Research Square

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Are vegan women at a disadvantage regarding bone mineral density during peak bone mass acquisition? Findings from the BELIEVE (Bone mEtabolism Legacy In fEmale Vegetarians) study

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Abstract

Purpose

To compare bone mineral density in strict vegetarian and omnivorous women aged 20 to 35 years, a period corresponding to peak bone mass aquisition, and to investigate dietary, biochemical, and body composition factors associated with low BMD for age.

Methods

This cross-sectional study included 61 strict vegetarian women and 60 omnivorous controls recruited between December 2021 and June 2023. Participants underwent questionnaires, dietary assessment by 24-hour recall, laboratory testing, and DXA-based evaluation of bone mineral density, trabecular bone score, and body composition. Group comparisons were performed using the t-test or Mann-Whitney U test for continuous variables and Fisher's exact test for categorical variables, as appropriate. Univariate and multivariable linear and logistic regression models were used, and ROC curves assessed model discrimination.

Results

Strict vegetarian women had lower bone mineral density at all sites evaluated. Mean BMD was 0.931 ± 0.10 vs 1.005 ± 0.10 g/cm² at the lumbar spine, 0.773 ± 0.09 vs 0.849 ± 0.10 g/cm² at the femoral neck, and 0.907 ± 0.09 vs 0.977 ± 0.09 g/cm² at the total femur, with a mean difference of 0.07 g/cm² across sites, $p < 0.001$. Strict vegetarian women also had lower Z-scores and trabecular bone score, higher CTX, PTH, alkaline phosphatase, and vitamin D deficiency prevalence, and lower intakes of protein, calcium, and vitamin D. Low BMD for age was mainly associated with higher CTX, calcium intake below 400 mg/day, and low muscle mass. Among strict vegetarians, low BMD for age was associated with 10.31-fold higher odds, while inadequate calcium and protein intake were more common in women with this outcome.

Conclusion

Strict vegetarian women had lower BMD and greater bone turnover during peak bone mass years. These findings suggest potentially modifiable nutritional risks, especially low calcium, vitamin D, and protein intake, supporting the need for nutritional monitoring and supplementation when needed.

Introduction

The number of individuals adopting vegetarian dietary patterns has increased steadily in recent years. In Brazil, it is estimated that 7% to 9% of the population over 16 years of age follows some form of vegetarian diet [1]. In the United States, recent data indicate that approximately 1.4% of the population identifies as strict vegetarian, excluding all animal-derived foods from their diet [2]. Veganism, however, extends beyond dietary practices and represents a lifestyle that seeks to avoid animal exploitation in all forms, including the use of

products derived from animals, such as leather and other animal-based goods. This sustained growth has attracted increasing interest from the scientific community, driving investigations into the potential effects of vegetarian diets on overall health, and particularly on bone health, especially in light of the rapid expansion of this population group.

The literature presents conflicting findings. Some observational studies suggest that strict vegetarian diets may increase the risk of osteoporosis and fractures compared with omnivorous diets, whereas others indicate potential benefits of this dietary pattern for bone health [3, 4]. The five most recent meta-analyses on the topic included individuals aged 20 to 80 years and, overall, reported less favorable bone outcomes among vegetarians than among omnivorous controls, particularly among women and individuals older than 50 years[5–9].

Modifiable factors, such as dietary choice, may have a more pronounced impact during the period of peak bone mass acquisition [10]. Inadequate intake of essential nutrients during this phase may result in lower bone accrual before the physiological decline associated with aging, thereby increasing the future risk of osteoporosis [11]. Thus, an important gap in the literature remains: the scarcity of studies assessing bone mineral density (BMD) in vegetarian individuals during the period of peak bone mass consolidation.

To address this gap, we conducted a cross-sectional study comparing BMD between strict vegetarian and omnivorous women aged 20 to 35 years, during the period of peak bone mass acquisition.

Materials and methods

Sixty-two strict vegetarian women and sixty-one omnivorous women, all young, were recruited through digital channels between December 2021 and June 2023. The sample size was determined using lumbar spine BMD as the primary study variable and Student's t-test for the calculation. Assuming 90% power, 5% significance, and a detectable difference of 0.06 g/cm³ between the two independent groups, the required sample size was 60 participants per group. The final analyzed sample comprised 57 strict vegetarian women and 56 omnivorous women, which remained close to the planned sample size.

Since veganism may encompass ethical and lifestyle practices beyond dietary intake, participants who excluded all animal-derived foods from their diet (the strict vegetarians) were classified and are referred to throughout this manuscript as vegetarians.

Inclusion criteria for the vegetarian group were: female, age 20–35 years old, white ethnicity, following a strict vegetarian diet (complete exclusion of all animal products) for ≥ 2 years, with regular menstrual cycles or amenorrhea induced by contraceptive methods, who signed the informed consent form. The only difference in the criteria for the control group was the adoption of an omnivorous diet (animal products included). Exclusion criteria for the study group was the current adoption of a ovo-lacto-vegetarian diet, and for both groups were conditions or medications known to affect bone health, including chronic pulmonary, gastrointestinal, endocrine, rheumatologic, renal, or hepatic diseases; history of bariatric surgery; cancer; or use of glucocorticoids or anabolic agents.

