Clinical Rheumatology (2019) 38:3261–3268
https://doi.org/10.1007/s10067-019-04655-6

ORIGINAL ARTICLE

Evaluation of the relationship between osteoporosis, balance, fall risk, and audiological parameters

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Received: 8 January 2019 / Revised: 12 June 2019 / Accepted: 20 June 2019 / Published online: 8 July 2019
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Abstract

The aim of the study is to investigate the factors such as balance and audiology parameters and bone mineral density (BMD), which were thought to be associated with the increased risk of fall in osteoporotic patients. Ninety-nine female patients between the ages of 40 and 75 were included in the study. Noise exposure, tinnitus, and vertigo were investigated. BMD measurement, Berg Balance Scale (BBS), Timed Up and Go (TUG), and stabilometry tests were applied to the patients. Patients were divided into three groups according to BMD measurements. Patients with a *T* score of − 1 and below were considered normal (control) (group 1), those with a *T* score of − 1 to − 2.5 were considered osteopenic (group 2), and those with a T score of − 2.5 and above were considered osteoporotic (OP) (group 3). BBS was 42.06 ± 5.00, 47.74 ± 5.18, and 51.65 ± 3.64 in groups1, 2, and 3, respectively. The difference between the groups was statistically significant ($p = 0.001$). OP patients had higher oscillation values in all measurements compared with the control group. However, the difference was statistically significant especially on mobile platforms ($p < 0.05$). Mean tones of pure tone thresholds at 500–8000 Hz for ears were significantly different in patients with OP compared with controls ($p < 0.05$ for 500–2000 Hz, $p < 0.01$ for 4000–8000 Hz). This study demonstrated that BMD reduction was correlated with balance parameters and audiological measurements. Therefore, it can be concluded that OP may affect the risk of fracture occurrence not only by decreasing BMD but also by increasing the risk of falling.

Key Points

- *In the present study, the effects of balance and audiology parameter measurements on osteoporosis (OP) were investigated. In addition, the associations between vertigo, tinnitus, history of falling, body made index, vitamin D, and calcium values and osteoporosis were evaluated.*
- *We determined that bone mineral density (BMD) reduction was related to balance and audiological parameters. It can be speculated that OP may affect the risk of fracture occurrence not only by decreasing BMD but also by increasing the risk of falling. We think that early diagnosis, appropriate treatment, and rehabilitation of hearing loss and OP may decrease the incidence of falling and improve the quality of life of the affected individuals.*

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Keywords Audiological parameters · Balance · Falling · Osteoporosis

Introduction

Osteoporosis (OP) is a multifactorial systemic disease characterized by decreased bone mass, microarchitecture decomposition, and increased bone fragility [1, 2]. In OP, pathological fractures are frequently seen in the thoracolumbar vertebrae, hip, and wrist. It is estimated that the number of patients with osteoporotic hip fractures worldwide is more than 200 million [3]. Osteoporosis-associated fractures cause morbidity/mortality and result in a significant burden on the healthcare system, with reduced quality of life, psychological effects, limitation of freedom, and economic cost increases [4, 5].

The OP definition of the World Health Organization (WHO) has been used globally since the mid-1990s as a method based on dual-energy X-ray absorptiometry (DXA) and bone mineral density (BMD) [6, 7]. There is increasing evidence that the risk of fracture is doubled for each standard deviation in the assessment of BMD and DXA. However, in recent years, it has been increasingly recognized that low BMD should be accepted as a risk factor for bone fragility rather than a pathology in itself [8, 9].

Together with impaired bone turnover, muscle weakness and balance and hearing dysfunction are commonly seen along with aging. It is also important to evaluate the parameters of hearing, balance, and bone quality in order to develop effective measures to prevent falling in the early period of OP. In advanced ages, the changes in BMD may be accompanied by vestibulocochlear degeneration and balance influences in the ear. Studies revealed that bone and muscle quality, vestibulocochlear function, and postural balance are critical for balance control in osteoporotic patients [10, 11].

The aim of this study is to investigate the association between BMD and parameters of balance and audiology which are thought to be related to increased risk of falling in OP patients.

