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Sarcopenia in Postmenopausal Women: Associations with Age at Menopause and Osteoporosis

Postmenopozal Kadınlarda Sarkopeni: Menopoz Yaşı ve Osteoporoz ile İlişkisi

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Abstract

Objective: To investigate the relationship between age at menopause, osteoporosis, and sarcopenia in postmenopausal women.

Materials and Methods: This cross-sectional study included 128 postmenopausal women. While sarcopenia was defined according to European working group on sarcopenia in older people criteria, osteoporosis was diagnosed by dual-energy X-ray absorptiometry. Associations between sarcopenia, age at menopause, and osteoporosis were examined using chi-square tests, One-Way ANOVA, and standard/penalized binary logistic regression.

Results: Probable sarcopenia was identified in 19.5% of participants (n=25), and sarcopenia in 21.1% (n=27). The frequency of osteoporosis was 19.7% in those without sarcopenia, 48.0% in those with probable sarcopenia, and 82.0% in those with sarcopenia. Mean age at menopause was significantly lower in individuals with sarcopenia compared with those with probable sarcopenia and those without sarcopenia (41.4 vs. 45.0 vs. 46.0 years, respectively; p<0.001). In the penalized multivariable binary logistic regression analysis, after adjusting for chronological age and body mass index, osteoporosis demonstrated a borderline non-significant association with sarcopenia [odds ratio (OR), 3.59; 95% confidence interval (CI), 0.96-14.76; p=0.058]. On the other hand, a statistically significant independent association was found between earlier age at menopause and sarcopenia (OR, 0.89; 95% CI, 0.78-0.99; p=0.041).

Conclusion: While earlier age at menopause was independently associated with sarcopenia in postmenopausal women, robust studies with large sample sizes are needed to more clearly establish the statistical and clinical significance of the association between osteoporosis and sarcopenia.

Keywords: Age at menopause, osteoporosis, postmenopausal women, sarcopenia

Öz

Amaç: Postmenopozal kadınlarda menopoz yaşı, osteoproz ve sarkopeni arasındaki ilişkiyi incelemektir.

Gereç ve Yöntem: Bu kesitsel çalışmaya 128 postmenopozal kadın dahil edildi. Sarkopeni tanısı yaşlılarda sarkopeni üzerine Avrupa çalışma grubu kriterlerine göre konarken osteoporoz tanısı çift enerjili X-ışını absorpsiyometri ile kondu. Sarkopeni, menopoz yaşı ve osteoporoz arasındaki ilişkiler ki-kare testleri, tek yönlü ANOVA ve standart/kısıtlanmış ikili lojistik regresyon kullanılarak incelendi.

Bulgular: Katılımcıların %19,5'inde (n=25) muhtemel sarkopeni saptanırken, %21,1'inde (n=27) ise sarkopeni tespit edildi. Osteoporoz sıklığı, sarkopeni olmayanlarda (%19,7), muhtemel sarkopeni olanlarda (%48,0) ve sarkopeni olanlarda (%82,0) idi. Menopoz yaşı ortalaması, sarkopeni olan bireylerde muhtemel sarkopeni olan ve sarkopeni olmayan bireylere kıyasla anlamlı olarak daha düşüktü (sırasıyla 41,4, 45,0 ve 46,0 yıl; p<0,001). Kısıtlanmış çok değişkenli ikili lojistik regresyon analizinde, kronolojik yaş ve vücut kitle indeksi kontrol altına alındığında, osteoporoz sarkopeni ile istatistiksel olarak anlamlı olmayan sınırda bir ilişki gösterdi [olasılık oranı (OR): 3,59; %95 güven aralığı (GA): 0,96-14,76; p=0,058]. Diğer yandan, erken menopoz yaşı ile sarkopeni arasında ise istatistiksel olarak anlamlı bağımsız bir ilişki bulundu [OR (%95 GA): 0,89 (0,78-0,99), p=0,041].

Sonuç: Postmenopozal kadınlarda erken menopoz yaşı ile sarkopeni arasında bağımsız bir ilişki saptanırken, osteoporoz ve sarkopeni arasındaki ilişkinin istatistiksel ve klinik önemini daha net ortaya koymak için büyük örneklemli sağlam çalışmalara ihtiyaç vardır.