Participants were recruited through social media posts (Instagram© @reumato.clara, @pesquisa.veg.unifesp), and posters displayed at local vegetarian restaurants. After initial screening confirmed eligibility and informed consent signed, data collection occurred at the Bone Densitometry Laboratory of the Federal University of São Paulo (UNIFESP).

Participants completed validated questionnaires assessing sociodemographic characteristics, osteoporosis risk factors (Annex 1 – Supplementary Material), physical activity levels (Baecke questionnaire; Annex 2 – Supplementary Material), supplement use, and time in the strict vegetarian diet [12, 13]. Handgrip strength was assessed according to the standardized protocol [14].

Blood samples were collected for biochemical assessment of calcium, phosphorus, alkaline phosphatase, creatinine, parathyroid hormone, albumin. 25-hydroxyvitamin D was measured using a chemiluminescence assay, and deficiency was defined as a serum concentration < 20 ng/mL [15]. Bone turnover markers, including P1NP (procollagen type 1 N-terminal propeptide) and CTX (C-terminal telopeptide of type I collagen), were analyzed using eletrochemiluminescence methods.

Bone mineral density was measured via dual-energy X-ray absorptiometry (DXA) (Hologic QDR 4500 A; Discovery model) at the lumbar spine (L1-L4), femoral neck, total hip. Low BMD for age was defined at Z-Score < -2 [16]. Additional DXA assessments included trabecular bone score (TBS), total body composition for calculation of the Baumgartner index (low muscle mass defined as < 5.45), and fat mass index (FMI), which was categorized according to adiposity status from low to obesity [17, 18].

Participants also completed a 24-hour dietary recall, which was analyzed by a registered nutritionist using Food Processor® software (version 11.14.9) to quantify intake of calories, macronutrients (carbohydrates, protein, fat), and micronutrients (calcium, vitamin D, vitamin K, iron, magnesium, phosphorus, sodium, potassium, caffeine [19, 20]. They were also categorized according to low protein intake (< 0.8 g/kg/day) and low calcium intake (< 400 mg/day and < 800 mg/day) [21, 22].

The Ethics Committee on Research of the Federal University of São Paulo accepted the Project in 2021, with the protocol 0405/2021, and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. And it was approved in Plataforma Brasil with CAAE 45566621.0.0000.5505 in 27/06/2021. The study was funded by the remaining funds of the Brasilian Rheumatology Society in July 2022 [23].

Statistic Analysis

Statistical analyses were performed using RStudio version 2024.12.0 + 467 and Jamovi version 2.3.28.

Continuous variables are presented as mean ± standard deviation, median (interquartile range), or frequencies (%), as appropriate. The significance level was set at $p < 0.05$.

Continuous variables had their distribution evaluated using the Shapiro-Wilk test, and their variance evaluated using Levene's test.

For comparisons between groups with normal distribution, the Student's t-test was performed, and the Mann-Whitney test for comparisons between groups with non-normal distribution. Effect size was determined using Cohen's d test, classified as low (between 0.2 and 0.5), moderate (between 0.5 and 0.8), and high (above 0.8).

For categorical variables, the Chi-square test and Fisher's test were performed to test the significance of the association between groups.

Univariate linear regressions were conducted with all variables. Subsequent multivariate linear and logistic regressions included variables with $p < 0.05$ in correlation or univariate analyses using the forward selection method. Logistic regressions focused on the categorical outcomes of Low BMD for Age (Z-score < -2), and particularities of the vegetarian group were also analyzed. ROC (Receiver Operating Characteristic) curves were constructed in Jamovi, to evaluate the discriminatory capacity of the logistic regression models in predicting Low BMD for Age.

Potential sources of bias were minimized through strict inclusion/exclusion criteria, matched recruitment procedures, standardized measurements, and adjustment for relevant covariates in multivariable analyses. Sensitivity analyses were also performed to assess the influence of participants with amenorrhea and underweight.

Results

Participant Characteristics

A total of 207 participants were initially contacted. Figure 1 depicts the participant selection and inclusion flow.

BMD: bone mineral density.

Table 1 summarizes the sociodemographic profile and osteoporosis risk factors in vegetarian women and their controls. The groups were comparable across most variables, with differences observed only in contraceptive use, alcohol consumption, and vitamin D supplementation which was more frequent among vegetarian women. Among the study participants, the mean duration of strict vegetarian diet was 4.48 years (95% CI: 3.97–4.99).

