RESEARCH

The relationship between the calcaneal bone mineral density and the mental index in post-menopausal females

E Jagelaviciene^{*,1}, A Krasauskiene², R Zalinkevicius², R Kubilius³ and I Vaitkeviciene¹

¹Department of Dental and Oral Pathology, Lithuanian University of Health Sciences, Kaunas, Lithuania; ²Institute of Endocrinology, Lithuanian University of Health Sciences, Kaunas, Lithuania; ³Department of Maxillofacial Surgery, Lithuanian University of Health Sciences, Kaunas, Lithuania

Objectives: The aim of the study was to determine the relationship between the bone mineral density in the calcaneus and the mental index (MI) of the mandible in post-menopausal females, and to evaluate the diagnostic threshold of the index.

Methods: The post-menopausal females aged 50 years and older were examined using panoramic radiography of the mandible for mandibular cortical width measurements at the mental foramen (mental index, MI) determination and DXL Calscan P/N 031000 (Demetech AB, Solna, Sweden) for the examination of calcaneal bone mineral density (BMD). The statistical analysis was performed to determine the tendencies between the data.

Results: According to the T-score values of calcaneal BMD, the subjects were distributed into T₁, T₂ and T₃ groups. BMD differences between the groups were statistically significant ($p < 0.001$). The panoramic radiographic examination of the mandible was performed, MI (mm) was determined and the mean values in the groups were calculated. The differences of MI mean values between the groups were statistically significant ($p < 0.001$). In the general group, a statistically significant relationship was found between calcaneal BMD, T-score and MI ($p < 0.001$). In the logistic analysis, the diagnostic threshold of MI was 3 mm (sensitivity 73.5%; specificity 72.6%).

Conclusions: A diagnostic threshold for MI of 3 mm or less is suggested as the appropriate threshold for referral of calcaneal BMD reduction.

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Introduction

The aging population accompanied by chronic diseases is one of the major issues of the twenty-first century, which makes the studies of factors that help to prevent such diseases a necessity.¹ Osteoporosis (OP) is one of such chronic diseases, and is common in a significant part of the elderly population—especially in post-menopausal females. OP is a disease that spreads in the bone tissue of the skeleton and results in the reduction of bone mineral density (BMD).

Skeletal bones differ in their anatomical structure owing to differing distributions of cortical and trabecular bone. The trabecular bone has a greater surface area and responds faster to metabolic changes than does cortical bone.² In addition, owing to the effect of a variety of factors, the reduction of BMD in different bones occurs at different rates at different periods of life.

Changes in the bone tissue of the skeleton and the mandible share many common risk factors—age, race, menopause, genetic factors, cigarette smoking, calcium and medication use, and family history of the disease.^{3,4} Studies performed during the last decades indicated a link between changes in the mandibular cortical bone and the general BMD of the skeleton. Some authors

*Correspondence to: Dr Egle Jagelaviciene, Department of Dental and Oral Pathology, Lithuanian University of Health Sciences, Eiveniu street2, Kaunas LT-50009, Lithuania. E-mail: egle.jagelaviciene@takas.lt
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state that this link is strong and shows that mandibular cortical width is significantly associated with general OP.^{5–7} Other researchers have found no such correlation, or think that it has little reliability.^{8,9} Clinicians pointed to the panoramic radiographic examinations performed daily by the dentists and the resulting mandibular cortical bone indices—mandibular cortical index (MCI), mental index (MI), panoramic mandibular index (PMI)—as diagnostic criteria of skeletal BMD, which could be used for selecting patients with BMD changes.¹⁰ The width of the cortical bone in the mandibular base at the mental foramen, considered to be the MI, will be discussed in this article. Owing to its anatomical composition, the bone tissue of the maxilla is rarely studied.

The invention of the peripheral osteodensitometer DXL Calscan (P/N 031000; Demetech AB, Solna, Sweden) stimulated studies and comparisons of the calcaneal BMD data with simultaneous frequently performed panoramic radiography data in dentistry stimulated the mandibular cortical bone analysis. Possible associations between the tissue changes in these two bones have not yet been researched widely enough. The calcaneus and mandible are different in their anatomical structure: cortical bone predominates in the mandible (80%), trabecular bone in the calcaneus (95%).^{11,12}

Demineralization of the trabecular bone occurs at a faster rate owing to the lack of permanent mechanical stress on it.² Therefore, physical load permits high calcaneal BMD,¹³ whereas it is known that physical activity of the elderly is limited owing to individual causes.

