



Audiovestibular functioning of post-menopausal females with osteoporosis and osteopenia

Manisha K. Juneja ^{a,*}, Sanjay Munjal ^b, Anuradha Sharma ^c, Ashok K. Gupta ^c, Sanjay Bhadada ^d

^a Speech and Hearing Unit, ENT Department, GMCH, Sec-32, Chandigarh, India

^b Speech & Hearing Unit, Dept. of Otolaryngology, PGIMER, Chandigarh, India

^c Dept. of Otolaryngology, PGIMER, Chandigarh, India

^d Dept. of Endocrinology, PGIMER, Chandigarh, India

ARTICLE INFO

Article history:

Received 20 April 2020

Received in revised form

29 July 2020

Accepted 29 July 2020

Keywords:

Hearing loss

Audio-vestibular testing

Pure tone audiometry (PTA)

OAE'S

Speech audiometry

VEMP

Sensorineural hearing

ABSTRACT

Introduction: Osteoporosis and osteopenia are progressive disorders characterized by decreased bone mass, especially in postmenopausal women. These can be associated with body pain, fractures, hearing loss and balance disorders. The present study aims to evaluate audio-vestibular function in post-menopausal patients with osteopenia or osteoporosis.

Methods: The study included 48 postmenopausal women (new subjects) diagnosed with osteoporosis (n = 23) or osteopenia (n = 25) in the age range of 50–66 years, as well as 28 normal women as controls. Audiological testing included pure tone audiometry (conventional and extended high-frequency audiometry), speech audiometry, impedance audiometry and otoacoustic emissions, including both transient evoked otoacoustic emissions (TEOAEs) and distortion product otoacoustic emissions (DPOAEs). All subjects also underwent vestibular evoked myogenic potentials testing (both ocular and cervical VEMPs).

Results: In the present study, hearing was worse at all frequencies in the osteoporosis group in comparison with the osteopenia and control groups, with worse speech recognition and discrimination scores and OAEs. Vestibular function was affected in 95.65% of women with osteoporosis and 76% of those with osteopenia.

Conclusion: Osteoporosis and osteopenia are risk factors for vestibular dysfunction and hearing deficits in postmenopausal women. Thus, hearing and vestibular function should be monitored by audiological and vestibular testing periodically in these individuals.

© 2020 PLA General Hospital Department of Otolaryngology Head and Neck Surgery. Production and hosting by Elsevier (Singapore) Pte Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

1. Introduction

Osteoporosis and osteopenia are progressive disorders characterized by decreased bone mass and increased bone brittleness that can potentially result in bone fractures (Riis, 1993). Osteoporosis, also called “a silent disease,” remains asymptomatic until it reaches the advanced stage (Kanis et al., 2013). Data from a World Health Organization (WHO) survey shows that this disorder is the second most critical health problem worldwide, following cardiovascular diseases (World Health Organization, 1994). A recent study in 2017

indicated that 29% of the Indian population has osteoporosis per consensus data (Ramalingaiah, 2017).

Osteoporosis and osteopenia can occur at any age, especially in postmenopausal women (Nilas and Christiansen, 1987), and may lead to body pain, fractures, hearing loss and balance disorders (Bigelow et al., 2016; Zuniga et al., 2012; Burke-Doe et al., 2008). A meta-analysis of five studies from different countries found that a decrease in bone mineral density (BMD) or osteoporosis was significantly associated with hearing loss (Upala et al., 2017). A nationwide cohort study of the Korean population concluded that osteoporosis increased the risk of sudden sensorineural hearing loss in patients aged ≥ 50 years (Kim et al., 2018). Hearing loss in individuals with osteoporosis or osteopenia can be conductive, sensorineural or mixed, potentially due to otosclerosis, ossicular fracture and neural degeneration (Matsuo et al., 2005; Doherty and Linthicum, 2004). A few studies have demonstrated that patients

* Corresponding author. Speech and Hearing Unit, ENT Department, GMCH, Chandigarh, 160047, India.

E-mail address: manishatherapist1978@yahoo.co.in (M.K. Juneja).

Peer review under responsibility of PLA General Hospital Department of Otolaryngology Head and Neck Surgery.

with osteoporosis may suffer from balance disorders as well as hearing loss (Gargeshwari et al., 2018; Mendy et al., 2014).