Materials and methods

Study design

The study was performed on 105 female patients who were aged between 40 and 75 years and admitted to the physical therapy clinic between January and July 2018, with the complaints of common back and low back pain, length reduction, weakness, and inability to walk long distances. The study was carried out according to the Declaration of Helsinki after the approval of the local ethics committee (dated 25 October 2017 and protocol number 03). All participants were informed about the procedures to be performed, and an informed written consent was obtained from each patient prior to the study. This single-center research was designed as a prospective, controlled, and comparative study.

Study population

Four out of 105 women were excluded from the study because of the incompatibility with balance tests, and two were excluded due to inability to perform hearing tests. The exclusion criteria included the presence of neurological diseases with balance dysfunction, musculoskeletal disease with deformity of lower extremities, diabetes mellitus, peripheral neuropathy, vestibulopathies, history of autological disease or early-onset hearing loss, systemic illnesses which may disturb standing, and known cognitive dysfunction.

Initial assessment

Demographic data including age, height, body weight, body mass index, concomitant disease, and history of fall were recorded. Exposure to noise and the presence of tinnitus and vertigo were assessed. Serum calcium and vit D results were recorded. The Berg Balance Scale (BBS) and Timed Up and Go (TUG) test were performed [12, 13]. The static balance was assessed using a portable force platform. Balance tests were conducted by a trained research assistant. These tests were repeated three times and averaged.

Bone mineral density assessment

BMD values of the patients were measured from the anteroposterior aspect of the lumbar vertebrae (L1 to L4) and the proximal femur with the Hologic QDR 4500 (Bedford, MA) device. The cases were separated into three groups according to the World Health Organization criteria: group 1 ($n = 31$) was composed of women with normal bone mineral density (BMD) in the vertebrae or femur neck (control, T scores greater than − 1 standard deviation (SD)), group 2 ($n = 34$) consisted of women with low bone density (osteopenia, T scores between − 1 and − 2.5 SD), and group 3 ($n = 34$) consisted of women with osteoporosis (T score lower than − 2.5 SD [2, 8].

Balance evaluation

The Berg Balance Scale is a simple, safe, and short test that is aimed at measuring the ability of a person to maintain balance while performing functional tasks. This test consists of 14 items which investigate the movements where the support area decreases and the position is hard to maintain. BBS is commonly used in older people, and the balance is considered to be good if the score is 45 or above [12].

TUGO is applied to assess the balance function and fall risk. Participants were seated on a back-supported chair. A sign was marked on the floor 3 m ahead on the chair. The patients were instructed to get up from the chair, walk up to the sign, turn around in their own circles, walk up to the chair, and sit down. The time of performance was measured in seconds [13].

Stabilometry is a technique used for evaluating static balance. The anteroposterior (AP) and mediolateral (ML) oscillations of the body were measured in the patients while standing on a force platform [14, 15]. The subjects underwent stabilometry measurements on a portable force platform (SportKAT 4000, Carlsbad, USA). The subjects were asked to maintain their static posture for 30 s by fixing their eyes on the screen. The measurements started after the first pass of the self-adjustment of the subject. For the evaluation of balance, eye-open fixed platform (FPEO), eye-closed fixed platform (FPEC), eye-open mobile platform (UPEO), and eye-closed mobile platform (UPEC) positions were measured.

Audiological evaluation

Hearing test measurements were performed by an experienced audiometrist under the supervision of an otorhinolaryngologist at an otorhinolaryngology outpatient clinic. Tympanogram, stapes acoustic reflex, and Toynbee and Valsalva maneuvers were applied using an Interacoustics AZ 26 (226 Hz, Interacoustics, DK-5610 Assens, Denmark) impedance meter for the participants. The pure voice and speech audiometry tests were performed using the Interacoustics AC40 Pure Tone Audiometer. Tympanometric data were classified as type A, B, or C tympanograms. Acoustic reflexes were simultaneously recorded and analyzed. Evaluations were performed at 125–8000-Hz intervals in the pure audio test. For each set of tests, the mean values of air and bone conduction at each frequency value were calculated for all groups.