Table 1
Sociodemographic profile, osteoporosis risk factors and supplement use

Sample size	**Vegetarians**	**Omnivores**	**p**
	n = 61	**n = 60**	
Age (years)	26 (24; 30)	27 (23.8; 31)	0.79*
Income < 5 MW	63.9% (39)	60% (36)	0.83
5–10 MW	24.6% (15)	25% (15)	
> 10 MW	11.5% (7)	15% (9)	
BMI (kg/m²)	22.30 (20.1; 24.3)	22.40 (21.0; 24.63)	0.53*
Underweight	6.6% (4)	5% (3)	0.84
Healthy	70.5% (43)	71.7% (43)	
Overweight	18% (11)	15% (9)	
Obesity	4.9% (3)	8.3% (5)	
FH femur fracture	4.9% (3)	3.3% (2)	1.00
Previous fracture	27.9% (17)	26.7% (16)	0.88
Amenorrhea > 3 months	21.3% (13)	25% (15)	0.63
Due to underweight	6.6% (4)	0	0.02
Due to contraceptives	8.2% (5)	23.3% (14)	
Contraceptive Methods	32.8% (20)	15% (9)	**< 0.001**
No contraceptive method	9.8% (6)	33.3% (20)	
Oral contraceptives	19.7% (12)	31.7% (19)	
IUD	37.7% (23)	20% (12)	
Condoms only			
Smoking	11.5% (7)	8.3% (5)	0.059
Tobacco load (pack-years)	0.279 ± 0.66	0.100 ± 0.35	0.072*
Weekly dose of alcohol	2 (0; 3)	0 (0; 2)	**0.01***
Sedentary	11.5% (7)	11.7% (7)	0.97
BAECKE score	7.86 ± 1.81	8.06 ± 1.42	0.50
Hand grip (kgf)	22 (19.5; 25)	22.5 (20; 24)	0.95*
Supplement use	4.9% (3)	0	0.08

MW: minimum wages; FH: family history; BMI: body mass index; CM contraceptive methods; IUD: intrauterine device

Sample size	Vegetarians	Omnivores	p
	n = 61	**n = 60**	
Calcium	41% (25)	13.3% (8)	**< 0.001**
Vitamin D	44.3% (27)	35% (21)	0.29
Protein			
Time on the diet (years)	4.48 ± 1.99		
Strict vegetarian	8.27 ± 5.11		
No meat consumption**			
MW: minimum wages; FH: family history; BMI: body mass index; CM contraceptive methods; IUD: intrauterine device			

Values are presented as a mean ± one standard deviation (SD).

*Mann-Whitney6 results in median and interquartile ranges 25 and 75

**Time on ovo-lacto-vegetarian diet + time on strict vegetarian diet

p < 0.05 considered significant. Significant p shown in bold.

Bone Mineral Density, Body Composition, Laboratory and Dietary Analysis

In the assessment of DXA, both BMD and Z-scores, as shown in Table 2, were lower in vegetarian women than in controls across all skeletal sites. At each site, BMD was on average 0.07 g/cm² lower in the vegetarian group, with moderate effect size indicated by Cohen's d test for all sites.

The Z-scores were also lower among vegetarian women. Effect size analysis showed a large effect for the lumbar spine Z-score (Cohen's d > 0.8), whereas the femoral neck and total femur showed moderate effect sizes. Considering that a Z-score below − 2.0 indicates low BMD for age, this condition was more frequent among vegetarian women, affecting 16.4% (10) of the sample. TBS, also shown in Table 2, was lower in the study group, with a mean difference of 0.04 between groups.

Regarding body composition, as presented in Table 2, the groups were similar in terms of fat mass index, with no differences in FMI classification from underweight to obesity. The Baumgartner index was higher in controls. Low muscle mass occurred in 24.6% of vegetarian women and 15% of omnivores, with no statistically significant difference.

Table 2
Bone densitometry and body composition data

Sample size	Vegetarians	Omnivores	p	Cohen's d
	n = 61	n = 60		
Bone densitometry				
Lumbar spine BMD (g/cm²)	0.931 ± 0.10	1.005 ± 0.10	**< 0.001**	-0.71
Z-score lumbar spine	-0.95 ± 0.94	-0.13 ± 0.91	**< 0.001**	-0.87
Femoral neck BMD (g/cm²)	0.773 ± 0.09	0.849 ± 0.10	**< 0.001**	-0.74
Z-score femoral neck	-0.62 ± 0.84	-0.00 ± 0.91	**< 0.001**	-0.71
Total hip BMD (g/cm²)	0.907 ± 0.09	0.977 ± 0.09	**< 0.001**	-0.71
Z-score total hip	-0.25 ± 0.79	0.24 ± 0.81	**< 0.001**	-0.62
Low BMD for age	16.4% (10)	1.7% (1)	**0.005**	
TBS	1.510 (1.47; 1.56)	1.55 (1.50; 1.60)	**0.002***	
Body composition				
FMI (kg/m²)	8.06 ± 2.67	8.41 ± 3.40	0.55	
Low fat mass	8.1% (5)	3.2% (3)	0.39	
Healthy	60.6% (37)	72.1% (44)		
Overweight	26.2% (16)	18% (11)		
Obesity	4.9% (3)	6.5% (4)		
Baumgartner's index (kg/m²)	6.0 (5.45; 6.58)	6.39 (5.86; 7.00)	0.008*	
Low muscle mass (< 5.45)	24.6% (15)	15% (9)	0.18	

BMD: bone mineral density; FMI: fat mass index

p < 0.05 considered significant. Significant p shown in bold.

Values are presented as a mean ± one standard deviation (SD).

**Mann-Whitney test; results are presented as median (25th–75th percentiles).*

Table 3 presents the laboratory analysis of the participants. Vegetarian women showed higher median values of albumin, serum calcium, alkaline phosphatase, and PTH.