Most existing studies so far have focused on the association between BMD and cochlear function, and research on the impact of osteoporosis and osteopenia on vestibular function in postmenopausal women is sparse. Also, results in studies showing hearing loss in osteoporosis and osteopenia, especially in postmenopausal females, are variable especially regarding the type of hearing loss. There also lack data on extended high frequency hearing in postmenopausal women with osteoporosis and osteopenia. It was against this background that the current study was planned.

1.1. Aim of the study

The study aims to prove the hypothesis that osteoporosis and osteopenia increase the risk of hearing loss and vestibular dysfunction in postmenopausal women.

1.2. Objectives

To study the prevalence of hearing loss in postmenopausal patients with osteoporosis or osteopenia as compared to the control group.

To compare hearing in postmenopausal patients with osteoporosis or osteopenia with a control group.

To assess and compare vestibular function in postmenopausal patients with osteoporosis or osteopenia and in a control group.

2. Materials and methods

The present study quantitatively analyzed audiological and vestibular test data, using a deductive analytical research approach with a cross-sectional study design in postmenopausal females with osteoporosis or osteopenia.

2.1. The subjects were divided into three groups according to BMD measurements by dual-energy X-ray absorptiometry (DEXA)

DEXA value T-scores for osteoporosis and osteopenia were calculated by comparing to specific normative range for patients of matched gender and ethnicity (Table 1).

Subjects.

Group 1: postmenopausal subjects with normal BMD values (n = 28, mean age = 59.18 ± 4.39 years), i.e. control group

Group 2: postmenopausal subjects with osteopenia (n = 25, mean age = 58.80 ± 4.35 years)

Group 3: postmenopausal subjects with osteoporosis (n = 23, mean age = 60.78 ± 4.54 years)

Age were matched across the groups (Table 2).

Inclusion criteria included osteoporosis or osteopenia with no previous history of hearing loss or middle ear pathology, no apparent history of noise exposure, noise trauma or head injury. Patient evaluation was performed after obtaining ethical clearance and

Table 1
Diagnostic categories based on T-score recommended by WHO (Czerwiński et al., 2007) (Czerwiński et al., 2007).

Normal	scores better than -1.1
Osteopenia	scores between -1.1 and -2.5
Osteoporosis	scores ≥ -2.6

Table 2
Age among osteoporosis, osteopenia and control groups.

Groups	N	Mean Age (years)<	SD	F ratio
Osteoporosis	23	60.78	4.54	1.35
Osteopenia	25	58.80	4.35	
Control	28	59.18	4.39	

SD: Standard deviation.

written consents. Ear, nose and throat examination was conducted and demographic data, including sex, age, qualification and income were obtained for all the patients as well as the control subjects.

2.2. Audiological assessment

All participants underwent pure tone audiometry, speech reception threshold (SRT), speech discrimination score (SDS) and otoacoustic emissions (OAEs) testing. Only subjects having type A tympanogram were included in this study.

2.2.1. Pure-tone audiometry was conducted at octave conventional and extended high frequencies (0.25 kHz–18 kHz) in a sound-treated room by the same audiologist with a calibrated clinical audiometer (Madsen Orbiter 922)

The TDH 39 headphones was used for conventional frequency audiometry and the HDA 2000 headphones for extended high frequency audiometry. Bone-conduction thresholds were measured at 250 Hz–4000 Hz using a B-71 bone vibrator. Three pure-tone averages (PTAs) were computed based on air conduction thresholds, i.e., PTA 1 for 500, 1000 and 2000 Hz, PTA 2 for 4000, 8000 and 10,000 Hz and PTA3 for 12.5, 16 and 18 kHz. Hearing loss was graded based on the following (Clark, 1981).

Hearing category	Audiometric threshold (dB HL)
Normal	-10–15
Slight loss	16–25
Mild loss	26–40
Moderate loss	41–55
Moderately severe loss	56–70
Severe loss	71–90
Profound loss	>91

2.2.2. Tympanometry

A Maico (MI34) middle ear analyzer was used to assess eardrum compliance using a probe tone of 226 Hz at 85 dB SPL by varying pressure from +200 daPa to -400 daPa.

2.2.3. Otoacoustic emissions

Both distortion product and transient OAEs were measured using the Smart OAE version 1.0 (Beta Version) (Intelligent Hearing System, USA) and an ER-10D probe. Nonlinear clicks (100 μs, 85 dB peSPL) at 19.3/s were used for TEOAE testing, for 1024 sweeps of 20 ms, one ear at a time. TEOAEs were deemed present if the signal to noise ratio (SNR) at three consecutive frequencies was above 6 dB. DPOAEs were measured from 500 to 8000 Hz and considered as present if SNR was above 6 dB at three consecutive frequencies.