Statistical analysis

SPSS 17.0 (IBM Statistics for Windows version 17, IBM Corporation, Armonk, New York, USA) was used for analysis of the variables. Compatibility of data with normal distribution was checked with the Shapiro-Wilk test, and homogeneity of variance was evaluated by the Levene test. Quantitative variables were presented either as mean ± SD (standard deviation) or as median and range (minimum–maximum). Categorical variables were expressed as *n* (number) and percent (%). ANOVA and Tukey tests were used for group comparisons. A p value of < 0.05 was accepted as statistically significant.

Sample size of the study was determined by using power analysis (G*Power 3.1.9.2; University of Düsseldorf, Germany) (power 0.80/α 0.05/β 0.2).

Results

Mean ages of patients between 3 groups were similar (group 1, 58.82 ± 9.69; group 2, 59.48 ± 7.54; and group 3, 59.37 ± 8.05 years of age; $p = 0.428$). There were statistically significant differences among groups in terms of BBS scores ($p = 0.001$). BMI levels of groups 2 and 3 were significantly lower than that of the control group ($p = 0.001$). Demographic features of the groups are presented in Table 1.

For both ears, mean pure tone thresholds at 500–8000 Hz were significantly different in osteoporosis patients compared with controls ($p < 0.05$ for 500–2000 Hz; $p < 0.01$ for 4000–8000 Hz) (Table 2). There were no statistically significant differences between groups 2 and 3 (Fig. 1). Although no difference was observed between the control and osteopenic patients in the frequency of 500–2000 Hz ($p > 0.05$), there was a difference in the left ear for 4000–8000 Hz ($p < 0.05$).

Figures 2, 3, and 4 display the stabilometric measurements of eyes open and closed in fixed and mobile platforms. There were significant differences between the osteoporotic and control groups in terms of FPEO, UPEO, and UPEC values in the ML plane ($p = 0.049$, 0.043, and 0.038, respectively). Osteopenic patients had higher oscillation values in all measurements compared with the control group, but the difference was statistically significant only in mobile platforms ($p < 0.05$). It was observed that the most significant difference occurred especially when the patient was on a mobile platform and eyes were closed during ML displacement (Fig. 2).

AP oscillation values are presented in Fig. 3. FPEO, UPEO, and UPEC values were significantly different in the AP plane ($p = 0.022$, 0.016, and 0.015, respectively).

The vectorial oscillation values are shown in Fig. 4, and the results were similar to the ML plane results.

BMI was negatively correlated with BBS ($r = -0.394$, $p = 0.001$). Tinnitus was found to be correlated with FPEC ML ($r = 0.210$, $p = 0.037$), AP ($r = 0.227$, $p = 0.024$), and V ($r = 0.210$, $p = 0.037$). There was a strong relationship between history of falling and the TUG test ($r = 0.651$, $p = 0.001$). Associations between stabilometric values, TUG, vertigo, tinnitus, and history of falling are represented in Table 2.

Discussion

In the present study, the effects of balance and audiology parameter measurements on OP were investigated. In addition,

Table1 Demographic features of the study population

	Control ($n = 31$)	Osteopenia ($n = 34$)	Osteoporosis ($n = 34$)	p
Age (days)	58.82 ± 9.69	59.48 ± 7.54	59.37 ± 8.05	0.428
BMI	33.99 ± 3.94	31.74 ± 4.50	28.74 ± 4.36	0.001
Smoking (yes/no)	3/28	3/31	5/29	0.708
Noise exposure (yes/no)	10/21	5/29	4/30	0.080
Tinnitus (yes/no)	5/26	11/23	16/18	0.086
Vertigo (yes/no)	4/27	10/24	15/19	0.214
BBS	51.65 ± 3.64	47.74 ± 5.18	42.06 ± 5.00	0.001
Fall history (yes/no)	4/27	8/26	16/18	0.119
Vit D	24.69 ± 20.15	22.85 ± 26.63	13.45 ± 6.98	0.057
Ca	9.59 ± 0.37	9.52 ± 0.33	9.45 ± 0.45	0.344
TUG	9.41 ± 2.53	15.97 ± 2.90	18.79 ± 3.15	0.156

Data are expressed as the mean ± SD or n (%), unless otherwise noted. Chi-square test (Monte Carlo), one-way ANOVA (with Tukey HSD)

BBS Berg Balance Scale, *BMI* body mass index, *Ca* serum calcium, *TUG* Timed Up and Go

the associations between vertigo, tinnitus, history of falling, BMI, vitamin D, and calcium values and osteoporosis were evaluated. It was found out that high BMI, low vitamin D levels, decreased level of hearing, and increased ML oscillation in the eye-closed situation especially in the mobile platform were positively correlated with a BMD decrease (osteoporosis-osteopenia).