Although vitamin D levels were similar in both groups, the frequency of vitamin D deficiency, defined as levels below 20 ng/dL, was significantly higher among vegetarian women.

Markers of bone turnover, CTX and P1NP, were also significantly higher in vegetarian women compared with omnivores.

Table 3
Analysis of laboratory results

Sample size	**Vegetarians**	**Omnivores**	**p**
	n = 61	**n = 60**	
Albumin (mg/dL)	4.72 ± 0.32	4.45 ± 0.28	**< 0.001**
Creatinin (mg/dL)	0.70 (0.60; 0.80)	0.79 (0.73; 0.79)	**< 0.001***
Calcium (mg/dL)	9.6 (9.2; 9.7)	9.4 (9.2; 9.6)	**0.05***
Phosphorus (mg/dL)	3.83 ± 0.48	3.68 ± 0.45	0.07
Alkaline phosphatase (U/L)	67 (54; 78)	56.5 (46; 63.75)	**< 0.001***
PTH (pg/mL)	39 (28; 52)	31.5 (22.75; 39.5)	**0.003**
CTX (ng/mL)	0.544 (0.459; 0.734)	0.384 (0.292; 0.487)	**< 0.001***
P1Np (mcg/L)	72.6 (60.7; 88.1)	52.35 (22.75; 39.5)	**< 0.001***
25(OH)Vitamin D (ng/mL)	26 (18; 30)	26.5 (22.75; 36)	0.06*
< 20 ng/dL	27.9% (17)	13.3% (8)	0.04

PTH: parathyroid hormone; CTX: C-terminal telopeptides; P1NP: procollagen type 1 N-terminal propeptide; 25(OH) vitamin D: 25-hydroxyvitamin D; < 20ng/dL: Deficient in 25(OH)vitamin D.

p < 0.05 was considered statistically significant. Significant p shown in bold.

Values are presented as a mean ± one standard deviation (SD).

**Mann-Whitney test; results are presented as median (25th–75th percentiles).*

The results of the analysis of macro and micronutrients in the participants' diets are presented in Table 4. Regarding macronutrients, vegetarian women had a higher intake of carbohydrates and fiber, and lower intake of protein and fat. Approximately 26% of the vegetarian women had inadequate protein intake, defined as intake below 0.8 g/kg. In contrast, they showed significantly higher intake of polyunsaturated fats and lower intake of saturated and monounsaturated fats.

With respect to micronutrients, the study group had lower intake of calcium, vitamin D, and phosphorus. On the other hand, they consumed greater amounts of vitamin K, iron, magnesium, and potassium, nutrients typically abundant in plant-based foods.

Table 4
Analysis of macro and micronutrientes in the diet

Sample size	**Vegetarians**	**Omnivores**	**p**
	n = 57	**n = 56**	
Calories (kcal)	1611.56 (1258.29; 1901.33)	1555.70 (1217.21; 1806.83)	0.507*
Carbohydrates (g)	225.38 (186.67; 305.33)	186.44 (125.47; 226.39)	**< 0.001***
Proteins (g)	66.13 (46.54; 98.01)	94.63 (69.30; 111.20)	**0.003***
Protein-weight ratio (g/kg)	1.12 (0.79; 1.66)	1.52 (1.06; 1.91)	**0.017***
Protein consumption below 0.8g/kg	26.3% (15)	10.7% (6)	**0.033**
Fats (g)	38.92 (27.52; 57.18)	50.41 (37.04; 69.44)	**0.035***
Saturated fats (g)	9.49 (5.78; 14.73)	19.26 (14.01; 24.87)	**< 0.001***
Monounsaturated fats (g)	11.14 (5.75; 15.56)	14.17 (9.58; 19.41)	**0.009***
Polyunsaturated fats (g)	8.29 (5.28; 12.73)	6.13 (4.50; 8.33)	**0.018***
Fibers (g)	32.88 (25.73; 46.84)	16.85 (9.69; 21.91)	**< 0.001***
Vitamin D (UI)	0.850 (0.00; 48.34)	103.82 (33.39; 148.50)	**< 0.001***
Vitamin K (mcg)	92.20 *(47.41; 202.95)*	33.65 (13.82; 88.65)	**< 0.001***
Calcium (mg)	491.22 (342.83; 883.70)	660.15 (509.64; 925.81)	**0.04***
Below 400mg/day	35.1% (20)	14.3% (8)	**0.01**
Below 800mg/day	70.2% (40)	66.1% (37)	0.64
Iron (mg)	16.98 (11.44; 38.46)	9.54 (7.21; 12.67)	**< 0.001***
Magnesium (mg)	324.46 (217.81; 401.22)	187.39 (128.09; 271.37)	**< 0.001***
Phosphorus (mg)	739 (516; 1141)	980 (727; 1376)	**0.03***
Sodium (mg)	1476.3 (1134; 2018.9)	1816.9 (1003.8; 2343.2)	0.07*
Potassium (mg)	2632.1 (2105; 3611.7)	2200.5 (1031.7; 3065.8)	**0.003***
Caffein (mg)	12.4 (0; 94.7)	77.3 (0; 96.0)	0.16*

$p < 0.05$ was considered statistically significant. *Significant p shown in bold.*

**Mann-Whitney test; results are presented as median (25th–75th percentiles).*

Linear Regressions

Initially, univariate linear regression analyses were performed to explore the association between each variable and low BMD for age, as detailed in Table 5. The full set of univariate results is provided in Supplementary Table 1, whereas only significant associations with acceptable model fit were highlighted in the main text.