2.3. Vestibular testing

Vestibular-evoked myogenic potentials (VEMPs) were generated as inhibitory electrical potentials in response to sound

stimulation (Neuro Audio, Russia, Version 1.0.95). Table 3 shows the parameters used in the study. Both ears of all patients and control subjects were tested.

2.3.1. cVEMP

cVEMPs were recorded from the sternocleidomastoid muscle (SCM) with the subject in a sitting position and the head rotated away from the stimulated side. The inverting (–) electrode was placed at the sternoclavicular junction; non-inverting (+) electrode at the midpoint of the upper ½ of ipsilateral SCM muscle and ground electrode at the forehead. P1, N1 peak latencies and P1–N1 amplitudes were recorded.

2.3.2. oVEMP

Ocular vestibular evoked myogenic potentials were also recorded with the subject in a sitting position and instructed to look 30° superomedially at a fixed point to facilitate responses. The non-inverting electrode was placed approximately 1 cm below the center of the lower eyelid, the inverting electrode about 1 cm below the non-inverting electrode on the cheek and the ground electrode on the forehead. N1, P1 peak latencies and N1–P1 amplitudes were recorded.

3. Results

3.1. Pure tone audiometry results in patients with osteoporosis or osteopenia

3.1.1. Patients with osteoporosis

PTA 1 showed normal hearing in 21 patients (91.3%) and mild SN hearing loss in 2 (8.69%). The result of PTA2 indicated mild SN hearing loss in 8 patients (34.7%), moderate SN hearing loss in 3 (13.04%), and moderately severe SN hearing loss in 12 (52.17%). PTA3 revealed moderately severe SN hearing loss in 8 patients (36.36%) and severe SN hearing loss in 15 (65.21%) (Fig. 1).

3.1.2. Patients with osteopenia

PTA 1 showed normal hearing in 24 patients (96%) and mild SN hearing loss in 1 patient (4%). PTA2 indicated normal hearing in 4 patients (16%), mild SN hearing loss in 16 (64%) and moderate SN hearing loss in 5 (20%). PTA3 revealed moderately severe SN hearing loss in 18 patients (72%) and severe SN hearing loss in 7 (28%) (see Fig. 2).

Table 4 shows better low, mid and high pure tone average thresholds in the control group than in the osteopenia and osteoporotic groups in both ears ($p < 0.05$). The osteoporosis group had the worst hearing sensitivity at all frequencies, followed by the osteopenia and the control group (Fig. 3).

3.2. Speech audiometry

Table 5 shows the speech reception threshold (SRT) and speech discrimination scores (SDS) in all groups for both ears, with statistically significant difference among the three groups in speech

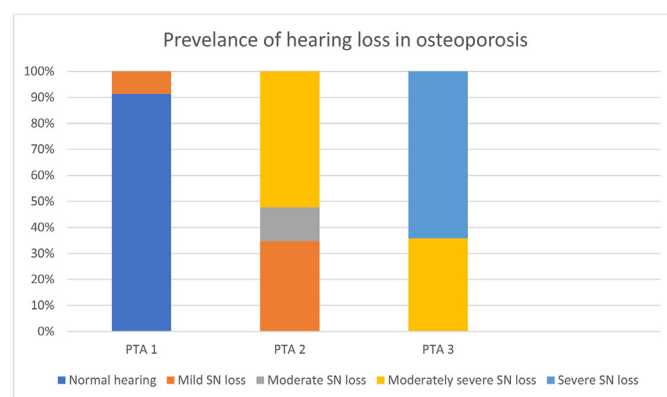


Fig. 1. Hearing results in patients with osteoporosis.

reception threshold ($p < 0.01$) for both ears and in speech discrimination score only for the right ear (Fig. 4).

3.3. Otoacoustic emissions

TEOAEs were present in 7 patients with osteoporosis (30%), 8 patients with osteopenia (32%) and 10 control subjects (35%). DPOAEs were present (SNR \Rightarrow 6 dB at three consecutive frequencies) in 8 osteoporotic patients (34.78%), 11 patients with osteopenia (44%) and 36 control subjects (46%).