The mandible is functionally an active bone as it is influenced by the force of mastication muscles. Therefore, reduction in number of teeth predetermines development of the gradual decrease of bone mass,¹⁴ thus making the layer of the cortical bone thinner.

Age-related risk factors create the conditions for the development of uneven bone resorption in these bones. For females, the calcaneal BMD begins to reduce from the age of 35 years at a rate of 1.2% a year¹⁵ and continues to be lowered during the entire post-menopausal period; however, bone resorption proceeds in the trabecular bone. At the age of 60–70 years, this process also becomes more intense in the cortical bone¹⁶ when the resorption spreads in the whole calcaneal bone tissue.

The changes in the mandibular cortical bone become manifested in individuals older than 50 years of age. At the age of 70 years, the mass of mandibular bone tissue in females is being reduced by 1.5% a year.¹⁷ Literature sources indicate that during aging the vestibular surface of the mandible and the width of the cortical bone in the mandibular base become reduced.¹⁸ Therefore, changes in both the bones allow the early detection of bone reduction in one of them taken separately.

The aim of this study was to determine the link between calcaneal BMD and MI calculated according to panoramic radiograms of the mandible in post-menopausal females, and to evaluate the diagnostic validity of this index.

Materials and methods

The study was performed in the Institute of Endocrinology and the Department of Dental and Oral Diseases at the Lithuanian University of Health Sciences (LUHS) Kaunas, Lithuania, with the permission of the Regional Biomedical Research Ethics Committee (no. BE-2-13). The study included post-menopausal and elderly females aged 50–77 years. The inclusion criteria were as follows: good or satisfactory general health status, 1 year free of the use of hormone preparations or medications that could affect bone metabolism, absence of diseases leading to secondary OP, cigarette smoking or alcohol abuse and presence of teeth in the mandible. The main exclusion criteria were lack of motivation, surgical treatment of the mandible and a periodontal disease undergone within the previous 6 months, and restoration of the mandible function with implants.

A questionnaire was completed by all subjects to collect data on the subjects' age, sociodemographic status, cigarette smoking and alcohol abuse, and usage of preparations affecting calcium and bone tissue metabolism; the onset, causes and duration of the post-menopausal period; bone fractures and their causes; family history of OP; general disorders of the body that might affect bone tissue changes; history of surgical periodontal treatment; and daily physical activity. The subjects also underwent clinical examination of the periodontal state.

Examination of bone mineral density in the calcaneus

Calcaneal BMD was examined using dual-energy X-ray and laser (DXL) bone osteodensitometer. The target zone in the calcaneus was automatically selected by software, and automated internal calibration was performed before every scan.

The subjects could choose which calcaneus—the right or the left—should be examined, but the recommendation was to examine a healthy leg with no pain or previous fractures. The examined leg was placed in the DXL Calscan foot compartment at its lowest site and fixed, as a suitable position of the calcaneus during the examination affects the accuracy of the findings. The software of the DXL Calscan device automatically calculated the region of interest (ROI) where calcaneal BMD had to be evaluated.

The DXL Calscan software calculated the results of calcaneal BMD measurement (g cm^{-2}), bone mineral mass (g), the measured area (cm^2) and the mean external heel thickness (mm); the software also calculated T- and Z-scores. The measurements were graphically presented on the computer monitor. The depicted risk of osteopaenia and OP was marked in lines and fields of different colours. The device irradiation dose was $0.2 \mu\text{Sv}$.

The T-score determined during DXL Calscan examination met the criteria set by the World Health Organization (WHO).^{19,20} On this basis, the subjects did not undergo any additional vertebral densitometry.

The calcaneal BMD data were analysed according to the diagnostic criteria for OP proposed by the WHO, and the subjects were distributed into the following groups: T₁, subjects with normal BMD (T-score > -1); T₂, subjects with osteopaenia (-1 ≥ T-score > -2.5); and T₃, subjects with osteoporosis (T-score ≤ -2.5).

