RESEARCH

Use of digital panoramic radiography as an auxiliary means of low bone mineral density detection in post-menopausal women

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Objectives: To correlate the radiomorphometric indices obtained using digital panoramic radiography (DPR) with bone mineral densities, evaluated by the dual-energy X-ray absorptiometry test, in a population of post-menopausal females to identify patients with asymptomatic low bone mineral densities.

Methods: The morphology of the mandibular cortex was evaluated using the mandibular cortical index (MCI) and the inferior mandibular cortex width was evaluated using the mental index (MI) in 64 female patients who had undergone dual-energy X-ray absorptiometry assessment. Of these patients, 21 were diagnosed with osteopaenia and 20 with osteoporosis, and 23 were normal. Three new indices for evaluating the inferior mandibular cortex width were designed: the mental posterior index 1 (MPI1), MPI2 and MPI3. Statistical analyses were performed using the χ^2 and Kruskal–Wallis tests and the receiver operating characteristic curve.

Results: There were significant differences between the normal and lower bone mineral density groups (osteopaenia and osteoporosis) for MCI ($p < 0.01$). In the osteoporosis group, the MI, MPI1, MPI2 and MPI3 were significantly different from the normal and osteopaenia groups ($p < 0.05$). The MI, MPI1, MPI2 and MPI3 showed that there is an area in the mandibular cortex, located between the mental foramen and the antegonial region, which is valid for identifying females at high risk for osteoporosis.

Conclusions: The MCI, MI, MPI1, MPI2, and MPI3 radiomorphometric indices evaluated using DPR can be used to identify post-menopausal females with low bone densities and to provide adequate medical treatment for them.

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Introduction

Osteoporosis is considered a public health problem by the World Health Organization (WHO), and it is therefore important to identify asymptomatic individuals in the early stages of bone mass reduction, because this disease has relevant social and economic impacts.¹

In the USA, the estimated expenditure on osteoporosis and related fractures is US\$10–15 billion per annum.¹

Osteoporosis is a silent, complex, multifactorial, chronic disease characterized by the progressive loss of bone density, which leads to the risk of imminent fractures.² At present, the evaluation of bone mineral density (BMD) is the main diagnostic tool in osteoporosis, and it is the most effective and accurate measurement for identifying and monitoring the disease.¹ BMD evaluation by dual-energy X-ray absorptiometry (DXA) testing is considered the

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gold standard for fracture risk prediction.^{3,4} However, in addition to not being recommended by the WHO as a triage screening tool for osteoporosis, it has a high financial cost.^{1,5} By contrast, the routine use of panoramic radiographs in planning the prosthetic, orthodontic and implant treatment for elderly patients has made it possible to establish a database of the mandibular skeletal characteristics of these patients. Panoramic radiographs are also economically feasible and result in low patient exposure to radiation.⁶

Because the bones of the oral cavity are similar in structure and physiology to various other bones in the skeleton, several studies have been conducted with the object of detecting whether these skeletal changes in the mandible are specific to the osteoporotic stage. Both the morphology and the width of the mandibular cortex have been evaluated in different regions of the inferior mandibular cortex using the definitions of various radiomorphometric indices, with the goal at all times of seeking a predictor of low bone density that is capable of identifying asymptomatic patients.^{3,5–16} However, none of the studied indices have been found to be both sensitive and specific for identifying individuals predisposed to having osteoporosis, and, therefore, determining the patients who should be selected for bone mineral density measurements continues to be a subject of important investigation.⁴

Therefore, the aim of the present study was to correlate the radiomorphometric indices obtained on digital panoramic radiography (DPR) with the bone mineral densities of the lumbar spine and femoral neck evaluated using DXA, in a population of post-menopausal females, to identify patients with asymptomatic low bone densities.