3.4. Vestibular myogenic potentials (VEMPs)

cVEMP and oVEMP were affected in 95.65% and 87.33% of the patients with osteoporosis; and in 68% and 28% of the patients with osteopenia, respectively, with statistically significant differences as compared to the control group ($p < 0.01$).

Table 6 and Fig. 5 shows Mean cVEMP latencies and amplitudes among the three groups, showing the most prolonged latencies and lowest amplitudes in the osteoporosis group, followed by the osteopenia and then the control group.

Table 7 and Fig. 6 show mean oVEMP latencies and amplitudes among the groups. The most prolonged latencies and lowest amplitudes are seen in the osteoporosis group, followed by the osteopenia group and then the control group ($p < 0.01$).

4. Discussion

4.1. Audiological results

Our findings demonstrate sensorineural hearing loss over conventional and extended high frequencies as well as affected OAEs in both the osteoporosis and osteopenia groups, suggesting hair cell damage at all frequencies, although more so for high frequencies. We have not come across a single study comparing hearing over conventional and extended high frequencies in patients with

Table 3

Stimulus and acquisition parameters for VEMPs.

Stimulus parameters		Acquisition parameters	
Stimulus	500 Hz tone burst	Filter setting	30–1500 Hz
Transducer	ER3Ainsert phones	Time window	50msec
Onset phase	Rarefaction	Number of sweeps	100
Intensity	95dBnHL	Notch filter	On
Rate	3.1/s	Channel (–)	Ipsilateral- cVEMP Contra- oVEMP

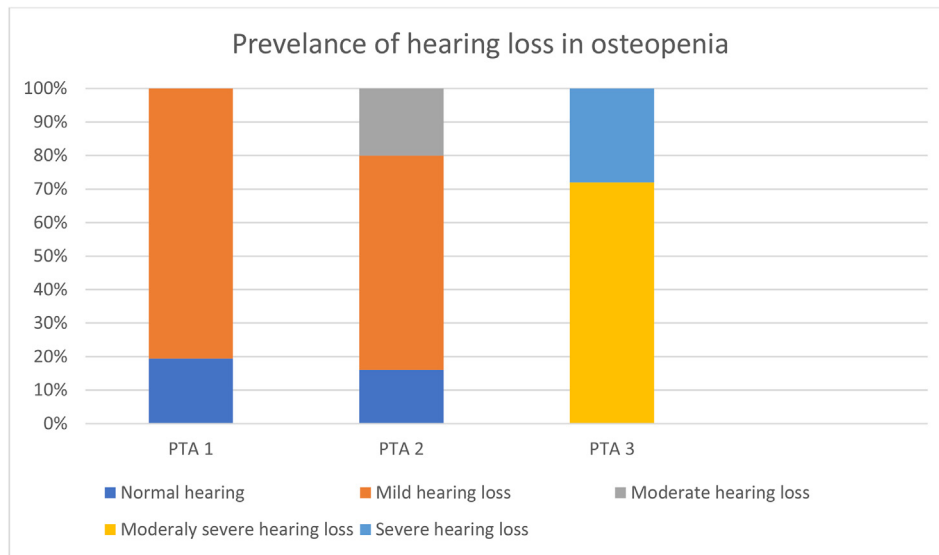


Fig. 2. Prevalence of hearing loss in patients with osteopenia.

Table 4
Pure tone average thresholds across osteoporosis, osteopenia and control groups (dB HL).

		Osteoporosis Mean SD		Osteopenia Mean SD		Control Mean SD		F-value
PTA1 (500 Hz,1000 Hz,2000 Hz)	Right	21.88	1.690	20.60	2.45	20.24	2.26	3.89*
	Left	23.62	2.28	19.82	1.94	19.37	2.69	24.44*
PTA2 (4 KHz,8 KHz,10 KHz)	Right	52.03	10.27	42.27	17.97	32.38	4.83	16.68**
	Left	47.75	10.60	39.67	9.94	32.62	5.04	19.10**
PTA 3 (12.5 KHz,16 KHz,18 KHz)	Right	76.09	8.90	67.33	8.91	62.11	5.45	20.40**
	Left	75.38	5.35	69.67	8.25	63.10	4.60	24.76**

SD: Standard deviation × p < 0.05.
**p < 0.01.

