 6-month postoperative condition. Also, the Mini-Mental State Examination and the Katz index were used to verify that none of the volunteers suffered from cognitive impairment [14] or functional dependency [15], respectively. After exclusion criteria were applied, a total of 234 (46.8%) community-dwelling women engaged in the study.

All participants were informed about the study procedures and voluntarily signed an informed consent form. All experiments on human subjects were conducted in accordance with the Declaration of Helsinki, and the study protocol was previously approved by the University of Brasilia Review Board, under protocol no. 1,223,636/2015.

### Body composition and osteoporosis classification

Initially, subjects were weighed on a digital scale to the nearest 50 g (Lider®, P150M, São Paulo, Brazil) and height was measured with a wall stadiometer (Sanny®, São Paulo, Brazil). Body mass index was calculated dividing body weight by the square of the height ( $\text{kg}/\text{m}^2$ ) of the volunteers.

Body composition was measured using dual-energy X-ray absorptiometry (DXA) (lunar model 8743, GE Medical Systems, USA) according to procedures specified elsewhere [16]. Briefly, subjects laid face up on the DXA table with body carefully centered. As recommended by the EWGSOP [8], relative appendicular FFM was obtained ( $\text{kg}/\text{m}^2$ ). Of note, previous reports demonstrate that appendicular FFM is more strongly correlated to whole-body muscle mass than is total FFM [17]. Thus, the lowest tertile of the distribution for relative appendicular FFM was classified as low muscle mass [18].

BMD values and *T*-scores were also determined using DXA. The scans included total body, as well as lumbar spine and femoral neck sites. The scan procedure for each site was performed separately according to the manufacturer's recommendations. BMD was presented as measured values ( $\text{g}/\text{cm}^2$ ).

All subjects were screened for osteoporosis which was verified by general practitioner based on BMD values at the hip or spine  $\leq 2.5$  standard deviations below the mean BMD of a young-adult reference population, according to the World Health Organization specifications [19].

All measurements were carried out by the same trained technician, and the equipment was calibrated according to manufacturer specifications. A single individual was scanned for six consecutive days in the equipment and observed coefficients of variation were 0.9% for FFM and 1.9% for fat mass. Also, coefficient of variation was 0.7% for lumbar spine and whole-body BMD, and 2.4% for femoral neck BMD.

### Isokinetic muscle torque

Knee extensor peak torque (PT) was measured using an isokinetic dynamometer (Biodex 4, Biodex Medical, Inc., Shirley, NY, USA). After a warm-up involving two sub-maximal sets of 10 repetitions, the testing protocol consisted of two sets of four knee extensions at  $60^\circ\text{s}^{-1}$  with 60 s between sets [20]. The recorded value was the single muscle contraction that elicited the highest PT throughout the protocol. Participants were asked to perform the movement with their maximal strength while verbal encouragement was offered.

After a full explanation of the procedures, participants were seated on the dynamometer which was then carefully adjusted. The rotation axis of the dynamometer arm was oriented with the lateral condyle of participants' dominant femur. Both arms were positioned crossed over the chest, and Velcro belts were used at the trunk, pelvis, and thigh to avoid possible compensatory movements. Participants were asked to perform the movement with their maximal strength while verbal encouragement was offered. The cutoff for low muscle strength was set at 76.4 Nm (the lowest tertile of the distribution for isokinetic PT at  $60^\circ\text{s}^{-1}$ ) [21]. Calibration of the equipment was performed according to the manufacturer's specifications before every testing session. Test–retest reliability coefficient value for knee extensor peak torque was 0.91 in our laboratory.

### Functional performance

Functional performance was measured using the timed up-and-go test (TUG) [22]. Procedures were fully explained before assessments and were followed by a familiarization attempt. In brief, volunteers were individually seated in a standard chair with 45 cm of height, with the back against the chair, both arms resting along the body, and both feet completely resting on the floor. Volunteers were instructed to, on the word “go,” get up and walk 3 m forward, as fast as possible, turn around a cone, return to the chair, and sit down again. The best performance after three attempts with 60 s of rest intervals was recorded for subsequent analyses.