Materials and methods

Patient population

This research was approved by the local ethics committee and was conducted from October 2010 to May 2011. The sample consisted of 64 post-menopausal females aged between 50 years and 75 years (mean age $\pm$ standard deviation, 63.1 ± 7.5). Patients who smoked, used alcohol or medications that affect bone metabolism or who had metabolic bone disease, cancer, renal compromise, liver disease, a destructive bone lesion in the mandible, previous surgery in the mandible, a non-vertebral fracture or osteoporotic vertebrae at the time of the DXA assessment were excluded from the study.

Bone mineral density assessment and digital panoramic radiography acquisition

The body bone densitometry tests were performed using central DXA (Lunar Prodigy Primo™; GE Medical System Lunar, Madison, WI) covering the lumbar spine (L1–L4) and proximal femur regions, and the T-score calculation was based on the National Health and Nutrition Examination Survey III (NHANES III), as recommended by the International Osteoporosis Foundation.²

Osteopaenia was defined as a BMD T-score of -2.5 to -1.0 , according to the WHO classification. Osteoporosis was defined as a BMD T-score less than -2.5 .² Only females who had the same diagnosis at both sites were selected.

DPR was obtained a maximum of 1 month after DXA, using a KODAK 8000C Digital Panoramic and Cephalometric System (Eastman Kodak Company, Rochester, NY) appliance, at 140 kHz, 60–90 kV and 2–15 mA. The linear measurements and qualitative evaluations of the radiographs were performed using Kodak Dental Imaging Software (Kodak Dental Systems, Rochester, NY).

Image analysis

The radiomorphometric indices evaluated on DPRs provided two types of measurements: one qualitative, with reference to the mandibular cortical morphology, and the other quantitative, with reference to the width of the inferior mandibular cortex.

Mandibular cortical morphology evaluated by the mandibular cortical index (MCI) has been used to assess the bone quality and to observe the signs of osteoporosis.^{5,13} The MCI refers to the inferior mandibular cortical shape and is categorized into three groups, according to the criteria described by Klemetti *et al*,¹¹ as follows: C1 = a normal cortex, in which the endosteal margin of the cortex is even and sharp on both sides; C2 = a mild to moderately eroded cortex, in which the endosteal margin shows semilunar defects (lacunar resorption) or seems to form endosteal cortical residue (one to three layers) on either or both sides; and C3 = a severely eroded cortex, in which the cortical layer forms heavy endosteal cortical residues and is clearly porous.

The inferior mandibular cortical width was analysed using four quantitative indices. The first, called the mental index (MI), is the measurement of the cortical width in the mental foramen region and is assessed according to the technique described by Ledgerton *et al*.¹⁷ Three new indices, derived from the MI, were introduced in this study to evaluate the inferior cortex of the mandibular body: the mental posterior index 1 (MPI1), MPI2 and MPI3. These new indices were obtained by tracing the lines perpendicular to the base of the mandible, passing 1 cm posterior to MI, 2 cm posterior to MI and 3 cm posterior to MI for MPI1, MPI2, and MPI3, respectively (Figure 1). The radiographs were evaluated by two double-blinded observers. The measurements were taken on the right and left sides of each DPR in triplicate at intervals of 1 month to evaluate the intraobserver and interobserver repeatability.

Statistical analyses

All of the subjects were classified into three groups (normal, osteopaenia or osteoporosis) based on their skeletal BMD. In the evaluation of the morphological data (MCI), the area under the receiver operating characteristic curve (A_z value) was calculated using BioEstat Software, v. 5.0 (Instituto de Desenvolvimento Sustentável Mamirauá,

Figure 1 Acquisition of the mental index (MI), mental posterior index 1 (MPI1), MPI2 and MPI3. The MI is obtained by measuring the mandibular cortical thickness at the height of the centre of the mental foramen. The MPI1 is obtained by measuring the mandibular cortical thickness 1 cm posterior to the MI. The MPI2 is obtained by measuring the mandibular cortical thickness 2 cm posterior to the MI. The MPI3 is obtained by measuring the mandibular cortical thickness 3 cm posterior to the MI.