Anahtar kelimeler: Menopoz yaşı, osteoporoz, postmenopozal kadın, sarkopeni

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Introduction

Sarcopenia is a progressive, generalized disorder of the skeletal muscles associated with an increased risk of adverse outcomes, such as falls, fractures, physical disability and death (1-3). The prevalence of sarcopenia in the elderly population ranges between 12% and 27%, depending on the classification method used (4). The prevalence also varies according to sex. Although this is a controversial topic, the prevalence of sarcopenia in older women is generally higher than in older men, depending on the classification used (4).

One of the main factors for the sex difference in the prevalence of sarcopenia is attributed to menopause that women experience (5). The menopausal period is characterized by a dramatic decrease in cessation of ovarian follicular activity (6), which not only affect productivity but also affect a woman's metabolism, bone health and muscle function (7-10). Along with the decline in estrogen levels, numerous metabolic pathways, including those related to muscle and bone physiology, are affected. Changes in the metabolism of proteins, carbohydrates and fats result in a decrease in muscle and bone mass (11), which has direct and indirect effects on functionality. Beyond aging and alongside it, the menopausal state has been identified as risk factor for sarcopenia development in women (9). Conceptually, the relationship between sarcopenia and menopause is not only confined to the menopausal period (i.e., the physiological changes that occur during this time). Both premature menopause and the length of the postmenopausal period are also risk factors for developing sarcopenia (12,13). Age at menopause is another factor that may be associated with sarcopenia, in addition to premature/early menopause and the length of the postmenopausal period (14,15). Although the premature/early menopause, the age at menopause, and the length of the postmenopausal period are interrelated, they are not exactly the same concepts. The age at menopause addresses the transition process more gradually, rather than classifying women as experiencing premature/early menopause or entering menopause at the normal expected age. Under this approach, a woman who enters menopause at 44 is not distinguished sharply from one who enters menopause at 45. This approach also mitigates the limitations of placing women who enter menopause at ages 45 and 55 in the same category. In addition, the relationship between the duration of the postmenopausal period and chronological age is likely stronger than that between the other two factors. This may complicate the relationship between sarcopenia and the duration of the postmenopausal period, making it difficult to reach a definitive conclusion.

Starting from the onset of menopause the combination of reduced bone mass and muscle mass/function during the postmenopausal period may lead to increase in fracture risk (16). Accordingly, to focus on both sarcopenia and osteoporosis simultaneously in terms of preventing fractures during the postmenopausal process is of importance. In this respect, this study aimed to investigate whether age at menopause and osteoporosis are associated with sarcopenia in postmenopausal women. Despite certain limitations (such as the possibility that the relationship between age at menopause and sarcopenia may not be linear), this study focused on the relationship between age at menopause and sarcopenia for the reasons explained above. The hypothesis was that age at menopause and existence of osteoporosis are independently associated with sarcopenia after adjustment for confounding factors.

Materials and Methods

Approval for this cross-sectional observational study was obtained from the Local Ethics Committee of İzmir Katip Çelebi University (decision no: 0167, dated: 03/21/24), and the study was conducted in accordance with the relevant guidelines and regulations of the Declaration of Helsinki. Participants were informed about the study and their written consent was obtained. After obtaining the ethics committee approval, the participants were evaluated between March 22, 2024, and December 31, 2024.

Participants

This study included postmenopausal women aged 50-80 who attended the physical medicine and rehabilitation clinic at a tertiary care hospital and who had dual-energy X-ray absorptiometry (DXA) results taken within the last year. The following individuals were excluded from the study: Participants with impaired cognitive function; those with serious medical conditions, including stroke, severe cardiovascular disease, or a history of severe pulmonary disease; those with rheumatic disorders; those with prostheses or implants in the lower extremities; those with spinal cord injury; those with a history of spinal surgery; those receiving glucocorticoid therapy; and those with a diagnosis of cancer. Participants were included in the study on a consecutive basis.