One of the most important factors affecting morbidity and quality of life in osteoporotic patients is the bone fractures which may occur due to falling [3, 5]. In order to decrease risk of falling, definition of the risk factors and development of treatment alternatives are mandatory. Several factors including impaired walking, sedentary lifestyle, vestibulopathy, balance dysfunction, increased postural oscillation, and decreased muscle mass were defined for risk of falling. The risk is directly proportional to the number of risk factors [4, 16].

Studies evaluating the stabilometry and dynamic balance measurements in postmenopausal women reported conflicting results. In a study investigating balance dynamics, normal young, old non-OP, and old OP women were compared in terms of BBS and TUG tests. Authors determined that TUG and BBS scores were better in young women than in other groups; however, there was no difference between the other two groups [17]. In another study evaluating the association

Table 2 The relationship between stabilometric parameters with TUG, vertigo, tinnitus, and fall history

	Fall history		TUG		Vertigo		Tinnitus	
	r	p	r	p	r	p	r	p
TUG	0.651**	0.001			0.048	0.634	0.050	0.623
FPEO ML	0.126	0.213	0.017	0.990	0.161	0.112	0.010	0.919
FPEC ML	0.222*	0.027	0.029	0.203	0.235*	0.019	0.201*	0.011
UPEO ML	0.170	0.175	0.245*	0.014	0.257*	0.010	0.161	0.112
UPEC ML	0.282**	0.005	0.186	0.066	0.373**	0.001	0.266**	0.008
FPEO AP	0.015	0.883	0.048	0.640	0.153	0.130	0.055	0.592
FPEC AP	0.073	0.472	0.33**	0.002	0.316**	0.001	0.127	0.212
UPEO AP	0.147	0.146	0.098	0.334	0.307**	0.002	0.046	0.648
UPEC AP	0.204*	0.043	0.072	0.481	0.346**	0.001	0.258**	0.01
FPEO V	0.115	0.256	0.030	0.766	0.152	0.134	0.015	0.880
FPEC V	0.139	0.170	0.027	0.788	0.248*	0.013	0.022	0.828
UPEO V	0.174	0.085	0.092	0.365	0.512**	0.001	0.101	0.318
UPEC V	0.128	0.207	0.104	0.305	0.538**	0.001	0.123	0.225

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

TUG Timed Up and Go, *AP* anteroposterior, *ML* mediolateral, *FPEC* eye-closed fixed platform, *FPEO* eye-open fixed platform, *UPEO* eye-open mobile platform, *UPEC* eye-closed mobile platform, *V* velocity

