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Original Article

Digital panoramic radiography as a tool for analyzing the quality of trabecular bone microarchitecture

Radiografia panorâmica digital como ferramenta de análise da qualidade da microarquitetura óssea trabecular

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Resumo

Introdução: A osteoporose é uma doença metabólica caracterizada pela redução da densidade mineral óssea, muitas vezes acompanhada da perda de qualidade da microarquitetura óssea trabecular. **Objetivo:** Avaliar a qualidade da microarquitetura óssea trabecular em radiografia panorâmica digital a fim de identificar precocemente a sua degradação, possibilitando melhor predição do risco de fraturas por fragilidade. **Material e método:** A amostra consistiu de 68 pacientes do sexo feminino, pareadas por idade, e divididas em 3 grupos conforme resultado densitométrico. Foram aferidos os valores de Trabecular Bone Score e realizadas radiografias panorâmicas digitais. A análise fractal com box counting foi feita na região de pré-molares e ângulo da mandíbula, com regiões de interesse medindo 64x64 e 80x120 pixels. Na análise estatística utilizou-se a correlação de Pearson entre os resultados de Trabecular Bone Score e de análise fractal obtidos em cada grupo, utilizando-se a idade como variável de controle e através de atribuição de grupos etários individualizados intragrupos. **Resultado:** Identificou-se correlação moderada nas regiões de interesse de 64x64 e 80x120 pixels, em ângulo da mandíbula no grupo Osteoporose e no grupo normal. Também se obteve correlação moderada utilizando a idade como variável de controle nas regiões de interesse de 64x64 pixels, em região de pré-molares. A análise intragrupos, considerando a faixa etária, resultou em correlação forte, no grupo osteoporose e moderada nos grupos osteopenia e normal. **Conclusão:** A análise fractal em radiografias panorâmicas digitais se mostrou promissora como instrumento preditivo da qualidade de microarquitetura óssea.

Descritores: Radiografia panorâmica digital; densitometria óssea; qualidade óssea; fratura por fragilidade.

Abstract

Introduction: Osteoporosis is a metabolic disease characterized by reduced bone mineral density, often accompanied by loss of quality of trabecular bone microarchitecture. **Objective:** To assess the quality or degradation of trabecular bone microarchitecture in digital panoramic radiography to better predict the risk of fragility fractures. **Material and method:** The sample included 68 female patients, age-matched, and divided into three groups according to densitometric results. Trabecular Bone Score values were measured and digital panoramic radiographs were taken. Fractal analysis with box counting was conducted in the region of premolars and angle of the mandible, with regions of interest measuring 64×64 and 80×120 pixels. In the statistical analysis, Pearson's correlation was applied between the Trabecular Bone Score and fractal analysis results obtained in each group, using age as a control variable and assigning individualized age ranges within groups. **Result:** A moderate correlation was identified in the regions of interest of 64×64 and 80×120 pixels at the angle of the mandible in the osteoporosis group and in the normal group. A moderate

correlation was also obtained using age as a control variable in the 64x64 pixel regions of interest in the premolar region. Considering age range, the within-group analysis presented a strong correlation in the osteoporosis group and moderate correlation in the osteopenia and normal groups.

Conclusion: Fractal analysis in digital panoramic radiographs was shown to be a promising predictive instrument of bone microarchitecture quality.

Descriptors: Digital panoramic radiography; bone densitometry; bone quality; fragility fracture.

INTRODUCTION

Menopause represents a gradual transition from the reproductive to the non-reproductive phase, during which the production of the hormones estrogen and progesterone decreases[1]. This hormonal lag causes matrix loss and increases bone fragility, raising the incidence of fractures and creating a public health problem[2].

Osteoporosis has great personal and economic impact. Personal impact on patients includes fractures that affect work capacity, and are associated with early deaths and several impairments in quality of life. Patients take a long time to recover the same general health status experienced before the fracture, and often cannot achieve it[3]. Hip fractures (proximal part of the femur) are the major complications of the disease due to their high morbidity and mortality levels[4].

Osteoporosis is diagnosed mainly by analyzing bone mineral density (BMD) using dual-energy X-ray absorptiometry (DXA), which has been considered as the standard reference test to diagnose this disease by the WHO since 1994. This method allows detecting patients at high risk of metabolic bone disease, estimating the degree of bone loss, and monitoring treatment[5].

Despite its widespread use to assess fracture risk in medical clinics, measuring BMD by DXA has disadvantages. This technique cannot assess other skeletal indices, such as bone regeneration rate, trabecular bone microarchitecture (TBM), and microdamage, all of which are important indicators of bone resistance[6].