The cutoff for low functional performance was the highest tertile for the time required to complete the test [18].

### Stages of sarcopenia

Stages of sarcopenia were classified according to EWGSOP specifications [8]. Volunteers were stratified into four different groups: nonsarcopenia, presarcopenia, sarcopenia, and severe sarcopenia. Each of these sarcopenia stages considered outcomes from body composition (relative appendicular FFM [ $\text{kg}/\text{m}^2$ ]), isokinetic muscle strength (PT at  $60^\circ\text{s}^{-1}$  [ $\text{Nm}$ ]), and functional performance (TUG[s]) tests. Presarcopenia was characterized by low muscle mass, but normal muscle strength and functionality. Sarcopenia condition was characterized by low muscle mass, in addition to low muscle strength or low functional performance. Finally, severe sarcopenia was characterized by meeting concomitantly all three criteria. Subsequent analyses were also conducted into two groups: reference and sarcopenia pooled. The reference group was composed by subjects classified as nonsarcopenia and presarcopenia, while sarcopenia pooled combined volunteers of sarcopenia and severe sarcopenia groups.

### Statistics

Descriptive characteristics are presented as means and standard deviations, unless otherwise noted. The Kolmogorov–Smirnov test was used to verify data distribution normality. Sarcopenia-related traits were divided into tertiles, and the cutoff values to identify low muscle mass, low muscle strength, and low functional performance were the worst-performing tertile. Between sarcopenia stages comparisons were applied by ANOVA one way with Bonferroni correction. The procedure was repeated including potential covariates such as medications use, hormone replacement therapy, physical activity levels, and smoking status. Eta squared ( $\eta^2$ ) for between-group effect sizes were calculated and interpreted as follows: small effect ( $< 0.01$ ), small to medium effect (0.01 to 0.10), and medium to large (0.10 to 0.25) [23].  $\chi^2$  was performed to assess differences in medication use, hormone replacement therapy, physical therapy, and smoking by sarcopenia stages. Logistic regression was used to calculate the association (odds ratio (OR) and 95% confidence interval (CI)) between sarcopenia stages and osteoporosis, with adjustments for potential confounding variables. Data were considered significant at  $P < 0.05$ , and statistical analyses were performed using SPSS 20.0.

### Results

Table 1 shows descriptive characteristics of the participants according to sarcopenia stages. The number of volunteers in

**Table 1** Descriptive characteristics of the sample stratified according to each stage of sarcopenia and its between-group comparisons. Data are expressed as mean and standard deviation for continuous variables, and frequency and 95% confidence interval for categorical variables

	Nonsarcopenia (n = 177)	Presarcopenia (n = 26)	Sarcopenia (n = 17)	Severe sarcopenia (n = 14)	P	Eta <sup>2</sup>
<b>Continuous variables</b>						
Age (years)	67.58 ± 5.95	67.68 ± 5.79	71.82 ± 5.84*†	75.42 ± 6.20*†	< 0.01	0.104
Menopause (years)	20.11 ± 9.77	18.68 ± 9.32	21.82 ± 8.55	30.25 ± 12.76*†‡	< 0.01	0.056
Body mass (kg)	71.04 ± 10.88	56.68 ± 6.00*	57.40 ± 9.11*	58.43 ± 9.23*	< 0.01	0.248
Height (m)	1.56 ± 0.06	1.57 ± 0.05	1.55 ± 0.06	1.51 ± 0.06*†	0.04	0.036
Body mass index (kg/m <sup>2</sup> )	29.13 ± 4.03	22.98 ± 2.30*	23.79 ± 3.12*	25.44 ± 3.09*	< 0.01	0.276
Body fat (%)	45.11 ± 5.62	41.25 ± 5.18*	41.55 ± 7.05*	44.88 ± 7.44	< 0.01	0.059
FFM (kg)	36.61 ± 3.84	31.90 ± 2.79*	31.25 ± 3.32*	29.88 ± 2.31*	< 0.01	0.290
Appendicular FFM (kg)	15.36 ± 1.71	12.88 ± 0.99*	12.11 ± 1.18* †	11.66 ± 1.02*	< 0.01	0.403
Relative AFFM (kg/m <sup>2</sup> )	6.30 ± 0.55	5.22 ± 0.28*	5.04 ± 0.45*	5.10 ± 0.33*	< 0.01	0.490
Isokinetic PT 60°s <sup>-1</sup> (Nm)	90.67 ± 25.24	92.51 ± 14.75	68.11 ± 7.81*†	54.63 ± 11.59*†	< 0.01	0.155
Timed up-and-go (s)	7.10 ± 1.30	6.42 ± 0.69*	7.20 ± 1.05†	9.20 ± 1.06*†‡	< 0.01	0.164
<b>Categorical variables % (95% CI)</b>						
Alcohol consumption	33.0 (26.1–40.3)	44.0 (24.0–64.0)	35.3 (11.8–58.8)	7.7 (0.1–23.1)	0.158	5.192
Smoking	3.4 (0.6–6.3)	0	5.9 (0.0–17.6)	0	0.627	1.745
Previous falls	34.1 (27.0–40.9)	28.0 (12.0–44.0)	29.4 (11.8–52.9)	46.2 (15.4–76.9)	0.768	1.138
Physically active	27.3 (18.8–31.8)	36.0 (20.0–56.0)	23.5 (5.9–47.1)	30.8 (7.7–53.8)	0.821	5.148
Hormonal replacement	11.9 (7.4–16.5)	8.0 (0.0–20.0)	5.9 (0.0–17.6)	0	0.479	2.481