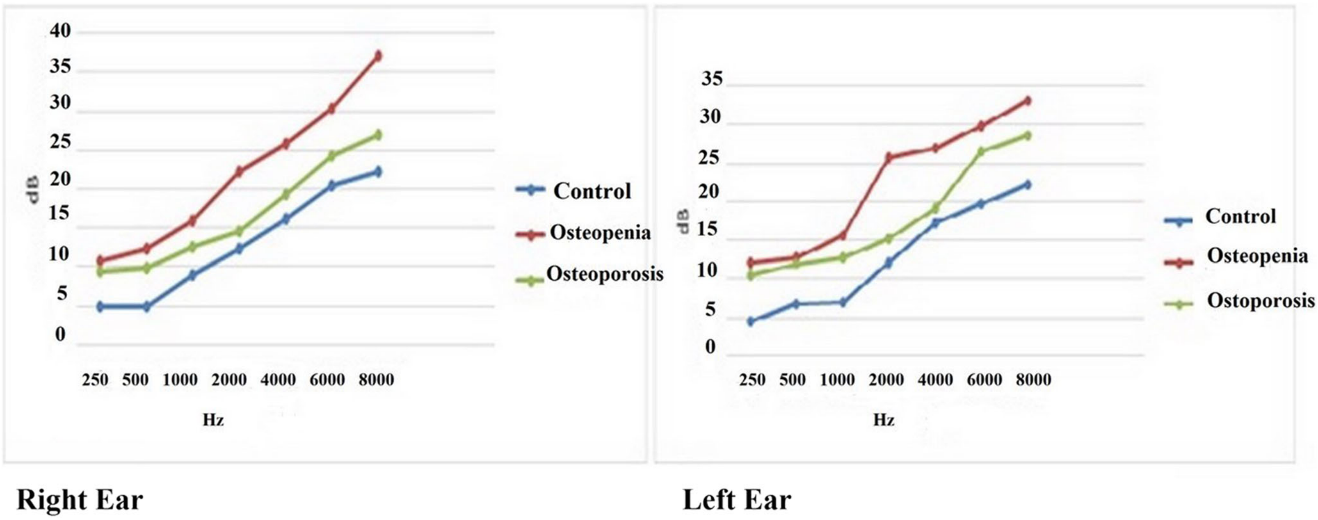
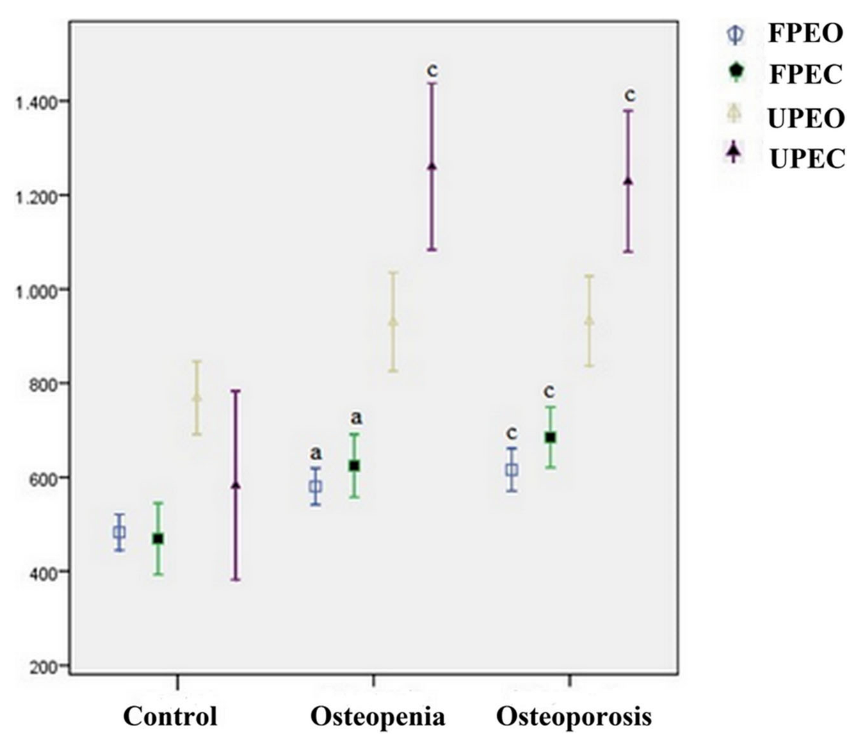


Fig. 1 Distribution of right and left ear hearing frequencies according to groups

between OP and postural instability, Gunendi et al. [18] divided women into premenopausal, postmenopausal non-OP, and postmenopausal OP groups. All patients underwent static, dynamic, and functional balance evaluations with stabilometry, TUG, BBS, and four square step tests. Authors found out that premenopausal women had better static, dynamic, and functional balance scores than postmenopausal women. Other studies reported conflicting results about the association between the presence of OP and its impact on postural balance [19, 20].

The present study revealed that BBS is significantly disturbed in OP patients and TUG values were significantly higher in women with the history of falling. İn addition, osteoporotic and osteopenic patients had higher oscillation values in all measurements compared with the control group, but the difference was statistically significant especially in mobile platforms. There were significant differences between OP and control groups in terms of FPEO, UPEO, and UPEC values in the mediolateral plane. It was also noted that the vector oscillation values were similar to the ML plane results.

