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Effect of the body mass index, basal metabolic rate, and body fat on the radiofrequency echographic multi-spectrometry (REMS)-based bone mineral density and fracture risk: a cross-sectional study

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Abstract

Radiofrequency echographic multi-spectrometry (REMS) is a method to assess bone mineral density (BMD) of the axial skeleton, fragility score (FS), body mass index (BMI), basal metabolic rate (BMR), and body fat (BF) in %. The aim of the study was to investigate the influence of the BMI, BMR, and BF on the BMD and fracture risk with REMS. We conducted a cross-sectional study among 313 women, aged 20–90 years who underwent a screening for osteoporosis with REMS. Kruskal–Wallis was used to analyze the differences in BMI, BMR, and BF between the groups according to the BMD: normal BMD, osteopenia and osteoporosis and differences in the FS, fracture risk assessment (FRAX) for major osteoporotic fractures and for hip fractures (HF) according to the BMI groups: underweight, normal weight, overweight, obese, and extreme obese. Linear regression was used to assess the correlations BMI–BMD, BMR–BMD, and BF–BMD. BMI, BMR, and BF differed significantly between the groups according to the BMD ($p < 0.001$, $p = 0.028$, and $p < 0.001$, respectively). BMR showed high positive correlation to BMD ($R = 0.765$) with 95% confidence interval (CI) [0.715, 0.807] and significance of $p < 0.001$. BMI correlated significantly to BMD ($p < 0.001$), the correlation was low positive ($R = 0.362$) with 95% CI [0.262, 0.455]. In the BMI groups, there was significant difference in FRAX for HF and FS with p value 0.014 and < 0.001, respectively. Subjects with low BMI, BMR, and BF are at high risk for osteoporosis. Underweight women show significantly high fracture risk, assessed with FRAX and FS.

Keywords Body mass index · Basal metabolism · Body fat · Fracture · Risk · REMS

Introduction

Osteoporosis is a disease of the bone metabolism and has been in the focus of research in the recent years [1, 2]. It is characterized by reduced bone mineral density (BMD) as well as microarchitectural deterioration, which may lead to fragility fractures [3]. The causes and risk factors for osteoporosis researched by various working groups include patient age, weight, previous illnesses, use of drugs, etc. [4, 5].

Increased body weight has been shown to have a positive impact on BMD. The body composition consists mainly of body fat mass (FM) and lean mass (LM) and plays a major role in BMD depending on age. A close association between LM and bone mass has been demonstrated in young healthy women with normal weight [6–8]. In postmenopausal women, FM and body weight have a greater influence on BMD [9, 10]. Furthermore, both body fat (BF) in % and LM were able to show a positive correlation to BMD obtained with dual-energy X-ray absorptiometry (DXA) [9]. The relative proportion of FM to LM has a direct influence on BMD. If the FM/LM ratio is < 1, both are significantly associated with BMD. If the FM/LM ratio is > 1, the positive influence of FM predominates. Adipocytes appear to be the cause for the positive influence of adipose tissue on bone density by

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The study was approved by the ethics commission for scientific research of the Medical Faculty, Trakia University, Stara Zagora, Bulgaria. (Protocol number: 26, date 01.06.2023).

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producing bone-active hormones, including estrogen, adiponectin, leptin, etc. [10–12]. The hormone leptin in particular has become the focus of some work in recent years. Its receptors are located on the osteoblasts which leads to an increased proliferation and differentiation. Furthermore, it acts via the regulation of osteoprotegerin and NFκB (RANKL) to reduce osteoclast activation and bone resorption [13]. The weight of the FM and LM induces mechanical stress on the bone and furthers the increase of its mass and strength.

Moreover, previous authors demonstrated the impact of the body composition on the fracture risk. A connection between BF in % and non-osteoporotic fractures has already been shown in several studies [14, 15]. Ensrud et al. showed that patients with low BF in % and LM had an increased risk of hip fracture [16]. Premaor et al. found a higher hip fracture rate in postmenopausal women with obesity than in women with normal weight [17]. In contrast, several studies have shown a positive influence of obesity on the risk of hip fractures [18, 19].