Table 5
Univariate linear regression analysis of factors associated with bone mineral density

	Lumbar spine			**Femoral neck**			**Total hip**		
	β	**p**	**R²**	**β**	**p**	**R²**	**β**	**p**	**R²**
BMI	0.002	**0.002**	0.08	0.007	**0.002**	0.08	0.002	**< 0.001**	0.10
FMI	0.003	**0.009**	0.06	0.008	**0.008**	0.06	0.008	**0.005**	0.068
Baumgartner	0.03	**< 0.001**	0.09	0.03	**0.001**	0.09	0.04	**< 0.001**	0.14
TBS	0.57	**< 0.001**	0.17	0.39	**0.002**	0.08	0.45	**< 0.001**	0.12
Albumin	-0.05	0.054	0.03	-0.08	**0.008**	0.06	-0.09	**0.001**	0.09
CTX	-0.18	**< 0.001**	0.16	-0.12	**0.006**	0.067	-0.12	**0.002**	0.086

β: regression coefficient; R²:coefficient of determination; BMI: Body mass index; FMI: Fat mass index; TBS: Trabecular bone score; CTX: C-terminal telopeptides.

p < 0.05 was considered statistically significant. *Significant p shown in bold.*

In the univariate regressions, the strongest associations with BMD at the lumbar spine were observed for TBS ($R^2 = 0.17$), CTX ($R^2 = 0.16$), and Baumgartner index ($R^2 = 0.09$). For the femoral neck, the best associations were TBS ($R^2 = 0.08$), CTX ($R^2 = 0.067$), Baumgartner index ($R^2 = 0.09$), and BMI ($R^2 = 0.08$). For total hip, the main associated variables were BMI ($R^2 = 0.10$), Baumgartner index ($R^2 = 0.14$), TBS ($R^2 = 0.12$), CTX ($R^2 = 0.086$), and albumin ($R^2 = 0.09$).

Variable selection for the multivariable linear and logistic regression models was performed using the forward selection method, including only variables with *p* < 0.1 or biological plausibility as potential determinants of low BMD for age.and the results are shown in Table 6.

Table 6
Multivariable linear regression models of bone mineral density at the lumbar spine, femoral neck, and total hip.

BMD	Lumbar spine			Femoral neck			Total hip		
	β	p	95% CI	β	p	95% CI	β	p	95% CI
Intercept	0.87	< 0.01	-	0.66	< 0.001	-	0.75	< 0.001	-
Baumgartner	0.02	0.008	0.007;0.04	0.03	0.005	0.009;0.05	0.03	< 0.001	0.01;0.05
CTX	-0.16	< 0.001	-0.24; -0.08	-0.09	0.02	-0.17; -0.01	-0.09	0.01	-0.17; -0.02
R^2	0.21	-	-	0.13	-	-	0.19	-	-

B: regression coefficient; 95% CI: 95% confidence interval; BMD: bone mineral density; CTX: C-terminal telopeptide of type I collagen; R^2: coefficient of determination.

$p < 0.05$ was considered statistically significant. *Significant p shown in bold.*

In the multivariable linear regression models, BMD remained significantly associated with variables related to body composition and bone turnover. For lumbar spine BMD, the model explained 21% of the variance in the outcome, while it explained 13% for femoral neck BMD and 19% for total femur BMD. The Baumgartner index was positively associated with BMD, whereas CTX showed a negative association across the models.

Logistic Regressions

In the binary logistic regression analyses, presented in Table 7, models were constructed for the outcomes of low BMD for age.

Table 7
Logistic regression model for low bone mineral density for age

	Low BMD for Age			
	β	p	OR	95% CI
Intercept	-5.44	< 0.001	-	-
CTX	2.76	**0.03**	15.72	1.27;194.04
Calcium intake < 400mg	2.25	**0.01**	9.47	1.63;55.23
Low muscle mass	1.89	**0.04**	6.63	1.08;40.73
R^2	0.24			
AUC	0.84			
Accuracy	0.91			

β: regression coefficient; OR: odds ratio; 95% CI: 95% confidence interval; CTX: C-terminal telopeptide of type I collagen; R²: coefficient of determination; AUC: area under the curve.

p < 0.05 was considered statistically significant. *Significant p shown in bold*

The logistic regression model for low BMD for age showed an R^2 of 0.24 and an overall accuracy of 91%, with 99% sensitivity and 10% specificity. CTX and calcium intake below 400 mg/day were positively associated with the outcome. The corresponding Receiver operating characteristic (ROC) curve is presented below in Fig. 2.