Diagnosis of Sarcopenia

The diagnosis of sarcopenia was based on the European working group on sarcopenia in the elderly (EWGSOP2) criteria (1). Accordingly, the evaluation was based on muscle strength assessment, appendicular skeletal muscle measurement, and physical performance.

Muscle strength was assessed using a hand-grip strength test with a dynamometer (Jamar Hydraulic Hand Dynamometer, Patterson Medical, Warrenville, IL, USA). Patients were seated in a standard chair with their forearms resting on the armrests. They were then asked to grip the dynamometer as tightly as possible. A total of six measurements were taken, three for each arm. Ideally, patients were encouraged to squeeze with maximum force for three to five seconds during each trial. The highest value obtained from the six measurements was reported (17). Muscle strength was considered low if measured ≤16 kg for women (1).

Appendicular muscle mass measurement was assessed using bioelectrical impedance analysis (BIA) with the Tanita BC-601 body composition monitor (Tanita, Tokyo, Japan). A height-adjusted appendicular skeletal muscle mass of <5.5 kg/m² in women was considered low muscle mass (1). The BIA is a non-invasive method that can be used as an alternative to techniques such as DXA, computed tomography and magnetic resonance imaging. Rather than measuring muscle mass directly, BIA estimates it using a regression equation. To the best of our knowledge, although the regression equation for this device has not been disclosed, it includes variables such as impedance, gender, age and height (18,19). BIA demonstrates strong criterion validity, showing high correlation with DXA-derived measurements for fat-free mass (FFM) (19,20). BIA systems often prioritized over DXA due to their cost-effectiveness, portability, ease of operation. Furthermore, BIA offers a non-ionizing alternative to DXA. In this study a device that performs BIA measurements was used due to its availability and the fact that it does not emit radiation.

Physical performance was assessed using the short physical performance battery (SPPB) (21). The SPPB is a composite test combining walking speed, chair rise and balance results. Scores range from 0 (worst performance) to 12 (best performance). The maximum possible score is 12. A score of ≤8 indicates poor physical performance (21).

According to these assessments, individuals with no loss in muscle strength, muscle mass, or physical performance were classified as not having sarcopenia; those with only muscle strength loss were classified as having probable sarcopenia; and those with muscle strength and mass loss were classified as having sarcopenia (1). Individuals with severe sarcopenia in whom all three components were impaired were merged into the sarcopenia group for the analysis.

All sarcopenia components (muscle strength, mass, and physical performance) were assessed by the same trained clinician using calibrated equipment (JAMAR dynamometer and Tanita BC-601 body composition monitor) according to a pre-defined EWGSOP2 protocol.

Diagnosis of Osteoporosis

Osteoporosis was diagnosed based on bone mineral density (BMD) measurements obtained using DXA. Participants were classified as having normal BMD if the T-score was >-1.0, osteopenia if the T-score ranged from -1.0 to -2.49, and osteoporosis if the T-score was ≤-2.5, or ≤-1.0 in the presence of a history of at least one fragility fracture (22). Diagnostic criteria for osteoporosis were consistently applied based on DXA scores and fracture history to ensure categorical accuracy.

Assessment of Balance

Balance, a clinically important factor associated with sarcopenia and osteoporosis as well as fall risk and subsequent fracture development, was also assessed. Balance was assessed using the Berg balance scale (BBS) (23,24) by the same trained clinician. The scale contains 14 items, and for each item, the patient's performance is observed and scored on a scale of 0 to 4. If the patient is unable to perform the activity at all, a score of 0 is given; if the patient completes the activity independently, a score of 4 is given. The maximum score is 56, with 0-20 points indicating balance impairment, 21-40 points indicating acceptable balance, and 41-56 points indicating good balance (23). The reliability and validity of this scale in Turkish have been established by Sahin et al. (24)

