Comparative evaluation of bone densities in edentulous and dentulous areas by fractal analysis on panoramic radiographs - A retrospective study

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Abstract

Aim: Aim of the study was to evaluate the difference in bone trabecular pattern in terms of fractal dimensions (FD), in edentulous and dentulous areas on contralateral sides of the same patient’s radiograph.

Methodology: A retrospective study using box counting method of fractal analysis was performed on pre-processed 97 digital orthopantomographs (OPGs), after subjecting to inclusion and exclusion criteria with the fractal three software.

Results: The mean FD of dentulous and edentulous regions was 1.812 ± 0.085 and 1.728±0.105 (P < 0.005), respectively, calculated by paired sample tests. Higher age group (Group 3) had lower FD values than other two groups (P > 0.01). Female sex had lower FD values than males (P > 0.01).

Conclusion: The tooth loss (edentulous state) is associated with low FD, compared to tooth bearing areas. The method can be used to as a quick tool, to evaluate and compare the bone quality when prosthetic treatments are to be planned.

Keywords
Box counting, digital panoramic radiography, dental implants, fractal analysis, trabecular bone pattern

Introduction

Adding a unique dimension in diagnosis in the field of science is the incorporation of mathematics wherein morphometric analysis of irregular, complex but self-similar structures are evaluated through a phenomenon called as fractal analysis (FA). Resurgence of this astounding analysis has added light in the medical and dental clinical scenarios. FA contributes great lot in the estimation and quantification of trabecular bone structure for the analysis of bone changes in periapical pathologies, periodontal pathologies, systemic diseases and oncology. FA is a statistical texture analysis based on fractal geometry for describing complex structural patterns recognized and expressed as ratio termed as the “fractal dimension” (FD).

In a scenario where dental implants are to be planned, an ideal bone free of local disease and not reflecting an underlying systemic illness is needed along with a healthy quality bone to permit osseointegration in future. The quality of healthy bone is reflected by underlying trabecular pattern recognized on panoramic radiographs. The method relays on trabecular bone microarchitecture as a base for a potential low dose means of quantifying changes in site of interest, compared to that of computed tomography and dual-energy X-ray absorptiometry (DEXA) to obtain fair note on bone mineral content. The method of analyzing bone patterns on panoramic radiographs is reported to be unaffected by exposure parameters, alignment, and choice of region of interest (ROI) selected on the bone on radiograph. Among the various complex methods under FA, the simplest and accurate one to understand bone is box/tile counting algorithm. This is the most common used method to quantify the trabecular pattern by calculating the trabecular bone and bone marrow interface. This is used as preliminary assessing and prognosticating tool on bone quality in case of dental implants. The purpose of this study is to evaluate if edentulous sites had different bone quality compared to sites with teeth. This study is an attempt on digital orthopantomographs (OPGs) using box counting/tile counting method of FA. A long period of edentulism is known to cause bone loss and difficulties in planning prosthetic treatments at a later stage. This study is planned with ideology of a simple bone assessing tool (in edentulous areas) without considering “period of tooth loss.”
Methodology

Data collection and sampling method

The current retrospective study wherein digital OPGs available from the database for period of 6 months were taken and were subjected to inclusion and exclusion criteria to obtain the final sample by the convenient non-randomized sampling. Ethical committee approval was obtained before analysis on images. Total OPGs for 6 months = 592; excluded based on criteria = 498, acquired sample for study = 94. All OPGs selected were re-evaluated by two oral radiologists, keeping the criteria in mind and to avoid inter observer’s bias. All exposure were made by Orthophos digital XG digital machine (Marketed by Sirona, Germany) under standardized exposure parameters of 64 kVp, 8 mA current and 14.01 seconds exposure time. Photoshop software (version 8, Adobe Systems, San Jose California) was used to extract the underlying bone patterns as described by Geraets and van der Stelt[7]. The final patterns were analyzed by Fractal 3 software (FA software). The obtained values from all desired sites (ROI) were tabulated and subjected to statistical analysis. Digital OPGs with dentulous and edentulous areas on the contralateral sides were considered under inclusion criteria. The various reasons for jaw bone trabecular alteration (evident periodontal and bone pathologies, gross radiographic errors) were considered as exclusion criteria. The sex and age distribution is tabulated in Tables 1 and 2, respectively.