Table 8
Logistic regression models for low BMD for age, protein intake below 0.8 g/kg/day, and calcium intake below 400 mg/day in the strict vegetarians group

	Strict vegetarians group					
	Intercept	**β**	**p**	**OR**	**95% CI**	**R²**
Low BMD for age	-0.13	2.33	**0.03**	10.31	1.26; 84.3	0.05
Protein intake below 0.8g/kg/day	-0.17	1.09	**0.03**	2.96	1.06; 8.35	0.02
Calcium intake < 400mg	-0.26	1.17	**0.01**	3.24	1.28; 8.18	0.04

β: regression coefficient ; *OR: odds ratio; 95% CI: 95% confidence interval; R²: coefficient of determination.*

p < 0.05 was considered statistically significant. *Significant p shown in bold*

Strict vegetarian women had 10.31 times higher odds of low BMD for age. Also, the likelihood of inadequate calcium intake (< 400 mg/day) was more than three times higher (OR = 3.24), and inadequate protein intake was also associated with higher odds (OR = 2.96), compared with the control group.

Discussion

Our results indicated lower BMD at all evaluated sites, along with higher percentages of low BMD for age (according to the Z-score) lower TBS. Vegetarian patients presented higher levels of serum CTX, PTH, and alkaline phosphatase, as well as a greater prevalence of vitamin D deficiency. The variables most strongly associated with the presence of low BMD for age were serum CTX, calcium intake below 400 mg per day, and the presence of low muscle mass.

Regarding dietary data, the vegetarian group showed higher intake of fibers, and polyunsaturated fatty acids, nutrients commonly associated with beneficial effects on cardiovascular health and lipid metabolismo [24]. In contrast, essential nutrientes for muscle and bone health such as protein, phosphorus, calcium and vitamin D had a lower intake in the study group.

Thus, although the vegetarians' dietary profile is more favorable from a cardiovascular and overall diet quality perspective, it presents limitations regarding the intake of nutrients critical for bone and muscle health.

The lower BMD observed in vegetarians was consistent with published meta-analyses. Across these meta-analyses, white women, strict vegetarians, and individuals over 50 years of age were the groups most affected by these diets in terms of BMD [5–9].

Although lower BMD and a higher prevalence of Z-score < − 2.0 were observed at all sites, none of the vegetarian women had low-impact fractures, which would meet the diagnostic criteria for osteoporosis and require treatment. However, low peak bone mass represents reduced bone reserve, constituting an important risk factor for the later development of osteoporosis during and after menopause [25].

In our study, logistic regression in the vegetarian group showed 10.31 times higher odds of presenting low BMD for age. Low BMD was mainly associated with higher serum CTX, calcium intake below 400 mg/day, and low muscle mass. Although the ROC curve showed acceptable discrimination, the low specificity suggests a higher rate of false-positive classifications. Therefore, the model may be more suitable as an initial screening tool than as a standalone diagnostic instrument.

Both groups were similar in age, income, fracture history, smoking, and sedentary behavior. Surprisingly, vegetarian women showed a nonsignificant trend toward higher smoking and alcohol use, but the cumulative smoking exposure was very low (0.279 pack-years), making its impact on BMD unlikely. Alcohol intake had a median of 2 drinks per week (vs. 0 in omnivores). This pattern contradicts the literature, which reports lower smoking and alcohol use in strict vegetarians [11]. FRAX™ defines risky alcohol use as ≥ 3 drinks per day; here, 2 drinks refers to weekly intake, suggesting minimal impact on BMD [26].

Regarding hormonal factors and their impact on BMD, amenorrhea for more than three months was similar between the two groups. Approximately 6.6% of vegetarians had weight-related amenorrhea at some point in life, without a reported diagnosis of anorexia at that time. In omnivores, most cases of amenorrhea were due to contraceptive use.

Among participants with amenorrhea, only one had Z-score < -2. To assess the influence of this factor, we performed a sensitivity analysis excluding the four participants with a history of amenorrhea for more than three months due to underweight (data not published). Even after this exclusion, the results remained similar, indicating that these participants did not act as outliers responsible for reducing BMD values in the vegetarian group.

Both groups had similar calories intake; however, protein consumption was significantly lower in vegetarians than in controls. The recommended ideal protein intake for sarcopenia and osteoporosis prevention in this age group is 0.8 g/kg/day [27]. Although the median protein intake among vegetarians remained within the adequate range, it was lower than in omnivores (1.12 g/kg vs. 1.52 g/kg), and they had 2.96 times greater odds of inadequate protein intake. Moreover, 26.3% of vegetarians did not meet the minimum recommendation, compared with only 10.7% of omnivores, highlighting the need for special attention to both the quality and quantity of protein in the vegetarian diet. In strict vegetarian diets, proteins come from foods that are also sources of carbohydrates and fiber, and the presence of fiber can interfere with nutrient bioavailability and intestinal absorption [28].

An interesting option to meet daily requirements would be supplementation with concentrated plant proteins [21]. In our sample, 44.3% of participants used supplements, yet some still did not reach the 0.8 g/kg/day target. This reinforces the importance of continuous nutritional follow-up for strict vegetarians to adjust protein intake and provide guidance on the best supplementation strategies.

Calcium intake was lower in strict vegetarians than in omnivores. Compared with the literature, median daily calcium intake in both groups (491 mg vs. 660 mg) was higher than the Brazilian average reported in the BRAZOS study (359–414 mg) but below the recommended 1000 mg/day for this age group [12, 29].