Fig. 2 Distribution of mediolateral displacements in the stabilometric platform according to groups. [a]$p < 0.05$, [c]$p < 0.001$, difference between the control group. FPEC, eye-closed fixed platform; FPEO, eye-open fixed platform; UPEO, eye-open mobile platform; UPEC, eye-closed mobile platform



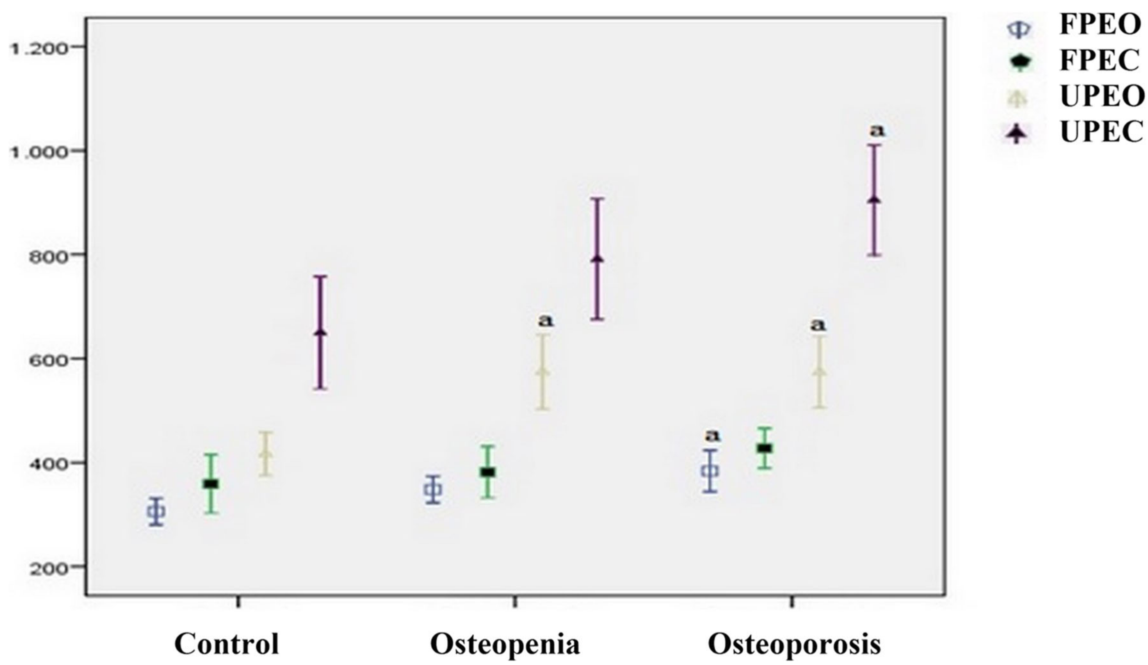
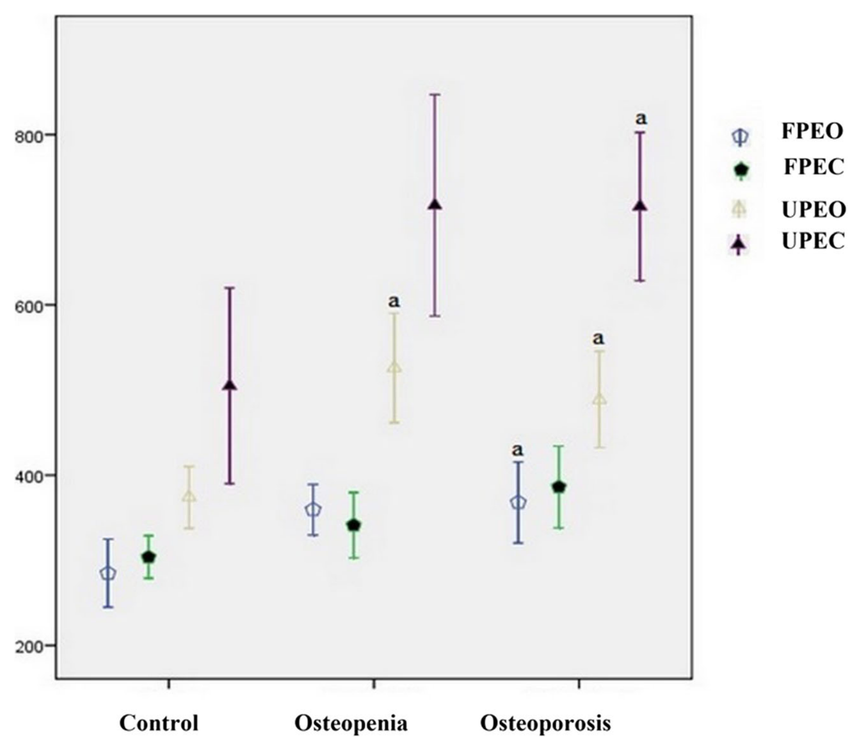