FFM fat-free mass, PT peak torque, CI confidence interval

\*Significant difference in relation to the nonsarcopenia group ( $P < 0.05$ );

†Significant difference in relation to the presarcopenia group ( $P < 0.05$ )

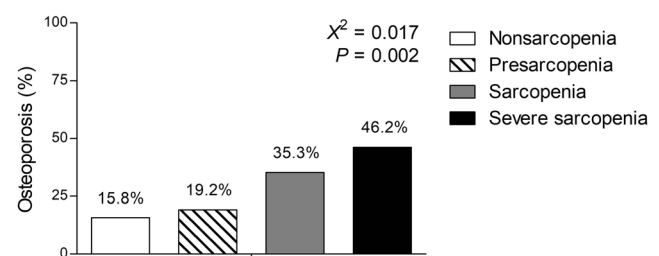
‡Significant difference in relation to the sarcopenia group ( $P < 0.05$ )

the nonsarcopenia, presarcopenia, sarcopenia, and severe sarcopenia groups were 177 (75.6%), 26 (11.1%), 17 (7.3%), and 14 (6%), respectively. It was observed that individuals in the sarcopenia and severe sarcopenia groups were older than the reference group ( $P < 0.01$ ;  $\eta^2_p = 0.104$ ; Table 1). Nonsarcopenic subjects presented higher body mass, body mass index, and body fat percentage when compared to other groups ( $P < 0.01$ ;  $\eta^2_p$  0.276). As expected, all sarcopenia traits (i.e., muscle mass, strength, and functional performance) were progressively lower as the severity of the condition increased (all  $P$  values  $< 0.01$ ;  $\eta^2_p$  0.155 to 0.490; Table 1). The prevalence of alcohol consumption, smoking, hormone replacement therapy, history of falls, and high physical activity level were 33% (95% CI 27–39.6), 3% (95% CI 0.9–5.7), 10.4% (95% CI 7–14.8), 33.5% (95% CI 27.4–40), and 1.7% (95% CI 0.4–3.5), respectively, with no difference between sarcopenia stages. The overall prevalence for osteoporosis was 19.2% (CI 95%; 14.5–24.4%). Rates of osteoporosis according to each stage of sarcopenia were 15.8%, 19.2%, 35.3%, and 46.2% for nonsarcopenia, presarcopenia, sarcopenia, and severe sarcopenia, respectively ( $P = 0.002$ ; Fig. 1).