In addition to lower calcium intake, vegetarian diets may provide calcium in less bioavailable forms due to higher fiber, phytate, and oxalate content and the more alkaline pH of their diet. They also had higher iron intake and greater vitamin D deficiency, conditions that further impair intestinal calcium absorption [28]. Calcium supplementation appears indispensable for this population to reach recommended intake. In our study, only 4.9% of participants took calcium supplements, and none of them had a Z-score below − 2.

In addition to lower calcium intake, vegetarians also exhibited lower vitamin D intake and a higher prevalence of vitamin D deficiency, also consistente with the literature [30]. These findings suggest that this condition may stimulate parathyroid hormone (PTH) secretion, potentially contributing to increased bone turnover [31]. This mechanism could help explain the higher levels of CTX and P1NP observed in our sample, as well as the lower bone mineral density identified in the vegetarian group.

Strenghts and Limitations

This study's strengths include being the first to perform this type of detailed analysis in Brazil, with a sample size larger than that of most studies included in meta-analyses that evaluated primary BMD outcomes in vegetarian versus omnivore women. It was the first study to assess TBS, Baumgartner index, and Fat Mass Index in strict vegetarians. It is also among the first to evaluate BMD at the period of peak bone mass acquisition, whereas most studies focus on the postmenopausal period.

The study also has limitations. Some data had to be approximated by the nutritionist using Food Processor® software. Some dietary analyses were not provided by participants, resulting in loss from the initial study population, though this loss was less than 10% of the initial participants.

Conclusion

The BMD of strict vegetarian women was lower than that of omnivore women at all evaluated sites. The combined analysis of diet and bone health laboratory parameters suggests that vegetarian women have increased bone turnover, likely due to lower calcium intake and bioavailability, together with a higher prevalence of vitamin D deficiency. This combination may explain the lower BMD observed. Although the vegetarian diet offers undeniable metabolic and cardiovascular benefits, there are important nutritional gaps that can be addressed with specialized follow-up and adequate calcium and vitamin D supplementation.

Declarations

Conflict of interest

The authors declare that they have no conflict of interest. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Ethical approval

Ethics committee approval conforming to the Declaration of Helsinki was obtained from the Federal University od São Paulo Ethics Comitee. All participants provided written informed consent to use their data for research purposes.

Consent to participate

Informed consent was obtained from all individual participants included in the study.

Consent to publish

Patients signed informed consent regarding publishing their data.

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Author Contribution

Conceptualization: [A.C.R.G, V.L.S, A.R.B.S], ...; Methodology: [A.C.R.G, A.R.B.S, I.R.C.O, G.G, C.H.M.C, V.L.S], ...; Formal analysis and investigation: [A.C.R.G, I.R.C.O, G.G], ...; Writing - original draft preparation: [A.C.R.G, V.L.S]; Writing - review and editing: [A.C.R.G, C.H.M.C, V.L.S], ...; Funding acquisition: [A.C.R.G, V.L.S], ...; Resources: [A.C.R.G, I.R.C.O, G.G], ...; Supervision: [A.R.B.S, C.H.M.C, V.L.S]

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Data availability

The data used and analysed for the purpose of this study are available from the corresponding author on reasonable request.