Panoramic radiographic examination

For the required radiomorphometric measurements of the mandibular cortical width for MI determination, a panoramic radiographic examination was performed in the X-ray laboratory at the LUHS Department of Dental and Maxillofacial Orthopaedics using a Panoramic PC-1000 panoramic X-ray machine (Panoramic Corporation, Fort Wayne, IN). The positioning was done following the technique described by Dutra *et al*.²¹ The exposure time was 14 s (equal in all cases); anodic current was 6 mA (also equal in all cases); and anodic voltage was 80–85 kV, depending on the patient's build. Panoramic radiograms were developed using an automated roentgenographic film processor. The panoramic radiography images were scanned using a scanner and were digitized at 300 dpi resolution and 8 bits per pixel greyscale format by applying a logarithmical algorithm.

Analysis of the panoramic radiograms

Following the technique described by Ledgerton *et al*, vertical linear measurements were performed in panoramic radiograms (Figure 1): the mandibular cortical width was measured on the line perpendicular to the mandibular base at the centre of the mental foramen.^{18,22,23} The measurements were performed on the left and the right sides of the mandible using MedCalc medical image

Figure 1 The vertical linear measurement in a panoramic radiogram. C, cortical width in the mandibular base at the mental foramen

analysis software (MedCalc Software bvba, Ostend, Belgium). The differences between one side and the contralateral side were evaluated, and the average of these measurements was calculated. The magnification coefficient in the investigated region was determined in the following way: a metal tape of known size was fixed horizontally, and a panoramic radiographic image was made in order to find out horizontal magnification; later the panoramic radiographic image was made using the same metal tape, which was fastened vertically, and vertical magnification was measured. The magnification coefficient was established according to metal tape length measured on panoramic radiogram divided by actual metal tape length. The average magnification factor of the vertical plane was calculated. The panoramic radiographic magnification coefficient was 0.9. The results of the measurement were corrected by the magnification coefficient. The findings were calibrated: the physician conducting the study performed triple measurements of the obtained images, and two independent researchers with experience in radiology carried out additional measurements, each of them performing analogous triple measurements.

Statistical analysis of the data

Statistical data analysis was performed using standard software packages Statistica v. 5.5 (StatSoft, Inc., Tulsa, OK), Excel v. 2000 (Microsoft Corporation, Albuquerque, NM) and SPSS[®] v. 13.0 (SPSS, Chicago, IL). The coded data on the patients were used in the analysis.

The sample volume was calculated during a pilot study. The power of the study (β) was selected to be 0.8, and the confidence level (α) 0.05.

The Kolmogorov–Smirnov test was used to verify the normal distribution of quantitative values. When the sample size was sufficient and the distribution normal, differences between mean values of the groups for independent samples were compared by applying Student's *t*-test.

Mean values and dispersions of several groups were compared applying the single-factor dispersion analysis of variance (ANOVA). The dependence of the attributes was evaluated using Pearson's correlation coefficient (*r*) and the regression line.

The receiver operating characteristic (ROC) was used to measure the validity of MI diagnostic threshold in the diagnosis of reduced calcaneal bone mineral density.

The significance level of 0.05 was chosen in the verification of a statistical hypothesis.

Results

Analysis of sociodemographic data

In total, 129 post-menopausal females were investigated; 95.3% of them were city residents; 55.0% had studied to higher education level; 57.4% showed that their general health status related to the skeletal BMD reduction was satisfactory; 75.9% (*n* = 98) of them were usually physically active more than 1 h per day.

Table 1 The mean (SD) values of mental index in the subject groups

T-score group	n	MI (SD) (mm)	p-value
T ₁	34	3.7 (0.9)	T ₁ vs T ₂ : $p = 0.07$
T ₂	65	3.3 (0.9)	T ₂ vs T ₃ : $p < 0.001$
T ₃	30	2.7 (0.7)	T ₁ vs T ₃ : $p < 0.001$
Total	129	3.3 (0.9)	
T ₂ + T ₃	95	3.1 (0.9)	

MI, mental index; SD, standard deviation; T₁, subjects with normal BMD (T-score > -1); T₂, subjects with osteopaenia ($-1 \geq$ T-score > -2.5); T₃, subjects with osteoporosis (T-score ≤ -2.5).