However, a software can be used associated with DXA to gather information about TBM, generating a trabecular bone score (TBS)[7]. TBS is an algorithm derived from DXA to assess bone microarchitecture and also the most sensitive method to identify patients at high risk of fracture. Large cohort studies with osteoporotic patients have often shown the clinical value of this measure[8].

In recent years, dental imaging has been studied as an auxiliary tool for assessing bone microarchitecture[9,10]. The most used method to assess this feature is fractal analysis (FA) correlated with the numerical value obtained by DXA. FA is a mathematical analysis numerically expressed as fractal dimension (FD) that describes complex and irregular forms[11,12]. Several studies, In turn, use digital panoramic radiographs (DPRs) for the early diagnosis of Osteoporosis[13] and Osteopenia[14] due to the regular use of these examinations in dental treatment.

Identifying TBM degradation is essential to predict the risk of osteoporotic fractures and establish an early treatment, reducing sequelae for patients and expenses for the health system. Dental imaging tests are then an auxiliary alternative for bone microarchitecture assessment since they are already often used in dental treatment. As an innovative proposal, this study used TBS as a measure to be correlated in bone analysis in DPR considering the method sensitivity in identifying TBM deteriorations.

MATERIAL AND METHOD

This is a cross-sectional study approved by the local Research Ethics Committee under no. CAAE-31475020.8.0000.5060. The sample included 68 patients who underwent DXA up to six months before, matched by age, ranging from 52 to 85 years old and divided into one of the

groups: osteoporosis (20), osteopenia (26), and normal (22). The TBS Osteo® software (Medimaps Group, Switzerland) applied to densitometry tests was used to obtain TBS.

The DPRs were taken by a single operator using the imaging tool Dentsply Sirona Orthophos SL (Bensheim, GER). Exposure factors were calibrated for the biotype of each patient. Individuals with intraosseous lesions or DPR findings that could affect the analysis were excluded. The DPRs were saved in TIFF format without compression and the images were imported into the Image J software (National Institutes of Health, USA) to select regions of interest (ROIs).

FA was conducted in the region of premolars and angle of the mandible, considered appropriate in previous studies[13,15,16]. ROIs sized 64×64 pixels and 80×120 pixels were selected for both regions, totaling 272 ROIs evaluated. The ROIs were positioned to cover the largest amount of trabecular bone as possible in the regions adjacent to the mental foramen and in the angle of the mandible, with the minimum possible interference of various anatomical structures (Figure 1).

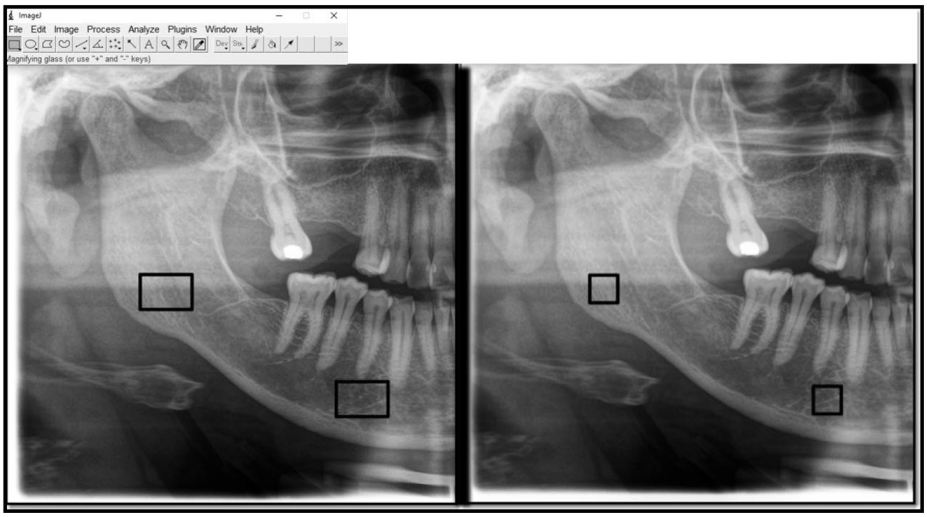

Figure 1. Region of interest selection.

FA followed the widely used protocol[17]. The image of the region of interest (ROI) was duplicated, blurred with Gaussian 35 filter, and the duplicate was then subtracted from the original ROI image. Grey value (128) was added and binarization, erosion, dilation, inversion, and skeletonization were conducted; finally, FD was estimated using the box counting method. Following this protocol, we obtained 272 FD values.