Between-group comparisons for BMD values and  $T$ -scores at total body, lumbar spine, and femoral neck are presented in Table 2. For whole-body BMD and  $T$ -scores, all sarcopenia stages exhibited significantly lower values when compared to

the nonsarcopenia group (all  $P$  values  $< 0.05$ ,  $\eta^2_p$  0.113 to 0.109), with no significant differences among presarcopenia, sarcopenia, and severe sarcopenia (Table 2). Regarding femoral neck site, it was observed that sarcopenic subjects (i.e., sarcopenia or severe sarcopenia) presented lower values for BMD and  $T$ -score when compared to nonsarcopenic subjects (all  $P$  values  $< 0.05$ ;  $\eta^2_p$  0.132 to 0.135). For lumbar spine, severe sarcopenia showed lower BMD and  $T$ -score values in relation to all remaining groups (all  $P$  values  $< 0.05$ ;  $\eta^2_p$  0.035 to 0.037; Table 2). When sarcopenia and severe sarcopenia were combined into a single group, BMD and  $T$ -score values at all measured sites showed to be significantly lower when compared to the reference group (all  $P$  values  $< 0.01$ ; Table 3).

Volunteers classified with severe sarcopenia presented significantly higher risk of osteoporosis (odds ratio 3.991; 95%



**Fig. 1** Proportion of osteoporosis according to each sarcopenia stage

**Table 2** Between-group comparison of bone mineral density and *T*-score. Data are expressed as mean and standard deviation

Variable	Nonsarcopenia ( <i>n</i> = 177)	Presarcopenia ( <i>n</i> = 26)	Sarcopenia ( <i>n</i> = 17)	Severe sarcopenia ( <i>n</i> = 13)	Overall <i>P</i>	Eta <sup>2</sup>
Lumbar spine BMD (g/cm <sup>2</sup> )	1.056 ± 0.146	1.039 ± 0.154	0.987 ± 0.164	0.950 ± 0.211*	< 0.05	0.035
Lumbar spine <i>T</i> -score	- 1.113 ± 1.184	- 1.290 ± 1.181	- 1.676 ± 1.346	- 1.991 ± 1.738*	< 0.05	0.037
Femoral neck BMD (g/cm <sup>2</sup> )	0.867 ± 0.115	0.834 ± 0.092	0.756 ± 0.115*	0.705 ± 0.149*	< 0.01	0.135
Femoral neck <i>T</i> -score	- 1.235 ± 0.837	- 1.460 ± 0.665	- 2.029 ± 0.834*	- 2.391 ± 1.072*	< 0.01	0.132
Total BMD (g/cm <sup>2</sup> )	1.090 ± 0.082	1.053 ± 0.088*	1.012 ± 0.092*	0.988 ± 0.123*	< 0.01	0.113
Total <i>T</i> -score	- 0.434 ± 1.040	- 0.892 ± 1.109*	- 1.394 ± 1.146*	- 1.691 ± 1.542*	< 0.01	0.109

*BMD* bone mineral density

\*Significant difference in relation to the nonsarcopenia group based on Bonferroni tests (*P* < 0.05)

CI 1.286–12.391); however, the significance was not maintained after adjustments for age and body mass index (Table 4). When sarcopenia and severe sarcopenia were combined into a group, a significantly higher risk of osteoporosis was noted in relation to the reference group (odds ratio 3.445; 95% CI 1.521–7.844). These results remained significant after adjustments for age and body mass index (odds ratio 2.515; 95% CI 1.046–6.047).

## Discussion

Consistent with previous reports [7, 11, 24, 25], the present study provides support for an association between sarcopenia and osteoporosis in postmenopausal women. This was the first study, however, to investigate the association between the EWGSOP-defined stages of sarcopenia, BMD, and the prevalence of osteoporosis. The salient findings indicate that a dose–response relationship exists between sarcopenia stages and bone-related phenotypes, with the severity of sarcopenia presenting the lower BMD values, and an increased risk for the presence of osteoporosis. In conjunction, the results presented here strengthen the clinical significance of the EWGSOP sarcopenia definition, and indicate that severe sarcopenia should be viewed with attention by health-professionals, including in the screening for osteoporosis and fracture risks.