The general mean age of the studied group was 62.5 [standard deviation (SD) 6.1] years, with 38% of them at the age of 60–64 years. The distribution of the mean age in the groups was the following: the mean age of patients in group T₁ was 59.4 (SD 6.4) years; in group T₂, 62.3 (SD 5.0) years; and in patients with OP (group T₃), 66.4 (SD 6.1) years. Differences in the mean age between the groups were statistically significant ($p < 0.001$).

The general mean duration of the post-menopausal period was 12.5 (SD 6.5) years. No clinical cases with menopause caused by chemotherapy, radiotherapy or medications were found; 91.5% ($n = 118$) of the females received no treatment with corticosteroids; 82.2% ($n = 106$) were not treated with osteoclast inhibitors; the rest of the subjects stated that they were treated with such preparations several years prior to the study.

Examination of the calcaneal bone mineral density

According to the T-scores of calcaneal BMD, the subjects were distributed into the following groups: group T₁, 34 (26%) healthy females with T-score of -0.1 (SD 0.6); group T₂, 65 (50%) subjects with osteopaenia and T-score of -1.8 (SD 0.4); and group T₃, 30 (23%) subjects with OP and T-score of -2.9 (SD 0.5). The total T-score in 129 subjects was of -1.6 (SD 1.1). T-score differences between the subject groups were statistically significant ($p < 0.001$).

Mean calcaneal BMD (g cm^{-2}) in the general group was 0.4 (SD 0.1); in group T₁, 0.5 (SD 0.04); in group T₂, 0.4 (SD 0.03); in group T₃, 0.3 (SD 0.03). BMD differences between subject groups were statistically significant ($p < 0.001$). The analysis showed that calcaneal BMD was statistically significantly dependent on the subjects' age ($r = -0.4$; $p < 0.001$).

Linear morphometric analysis of the mandible

The analysis showed that vertical and horizontal magnification at the mental foramen did not significantly affect the accuracy of the obtained data ($p > 0.05$).

No statistically significant differences were detected between MI on the left and the right sides ($p > 0.05$) of the mandible. The mean values of MI in different calcaneal BMD groups, with the differences between the groups calculated using ANOVA ($F = 9.9$; $\text{df} = 2$; $p < 0.001$), are presented in Table 1.

Subjects in groups T₂ and T₃ were characterized by a reduced calcaneal BMD.

During the data calibration, coefficients of variation (CVs) for MI performed by the three different researchers were calculated at 32.7%, 32.6% and 33.9%, respectively.

The relationship between calcaneal bone mineral density and mental index

The data of the analysis on the relationship between calcaneal T-score, BMD, and MI are presented in Table 2.

The data analysis showed that a statistically significant relationship between calcaneal BMD, T-score and MI was found only in the total general group. No such relationship was found in separate groups.

In order to determine and to evaluate the validity of the diagnostic threshold of MI, the ROC analysis (cut-off) was performed. When interpreting the ROC curves, calcaneal BMD reduction (osteopaenia + osteoporosis) was detected according to the probable values of the MI. MI contributed to a diagnosis of low bone mineral density (T-score > -1). The area under the ROC curve was 0.7 (SE = 0.06; 95% confidence interval = 0.6–0.8), indicating moderate accuracy. If the MI diagnostic threshold value was 3 mm, the sensitivity of the study would be of 73.5%, and specificity 72.6%.

According to the determined threshold diagnostic value, the MI data were assigned into subgroups: MI₁ subgroup, with MI less than 3 mm, 65 (50.4%) subjects; and MI₂ subgroup, with MI greater than or equal to 3 mm, comprising 64 (49.6%) subjects. The distribution of MI₁ and MI₂ values in the subgroups is presented in Table 3.

Discussion

This study investigated the calcaneus and the mandible—two bones characterized by high functional activity, yet different anatomical structure. Both the bones were analysed applying two different radiological techniques, and their results were compared.