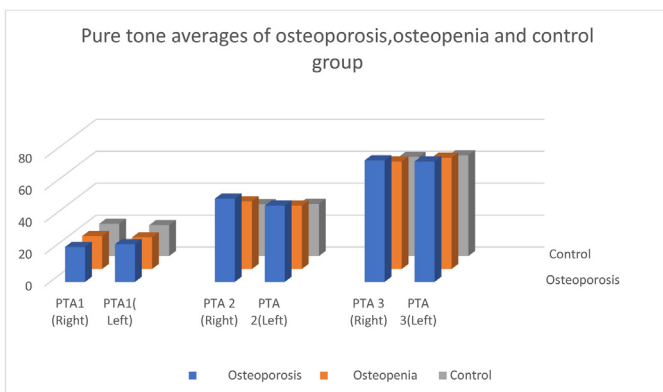


Fig. 3. Pure tone averages across osteoporosis, osteopenia and control groups.

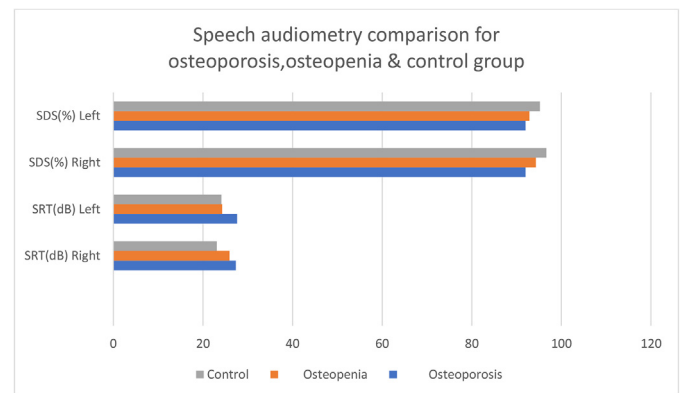


Fig. 4. Mean speech reception thresholds (SRT) and speech discrimination scores (SDS) across osteoporosis, osteopenia and control groups for both ears.

Table 5
Speech reception thresholds (SRT) and speech discrimination scores (SDS) across osteoporosis, osteopenia and control groups.

		Osteoporosis Mean SD		Osteopenia Mean SD		Control Mean SD		F-value
SRT(dB)	Right	27.35	1.11	25.92	2.22	23.11	2.85	24.15**
	Left	27.61	1.92	24.28	1.95	24.11	2.14	23.40**
SDS (%)	Right	92.00	4.82	94.29	4.95	96.64	2.98	6.79**
	Left	92.00	0.00	92.86	6.40	95.20	4.76	2.96

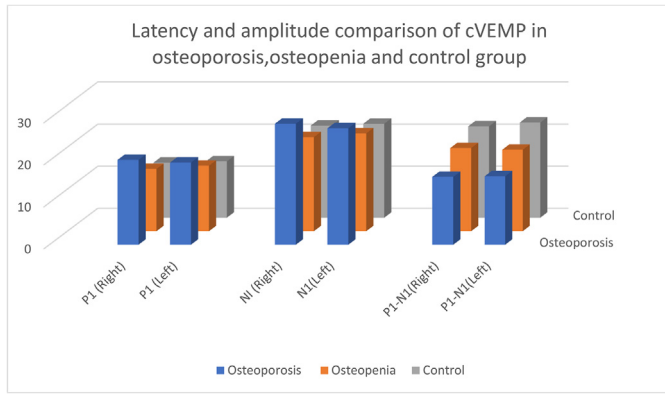


Fig. 5. Comparison of cVEMP latency and amplitude among the osteoporosis, osteopenia and control groups.

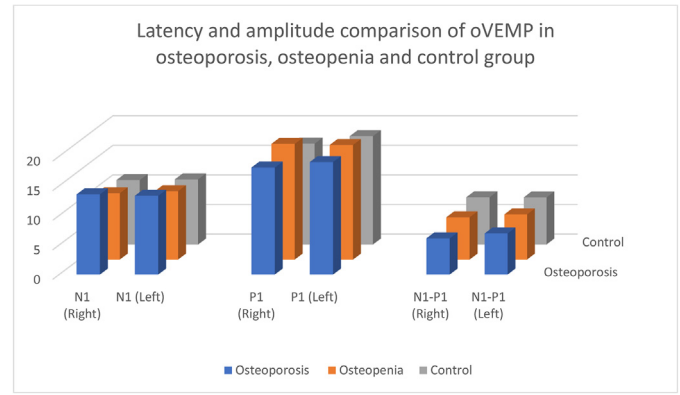


Fig. 6. Comparison of oVEMP latency and amplitude among the osteoporosis, osteopenia and control groups.