Sample Size

The sample size was determined using G*Power software (version 3.1.9.6, Universität Kiel, Germany). Based on the reported prevalence of sarcopenia in the general population (20% among non-Asian women) versus that of postmenopausal women in Türkiye (44%), an a priori sample size calculation was performed (25,26). Using the Exact test family for proportions (difference from constant/binomial test), a minimum requirement of 40 participants was indicated, assuming a power of 0.90, a two tailed significance level of 0.05, and an effect size (g) of 0.24 (large effect size). Given that the 44% rate also included individuals with probable sarcopenia, and to accommodate subgroup analyses while ensuring robust parameter estimation in multivariate logistic regression models, the target sample size was increased to at least 100 participants.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 27.0 (IBM Corp., Armonk, NY, USA). Categorical variables are presented as frequencies and percentages, and continuous variables as mean ± standard deviation. The normality of continuous variables was assessed using the Shapiro-Wilk test. Comparisons among groups defined by sarcopenia status (no sarcopenia, probable sarcopenia, and sarcopenia) were conducted using One-Way Analysis of Variance for normally distributed continuous variables. In post-hoc analyses, the Tukey test was applied when the assumption of homogeneity of variances was met, whereas the Dunnett T3 test was used when this assumption was violated. Categorical variables were compared using the chi-square test or exact test, as appropriate. For ordinal categorical variables chi-squared tend test was also performed. Standard multivariable binary logistic regression analyses was performed to examine the associations of sarcopenia (dependent variable) with age at menopause and osteoporosis (independent variables) (Model 1). Chronological age and body mass index (BMI) were included in the regression models as potential confounding variables (Model 2 and 3). A binary logistic regression analysis with Firth's penalized likelihood approach was also performed to examine the association between sarcopenia (dependent variable) and osteoporosis, age at menopause, chronological age, and BMI (independent variables). The Firth's method was preferred due to the relatively small sample size and low number of events, in order to reduce small-sample bias and to address potential issues of separation. All variables were entered simultaneously into the model based on their clinical relevance. Internal validation and parameter

stability of Model 3 were rigorously verified through a 1.000-fold bootstrapping procedure, ensuring the robustness of the estimates. The model's calibration was measured by the mean absolute error (MAE), and the consistency of its discrimination was assessed using the optimism-corrected C-index. Penalized regression and model validation analyses were carried out using R software (R: A Language and Environment for Statistical Computing, R Core Team, R Foundation for Statistical Computing, Vienna, Austria, 2024, https://www.R-project.org), specifically employing the logistf and rms packages, respectively. A p-value ≤0.05 was considered statistically significant.

Results

A total of 128 postmenopausal women were included in the study, with a mean age [standard deviation (SD)]) of 63.7 (7.6) years. The mean age at menopause was 44.8 (5.7) years, and the mean BMI fell within the overweight range. The most frequently observed comorbid conditions were hypertension and diabetes mellitus. The demographic and clinical characteristics of the participants are presented in Table 1.

According to the EWGSOP2 criteria, 25 participants (19.5%) were classified as having probable sarcopenia, while 27 participants (21.1%) were classified as having sarcopenia. Comparisons of demographic and clinical characteristics according to sarcopenia status are presented in Table 2. Sarcopenia was significantly associated with older age, the presence of osteoporosis, a history of falls, fragility fractures, and lower balance scores (all p<0.05). In addition, sarcopenia showed a significant linear association with age (χ^2_{trend} =20.569, total χ^2 =29.180, p<0.001). A similar linear association was observed between sarcopenia and osteoporosis (χ^2_{trend} =33.073, total χ^2=33.389, p<0.001). Furthermore, age was significantly linearly associated with osteoporosis (χ^2_{trend} =5.696, total χ^2=6.015, p=0.017). Mean age at menopause differed significantly across the groups, with the lowest values observed in the sarcopenia group (p<0.001). The BBS score was significantly higher in participants without sarcopenia than in those with probable or definite sarcopenia (p<0.001).