Table 2 The relationships between the calcaneal BMD and MI in the subject groups

T-score group	n	Calcaneal T-score dependence on MI	Calcaneal BMD (g cm^{-2}) dependence on MI
T ₁	34	$r = 0.2$; $p = 0.4$	$r = 0.2$; $p = 0.4$
T ₂	65	$r = 0.2$; $p = 0.3$	$r = 0.2$; $p = 0.2$
T ₃	30	$r = 0.1$; $p = 0.8$	$r = 0.1$; $p = 1.0$
Total	129	$r = 0.4$; $p < 0.001$	$r = 0.4$; $p < 0.001$

BMD, bone mineral density; MI, mental index; T₁, subjects with normal BMD (T-score > -1); T₂, subjects with osteopaenia ($-1 \geq$ T-score > -2.5); T₃, subjects with osteoporosis (T-score ≤ -2.5).

Table 3 MI values in the subgroups MI₁ and MI₂

T-score group	Subgroup MI ₁		Subgroup MI ₂		p-value
	n	Mean (SD)	n	Mean (SD)	
T ₁	10	2.5 (0.3)	24	4.2 (0.7)	$p < 0.001$
T ₂	33	2.6 (0.4)	32	4.1 (0.7)	$p < 0.001$
T ₃	22	2.4 (0.4)	8	3.7 (0.3)	$p < 0.001$

BMD, bone mineral density; MI, mental index; MI₁, subjects with MI < 3mm; MI₂, subjects with MI ≥ 3mm; SD, standard deviation; T₁, subjects with normal BMD (T-score > -1); T₂, subjects with osteopaenia (-1 ≥ T-score > -2.5); T₃, subjects with osteoporosis (T-score ≤ -2.5).

Mann-Whitney *U*-test was used for this analysis.

Skeletal BMD measurement techniques are continuously being improved, and the results of the measurements are analysed because osteodensitometers have different technical characteristics that affect diagnostic thresholds. Calcaneal BMD data obtained by using different osteodensitometric equipment may correlate well ($r = 0.9$), and yet the T-scores may differ.²⁴ This depends on different regions of interest in the calcaneus. Kröger *et al*²⁵ and Jergas and Genant²⁶ suggested that diagnostic thresholds should be confirmed separately for each region of interest and each examination technique.

Calcaneal BMD may help to predict bone fractures as accurately as BMD measured in spinal bones or the femur by using DXA. The decrease in calcaneal BMD even by 1 SD increases the risk of any osteoporotic fracture by 86%.²⁷ Peripheral BMD measurements are performed by using portable devices, which facilitate patient selection. DXL Calscan belongs to such a group of osteodensitometers, and in 2004 it was approved for diagnostic studies of the calcaneus.^{28,29} The system consists of a standard DXA and laser equipment that measures BMD according to the tripartite (bone, muscle, adipose tissue) model.^{19,30} The patients did not require any special protection or preparation prior to the examination.

Medical literature has published the results of calcaneal BMD measurement with DXL and has indicated that the T-score determined during this examination meets the criteria set by WHO, and the technique proved to be optimal and accurate in the diagnosis of OP.¹⁹ Moreover, Kullenberg and Falch¹⁹ determined sensitivity of 80% when prognosticating OP and 82% when prognosticating osteopaenia, with specificity of 82% when prognosticating OP and 89% when prognosticating osteopaenia of calcaneal DXL examination, whereas Thorpe and Steel³¹ determined the diagnostic threshold of DXL Calscan for the calcaneus, which could be applied only to post-menopausal females.

Because of the calcaneal bone structure in 95% consisting of trabecular bone, the calcaneal BMD evaluated with the DXL Calscan device better reflects the BMD changes developed in the spine or the femur than in the other sites examined by applying peripheral osteodensitometric techniques, and so this device is

especially suitable for choosing preventive measures, and is reliable in the diagnosis of post-menopausal OP.^{29,31} Calcaneal BMD measurements are unaffected by renal diseases, aortic calcification, osteoarthritis, spinal deformations or fractures.

Cortical width changes in the mandibular base and development of general osteoporotic processes in the skeleton have been studied by a number of researchers.^{4,7,32–34} It would be difficult to compare our results with those of other studies; a survey of literature sources did not identify any analogous studies. Several calcaneal BMD studies with the application of the DXL Calscan device have been reported, yet none of them compared calcaneal BMD with mandibular bone changes measured by panoramic radiography, and there were also differences in the studied contingent.^{19,29–31,35–38} The studies employed different panoramic radiography or quantitative computed tomography techniques, and therefore the authors' interpretations of the obtained findings differed as well. Data presented in those articles were frequently not adjusted to the magnification coefficient of the panoramic radiograph, and the position of the jaw during the examination or the direction of the X-rays was not indicated. In the panoramic radiographic image, it is very important to determine clearly where cortical bone merges into trabecular bone. The measurements are accurate when cortical bone is measured from the clear line of the internal margin.

