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Fractal dimension and mandibular cortical width in normal and osteoporotic men and women

Rafael Sindeaux[a,1], Paulo Tadeu de Souza Figueiredo[b,1], Nilce Santos de Melo[c,2], Ana Tereza Bittencourt Guimarães[d,5], Leonardo Lazarte[e,3], Fernando Borges Pereira[a,1], Ana Patrícia de Paula[f,4], André Ferreira Leite[b,*]

[a] University of Brasília, Brazil
[b] Oral Radiology, Department of Dentistry, Faculty of Health Science, University of Brasília, Brazil
[c] Oral Pathology, Department of Dentistry, Faculty of Health Science, University of Brasília, Brazil
[d] Biostatistics, Biological Sciences Department, State University of West Paraná, Paraná, Brazil
[e] Department of Mathematics, University of Brasília, Brazil
[f] Hospital de Base of Federal District, Brasília, Brazil

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ABSTRACT

Objective: To verify whether fractal dimensions (FD) on the mandibular trabecular and cortical bone and mandibular cortical width (MCW) differ between patients with normal bone mineral density (BMD) and osteoporosis.
Study design: In this retrospective study, 133 dental panoramic radiographs from men aged >60 years and postmenopausal women with a bone densitometry report of the lumbar spine and hip classified as either normal or osteoporotic were selected. Fractal dimensions of five standardized trabecular and cortical mandibular regions of interest and mandibular cortical width were measured on the panoramic radiographs by an experienced oral radiologist, blinded to the densitometric diagnosis. The following statistical analyses were performed: ANOVA and a forward logistic stepwise regression to verify associations between dental panoramic measurements and the densitometric diagnosis. *P* values less than .05 indicated statistical significance.
Main outcome measures: Fractal dimension and mandibular cortical width.
Results: Differences were found in the FD values on mandibular cortical bone and MCW between patients with normal BMD and with osteoporosis, but not in the FD values of trabecular bone. The odds of having lower mean values of MCW and FD on cortical bone were 2.16, 3125 and 1005 times in osteoporotic patients, respectively, compared with patients with normal BMD.
Conclusion: The values of FD analysis on mandibular cortical bone and MCW were lower in women with osteoporosis. A well-adjusted logistic regression model showed that cortical bone measurements might be considered as auxiliary tools to referring patients for DXA exam.

1. Introduction

Osteoporosis is a disease characterized by reduced bone strength and increased susceptibility to fractures secondary to a minor or no trauma. The bone strength primarily reflects in the integration of bone mineral density and quality [1]. The aging of worldwide populations may explain the increased incidence of osteoporosis. Fragility fractures related to this common bone disease are an important cause of mortality and morbidity that implies social and economic burdens [2].

Although postmenopausal women are more likely to develop osteoporosis and have the highest fracture risk, men have greater chance of being undertreated, being undiagnosed or dying from fractures than women [3]. Therefore, the identification of high-risk individuals for osteoporotic fractures is the basis of any preventive osteoporosis program. Early intervention may maximize bone mass retention and enhancement and, thus, reduce the risk of fracture.

Currently, osteoporosis diagnosis is based on the identification of different risk factors, the most important being low bone mineral

* Corresponding author at: Campus Universitário Darcy Ribeiro, Asa Norte, Zip Code 70910-900, Brazil. Tel.: +55 61 99511168; fax: +number: +55 61 35635946.
E-mail addresses: andreleite@unb.br, andrefleite@uol.com.br (A.F. Leite).
1 Address: Campus Universitário Darcy Ribeiro, Zip Code 70910-900, Brazil.
2 Address: Campus Universitário Darcy Ribeiro, Asa Norte, Zip Code 70910-900, Brazil.
3 Address: Campus Universitário Darcy Ribeiro, Asa Norte, Brazil.
4 Address: SMHS, Área Especial, Q. 10, Zip Code 70330-150, Brasília, Brazil.
5 Address: Rua Universitária 2069, Cascavel, Paraná, Brazil. Zip Code 85819-110.

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density (BMD) of the femur or lumbar spine [4]. BMD is routinely determined by dual-energy X-ray absorptiometry (DXA). Although BMD is a strong determinant of bone strength [5], many patients without densitometric diagnosis of osteoporosis are at increased risk of fracture, and a high percentage of fractures can occur in patients with normal BMD T-score [6]. Consequently, in order to properly assess fracture, other factors are important to be taken into account, such as clinical risk factors, as well as microarchitecture of bone [7].

The bone microarchitecture is changed in osteoporotic patients. Osteoporosis decreases the thickness and number of trabeculae and increases trabecular separation. Therefore, it alters X-ray attenuation in the bone and thereby changes the density and texture of the image [8]. The trabecular bone exhibits fractal properties, such as self-similarity and lack of well-defined scale [9,10]. Due to the fractal properties of bone, some authors have focused on evaluating bone diseases, such as osteoporosis, by fractal dimension (FD) analysis [11–14]. A recent study has demonstrated that bone texture parameters, including FD, improve failure load prediction when added to BMD [14].