Table 1. Demographic, lifestyle and clinical characteristics of the study sample, n=128

Age, year, mean (SD)	63.7 (7.6)
BMI, kg/m^2, mean (SD)	28.6 (6.3)
Age at menopause, year, mean (SD)	44.8 (5.7)
Smoking, n (%)	16 (12.5)
Alcohol consumption, n (%)	9 (7)
Hypertension, n (%)	67 (52.3)
Diabetes mellitus, n (%)	40 (31.3)
Hypothyroidia, n (%)	26 (20.3)
Knee osteoarthritis, n (%)	21 (16.4)
Cardiovascular disease, n (%)	8 (6.3)
Regular exercise, n (%)	13 (10.2)
Fragility fracture, n (%)	12 (9.4)
Fall, n (%)	48 (37.5)

BMI: Body mass index, SD: Standard deviation

Standard and penalized multivariable binary logistic regression analysis demonstrated that age at menopause significantly associated with sarcopenia after adjustment for chronological age and BMI [odds ratio (OR) =0.89, 95% confidence interval (CI): (0.78 to 0.99), p=0.041] (Table 3). The association between osteoporosis and sarcopenia remained at the threshold of statistical significance after adjustment for age and BMI (OR =3.59, 95% CI: 0.96 to14.76, p=0.058) (Table 3). Standard full model (Model 3) explained 69.9% (Nagelkerke R^2, from the Model 3) of the total variance, indicating a strong explanatory power for the identified associations and large data representativeness (MAE =0.008). Validation results revealed a Somers' Dxy of 0.916 and a remarkably low optimism index of 0.018. The corrected Dxy was 0.898, corresponding to an optimism-corrected C-statistic (area under the curve) of 0.949.

Discussion

The present study investigated sarcopenia and its association with age at menopause and osteoporosis. The main findings indicated that earlier age at menopause was significantly and independently associated with sarcopenia. While the association between the osteoporosis and sarcopenia did not reach statistical significance, the magnitude of the effect (OR) suggests a potential clinical relevance despite the statistical uncertainty reflected by the wide confidence interval.

The multivariate analysis revealed that age at menopause was more strongly and independently associated with sarcopenia than osteoporosis. This finding is supported by recent molecular evidence indicating that estrogen withdrawal impacts skeletal muscle through pathways distinct from bone mineral loss. Specifically, the loss of ERα-mediated satellite cell proliferation (27) and the acceleration of mitochondrial dysfunction (28) suggest that muscle tissue may be more sensitive to the duration of estrogen deficiency than the bone matrix is to mineral resorption during the early menopausal transition. While osteoporosis and sarcopenia often coexist as osteosarcopenia, the earlier onset of estrogen deficiency may trigger a more immediate catabolic state in muscle through the upregulation of pro-inflammatory cytokines and alterations in myosin heavy chain proteomes, independent of the slower bone remodeling cycle (9,29).

Reduced muscle strength can result in functional impairments, including difficulty rising from a chair, decreased walking speed, challenges in stair climbing, and impaired balance (30-32). Women typically experience a marked decline in muscle mass and strength between the ages of 50 and 60 years (33-36). Evidence regarding the role of estrogen replacement therapy in mitigating this loss remains inconsistent; while some meta-analyses report modest strength improvements (37), other longitudinal studies

Table 2. Comparison of participants' demographic and clinical characteristics according to the sarcopenia status

	No sarcopenia (n=76)	Probable sarcopenia (n=25)	Sarcopenia (n=27)	p-value
Age, years, mean (SD)	60.8	67.7 (6.3)[a]	68.0 (7.2)[a]	< 0.001
Age categoria, n (%) 50-59 years 60-69 years ≥70 years	 38 (50) 27 (36) 11 (14)	 01 (4) 14 (56) 10 (40)	 02 (07) 15 (56) 10 (37)	< 0.001
Osteoporosis, n (%) Osteoporosis	 15 (20)	 12 (48)	 22 (82)	<0.001
Age at menopause, years, mean (SD)	46.0 (5.1)	45.0 (6.3)	41.4 (5.2)[b,c]	<0.001
Regular exercise, n (%)	9 (12)	1 (4)	3 (11)	0.530
BMI, kg/m², mean (SD)	29.3 (5.1)[d]	31.9 (5.8)[d]	21.8 (3.4)	<0.001
BMI category Normal Overweight Obesite	 13 (17) 32 (42) 31 (41)	 2 (8) 8 (32) 15 (60)	 19 (70) 8 (30) 0 (0)	<0.001
Fall, n (%)	18 (24)	15 (60)	15 (56)	0.001
Fragility fracture, n (%)	1 (1)	6 (24)	5 (19)	<0.001
Smoking, n (%)	12 (16)	2 (8)	2 (7)	0.407
Alcohol, n (%)	4 (5)	2 (8)	3 (11)	0.704
Comorbid disease, n (%)	65 (86)	25 (100)	25 (93)	0.057
BBS, mean (SD)	52.2 (5.2)	43.0 (7.4)[e]	42.7 (12.2)[f]	<0.001