Descriptive data analysis was performed and TBS values were then correlated with the values obtained by box counting using Pearson's correlation analysis. The significance level adopted was 5% ($p<0.05$) and the IBM SPSS 20 statistical package was used for this analysis.

To verify the interference of age in the results, Pearson's partial correlations were also conducted using patients' ages as control variables.

Using age as a control variable increased correlation coefficient values in some cases. Age ranges were thus determined to perform new within-group correlations, respecting a compatible sample number.

RESULT

As a result of the analysis, the correlation values between the variables were obtained and tabulated, and are represented in Table 1.

Table 1. Correlation between TBS and FD by anatomical region, according to study groups

Anatomical region	Angle of the mandible				Premolars region			
ROI Size	64 × 64		80 × 120		64 × 64		80 × 120	
	r	p- value	r	p- value	r	p- value	r	p- value
Osteoporosis	0.557	0.011*	0.245	0.297	-0.039	0.869	-0.110	0.643
Osteopenia	0.249	0.219	-0.071	0.729	0.306	0.128	0.315	0.117
Normal	-0.335	0.128	-0.245	0.271	0.365	0.095	0.268	0.228

*p<0.05; r=Pearson's r.

Table 2 shows the values recalibrated after adjusting the correlation according to study groups by patients' age.

Table 2. Partial correlation between TBS and FD by anatomical region according to the study groups and adjusted for patients' age

Anatomical region	Angle of the mandible				Premolars region			
ROI Size	64 × 64		80 × 120		64 × 64		80 × 120	
	r	p-value	r	p-value	r	p-value	r	p-value
Osteoporosis	0.611	0.005*	0.289	0.231	-0.192	0.432	-0.106	0.666
Osteopenia	0.249	0.229	-0.136	0.518	0.276	0.182	0.293	0.155
Normal	-0.317	0.162	-0.327	0.147	0.507	0.019*	0.063	0.785

*p<0.05; r=Pearson's r.

A moderate correlation between the numerical values of TBS and the FD values of the ROIs of 64×64 pixels was identified, obtained in the angle region in the osteoporosis group (r=0.557/ p=0.011).

Partial correlation with age as a control variable indicated a moderate correlation between the numerical values of TBS and the FD values of the 64×64 ROIs obtained in the angle of the mandible in the osteoporosis group (r=0.611/ p=0.005) and of the 64×64 ROIs obtained in the premolars region in the Normal Group (r=0.507/ p=0.019). For the other regions and groups, the correlation was weak or null.

These results obtained using patients' age as a control variable allowed conducting a more detailed within-group assessment. Table 3 shows the results obtained by determining within-group age ranges to perform new correlations.

Table 3. Partial correlation between TBS and FD by anatomical region according to the study subgroups and adjusted for patient age

Anatomical region	Angle of the mandible				Premolars region			
ROI Size	64 × 64		80 × 120		64 × 64		80 × 120	
	r	p-value	r	p-value	r	p-value	r	p-value
Osteoporosis (age ≥64 years)	0.838	0.001*	0.344	0.300	0.106	0.757	0.036	0.916
Osteopenia (age ≥59 years)	0.377	0.136	0.347	0.172	0.417	0.096	0.643	0.005*
Normal (age ≤57 years)	0.339	0.373	0.248	0.520	0.738	0.023*	0.294	0.442

*p<0.05; r=Pearson's r.

The statistical test applied to patients 64 years or older in the Osteoporosis group showed a strong correlation between the TBS and FD values measured in 64×64 ROIs in the angle of the mandible (r=0.838; p=0.001; N=11).

The statistical test conducted among patients 59 years or older in the Osteopenia group showed a moderate correlation between the TBS and FD values measured in the 80×120 ROIs of the premolar regions (r=0.643; p=0.005; N=17).

Accordingly, the statistical test conducted among patients 57 years old or younger presented a moderate correlation between the TBS and FD values measured in the 64×64 ROIs of the premolar regions (r=0.738; p=0.023; N=9).

The correlation analysis of the subgroups indicates that DPR efficacy in bone architecture assessment is related to patient's age, being assessed as directly proportional in the osteopenia and osteoporosis groups and as inversely proportional in the normal group.

