Pixel Intensity and Fractal Dimension of Periapical Lesions Visually Indiscernible in Radiographs

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Abstract

Introduction: The purpose of the study was to analyze pixel intensity (PI) and fractal dimension (FD) values in radiographs of chemically created but visually undetectable periapical lesions. Methods: Artificial lesions were created by applying 70% perchloric acid to the sockets of left and right first premolars in 12 cadaver mandibles. For preparation of relatively small lesions, the acid was applied for 30 and 60 minutes. Before and after each acid application, radiographs were taken (60 kVp, 7 mA, and 1.5 mm Al equivalent filtration for 0.12 second) with storage phosphor plates. An optical bench was used to standardize projection geometry. Image plates were scanned immediately after exposure, and the acquired images were saved uncompressed in TIF format. Six observers evaluated the images by using a 5-grade scale, and the images scored as “definitely absent” by all observers were used for the calculations of PI and FD. Box-counting FDs and differences in mean PI were computed for regions of interest at the apical areas of each premolar. Repeated-measures analysis of variance, Tukey test, and Pearson correlation coefficient test were used for statistical analysis. Results: A significant difference was found in FD values after both acid application periods (P < .05), whereas a difference in PI was detected only in images obtained after 60-minute acid application (P < .05). There was a negative correlation between FD and PI values (−0.754, P < .05). Conclusions: Calculation of FD can be a tool for the early detection of periapical lesions given the presence of baseline radiographs. (J Endod 2013;39:16–19)

Key Words

Fractal analysis, periapical lesion, trabecular bone

Radiographic examination is an essential component for the management of periapical pathosis (1). Detection and assessment of the location and extent of a periapical lesion are important for treatment planning, maintenance procedures, and prognostic determinations (2).

Intraoral radiography is the technique of choice for diagnosing, managing, and assessing endodontic disease (1, 3, 4); however, the amount of information that can be gleaned from radiographs is limited. Some studies have concluded that perforation or erosion of the overlying cortical plate is a necessary condition for periapical radiolucency lesions to be radiographically detectable (5, 6). Others have shown that extensive bone destruction may be present without any radiographic evidence (5).

Digital imaging, with its postprocessing capabilities, holds the possibility of qualitative and quantitative analyses of bone density and architecture (7). Thus, quantitative evaluation of the periradicular bone can be of help in the early detection of periapical pathology, which may affect treatment planning (8).

There are several methods of assessing trabecular structure in radiographs. Pixel intensity (PI) analysis is a simple method providing objective measures of radiographic density of alveolar bone (7). Fractal dimension (FD) analysis is a method to assess complex geometric structures quantitatively (9). In this method, a computer algorithm generates a single number, the FD, representing the complexity of the structure (10).

There are many dental studies in which fractal analysis has been used to analyze the structure of trabecular jaw bone (11, 12). Some have assessed the FD of bony changes associated with apical periodontitis, but they have mainly focused on early healing after root canal treatment (8, 13, 14). No study could be found that tested the capability of FD analysis for the detection of early periapical lesions or that used both PI analysis and FD measurements. Therefore, the aim of this study was to assess the value of PI and FD analyses for the diagnosis of chemically created, visually undetectable periapical lesions.

Materials and Methods

Specimens and Lesion Creation

Twenty-one first or second premolars with no root canal therapy from 12 dry human mandibles without evident periapical pathosis were used for the present study. As previously described (15), artificial periapical lesions were created by using 0.05 mL 70% perchloric acid saturated cotton pellets placed at the bottom of each tooth socket (16, 17). After the acid application, the cotton pellets were removed, and the sockets were washed with water and dried with cotton-tip applicators. The acid was applied for 30 and 60 minutes to create relatively small lesions (15).

Radiographic Technique

Each mandibular specimen was mounted in silicone paste and placed in the center of a Plexiglas block to ensure a reproducible relationship between x-ray unit, object, and image plate (blue storage phosphor plate [SPP]; Digora Optime system, Soredex Corporation, Helsinki, Finland). For the normalization of PI measurements, an aluminum (Al) step-wedge made of 99.5% pure aluminum with ten 1-mm incremental steps was attached to the SPPs. Before and after each acid application, exposures were...
made with a Gendex Oralix DC (Gendex Dental Systems, Milan, Italy) dental x-ray unit operating at 60 kVp, 7 mA, 0.12 second, and 1.5 mm Al equivalent filtration. The focus-receptor distance was 25 cm, and an optical bench was used to standardize irradiation geometry. Facing the x-ray tube and close to the mandible, a 20-mm-thick soft tissue equivalent material was placed.

**Image Evaluation**

Immediately after each exposure, the plates were scanned in the Digora Optime scanner. Resulting images were transferred to a personal computer (Toshiba Satellite 1900; Toshiba Corp, Tokyo, Japan) and evaluated by 3 radiologists and 3 endodontists for the presence or absence of periapical lesions by using a 5-grade scale: (1, definitely present; 2, probably present; 3, unsure; 4, probably absent; and 5, definitely absent). Observation conditions were optimized through use of the same computer monitor in a darkened room at a viewing distance of 50 cm. To minimize observer learning effects, images were displayed in a preset randomized order. Observers were not permitted to perform any image enhancements to avoid the production of various different digital images. The presence of a periapical lesion was defined as the periapical radiolucency exceeding at least twice the width of the periodontal ligament space. Images that received score 5 by all observers were used for PI and FD calculations. This meant that 56 images were used for the image analyses.