osteoporosis and osteopenia, to the best of our knowledge, although many audiological studies for frequencies up to 8 kHz in osteoporosis and osteopenia have been reported in the literature. The results in the present study are in line with studies by Henkin et al. (1972), Oghan and Coksuer (2012), Özkırış et al. (2013) and Jung et al. (2016). Studies by Kahveci et al. (2014) and Bhavya (2016) also found OAEs affected in these patients. In the present study, extended high-frequency audiometry was conducted to help measure cochlear function and diagnose sensory injury earlier than conventional audiometry (Tweed, 2001). Furthermore, it is a sensitive tool to identify underlying causes in individuals classified by conventional audiometry as having normal hearing but reporting difficulties in speech recognition (Shaw et al., 1996). All individuals in this study showed type A tympanograms, revealing normal middle ear status, similar to studies by Özkırış et al. (2013) and Bhavya (2016).

In the aging population, osteoporosis is a progressive bone disease that leads to reduced mineral density in all bones including the temporal bone, cochlear capsule, internal auditory canal, mandible and middle ear bone structures (Roth et al., 2011; Clark et al., 1995). Menopause also leads to a decline in estrogen levels.

Estrogen induces reduction in the rate of bone loss by inhibiting osteoclastic activity. Therefore, estrogen deficiency causes further irreversible erosion in bone density (Sayegh and Stubblefield, 2002). It has been hypothesized that demineralization of the cochlear capsule may lead to sensorineural hearing loss. Upala et al. (2017), in their meta-analysis, concluded that an imbalance between bone formation and resorption might lead to dysfunctional ionic metabolism resulting in sensorineural hearing loss. Similar to our study, Kahveci et al. (2014) and Özkırış et al. (2013) reported greater differences at higher frequencies than at lower frequencies among tested groups, although the underlying reason was not clear.

4.2. Vestibular test results

cVEMP and oVEMP were affected the most in patients with osteoporosis, followed by those with osteopenia and then the control group. Ekblad et al. (2000), Mendy et al. (2014), Li et al. (2015) and Bigelow et al. (2016) also found a positive correlation between reduced vestibular functions and low bone mineral density. In a study by Gargeshwari et al. (2018) on osteoporosis, osteopenia and control groups, both subjective and objective

Table 6

Mean and standard deviation of latency and amplitude of osteoporosis, osteopenia and control group for both ears in cVEMP.

Latency (msec)		Osteoporosis Mean SD	Osteopenia Mean SD	Control	F-value
P1	Right	20.20	14.82	13.10	300.14**
	Left	19.57	15.60	13.41	265.55**
N1	Right	28.80	22.38	21.92	215.59**
	Left	27.70	23.28	22.34	113.51**
Amplitude (microvolt)	Right	16.15	19.78	21.72	94.45**
	Left	16.30	19.38	22.63	155.63**

Table 7

OVEMP latency and amplitude across the osteoporosis, osteopenia and control groups.

Latency (msec)		Osteoporosis Mean SD	Osteopenia Mean SD	Control Mean SD	F-value
N1	Right	13.56	11.22	10.90	50.98**
	Left	13.32	11.56	11.01	99.23**
P1	Right	18.10	19.56	17.06	38.73**
	Left	19.03	19.38	18.32	17.90**
Amplitude (Microvolt)	Right	6.13	7.16	7.98	10.25**
	Left	6.97	7.64	7.96	86.69**

balance tests showed balance-related deficits in patients with osteoporosis and osteopenia.

Balance disorders are due to decreased calcium inside the vestibular system, as reported in many studies. Calcium plays a vital part in electrical signal transmission from end organs to higher centers with proper neurotransmitter support. A feature observed both in osteopenia and osteoporosis is the decrease in calcium, which may affect both sensory structures functioning in the peripheral vestibular system and neural transmission. These functional changes result in hearing loss, imbalance and other dysfunctions (Mendy et al., 2014). Vestibular function may also be affected by the role of estrogen in maintaining calcium homeostasis via coupled remodeling in postmenopausal women (Reifenstein and Albright, 1947). Research has proved that the cochlea and vestibule are functionally and anatomically associated. They share a continuous membranous labyrinth and similar receptor cell ultra-structures that are supplied by the labyrinthine artery. Along with hearing, vestibular functions can therefore also be affected (Zuniga et al., 2012; Ciaravella et al., 2007). Thus, we speculate that impaired vestibular function in these individuals may contribute to the risk of falls and, therefore, fractures.