Magnification of the panoramic radiography images was evaluated in the fragment at the mental foramen. A low value of the panoramic radiography magnification coefficient did not affect the accuracy of vertical linear measurements of the cortical bone width in the mandibular base. These results confirmed Yang's statement that the vertical magnification coefficient of the panoramic radiograph at the mental foramen of the mandible was constant, while changes in the horizontal magnification were extremely slight.^{39,40} For this reason, we evaluated the mental foramen fragment as a suitable and informative site for linear radiomorphometric measurements in agreement to Taguchi *et al*.³⁴

The MI in the groups allowed for proving its statistically significant relationship with calcaneal BMD, but only in the general group of post-menopausal females. No significant correlation was found between measurement data in different calcaneal BMD groups, but the mean value of the MI in females with OP was significantly lower than that in the other group. This corresponds to the conclusions reached in the studies performed by Taguchi *et al*.^{34,41}

Our data show that when the cortical bone width in the mandibular base is below 3 mm, a reduction of BMD in the calcaneus may be prognosticated. Owing to its high content of cortical bone, the mandible is less sensitive than the calcaneus to oestrogen shortage observed during the post-menopausal period. Devlin and Horner have proposed that 3 mm or less cortical bone width in the mandibular base at the mental foramen in post-menopausal females should be considered diagnostic

threshold value when prognosticating spinal and femoral osteopaenia (specificity of 98.7%; sensitivity of 8%) and osteoporosis (specificity of 93.6%; sensitivity of 25.9%).^{5,33} Data presented by Taguchi et al.³⁴ indicate that 90% of females whose cortical bone width in the mandibular base was <3 mm had reduced BMD, and 60% of such patients had osteoporosis. In an earlier study, Taguchi et al.⁴² noted that the 3 mm diagnostic threshold indicated high values of specificity. When the sensitivity values of the study were low, many undiagnosed cases of altered BMD could be expected. Taguchi et al. tried to prove that cortical bone width in the mandibular base ≤ 4.5 mm should be seen as a risk factor when prognosticating osteoporosis in the spinal vertebrae (sensitivity of 89.5%; specificity of 33.9%).

In 2007, Devlin et al.⁴³ presented the following conclusion of the OSTEODENT project: a cortical bone width less than or equal to 3 mm in the mandibular base is most commonly found in patients with OP, and thus such a diagnostic threshold should be considered and analysed. The evaluation of our findings showed that the diagnostic threshold value of the MI was close to that proposed by the authors of the OSTEODENT project when prognosticating BMD changes in the spine and the femur.

Calcaneal BMD is decreasing throughout the post-menopausal period, but bone resorption during this period is more rapid in the trabecular bone. Cortical

bone changes in the mandible begin in individuals over 50 years of age. These data show that the resorption in the cortical bone of the mandible and the calcaneus is not uniform, which may affect the results. However, in 22 out of 30 patients with OP, and in 33 out of 65 patients with osteopaenia, cortical bone width in the mandibular base was below the diagnostic threshold value. Therefore, one cannot rule out the hypothesis that a large proportion of post-menopausal patients with OP or reduced BMD may be diagnosed according to the cortical bone width in the mandible.

The differences in the results of studies may be affected by differences in the population, the studied sample and technical characteristics of panoramic radiographs. Cortical bone width in the mandibular base can be affected by age-related factors, loss of the occlusal load related to the removal of teeth in the maxilla, and by other local or individual factors affecting the mandible.

In conclusion, even though statistical dependence between the MI and calcaneal BMD in the group of patients with OP was not found, owing to a relatively small sample size, a detailed analysis of the results reliably showed that changes in the mandibular cortical width were related to the calcaneal BMD. A diagnostic threshold for MI of 3 mm or less is suggested as appropriate for referral of calcaneal BMD reduction.

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