Fig. 3 Distribution of anteroposterior displacement according to groups. [a]$p < 0.05$, difference between the control group. FPEC, eye-closed fixed platform; FPEO, eye-open fixed platform; UPEO, eye-open mobile platform; UPEC, eye-closed mobile platform

Low BMD is a well-known risk factor for fractures in postmenopausal women. In women, body weight increases BMD through the mechanical load on the skeleton and the estrogens stored in the fat tissue [21]. Prieto-Alhambra et al. [22] reported that the rates of hip fractures were significantly lower in overweight/obese women when compared with normal/low-weight ones. In this study, we determined that BMI levels were significantly lower in OP and osteopenia groups than in the control group and BMD values of OP patients with tendency to fall were significantly lower than those without.

A decrease in BMD may result in hearing loss in the elderly. A previous study reported that patients with otosclerosis had lower DXA scores when compared with normal subjects [23]. In a study in which the relationship between otosclerosis

Fig. 4 Distribution of vectorial displacements in the stabilometric platform according to groups. [a]$p < 0.05$, difference between the control group. FPEC, eye-closed fixed platform; FPEO, eye-open fixed platform; UPEO, eye-open mobile platform; UPEC, eye-closed mobile platform



and OP was investigated, the incidence of OP was significantly higher in patients with otosclerosis (15–4%), and the authors concluded that otosclerosis was significantly more likely correlated with the OP [24].

Kahveci et al. [25] prospectively evaluated 50 OP patients, 50 osteopenia patients, and 25 healthy controls with otological symptom scores, pure tone audiometry, word recognition test, and distortion product autoacoustic emission measurements. OP patients were found to have higher sensorineural type hearing loss. In addition, the mean pure tone audiometry findings of patients and controls were significantly different at 500–8000-Hz frequencies ($p < 0.01$ for 500–2000 Hz, $p < 0.05$ for 4000–8000 Hz). It was also noted that tinnitus complaints were higher in OP patients ($p < 0.01$).

In our study, the mean values of pure tone thresholds at 500–8000 Hz for both ears were significantly different in OP patients compared with controls. There was no difference between the control group and osteopenic patients at low frequencies of 500–2000 Hz, while there was a difference in the left ear for 4000–8000 Hz. Those findings suggested that BMD reduction may lead to hearing loss due to possible degeneration of middle ear ossicles or the cochlear capsule together with the metabolic changes.

The main limitations of our study were the fact that visual functions were not evaluated that might cause balance problems in patients with OP and the fact that the FRAX score was not calculated in the evaluation of OP and risk factors. Evaluating BMI, hearing, vit D, and balance parameters in patients with osteoporosis and excluding a large population that may lead to hearing, balance, and mobilization disorders before the study are the strengths of the study.

Conclusions

With aging, both hearing loss and OP may lead to increased risk of balance disturbances and falls and have a significant negative impact on the quality of life. We determined that BMD reduction was related to balance and audiological parameters. It can be speculated that OP may affect the risk of fracture occurrence not only by decreasing BMD but also by increasing the risk of falling. We think that early diagnosis, appropriate treatment, and rehabilitation of hearing loss and OP may decrease the incidence of falling and improve the quality of life of the affected individuals.

Compliance with ethical standards

Disclosures None.

Ethics committee approval The study was approved by the Clinical Research Ethics Committee of Sütçü Imam University School of Medicine.

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