Although FD has been proven to be efficient in evaluating bone quality on several bone sites, few studies have analyzed FD on dental panoramic radiographs of osteoporotic patients, with controversial results for the jaw bones [15–21]. Nevertheless, some previous studies have demonstrated that dental panoramic radiographs could be considered as a readily available screening tool for referring patients for bone densitometry for osteoporosis investigation, being applied to a large fraction of the elderly population [22–28]. The majority of the aforementioned studies was performed in postmenopausal women, and found a reduction of mandibular cortical width (MCW) in women with osteoporosis [22–26]. Therefore, the purpose of this study was to verify whether there were differences in FD and MCW on dental panoramic radiographs of men and women with normal BMD and osteoporosis.

2. Methods

This was a retrospective study based on images collected from the osteoporosis prevention and diagnosis program of the Federal District Health Department, Brazil, between 2008 and 2010. Initially, 300 records of patients with dental panoramic radiographs and DXA exams were selected. DXA and dental panoramic radiographs were performed at the same time. The study was approved by the Research Ethics Committee of the University of Brasília. Sample size calculation was estimated by population proportion, considering estimative maximum error of 0.05, degree of confidence of 90%, and the proportion of osteoporosis in our population. From these parameters, the calculated sample size for the studied population was composed by 133 elderly.

2.1. BMD assessment

The selected lumbar spine (L1–L4) and hip DXA scans were performed on the GE DPX-NT by the same technician. BMD values were classified as normal (T score ≥ -1.0), osteopenia ($-1.0 >$ T score > -2.5) and osteoporosis (T score ≤ -2.5), according to the WHO criteria. Osteoporosis was defined as a BMD T score of ≤ -2.5 at either the lumbar spine or the hip. The coefficients of variation of the lumbar spine and the hip measurements were 1% and 1.6%, respectively.

2.2. Dental panoramic radiographs

The selected dental panoramic radiographs were taken with the same panoramic machine (Rotograph Plus; Villa Medical System, Buccinosco, Italy). Patients were positioned in the device in such a way that the vertical line produced by the machine was aligned with the patient's sagittal plane and the horizontal line parallel to the floor.

2.3. Inclusion and exclusion criteria

Images from men aged >60 years and postmenopausal women with a bone densitometry report of the lumbar spine and hip classified as either normal or osteoporotic were selected. Images from subjects with osteopenia or from patients who were previously diagnosed with any metabolic bone disease other than osteoporosis and those who had taken medications affecting bone metabolism were excluded. Inadequate radiographic materials, presence of condensing osteitis, osteosclerosis, images with local destructive lesions of the mandible, and radiographs with undesirable anatomical structures or superimpositions of ghost images of anatomical structures were also excluded.

2.4. Fractal dimension

Dental panoramic radiographs were scanned in 8-bit gray-scale acquisition depth and 600 dpi spatial resolutions, with a scanner having transparency adaptor (Epson Exp, 1680Pro, Seiko Epson Corp, Nagano, Japan). Images were stored as JPEG format with a matrix of 7008×2975 pixels.

For fractal dimension analyses, five regions of interest (ROI) were selected on the right side of the panoramic images (Fig. 1A–D), three from the trabecular and two from the cortical bone of the mandible: (1) ROI – a square of 100×100 pixels in the trabecular bone, 2 mm anterior to the mental foramen; (2) ROI – a square of 50×50 pixels in the trabecular bone, 2 mm anterior to the mental foramen, inside the first ROI; (3) ROI – a square of 50×50 pixels in the trabecular bone, 2 mm inferior to the mental foramen; (4) ROI – an irregular shape in the basal cortical bone, distal to the mental foramen extending toward a line traced along the anterior border from the ascending ramus down to the lower border of the mandible; (5) ROI – an irregular shape in the basal cortical bone, distal to the mental foramen extending 2 mm. All ROIs were standardized. The ROIs from the trabecular bone were selected in order to avoid anatomical structures such as teeth and mandibular canal. Regarding the cortical bone, a modification of the method proposed in a previous study [19] was performed in order to select only the cortical portion of the bone.

Digital images were processed similar to the method designed by a previous study [27]. FD measurements were calculated in all ROIs using ImageJ version 1.45 s (a public domain program found on http://rsbweb.nih.gov/ij). Fig. 2 shows the sequence of procedures to calculate FD. First, the ROI was selected, cropped and duplicated. Then, the duplicated image was blurred with a Gaussian filter (sigma_35) to remove large-scale variations in brightness on the image. The blurred image was subtracted from the original ROI image and a gray value of 128 was added at each pixel location. The resultant image was then made binary and, with this process, the regions that represent trabecular bone were set to black and marrow spaces were set to white. The image was eroded and dilated to reduce the noise. After dilation, the image was skeletonized and was used for fractal analysis. FD was calculated by the box-counting method. The widths of the square boxes were 2, 3, 4, 6, 8, 12, 16, 32 and 64 pixels.

An experienced oral and maxillofacial radiologist made all MCW measurements and FD calculations once. This observer was blinded to the densitometric diagnosis of osteoporosis and normality. In a pilot study, the intraobserver coefficients of variations for MCW and FD measurements (made by the same radiologist) were as follows: MCW 2.8%, FD ROI1 4.3%, FD ROI2 5.2%, FD ROI3 6.0%, FD ROI4 1.5%, FD ROI5 4.0%.