Numerous tools have been developed to estimate the risk of future fractures in patients with osteoporosis. One of the most popular fracture risk assessment tools is FRAX [20]. Echolight recently developed a radiofrequency echographic multi-spectrometry (REMS) in which an assessment of the BMD, T-score, fragility score (FS), body mass index (BMI), basal metabolic rate (BMR), and BF in % is acquired after a scan of the lumbar spine. The technology showed a good correlation to the corresponding DXA values of the axial skeleton. [21–24]

The aim of the study was to assess the effect of the BMI, BMR, and BF in % on the REMS-based BMD of the lumbar spine and fracture risk measured with the FRAX tool and REMS-based fragility score among female subjects.

Methods

We conducted a cross-sectional study among 313 female subjects in the time period between June and July 2023, who underwent a screening for osteoporosis with REMS, including assessment of the BMD of the lumbar spine, BMI, BMR, BF, and fracture risk. The subjects should meet the following inclusion criteria: female gender and age between 20 and 90 years. Exclusion criteria were male gender, significant walking impairments, and metallic implants in the lumbar spine. The study acquired an approval from the ethics commission for scientific research of the Medical Faculty, Trakia University, Stara Zagora, Bulgaria (Protocol number: 26, date 01.06.2023). All patients, who were recruited, have signed an informed consent. The acquisition and assessment were carried out by the same health professionals for all subjects.

An echographic medical device called EchoStudio was used with the optional body composition software module, which is available during lumbar spine acquisition. At the end of the automatic data analysis, EchoStudio produces and displays medical reports. Each report presents:

1. All the information obtained natively by EchoStudio (patient's data, diagnosis output, information about the quality of the image, coming from the scan performed on the patient, and FRAX estimation)
2. Additional estimation of body composition (calculated values of BF, BMR, and BMI)

In particular, the BF in % is based on a multiple regression module, that takes into account abdominal measurements of total thickness of soft tissues between skin and lumbar vertebrae, subcutaneous fat thickness and muscle thickness and combines them with patient characteristics (age, sex, height, and weight). The model has been specifically adjusted to obtain a high correlation with impedentiometric measurements [25].

The body composition information, obtained by a REMS scan of the lumbar vertebrae, is reported in the medical report by the use of three different tables. An example of a medical report, achieved from body composition analysis module, is reported in Fig. 1.

The top table in the medical report includes BMI, total body weight, BF for the current patient, together with the value ranges, that are considered to be normal from a clinical point of view.

BF in % refers to the amount of FM in regard to the total body weight expressed as a percentage. Additionally, the raw "basal metabolism" and "activity metabolism" display the estimates obtained for the current patient, measured in kcal/day. Basal metabolism indicates the minimum amount of energy, required to maintain vital functions in an organism at complete rest, measured by the BMR in a fasting individual. Activity metabolism indicated the amount of calories needed according to the patient's specific average physical activity. The physical activity level is the most important driver of caloric needs. The central table in the medical report is related to the BF in % of the current patient, which is classified as underweight, slim, fit, overweight, and obese, according to the patient's age. The cell corresponding to the patient is highlighted using black borders. Lastly, the medical report displays the BMI of the current patient. BMI is a value defined as the body weight divided by the square of the body height, and it is expressed in kg/m^2. According to the World Health Organization (WHO) classification of the weight status, underweight was defined as BMI < 18.5 kg/m^2, normal weight as BMI 18.5–24.9 kg/m^2, overweight 25.0–25.9 kg/m^2, obese (including obesity class I) BMI 30–34.9 kg/m^2, and extreme obese (combining obesity class II and III) as