The present study is in agreement with previous evidences of an association between FFM and BMD in postmenopausal women [7, 26]. Walsh et al. [27] compared bone mineral content between normal and sarcopenic (based solely in terms of FFM) postmenopausal women, and observed that sarcopenic subjects also had significantly lower BMD values. Later, Liang et al. [28] corroborated these observations in an ethnically diverse young women population. Other evidences indicate that, in general, reduced lower limb FFM is accompanied by low BMD values [26, 29]. A positive relationship between FFM and BMD had also been ascertained in postmenopausal Brazilian women [10]. Currently, sarcopenia is not solely defined in terms of muscle mass, but also incorporate measures of muscle strength [8, 30], which is also related to bone health. Kritiz-Silverstein and Barrett-Connor [31] examined the association between grip strength and BMD in 649 women aged 65 years or older, and found that the strength index was related not only to forearm BMD, bone structure adjacent to the evaluated muscle group, but also to BMD at lumbar spine and hip. Dixon et al. [32] reported that, in women aged 50 years and over, low grip strength was associated with all examined BMD sites, and also with an increased risk of fractures. The question remains as to whether the clustering of low FFM and muscle strength would be more strongly related to low BMD and osteoporosis.

Sarcopenia and osteoporosis are two musculoskeletal conditions that are likely to be increasingly prevalent as the

**Table 3** Comparisons between reference group and sarcopenia pooled subjects regarding bone mineral density and *T*-score variables. Data are expressed as mean and standard deviation

Variable	Reference ( <i>n</i> = 203)	Sarcopenia pooled ( <i>n</i> = 30)	<i>P</i>	Eta <sup>2</sup>
Lumbar spine BMD (g/cm <sup>2</sup> )	1.054 ± 0.147	0.971 ± 0.182	< 0.01	0.032
Lumbar spine <i>T</i> -score	- 1.136 ± 1.182	- 1.806 ± 1.499	< 0.01	0.033
Femoral neck BMD (g/cm <sup>2</sup> )	0.863 ± 0.113	0.735 ± 0.130	< 0.001	0.122
Femoral neck <i>T</i> -score	- 1.264 ± 0.819	- 2.179 ± 0.939	< 0.001	0.120
Total body BMD (g/cm <sup>2</sup> )	1.085 ± 0.084	1.002 ± 0.104	< 0.001	0.094
Total body <i>T</i> -score	- 0.493 ± 1.058	- 1.517 ± 1.307	< 0.001	0.091

Reference nonsarcopenia + presarcopenia, *sarcopenia pooled* sarcopenia + severe sarcopenia, *BMD* bone mineral density



**Table 4** Odds ratio (confidence interval 95%) for osteoporosis regarding each stage of sarcopenia

	Odd ratios	CI 95%
Stages of sarcopenia		
Nonsarcopenia	1	
Presarcopenia		
Unadjusted	1.267	0.441–3.641
Adjusted <sup>†</sup>	1.303	0.441–3.850
Sarcopenia		
Unadjusted	2.661	0.922–7.679
Adjusted <sup>†</sup>	2.135	0.704–6.469
Severe sarcopenia		
Unadjusted	3.991	1.286–12.391
Adjusted <sup>†</sup>	3.036	0.899–10.249
Pooled sarcopenia (sarcopenia + severe sarcopenia)		
Unadjusted	3.445	1.521–7.844
Adjusted <sup>†</sup>	2.515	1.046–6.047

CI confidence interval

<sup>†</sup>Adjusted for age and body mass index

world's population ages. Both conditions share common etiological pathways, and there is a growing support for the notion that sarcopenia and osteoporosis are closely linked [7, 11, 24, 25]. It has been postulated that muscle contraction forces provide a mechanical stress on the bones, thus generating an important osteogenic stimulus [33]. In addition, later evidences provide support for the concept that a bidirectional bone-muscle crosstalk exists, which is probably mediated by cytokines, osteokines, myokines, and other growth factors [33]. In recognition of the close relationship between osteoporosis and sarcopenia, the term osteosarcopenia has been introduced [24] to describe the coexistence of both conditions.