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Figures

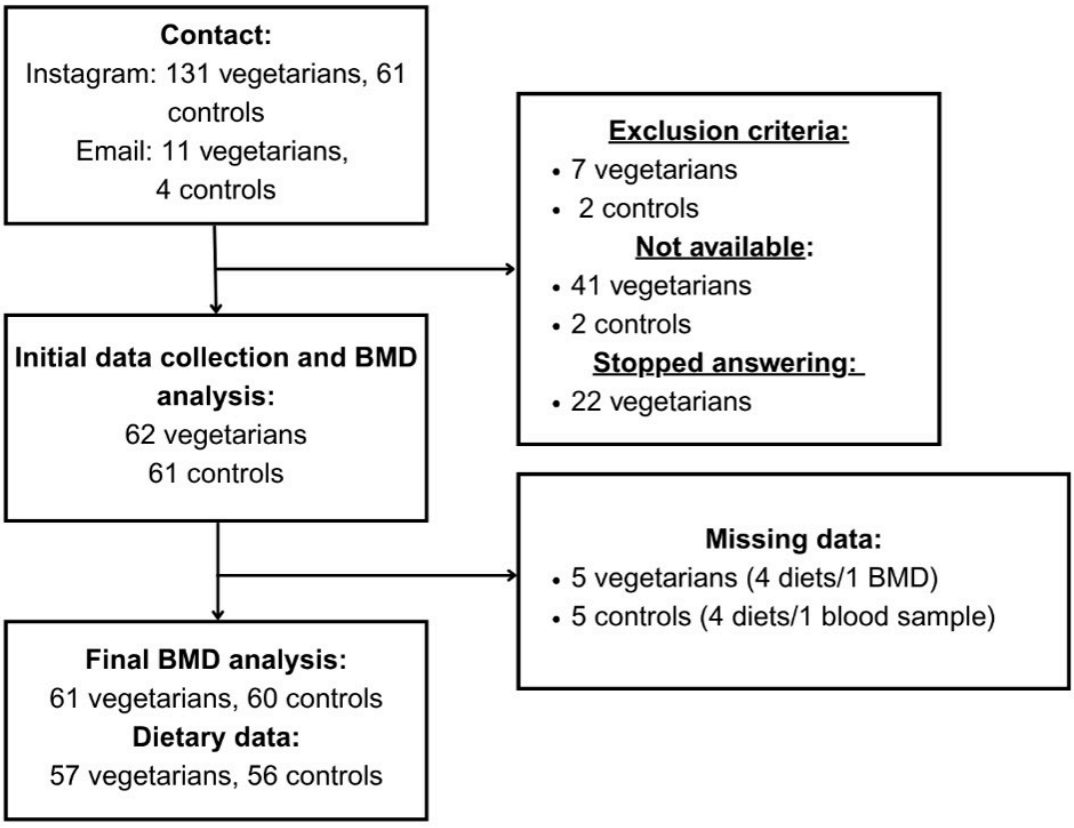


Figure 1

Flowchart of participant recruitment, exclusion and final sample

BMD: bone mineral density.

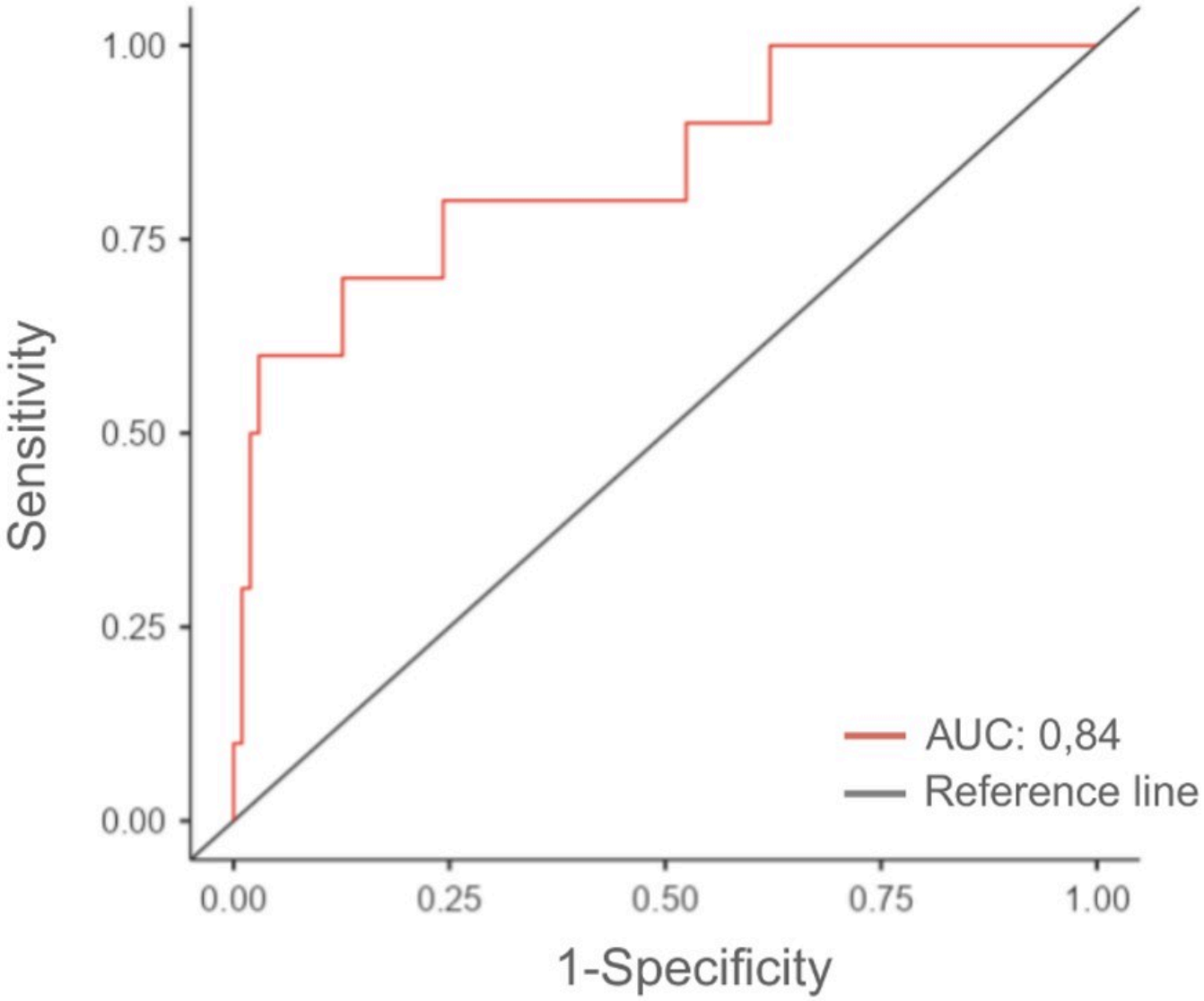


Figure 2

Receiver operating characteristic (ROC) curve for the logistic regression model predicting low BMD for age.

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