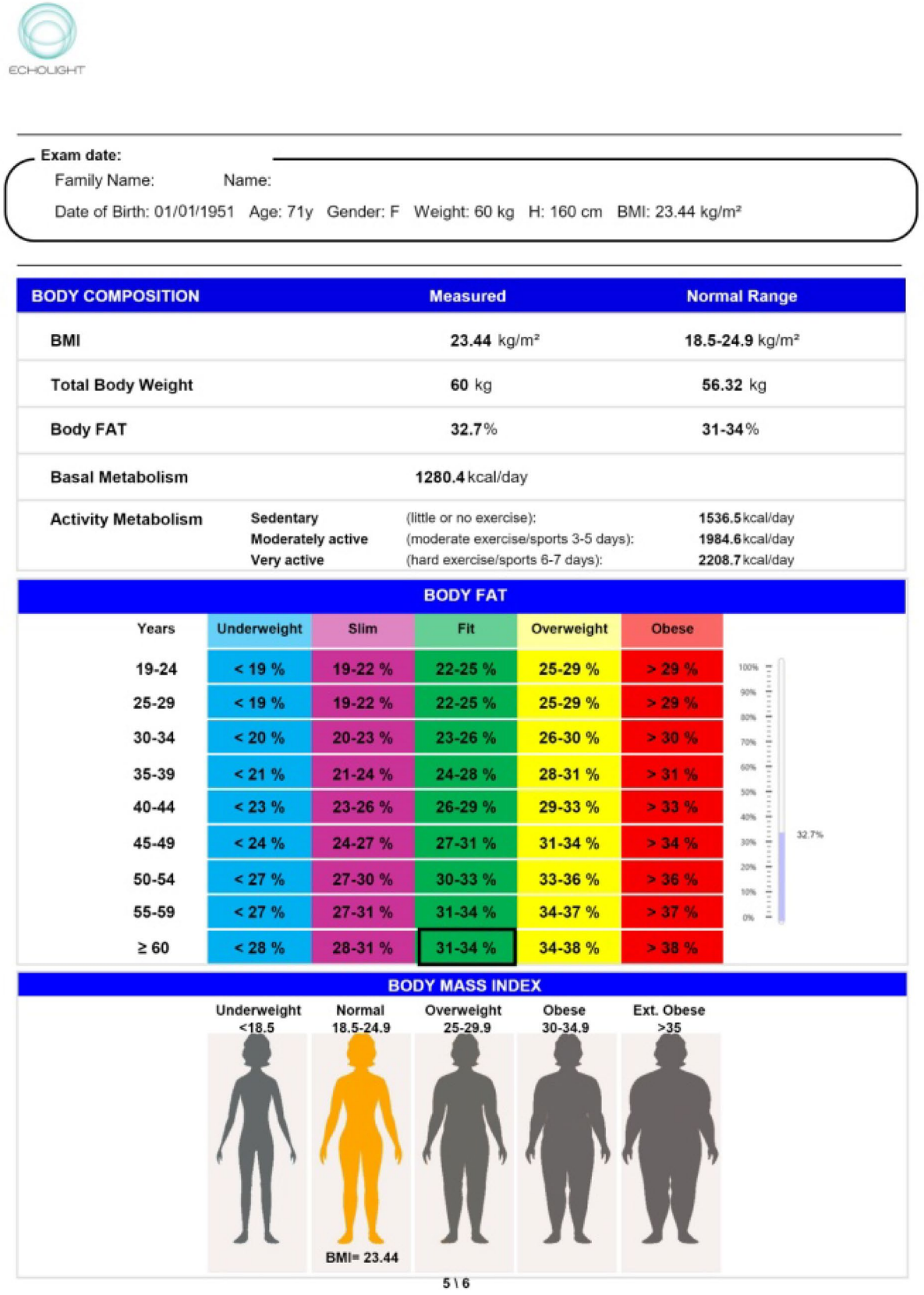

Fig. 1 A medical report acquired from a lumbar spine scan with body composition analysis module