The EWGSOP was created in 2010 to develop a consensual operational sarcopenia definition [8]. Moreover, the EWGSOP introduced the concept of sarcopenia staging, reflecting the gravity of the condition, with the aim of guiding its clinical management. Intuitively, it is thought that the negative impact of sarcopenia on clinical outcomes would be more severe with progressing sarcopenia stages. However, evaluation of these sarcopenia stages in relation to relevant clinical outcomes has been examined in only a handful of reports [18, 30, 34, 35], none of which including bone health traits. Morat et al. [34] observed that laboratory-based neuromuscular function significantly differs among the conceptual stages, while Huang et al. [35] have later observed that severe sarcopenia represents an independent risk for postoperative complications after gastrectomy for gastric cancer. More recently, Gadelha et al. demonstrated that the gravity of sarcopenia is linked to reduced balance [18] and increased incidence of falls [30]. Therefore, available data indicate that recognizing EWGSOP-defined sarcopenia stages is clinically

meaningful and may help to guide effective treatment strategies. It should be pointed out, however, that the working group just published the revised version of the consensus [36], which basically brings poor muscle strength to the forefront step, which should be subsequently examined for reduced muscle quantity or quality. For the detection of severe sarcopenia, the only change is that muscle quality may serve as an alternative for muscle quantity, and thus is expected that results presented here remain unchanged with the updated EWGSOP classification. Nevertheless, it is important that future studies explore the clinical significance of the revised operational definition.

The present study adds further support to the growing evidence that sarcopenia and osteoporosis frequently occur concomitantly, and brings the novel insight that bone health is progressively impaired with advancing sarcopenia stages. To reach clinical significance, however, the literature in the field should be interpreted in the light of its practical application. In particular, it would be relevant to incorporate latest knowledge into the prevention, screening, and treatment of osteoporosis. In this regard, current screening guidelines [37] [38] are mainly based on BMD measurement, which is usually conducted by DXA. Based on the osteosarcopenia concept, it is reasonable that when every woman undergoes bone densitometry evaluation, attention should also be demanded to muscle mass indexes, since the method provide concurrent measurement of both BMD and FFM. Moreover, considering that current sarcopenia definitions specify the presence of low muscle strength or physical function for the diagnosis of sarcopenia, it is rational that osteoporosis management approaches include such measures. The results of the present study indicate that severe sarcopenia, a stage characterized by low muscle mass, strength, and function, imposes an even higher risk for osteoporosis. Moreover, it can be postulated that older women with severe sarcopenia are at a crucial risk for fractures and related complications given the fact that besides presenting more fragile bones, they are also more prone to falls [18, 30], and thus should be viewed with attention by health-professionals acting in the promotion of bone health.

The novelty of the results and objective measures of sarcopenia and osteoporosis are strengths of the present study. Nevertheless, limitations should also be recognized. The fact that the study sample was composed by functionally independent community-dwelling women might raise the question as to whether the results apply to more frail sections of the older population. Also, sample size is relatively small due to the use of sophisticated techniques to define sarcopenia, as well as for osteoporosis ascertainment. Finally, the cross-sectional nature of the report and impossibility to address all potential confounders (i.e., medications classes and doses, comorbidity severity, and nutritional habits) precludes establishment of cause and effect relationship. Therefore, although the results presented here adds to the literature in the field, they should be

considered as preliminary and longitudinal investigations are recommended to assess the temporal relationship between sarcopenia stages, BMD, and the incidence of osteoporosis.

## Conclusion

The observed results provide support for the concept that a dose–response relationship exists between sarcopenia stages, BMD, and the presence of osteoporosis in older women. These findings strengthen the clinical significance of the EWGSOP sarcopenia definition and indicate that severe sarcopenia, a condition characterized by reduced FFM, muscle strength, and physical function, should be viewed with attention by health professionals, including when gauging the risk for osteoporosis and fractures.

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## Compliance with ethical standards

All participants were informed about the study procedures and voluntarily signed an informed consent form. All experiments on human subjects were conducted in accordance with the Declaration of Helsinki, and the study protocol was previously approved by the University of Brasilia Review Board, under protocol no. 1,223,636/2015.

**Conflicts of interest** None.

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