Belém, Brazil). The χ^2 test was used to determine the association between BMD status (DXA assessment) and morphological changes in the mandibular cortex (MCI). The significance level was $p < 0.01$. The area under the receiver operating characteristic curve was used to determine the sensitivity and specificity. True negatives (correct identification of a normal group), true positives (correct identification of a lower bone mineral density group), false positives and false negatives were calculated.

The Kruskal–Wallis test was used to determine the association between skeletal BMD and the morphometric measurements of the MI, MPI1, MPI2 and MPI3 mandibular cortical values. The significance level was $p < 0.05$.

Interobserver and intraobserver kappa agreement was calculated. For interpretation of the kappa statistic, values of 0.81–1.00 indicated very good agreement, 0.61–0.80 indicated good agreement, 0.41–0.60 indicated moderate agreement, 0.21–0.40 indicated fair agreement, and 0.20 or less indicated poor agreement.¹⁸

Results

Of the 63 post-menopausal females who participated in this study, 23 (35.94%) were normal, 21 (32.81%) had osteopaenia and 20 (31.25%) had osteoporosis on the basis of skeletal BMD (Table 1).

In the analyses of the morphological data (MCI) and morphometric indices (MI, MPI1, MPI2 and MPI3), the weighted kappa value for intraobserver agreement was more than 0.81 between the 2 measurements of the 2 observers. Similarly, the weighted kappa value for interobserver agreement was more than 0.81 for all of the indices. These results showed excellent intraobserver and interobserver agreement.

Table 1 Characteristics of 64 study subjects

Characteristic	Number of subjects ^a
Age sample (years)	63.1 $\pm$ 7.5
Diagnosis based on skeletal bone mineral density	
Normal	23 (35.94)
Osteopaenia	21 (32.81)
Osteoporosis	20 (31.25)

^aValues are given as mean $\pm$ standard deviation or n (%).

The χ^2 test showed a statistically significant association between skeletal BMD and MCI ($p = 0.0003$) for the lower BMD group (osteopaenia and osteoporosis). The area under the curve was 0.71, with 82% sensitivity and 60% specificity (Figure 2). The positive predictive value and the negative predictive value were determined to be 79% and 66%, respectively.

The Kruskal–Wallis test showed a statistically significant difference between the osteoporosis group and the normal and osteopaenia groups in all the cortical areas studied (Figure 3; Table 2). No differences were found between the normal and osteopaenia groups.

Discussion

In this study, the data evaluated from the panoramic radiograph were compared with those from the BMD evaluation by DXA testing. The WHO classification of BMD for the diagnosis of osteoporosis is based on extensive cross-sectional data in post-menopausal white females, showing a consistent correlation between BMD

Figure 2 Receiver operating characteristic (ROC) curve to determine sensitivity and specificity by evaluating the changes in the appearance of the mandible cortical index observed on digital panoramic radiographs for the lower bone mineral density group (osteopaenia and osteoporosis). Area under ROC curve = 0.71.

Figure 3 Mean measurements of the mandibular cortex in millimetres for different indices (MI, mental index; MPI, mental posterior index). * indicates significant differences between the osteoporosis group and the normal and osteopaenia groups according to the Kruskal–Wallis test ($p < 0.01$).

measured using DXA and lifetime fracture risk, so it is considered the gold standard method for the non-invasive diagnosis of osteoporosis.¹⁹ The BMD measurements in post-menopausal females need to be taken in both posterior–anterior spine projection and hip. As the pattern and magnitude of bone loss do not occur in an equal manner at all skeletal sites, the same patient may present different stages of bone loss at each site analysed, resulting in errors in classification.²⁰ With the aim of correctly classifying patients using the DXA assessment, the females who were selected for this study were in the post-menopausal period and had the same diagnosis on both sites.