Defining ROI

For the edentulous region, a 40 × 120 square unit area chosen from the “area defining” box of software. Similarly, for dentulous area, an average of 2-3 region values around the teeth was considered. For single rooted teeth, an average of two values, i.e. area mesial (M) to the tooth, and distal (D) to the tooth (35 × 120 square units) were considered. The regions were named as R1, R2, R3 and R4 for incisor, canine, premolar and molar regions, respectively (Table 3).

Image processing and pattern extracting

Digital OPG images obtained from database in JPEG format were processed by redefining and extracting the skeletonized counterpart of selected trabecular pattern as described by White and Rudolph (1999) later adopted by Geraets and van der Stelt[7]. The final patterns were analyzed by Fractal 3 software (FA software). The obtained values from all desired sites (ROI) were tabulated and subjected to statistical analysis. Digital OPGs with dentulous and edentulous areas on the contralateral sides were considered under inclusion criteria. The various reasons for jaw bone trabecular alteration (evident periodontal and bone pathologies, gross radiographic errors) were considered as exclusion criteria. The sex and age distribution is tabulated in Tables 1 and 2, respectively.

Results and Observations

The values of FD noted from various regions (R1-R4) and both ROIs (dentulous or edentulous) were tabulated and subjected to paired sample testing using the SPSS software (Statistical Package for Social Sciences - version 21 for Windows). The mean FD of dentulous and edentulous regions was 1.812 ± 0.085 and 1.728 ± 0.105 (P < 0.005), respectively, calculated by paired sample tests (Table 4). Higher age group (Group 3) had lower FD values than other two groups (P > 0.001). Female sex had lower FD values than males. The FD values lower in incisors region (Regions analyzed -1), compared to other teeth regions in our population.

Table 1: Mean FD of males and females

<table>
<thead>
<tr>
<th>AG (years)</th>
<th>Frequency (%)</th>
<th>Mean±SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AG 1 (&lt;20)</td>
<td>26 (26.8)</td>
<td>0.823±0.082</td>
</tr>
<tr>
<td>AG 2 (20-40)</td>
<td>43 (44.3)</td>
<td>0.772±0.169</td>
</tr>
<tr>
<td>AG 3 (40-60)</td>
<td>28 (28.9)</td>
<td>0.613±0.289</td>
</tr>
</tbody>
</table>

FD: Fractal dimensions, SD: Standard deviation, AG: Age group

Table 2: Mean FD of different AG

<table>
<thead>
<tr>
<th>AG (years)</th>
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FD: Fractal dimensions, SD: Standard deviation, AG: Age group

Table 3: Mean fractal dimensions (FD) of different RA

<table>
<thead>
<tr>
<th>RA (years)</th>
<th>Frequency (%)</th>
<th>Mean±SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA 1 (incisors region)</td>
<td>13 (13.4)</td>
<td>0.698±0.14</td>
</tr>
<tr>
<td>RA 2 (canine region)</td>
<td>6 (6.2)</td>
<td>0.728±0.12</td>
</tr>
<tr>
<td>RA 3 (premolar region)</td>
<td>31 (32.0)</td>
<td>0.814±0.06</td>
</tr>
<tr>
<td>RA 4 (molar region)</td>
<td>47 (48.5)</td>
<td>0.823±0.182</td>
</tr>
</tbody>
</table>

FD: Fractal dimensions, SD: Standard deviation, RA: Regions analyzed

Table 4: Comparison of FD in edentulous and dentulous regions

<table>
<thead>
<tr>
<th>Site</th>
<th>Mean±SD</th>
<th>95% CI of the difference</th>
<th>t value</th>
<th>Df</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dentulous</td>
<td>1.811±0.0859</td>
<td>0.0685 - 0.0988</td>
<td>10.777</td>
<td>96</td>
<td>0.001</td>
</tr>
<tr>
<td>Edentulous</td>
<td>1.728±0.1053</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

FD: Fractal dimensions, SD: Standard deviation, CI: Confidence interval
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The fascinating concept of FA dates back to early 1900’s when Bachelier in 1900, Kolmogorov in 1941, Mandelbrot in 1963 and Frish in 1995 pioneered the significance and uniqueness of this procedure.