BBS: Berg balance scale, BMI: Body mass index, SD: Standard deviation, [a]: Post-hoc comparison, different from no sarcopenia (adjusted p<0.001), [b]: Post-hoc comparison, different from no sarcopenia (adjusted p=0.001), [c]: Post-hoc comparison, different from probable sarcopenia (p=0.046), [d]: Post-hoc comparison, different from sarcopenia (adjusted p<0.001), [e]: Post-hoc comparison, different from no sarcopenia (adjusted p<0.001), [f]: Post-hoc comparison, different from no sarcopenia (adjusted p=0.001)

(38,39) found no significant differences across various hormonal states. Our results suggest that the timing of hormonal loss (age at menopause) may be a more critical factor for muscle health than the simple presence of a postmenopausal state.

The coexistence of osteoporosis and sarcopenia markedly compromises quality of life by substantially increasing fracture risk, physical frailty, and mortality (40-42). The present study suggests a potentially clinically relevant association between osteoporosis and sarcopenia, consistent with current conceptualizations of the muscle-bone axis (43-45). However, our multivariable logistic regression indicates that age and BMI acts as a powerful confounders. Nevertheless, in terms of osteoporosis, the stabilization of coefficients via Firth's method and the notably low optimism index obtained from bootstrap validation suggest that this association represents a stable clinical trend rather than a chance fluctuation. Despite these strengths, the study might have been constrained by a limited number of events per variable. This constraint is reflected in the wide confidence intervals, suggesting that while the internal consistency metrics are encouraging, the magnitude of this association should be interpreted with caution. The lack of nominal significance is likely attributable to the limited sample size rather than a lack of biological relationship, necessitating confirmation in larger study populations.

Regarding body composition, we observed an inverse association between BMI and sarcopenia. However, it is critical to acknowledge that an elevated body fat percentage can mask the underlying depletion of muscle mass, a condition increasingly recognized as sarcopenic obesity. In our cohort, individuals with probable sarcopenia often exceeded the threshold for obesity. For such populations, traditional screening metrics may lack sensitivity; therefore, diagnostic approaches that directly quantify skeletal muscle mass—independent of adiposity—are essential for an accurate assessment.

As balance plays a critical role in daily functioning, persistent balance impairments in individuals with sarcopenia can substantially hinder the performance of everyday activities. The present study demonstrates a progressive deterioration in balance as muscle strength and functional capacity decline from normal levels to those characteristic of sarcopenia. However, it should be acknowledged that balance impairment may also be influenced by factors other than sarcopenia. The coexistence of sarcopenia, osteoporosis, and balance impairment—together with the effects of ageing—may synergistically contribute to an increased risk of fractures.

Study Limitations

This study has several limitations. First, the cross-sectional design precludes causal inferences. Second, compared to DXA — the gold standard technique for measuring body composition — it has been reported that BIA overestimates FFM

Table 3. Association between sarcopenia and age at menopause with osteoporosis: Results of univariate, standard multivariate and penalized multivariate binary logistic regression analyses