Since the study of Klemetti *et al*,¹¹ several studies have demonstrated a significant correlation between MCI and DXA assessments, showing that the MCI morphological index has the potential to identify post-menopausal females with lower BMD values.^{6,12,14,21}

An important question in the application of MCI morphological index is its reproducibility. In most studies, high reproducibility, with an interobserver agreement ranging from 0.77 to 0.98, has been observed.^{11,13,14,22,23} Some studies have found poor to moderate inter- and intraexaminer kappa values and have attributed these results to variations in the examiners' judgement.^{12,24} For other authors, this variation is related to the amount of clinical experience and the specialty of the examiner, because these factors significantly increase the intra- and interexaminer agreement.^{21,25} In this study,

an interexaminer kappa value more than 0.81 was found for all of the indices, demonstrating excellent agreement.

The sensitivity found for the MCI in this study was close to that found in other studies, approximately 82%. However, the specificity and the positive and negative predictive values were greater, which may have resulted from grouping the patients with osteopaenia and osteoporosis in the lower BMD group.^{6,25,26} The accuracy obtained in this study was 71%, which was similar to that observed in previous studies.²³

There is disagreement among authors regarding the diagnosis—any evidence of cortical erosion (C2 or C3) or only cortical erosion of the C3 cortex—that should be used as an indicator for BMD measurement.^{3,13} Researchers who have classified patients at the C1/C2 threshold as a normal group have obtained high sensitivity and low diagnostic specificity, whereas those who classified patients at the C2/C3 threshold as a low bone mass group (osteopaenia/osteoporosis) obtained low sensitivity and high specificity.^{3,6,11,13,26,27} In this study, the latter form was used, resulting in a sensitivity of 82% and a specificity of 60%.

The advantage of the MCI is that it does not involve any measurement. It is an index of porosity, which should not be affected by minor differences in magnification between X-ray machines. The differences in resolution between the film/screen systems and the digital system used in the study centres did not seem to have any significant effect because the dental panoramic film/screen and digital systems were all working at similar speeds.³ This test is simple and can be applied by non-specialist dentists.⁵

The cortical thickness was analysed by means of 4 indices: the MI, MPI1, MPI2 and MPI3. To date, there has been the MI, which looks at the mandibular cortex below the mental foramen, and the antegonial index, which measures the cortical width at the anterior region of the gonion; however, the cortex located between these two points has never been analysed.¹⁴ Thus, to verify the correlation of cortical thickness with the mental foramen and the antegonial region using the BMD test, three new indices were designed: the MPI1, MPI2 and MPI3. After obtaining the MI index, the MPI1, MPI2 and MPI3 can be easily identified because each of them are 1 cm apart from one another. In this study, the measurements were determined using a software program which facilitated the reproducibility.

Table 2 Comparison of the median (Med) measurements $\pm$ standard deviation (SD) of the mandibular cortex in millimetres for the different indices (MI, MPI1, MPI2 and MPI3)

Index	Normal (Med $\pm$ SD)	Osteopaenia (Med $\pm$ SD)	Osteoporosis (Med $\pm$ SD) ^a
MI	3.90 $\pm$ 0.66	3.51 $\pm$ 0.51	2.5 $\pm$ 0.66
MPI1	3.37 $\pm$ 0.61	3.18 $\pm$ 0.42	2.31 $\pm$ 0.53
MPI2	3.00 $\pm$ 0.61	2.81 $\pm$ 0.40	2.31 $\pm$ 0.49
MPI3	2.65 $\pm$ 0.1	2.35 $\pm$ 0.40	2.11 $\pm$ 0.54

MI, mental index; MPI, mental posterior index.

^aSignificant differences between the osteoporosis and normal/osteopaenia groups according to the Kruskal–Wallis test ($p < 0.05$).