BMI > 35.0 kg/m^2 [25]. According to WHO, the diagnosis output was divided into normal (T-score > −1.0 SD), osteopenic (T-score between −1 and −2.5 SD), and osteoporotic (T-score of < −2.5 SD). Fracture risk is assessed through FS, fracture risk assessment tool (FRAX) for major osteoporotic fractures (MOF) and for hip fractures (HF). FS is a dimensionless parameter that estimates the skeletal fragility calculated by comparing the raw ultrasound spectral analysis with reference models of fragile and non-fragile bones. It can vary from 0 to 100, in proportion to the degree of fragility, independently from BMD [26]. The FRAX was calculated using age, sex, weight, height, and the following risk factors: previous fracture, family history of fracture, current smoking status, corticosteroids intake, diagnosis of rheumatoid arthritis and secondary osteoporosis, alcohol intake 3 or more units/day without inclusion of BMD [27].

Statistical analysis

The age, weight, height, BMI, BMR, BF, age of menopause, BMD, T-score, Z-score, BMD L1-L4, FRAX for MOF, FRAX for HF, and FS were summarized using the descriptive statistics: mean, median, minimum, maximum, standard deviation, and standard error of the mean. Kruskal–Wallis test was used to analyze the differences of BMI, BMR, and BF between the groups according to the BMD: normal BMD, osteopenia, and osteoporosis and differences of the FS, fracture risk assessment (FRAX) for MOF and for HF according to the BMI: underweight, normal weight, overweight, obese, and extreme obese. Linear regression was used to assess the correlations BMI–BMD, BMR–BMD, and BF–BMD.

Results

The mean age of total 313 subjects was 62 years (yrs.) ± 12 yrs. The mean weight and height were 69.6 kg ± 14.4 kg (range 39.4–127 kg) and 157.4 cm ± 8 cm (range 134–176 cm), respectively. BMI had a mean of 28.1 kg/m^2 ± 5.6 kg/m^2 (min. 14.9 kg/m^2 and max. 47.5 kg/m^2). The mean BF (%) was 37.7% ± 8.5% (range 9–52%) and the mean BMR was 1287.2 kcal/d ± 164.2 kcal/d (range 929.7–1908.4). Two hundred and sixty women were postmenopausal and the mean age of menopause was 47 yrs. ± 5 yrs. (range 36–56 yrs.). BMD of the lumbar spine had a mean of 0.852 g/cm^2 ± 0.125 g/cm^2 (range 0.613 g/cm^2—1.261 g/cm^2) and the T-score had a mean of − 1.8 SD ± 1.1 SD (between − 4.0 SD and 3.0 SD). The mean of the FS was 40.96 ± 19.71 (range 18.2–86.4). FRAX for MOF and FRAX for HF were 13.17% ± 9.15% and 3.95% ± 4.55%, as shown in Table 1.

Of total 313 subjects, 67 subjects (21.4%) were with normal BMD, 155 subjects (49.5%) were with osteopenia, and 91 subjects (29.1%) were with osteoporosis. BMI, BF (%), and BMR differed significantly between the groups with normal BMD, osteopenia, and osteoporosis ($p < 0.001$, $p = 0.028$, and $p < 0.001$, respectively). Women with osteoporosis had the lowest mean BMI and BMR compared to the groups with normal BMD and osteopenia, as shown in Table 2.

BMR, BMI, and BF (%) as independent variables were analyzed if they correlate to BMD and fit a linear model. BMR showed high positive correlation to BMD ($R = 0.765$) with 95% confidence interval (CI) [0.715,

Table 1 Descriptive statistics of the study population

	N	Mean	Median	Min	Max	S.E	SD
Age	313	62	62	24	88	1	12
Weight	313	69.6	67.0	39.4	127	0.8	14.4
Height	313	157.4	157	134	176	0.5	8.0
BMI	313	28.1	27.6	14.9	47.5	0.3	5.6
BF (%)	313	37.7	37.3	9	52	0.5	8.5
BMR (kcal/d)	313	1287.2	1257.9	929.7	1908.4	9.3	164.2
Age of menopause	260	47	49	36	56	0	5
BMD	313	0.852	0.842	0.613	1.261	0.007	0.125
T-score	313	− 1.8	− 1.9	− 4.0	3.0	0.1	1.1
Z-score	313	− 0.2	− 0.4	− 2.0	3.1	0	0.8
BMD L1	313	0.751	0.736	0.461	1.234	0.008	0.136
BMD L2	313	0.829	0.818	0.567	1.263	0.008	0.132
BMD L3	313	0.885	0.872	0.578	1.303	0.007	0.125
BMD L4	313	0.913	0.901	0.632	1.297	0.007	0.127
FRAX MOF (%)	279	13.17	12.45	1	57	0.53	9.15
FRAX HF (%)	279	3.59	3.21	2	36	0.26	4.55
FS	313	40.96	33.60	18.20	86.40	3.43	19.71