Oczeretko et al.[5] have demonstrated different methods of FA, used to measure roughed areas in dental radiographs, one of which is “box counting” method, adopted in our study. Fractal objects have three important features of self-similarity, chaos and non-integer FD. Geraets and van der Stelt[7] have first studied fractal properties of bone. They have stated that the fractal dimension of these complex structures replicated from medical investigations gives clue to current state and functions, aiding in the diagnosis of a medical condition. The concept of FA used in field of medical imaging and its applications include from evaluating states of hypoxia in case of pulmonary vessels to mammography in detection of breast cancers.[8,7]

Li et al.[9] has mentioned different methods of FA, on the cone-beam computed tomography (CBCT) images, where they identified that, the area of bony plates, the number of bony and marrow regions, the trabecular circumference were shown to be reflecting a fractal pattern.

FA was studied for routine periapical and periodontal changes and was reported to be a useful tool.[10,11] Trabecular bone around successful dental implants exhibits lower FD values 6 months after prosthodontic loading and displays stable bony microstructure at 12 months of follow-up.[12] Furthermore, studies showed FA in evaluating initial Osseointegration of dental implants, prosthetic loading changes, and peri-implantitis.[12,13] More essentially angiogenesis-related vascular patterns in cancer are measured by FA as part of morphometric analysis which is reflected by microvascular volume, and this is more significant and informative than the traditional microvascular density.[14] Age-related osteoporotic changes were evaluated in a study, which showed significant variations in FD of normal and osteoporotic patient assessment and also specified lower premolar region as suitable site for fractal analysis.[6,15] FD values from trabecular bone in peri-implant bone was scored and graded healthy when the dimensions matched to that of opposite side on digital panoramic radiographs.[16] The common oral premalignant lesions were understood regarding their grading (leukoplakia) and underlying vascular patterns (lichen planus) by suing this method.[17,18] FA gave a negative correlation with maturation of midpalatal suture, serving as postsurgical quantitative prognostic marker.[19] Thus, the method was adopted considered to have diagnostic implications and used in the context of dental imaging.

There are some disadvantages in this study. The image analysis is time consuming and sensitive process considering image a minor enhancement. The panoramic images have inherent magnification, which could attribute to errors of the final estimate.

FA is recommended on 3D digital images (CBCT) to derive bone quality estimates in 3 dimensions. The DEXA and CT scans

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Figure 1: Cropped image of digital orthopantomograph (panoramic view) showing tentative region of interest selected mesial to the mandibular lower first molar (Dentulous site, Regions analyzed-4)

Figure 2: Steps in obtaining a binary image for analysis, (a) duplication of images, (b-c) blurring with a Gaussian filter (Kernel size: 35), (d) resultant of subtraction of the blurred from the original image, (e) final binary image obtained by keeping the threshold at the gray value of 128

Figure 3: The same region of interest marked in fractal three software showing the fractal dimensions values calculated from binary image. The log versus log plot for 5 sequences of box counting depicted each part is a reduced copy of the entire structure.[1] The word fractal is derived from the Latin, “fractus:” Means “fracture” or “broken.” FA and determination of the FD has an important role in studying complex structures of the human body like the purkinje fibers of heart, branching of the arteries, neurons of the brain, trabecular bone patterns of the bone.[3]
remained the gold standard when analyzing bone quality. A larger sample size and reporting results in an overall comparative fashion were done to avoid these drawbacks. However, the simplicity of the method made it most useful tool to derive a rough idea on bone health since three decades.

Conclusion

The FD values obtained in this study showed statistically significant (P < 0.005) difference in sites with and without teeth. Thus, edentulism could be attributable to lower FD or bone quality. The need of early replacement is highlighted. The FA is a cost effective, method of assessing medical images for diagnostic and prognosis purposes.

Acknowledgment

We would like to thank NARO, Japan, for permitting (No: P60651) the use of fractal analysis system for the study purpose.

References