The statistical analyses showed that a patient with osteoporosis had MI, MPI1, MPI2 and MPI3 values that were significantly lower than those in a patient with normal BMD or osteopaenia. This result suggests that evaluating the mandibular cortex to identify patients at high risk for osteoporosis is not necessarily restricted to the point corresponding to the middle of the mental foramen; instead, there is a valid area of analysis that extends up to the antegonial region. There are difficulties in measuring the MI in the mental region owing to changes in cortical morphology, and recognition of the accurate position of the mental foramen can differ among different examiners.^{14,21} Therefore, in this study, extension of the area of analysis of the mandibular cortex might contribute to reducing errors in measurement and making it easier to use both in studies and in dental offices. The clinical use of this tool in tracking osteoporosis, particularly by untrained clinical dentists, will improve the selection of females at high risk for osteoporosis for further investigation.

Controversial results have been found in the literature with regard to the sensitivity and specificity of the MI index. Horner *et al*²⁸ found a sensitivity of approximately 8.3% and a specificity of 98.7%; thus, they concluded that because of low sensitivity, the MI index is not suitable for screening the osteoporotic population. In a study by Taguchi *et al*,¹⁶ the sensitivity and specificity found for identifying females with osteopenia were 79% and 50%, respectively, and the sensitivity and specificity for identifying females with osteoporosis were 90% and 45.3%, respectively. In this study, the sensitivity and specificity, respectively, for the lower BMD group were 84% and 62% for MI, 81% and 63% for MPI1, 82% and 61% for MPI2 and 80% and 61% for MPI3.

The value accepted as normal for the MI is equal to or greater than 3.1 mm, and an MI value less than 3 mm is recommended for use as the criterion for referring patients for bone densitometry examinations.^{27–29} The findings of this study suggest similar results for the MI and MCI1 indices in the osteoporotic group; however, future studies are necessary to demonstrate that cortical thickness is associated with the identification of low BMD for all of the morphometric indices (MI, MPI1, MPI2 and MPI3).

Magnification of the mandible in panoramic radiography is a known phenomenon, but it occurs unevenly throughout its structure. According to some authors,

the vertical and horizontal measurements obtained in a digital panoramic radiograph show greater magnifications in the anterior region and smaller magnifications in the posterior region.^{30,31} Vertical measurements are more reliable when the patient is properly positioned.^{31,32} The MPI1 is measured below the mesial root of the first molar, very close to the region of the premolars, where the MI is measured. Thus, considering the distance and location of the MI and MPI1, the difference in magnification might not be significant. The magnifications of the MPI1, MPI2 and MPI3 in relation to the MI have not been evaluated, and this is a limitation of this study.

With regard to the methodology, some authors have reported the use of digital panoramic radiographs, but few studies have used computerized measurements.^{25,29,33,34} The advantages of digital techniques over film techniques are lower radiation, faster communication of images, smaller storage space requirement, and lower contamination of the environment.^{35–37} Observers can use changes in brightness, contrast and magnification to improve the repeatability and reproducibility of any study.³⁷

This study has some limitations. No index differentiated a normal condition from osteopaenia, and DPR required operator input to identify the mental foramen correctly. Future studies should evaluate the magnification of these four morphometric indices. The cortical thicknesses that are associated with the identification of patients at high risk for osteoporosis could be established for MPI1, MPI2 and MPI3.

In conclusion, the thickness and shape of the mandibular cortex reflected the systemic condition of bone mass loss, and DPR could be used to identify patients at risk for low BMD. Using the MCI, patients with normal bone mass could be differentiated from those with reduced bone mass (osteopaenia/osteoporosis). The MI, MPI1, MPI2 and MPI3 showed that there is an area in the mandibular cortex located between the mental foramen and the antegonial region that is valid for identifying females at high risk for osteoporosis. The MI, MPI1, MPI2 and MPI3 identified females at high risk for osteoporosis but did not provide any distinction between normal and osteopaenic patients. Thus, the radiomorphometric indices MCI, MI, MPI1, MPI2 and MPI3 detected on DPR identified post-menopausal females with low bone densities and could be used to refer them for further investigation.

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