Table 2 Kruskal–Wallis test for BMI, BF (%), BMR (kcal/d) between the diagnosis groups regarding osteoporosis

Body composition parameter		*N*	Mean	Std. deviation	Std. error	Min	Max	*p* value
BMI	Normal BMD	67	31.6	6.4	0.9	19.3	47.5	< 0.001
	Osteopenia	155	27.9	4.9	0.4	17.3	42.7	
	Osteoporosis	91	25.9	4.7	0.5	14.9	37.7	
	Total	313	28.2	5.6	0.3	14.9	47.5	
BF (%)	Normal BMD	67	39.4	9.9	1.2	14.2	52	0.028
	Osteopenia	155	37.9	7.9	0.6	9	52	
	Osteoporosis	91	35.9	8.2	0.9	16.3	52	
	Total	313	37.7	8.5	0.5	9	52	
BMR (kcal/d)	Normal BMD	67	1481.5	168.8	20.6	1120.5	1908.4	< 0.001
	Osteopenia	155	1279.6	105.8	8.5	1008.3	1577.1	
	Osteoporosis	91	1157.1	89.6	9.4	929.7	1432.3	
	Total	313	1287.2	164.2	9.3	929.7	1908.4	

0.807] and significance of $p < 0.001$. The beta coefficient of 0.001 indicated that 1-cal decrease in BMR would cause a 0.1% decrease in BMD, Fig. 2. Even though, BMI correlated significantly to BMD ($p < 0.001$), the correlation was low positive ($R = 0.362$) with 95% CI [0.262, 0.455] and beta coefficient of 0.008, meaning that one unit change in BMI leads to a 0.8% change in BMD, Fig. 3. On the other hand, BF (%) correlation to BMD and linear model fit did not show statistical significance ($p = 0.058$).

According to the risk factors regarding the FRAX assessment, 101 subjects (32.27%) had a previous fracture, 1 subject (0.32%) had parent with fractured hip, 72 (23.00%) were current smokers, 35 (11.18%) were taking corticosteroids, 77 (24.6%) were diagnosed with rheumatoid arthritis (RA), 15 (4.79%) said to consume 3 or more units of alcohol daily. No patients had secondary osteoporosis, as shown in Table 3.

According to the weight status, 4 subjects (1.3%) were underweight, 88 subjects (28.1%) were with normal weight, 114 subjects (36.4%) were overweight, 67 subjects (21.4%)