DISCUSSION

DXA stands out as a precise method with low radiation doses when compared with other tests. However, other factors such as TBM deterioration, bone geometry, microdamage, bone regeneration, and age should be analyzed[18,19]. TBSOsteo® is a software applied to DXA that assesses bone health complementary to BMD and has been useful for predicting fracture risk[20]. Low amplitude fine texture fluctuations present higher TBS values whereas high amplitude coarse texture fluctuations present lower values[21]. Complementing results obtained by measuring BMD with TBS is relevant since several patients suffer bone fragility fractures with densitometric results classified as osteopenia and normal[22].

A recent study estimated that direct costs mainly related to fragility fractures were between US$5,000 billion and US$6,500 billion, considering only the U.S., Canada, and Europe[23]. Identifying degraded bone microarchitecture in more accessible examinations could prevent these fractures, which would significantly reduce financial impacts on health systems.

Dental radiographs are relatively inexpensive and are already used in most of the adult population. One of their main advantages is that the analysis of the trabecular pattern helps select women for the referral to DXA[24] tests and identify the risk before fracture[25].

Examinations such as periapical radiographs, panoramic radiographs, and cone-beam computed tomography have been studied for detecting osteoporosis. The methods used are diverse and include evaluation of pixel intensity[13], morphometric indices[26], FD calculation[27], and more recently artificial intelligence[28]. We used FD in this research considering the measure's low execution complexity and the use of free software. We chose DPR for examination since it has been widely used in studies[29] and presents low execution complexity, high availability, and low cost, being a viable alternative for implementation in health services.

Differences related to ROIs are important in using FA. The selection area and size of these regions are greatly diverse since variations mainly consider mandible regions and shapes are mostly square or rectangular, with different sizes[29-31].

In this study, we used ROIs of different size and shape, locating them in two regions of the mandible to assess the influence of these variations on the results. Considering a study that indicated no significant difference between the right and left side of the mandible in FD assessment[13], we chose to define the right side as a standard for the location of the ROIs. However, the left side was used to assess a couple of patients with some type of image interference on the right side. As expected, determining the location of the larger ROIs was more difficult because of the frequent interference of anatomical elements.

This study's objective is innovative since it focuses on analyzing bone microarchitecture and not bone mineral density. Previous studies corroborate the possibility of assessing trabecular microarchitecture, showing that changes in trabecular architecture occur equally throughout the bone structure and indicating that the spongy bone in the mandible may respond similarly to any other spongy bone in patients with osteoporosis[17].

Trabecular pattern analyzed from panoramic radiographs has shown to be a highly significant predictor of fracture risk, being more effective the older the patient is. However, these are results of a study which followed participants along 42 years[32], that is, a subjective analysis difficult to

replicate. Our study uses FA, eliminating subjectivity, and DPR, an accessible alternative of low complexity for predicting larger osteoporotic fractures.

In a recent study conducted with DPRs, the correlation between TBS values and values obtained from semi-automatic and automated software showed weak or absent correlation. Using a licensed software with a large interval between intraoral radiographs and TBS measurement, the authors concluded that semi-automatic and fully automated digital analyses of the trabecular pattern on intraoral radiographs do not help predict fracture risk[33]. The research sample was significant although the study did not standardize the interval between imaging exams or even the age-matching of volunteers distributed among the analysis groups. These elements may have interfered with the results found. In our study, the age of patients within the three groups was a variable which significantly affected the correlation between TBS and FD values.

We proposed using a public domain software for image analysis to make the technique accessible and reproducible. The time interval between radiographs and the application of TBSOsteo® was considered an important factor and thus restricted to a maximum of six months, as recommended by another study[34]. Using radiographs from image banks, obtained from different equipment, not taken for specific purposes, and taken by different operators[33] allows building a more significant sample. However, standardization is essential for achieving more reliable results. In this study, we chose to conduct a prospective assessment in which the same operator treated all patients, using the same equipment. This allowed obtaining greater control of the factors that could interfere in the results.

Knowledge of TBM represents an important predictive factor for fracture risk[35]. Obtaining accessible methods to assess this microarchitecture and its degree of degradation is therefore essential to prevent bone fragility fractures, thus improving the quality of life of patients and reducing public expenditures.

According to the results FA in DPR was a promising tool for assessing bone microarchitecture among the groups of patients evaluated considering that analyses showed moderate and strong correlations with TBS values. However, further studies are needed to determine numerical intervals of FD for normal, poorly degraded, or very degraded trabecular condition, establishing cutoff points for the technique in predicting bone fracture risk.

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CONFLICTS OF INTERESTS

The authors declare no conflicts of interest.

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