	Univariate		Multivariate model		
	b (se)	p-value	b (se)	p-value	OR (95% CI)
Age at menopause, years	0.14	0.001			
Osteoporosis, yes	2.49	<0.001			
Chronological age	0.10	0.001			
BMI, kg/m^2	0.46	<0.001			
			Model 1		
Age at menopause, years			-0.013 (0.05)	0.004	0.88 (0.80 to 0.95)
Osteoporosis, yes			2.44 (0.57)	<0.001	11.5 (3.80 to 34.98)
			Model 2		
Age at menopause, years			-0.13 (0.05)	0.006	0.88 (0.80 to 0.96)
Osteoporosis, yes			2.27 (0.58)	<0.001	9.64 (3.11 to 29.86)
Chronological age, years			0.08 (0.04)	0.034	1.08 (1.0 to 1.16)
			Model 3		
Age at menopause, years			-0.13 (0.07)	0.045	0.88 (0.77 to 0.99)
Osteoporosis, yes			1.42 (0.74)	0.055	4.12 (0.07 to 17.49)
Chronological age, years			0.12 (0.05)	0.016	1.13 (1.02 to 1.24)
BMI, kg/m^2			-0.46 (0.11)	<0.001	0.63 (0.51 to 0.78)
			Penalized model		
Age at menopause, years			-0.12 (0.06)	0.041	0.89 (0.78 to 0.99)
Osteoporosis, yes			1.28 (0.66)	0.058	3.59 (0.96 to 14.76)
Chronological age, years			0.11 (0.04)	0.012	1.11 (1.02 to 1.22)
BMI, kg/m^2			-0.41(0.09)	<0.001	0.66 (0.54 to 0.79)

AIC: Akaike information criterion, BMI: Body mass index, CI: Confidence interval, df: Degrees of freedom, OR: Odds ratio, se: Standard error
Model 1: X^2 =36.50, df =2, p<0.001; Hosmer-Lemeshow test: X^2 =9.68, df =8, p=0.288, Cox-Snell R^2 =0.248, Nagelkerke R^2 =0.386, AIC =101.4
Model 2: X^2 =41.35, df =3, p<0.001; Hosmer-Lemeshow test: X^2 =6.69, df =8, p=0.571, Cox-Snell R^2 =0.276, Nagelkerke R^2 =0.429, AIC =98.5
Model 3: X^2 =6.46, df =4, p<0.001; Hosmer-Lemeshow test: X^2 =1.20, df =8, p=0.997, Cox-Snell R^2 =0.450, Nagelkerke R^2 =0.699, AIC =65.4
Model 1 vs. Model 2: X^2 =4.81, df =1, p=0.028
Model 2 vs. Model 3: X^2 =35.11, df =1, p<0.001
Penalized model: Likelihood ratio test =70.88, df =4, p<0.001, AIC =65.8

at the individual level (19,20). This may have resulted in a lower frequency of diagnosing sarcopenia than is actually the case. Third, the presence of wide confidence intervals for certain ORs indicates a lack of statistical precision, likely attributable to an insufficient sample size. Fourth, the absence of a male control group limits the ability to disentangle the relative contributions of menopause versus chronological ageing. Finally, while age and BMI were identified as major confounders, other factors such as physical activity levels and nutritional status were not fully controlled for. It should be noted, however, evaluating the association between dynamic parameters (e.g., nutritional status and vitamin levels) and sarcopenia is better suited to prospective cohort studies than cross-sectional designs. Nevertheless, a more comprehensive analysis could be achieved by incorporating additional risk factors, such as physical activity and nutritional status, alongside a larger sample size to enhance the power of study.

Conclusion

In conclusion, this study demonstrates an independent association between sarcopenia and age at menopause along with chronological age and BMI. Although no statistically significant association was found between osteoporosis and sarcopenia, the findings suggest that there may be a potential clinical association. The coexistence of sarcopenia, osteoporosis, and balance impairment represents a high-risk phenotype for fractures in postmenopausal women. Early identification and integrated management strategies targeting both muscle strength and bone health are essential to improve functional outcomes in this population.

Ethics

Ethics Committee Approval: Approval for this cross-sectional observational study was obtained from the Local Ethics Committee of İzmir Katip Çelebi University (decision no: 0167, dated: 03/21/24), and the study was conducted in accordance

with the relevant guidelines and regulations of the Declaration of Helsinki.

Informed Consent: Participants were informed about the study and their written consent was obtained.

Footnotes

Authorship Contributions

Concept: E.M., N.Ö.S., İ.Ş., A.A., Design: E.M., N.Ö.S., İ.Ş., A.A., Data Collection or Processing: E.M., N.Ö.S., Analysis or Interpretation: E.M., N.Ö.S., İ.Ş., A.A., Literature Search: E.M., N.Ö.S., İ.Ş., A.A., Writing: E.M., N.Ö.S., İ.Ş., A.A.

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