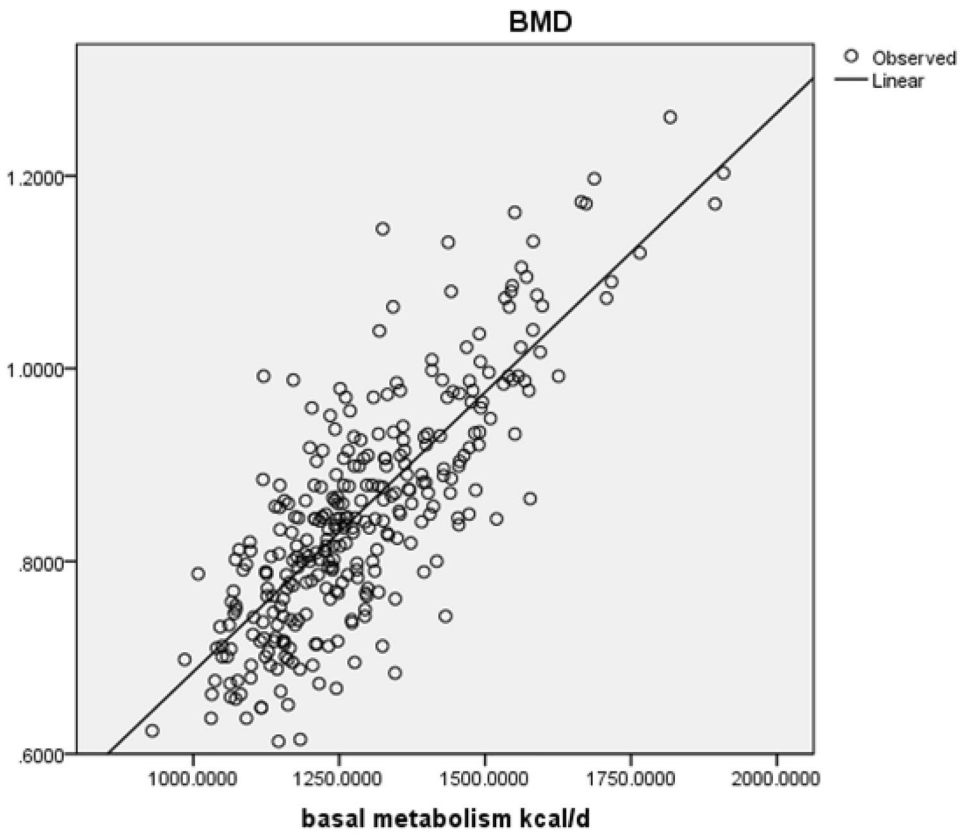

Fig. 2 Linear model of the relation between BMR and BMD

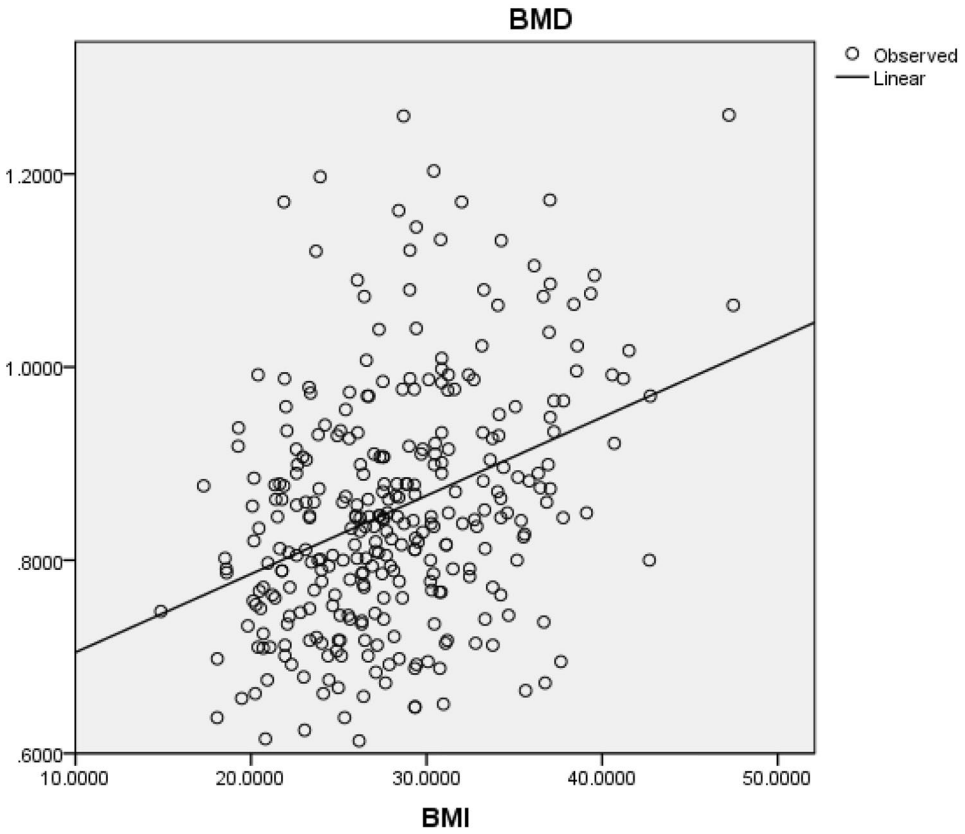

Fig. 3 Linear model of the relation between BMI and BMD

Table 3 FRAX risk factors answered by the patients

		N	%
Previous fracture	Yes	101	32.27
	No	212	67.73
Parent hip fracture	Yes	1	0.32
	No	312	99.68
Current smoking	Yes	72	23.00
	No	241	77.00
Corticosteroids	Yes	35	11.18
	No	278	88.82
RA	Yes	77	24.60
	No	236	75.40
Secondary osteoporosis	Yes	0	0
	No	313	100
Alcohol 3 or more units daily	Yes	15	4.79
	No	298	95.21

were obese, and 40 subjects (12.8%) were extreme obese. In the different BMI classification groups, there was significant difference in the means of FRAX for HF and REMS-based FS with p value 0.014 and < 0.001, respectively. Fracture risk decreased notably with the increase of BMI. FRAX for MOF did not show statistical significance, as shown in Table 4.

Discussion

Our results showed significant differences in BMI between the groups with osteoporosis, osteopenia, and normal BMD. The regression analysis demonstrated a significant low-positive correlation between BMI and BMD. The decrease of BMI accounted for 0.8% decrease in BMD and an increased likelihood for the diagnosis of osteoporosis. This agrees with previous studies, which reported that increased body weight has a positive effect on bone density [28–30]. Concerning BMI, only one study with REMS on 45 subjects showed significant differences between the diagnosis groups regarding osteoporosis, although several BMI groups (underweight, normal, and overweight) remained underrepresented [31]. In spite of that, our study is the first one to estimate the change of BMD in % as a result of a decrease in BMI.