4.3. Limitations

The sample size was small, owing to the time-bound nature of the study. Other vestibular tests were not conducted in the study.

4.4. Future investigations may study the correlation between BMD

The degree of hearing loss and vestibular function, imaging, electrophysiological test results and the relation between abnormal tests and the onset of menopause.

5. Conclusions

Osteoporosis and osteopenia are risk factors for vestibular dysfunction and hearing deficits in postmenopausal women. Hearing loss at high frequencies is present in these women and manifests its impact as difficulty in speech discrimination. Along with hearing, vestibular functions can also be affected. Thus, postmenopausal women with osteopenia and osteoporosis should undergo audiological and vestibular testing periodically to monitor hearing and vestibular status.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Compliance with ethical standards

- As Author Dr. Manisha K. Juneja, Dr. Sanjay Munjal, Dr. Anuradha, Dr. Ashok Gupta and Dr Sanjay Bhadada didn't receive any research financial grant, Hence all Authors declare that they have no conflict of interest.
- All procedures performed in studies involving human participants were done in Speech & Hearing Unit, Dept. of Otolaryngology, PGIMER, Chandigarh and accordance with the ethical standards of the institution
- Prior Informed consent was taken from the participants as well as from the concerned institution where the participants were taking treatment.

Ethical statements

My manuscript is not submitted in any other journal. The submitted work is original.

Declaration of competing interest

The presence or absence of the conflict of interest (COI): " Dr. Manisha K. Juneja, Dr. Sanjay Munjal, Dr. Anuradha, Dr. Ashok Gupta and Dr Sanjay Bhadada declare that they have no conflict of interest."