In our work, the BF (%) had a significant difference between the BMD groups. Women with osteoporosis had a lower BF (%) than women with osteopenia and normal BMD ($p = 0.028$). Regression analysis had a borderline p value, but it was not significant. Wang et al. examined 912 young women between the ages of 20 and 25 and they were also able to prove that a higher body FM has a protective effect on bone density [7]. Chen et al. examined both BMD and BF (%) in 50 Caucasian women. They came to the conclusion that BF (%) shows a moderate correlation to BMD

Table 4 Kruskal–Wallis test for the FRAX for HF, FRAX for MOF, REMS-based FS between the BMI patient groups

		N	Mean	Std. deviation	Std. error	Minimum	Maximum	*p* value
FRAX HF (%)	Underweight	4	6.37	4.251	2.125	1	11	0.014
	Normal weight	88	4.77	6.267	.692	0	36	
	Overweight	114	3.56	4.214	.409	− 2	21	
	Obese	67	2.78	2.446	.303	0	10	
	Extreme obese	40	2.28	3.115	.493	0	16	
	Total	313	3.59	4.546	.264	− 2	36	
FRAX MOF (%)	Underweight	4	13.40	6.682	3.341	4	21	0.624
	Normal weight	88	13.96	10.917	1.206	1	57	
	Overweight	114	13.57	9.593	.932	1	46	
	Obese	67	12.65	6.945	.861	3	28	
	Extreme obese	40	11.34	7.220	1.142	2	32	
	Total	313	13.17	9.152	.531	1	57	
REMS-based FS	Underweight	4	80.6	5.6	1.4	75.2	95.2	< 0.001
	Normal weight	88	58.2	7.2	0.6	54.4	73.6	
	Overweight	114	56.9	3.4	2.8	52.3	69.5	
	Obese	67	42.9	8.1	3.1	33.8	54.6	
	Extreme obese	40	26.2	5.4	1.4	18.2	31.4	
	Total	313	40.9	6.2	0.6	18.2	95.2	

[9]. However, no previous study using REMS assessed the difference in BF (%) between the groups with normal BMD, osteopenia, and osteoporosis. Moreover, we applied regression analysis assessing the correlation between BF and BMD and could show that the observed BF values between the BMD groups differed significantly. Despite that, the correlation between the two had a borderline *p* value and indicated that BF is not a key factor for BMD.

Furthermore, we were able to show a significant difference in the BMR between the BMD groups ($p < 0.001$). In subjects with normal BMD, we found a significantly higher BMR than in subjects with osteopenia and osteoporosis. The regression analysis demonstrated high positive correlation between BMR and BMD. The decrease in BMR by 1 cal would cause a 0.1% decrease in BMD. Choi and Pai examined BMR and BMD using DXA in 345 postmenopausal women and 224 elderly men. They were able to show that the prevalence of osteoporosis was higher in the group with BMR < 1230 kcal/d than in the group > 1230 kcal/d [32]. Thus, our results coincide with those of Choi and Pai. Whereas we analyzed, in more detail, the different BMD group in relation to BMR. Hsu et al. analyzed 289 women aged 40–80 years and were able to find a connection between BMR and BMD [33]. There are not any studies with REMS analyzing the correlation between BMR and BMD. Ours is the first one to predict the percent decrease in BMD caused by the decrease of BMR by 1 cal.

With regard to the fracture risk, we were able to show a significant difference in FRAX for HF, between the BMI groups. The lower BMI increases the risk of suffering hip fractures. This is consistent with Kanis et al., who described BMI in their work on the clinical application of FRAX as decisive for fracture risk [34].

We could not determine any significance between the BMI groups for FRAX for MOF ($p = 0.624$). Gnudi et al. examined the influence of BMI on various osteoporotic fractures. They were able to show that although a higher BMI has a protective effect on hip fractures; it raises the risk of proximal humerus fractures [35]. Likewise, the results of Prieto-Alhambra et al. show that while obesity has a protective effect on hip fractures, it also leads to a 30% increased risk of proximal humeral fractures [18]. Compston et al. examined the risk of osteoporotic fractures in women with and without obesity. In the obese group, the risk of proximal femoral fractures and ankle fractures was higher than in the non-obese group, whereas the risk of wrist fractures in the obese group was significantly lower than in the non-obese group [32]. When it comes to MOF, there are inconsistent results in the literature regarding the protective effect of obesity with regard to fracture risk. In addition to the BMI, the influencing factors for MOF appear to be diverse and not exclusively determined by body weight. This also agrees with our results, as we could not find a significant difference in FRAX MOF between the BMI groups. In addition, previous studies did not investigate in detail the differences in the FRAX MOF and FRAX HF between the BMI groups.

Our study showed a significant difference in the REMS-based FS between the BMI groups ($p < 0.001$). Currently, no other study has investigated the relationship between the REMS-based fragility score and BMI.

Nevertheless, the study has some limitations. In the first place, the group of subjects who were underweight remained underrepresented. Second, the assessment of comorbidities and risk factors was only carried out as part of the FRAX questionnaire which may slightly differ from the definitions given by the International Osteoporosis Foundation. Finally, the number of postmenopausal women outnumbered that of the premenopausal.

Conclusion

Body composition plays a vital role for the bone health. Subjects with low BMI, BF (%), and BMR are at high risk for osteoporosis. Although BF differs significantly among the subject groups with osteoporosis, osteopenia, and normal BMD, it is not a key factor in predicting BMD values. On the other hand, BMR showed the strongest correlation to BMD indicating that a decrease by 1 cal would cause a 0.1% decrease in BMD. Underweight women show significantly higher fracture risk, assessed with FRAX and REMS-based fragility score. Therefore, maintaining a balanced body composition through a healthy lifestyle and adequate nutrition is an important aspect of the prevention of osteoporosis and fragility fractures.

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Data availability Data available on request due to privacy/ethical restrictions.

Declarations

Conflict of interest The authors declare no conflict of interest.

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