References

- Bhavya, M., 2016. Audiological profile in osteoporosis. *Rare Dis. Orphan Drugs* 3, 25–32.
- Bigelow, R.T., Semenov, Y.R., Anson, E., Du Lac, S., Ferrucci, L., Agrawal, Y., 2016. Impaired vestibular function and low bone mineral density: data from the Baltimore Longitudinal study of aging. *J. Assoc. Res. Otolaryngol.* 17, 433–440.
- Burke-Doe, A., Hudson, A., Werth, H., Riordan, D.G., 2008. Knowledge of osteoporosis risk factors and prevalence of risk factors for osteoporosis falls and fracture in functionally independent older adults. *J. Geriatr. Phys. Ther.* 31, 11–17.
- Ciaravella, G., Bennequin, D., Laschi, C., 2007. Biomechanical study on the sensorial epithelium of otolithic organs for creating a biomimetic sensor in 2007. In: 29th Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE, pp. 4667–4670.
- Clark, K., Sowers, M.R., Wallace, R.B., Jannausch, M.L., Lemke, J., Anderson, C.V., 1995. Age-related hearing loss and bone mass in a population of rural women aged 60 to 85 years. *Ann. Epidemiol.* 5, 8–14.
- Czerwiński, E., Badurski, J.E., Marcinowska-Suchowierska, E., Osieleńec, J., 2007. Current understanding of osteoporosis according to the position of the World health organization (WHO) and international osteoporosis foundation. *Ortop. Traumatol. Rehabil.* 9, 337–356.
- Doherty, J.K., Linthicum Jr., F.H., 2004. Spiral ligament and stria vascularis changes in cochlear otosclerosis: effect on the hearing level. *Otol. Neurotol.* 25, 457–464.
- Ekblad, S., Bergendahl, A., Enler, P., Ledin, T., Möllen, C., Hammar, M., 2000. Disturbances in postural balance are common in postmenopausal women with vasomotor symptoms. *Climacteric* 3, 192–198.
- Gargeshwari, A., Jha, R.H., Singh, N.K., Kumar, P., 2018. Behavioral and objective vestibular assessment in persons with osteoporosis and osteopenia: a preliminary investigation. *Braz. J. Otorhinolaryngol.* 84, 744–753.
- Henkin, R., Lifschitz, M., Larson, A., 1972. Hearing loss in patients with osteoporosis and Paget's disease of bone. *Am. J. Med. Sci.* 263, 383–392.
- Kahveci, O.K., Demirdal, U.S., Yücedag, F., Cerci, U., 2014. Patients with osteoporosis have higher incidence of sensorineural hearing loss. *Clin. Otolaryngol.* 39, 145–149.
- Kanis, J.A., McCloskey, E.V., Johansson, H., Cooper, C., Rizzoli, R., Reginster, J.Y., 2013. Scientific advisory board of the European society for clinical and economic aspects of osteoporosis and osteoarthritis (ESCEO) and the committee of scientific advisors of the international osteoporosis foundation (IOF). European guidance for the diagnosis and management of osteoporosis in postmenopausal women. *Osteoporos. Int.* 24, 23–57.
- Li, C., Layman, A.J., Carey, J.P., Agrawal, Y., 2015. Epidemiology of vestibular evoked myogenic potentials: data from the Baltimore Longitudinal Study of Aging. *Clin. Neurophysiol.* 126, 2207–2215.
- Matsuo, K., Ito, M., Ogawa, K., Kanzaki, S., 2005, September. Osteoporosis of ossicles and hearing loss in mice. *J. Bone Miner. Res.* 20 (9), 2025 M ST, NW, STE 800, WASHINGTON, DC 20036-3309 USA: AMER SOC BONE & MINERAL RES.
- Mendy, A., Vieira, E.R., Albatineh, A.N., Nnadi, A.K., Lowry, D., Gasana, J., 2014. Low bone mineral density is associated with balance and hearing impairments. *Ann. Epidemiol.* 24, 58–62.
- Nilas, L., Christiansen, C., 1987. Bone mass and its relationship to age and menopause. *J. Clin. Endocrinol. Metab.* 65, 697–702.
- Oghan, F., Coksuer, H., 2012. Comparative audiometric evaluation of hearing loss between the premenopausal and postmenopausal period in young women. *Am. J. Otolaryngol.* 33, 322–325.
- Organization, W.H., 1994. Assessment of Fracture Risk and its Application to Screening for Postmenopausal Osteoporosis: Report of a WHO Study Group [meeting Held in Rome from 22 to 25 June 1992].
- Özkinriş, M., Karavaş, S., Kapusuz, Z., Balbaloğlu, Ö., Saydam, L., 2013. Does bone mineral density have an effect on hearing loss in postmenopausal patients? *Ann. Otol. Rhinol. Laryngol.* 122, 648–652.
- Ramalingaiah, A., 2017. Burden of osteoporosis in the urban Indian population. *EC Orthop* 7, 74–81.
- Reifenstein, E.C., Albright, F., 1947. The metabolic effects of steroid hormones in osteoporosis. *J. Clin. Invest.* 26, 24–56.
- Riis, B.J., 1993. Biochemical markers of bone turnover II: diagnosis, prophylaxis, and treatment of osteoporosis. *Am. J. Med.* 95, S17–S21.
- Roth, T.N., Hanebuth, D., Probst, R., 2011. Prevalence of age-related hearing loss in Europe: a review. *Eur. Arch. Oto-Rhino-Laryngol.* 268, 1101–1107.

- Sayegh, R.A., Stubblefield, P.G., 2002. Bone metabolism and the perimenopause overview, risk factors, screening, and osteoporosis preventive measures. *Obstet. Gynecol. Clin. N. Am.* 29, 495–510.
- Shaw, G.M., Jardine, C.A., Fridjhon, P., 1996. A pilot investigation of high-frequency audiometry in obscure auditory dysfunction (OAD) patients. *Br. J. Audiol.* 30, 233–237.
- Tweed, T.S., 2001. Hearing sensitivity in adults screened for selected risk factors. *J. Am. Acad. Audiol.* 12, 337–347.
- Upala, S., Rattanawong, P., Vutthikraivit, W., Sanguankeo, A., 2017. Associação significativa entre osteoporose e perda auditiva: uma revisão sistemática e met-análise. *Braz. J. Otorhinolaryngol.* 83, 646–652.
- Zuniga, M.G., Dinkes, R.E., Davalos-Bichara, M., Carey, J.P., Schubert, M.C., King, W.M., Walston, J., Agrawal, Y., 2012. Association between hearing loss and saccular dysfunction in older individuals. *Otol. Neurotol. Off. Publ. Am. Otol. Soc. Am. Neurotol. Soc. [and] Eur. Acad. Otol. Neurotol.* 33, 1586.