**Image Analyses**

The software used for all image analyses was the National Institutes of Health image program Image J, version 1.34 (National Institutes of Health, Bethesda, MD). In each image a rectangular region of interest (ROI) (100 × 60 pixels) was created at the apical area of each premolar and used for both PI and FD calculations (Fig. 1).

PI is a measure of the gray level value on a scale from 0 (black) to 255 (white). PI measurements were done by using the histogram analysis function of the software. The gray level value in the 6th step (middle one) of the Al wedge was sampled with 3 nonoverlapping (40 × 40 pixels) ROIs from which a mean pixel value in each image was calculated.

PI measurements in the images of the Al wedge were made to enable normalization of the ROI PI measurements. The normalized PI values of the periapical areas were then obtained by dividing the mean PI of the bone ROI by the mean PI of the Al wedge as proposed by Tosoni et al (7). Normalized PI measurements were obtained from the rectangular ROIs at the apical areas of each tooth in all images (before and after acid application). PI and FD were calculated with Image J (Fig. 2).

FD was calculated by using the box-counting method, proposed by White and Rudolph (18), from the ROIs of the mandibular premolar regions. Standard-sized (115 × 54 pixels) rectangular ROIs were created in each image and periapical area by using the ROI manager tool of the software. The aim of the whole procedure was to remove large-scale variations in brightness of the image caused by either differences in object thickness or presence of partially overlapping soft tissue. For this purpose, ROIs were duplicated and blurred by a gaussian filter (low-pass filter) with a diameter of 35 pixels (Fig. 2A and B). This procedure removes all fine-scale and medium-scale structures and leaves only large variations in density. The blurred area was subtracted from the original image, and a value of 128 was added to each resultant pixel (Fig. 2C). This step produces an image with a mean gray value of 128. The result is an image in which individual variations in the image reflect particular types of features with different brightness (ie, trabeculae and marrow spaces). The image was then made binary by segmenting the image into components that visually symbolize the trabeculae and marrow. This image was then inverted to make the trabeculae black (Fig. 2D). After eroding and dilating once, all high-frequency noise was eliminated from the image, and outlines of the structures were obtained. The resultant image was then skeletonized, that is, eroded until only the central line of pixels remained to reveal features that can be seen and measured. FD was calculated with Image J (Fig. 2E).

**Statistical Analysis**

Comparison of FD and PI measurements between groups of different acid durations was done by using repeated-measures analysis of variance (P = .05). Post hoc pairwise comparisons between FDs and
Results

There was a significant increase \((P < .05)\) in FDs of periapical bone after both 30-minute and 60-minute acid application (Table 1). A decrease in PIs was observed, but it was statistically significant \((P < .05)\) only after 60-minute acid application. Correlation between FD and PI was negative \((-0.754, P < .05)\).

Discussion

The result that FD values increase with decreasing bone density is in accordance with many previous reports \((9, 19–21)\). Ruttimann et al \((9)\) investigated the structural changes on 10 dry mandibular bone segments before and after decalcification with acid and found that the FD increased with demineralization irrespective of the radiographic projection angle. An \(in vivo\) study comparing the FD values in healthy patients and patients with a history of osteoporotic fractures reported an increase in FD in the osteoporotic group \((20)\). It was hypothesized that the loss of fine trabecular structures as a result of demineralization caused abrupt density changes in the radiographic image and thus changes in the FD \((9)\). In other words, increase in FD is a reflection of the increase in roughness of the image corresponding to architectural disorganization of the trabecular network by demineralization \((22)\).

Decrease in PI with decrease in bone density (mineralization) is expected and in agreement with previous reports \((7, 23)\). However, a statistically significant decrease in PIs was found after 60 minutes but not after 30 minutes of acid duration. In contrast, FD values were significantly different even after 30 minutes of acid exposure. Therefore, it may be postulated that FD analysis is a more sensitive method than PI analysis for the detection of early demineralization.

Results of studies evaluating bone healing after endodontic treatment found FD analysis helpful in detecting early changes in periapical trabecular pattern \((8, 13, 14)\).

Only 2 studies can be found in the dental literature in which both PI measurements and FD analysis have been used \((7, 23)\). Law et al \((23)\) found that FD evaluations were effective in distinguishing an osteoporotic group from a control group, but that PI evaluations were significantly more effective. Tosoni et al \((7)\) were not able to differentiate between 3 groups of postmenopausal women \((normal, osteopenic, and osteoporotic)\) by using FD analysis, whereas they were able to discriminate the groups by using PI measurements.

It was recently demonstrated that FD is correlated with image resolution \((24)\). In a study comparing the difference in FD in periapical and panoramic radiographs, it was shown that the lower resolution in panoramic radiographs eliminates finer bony trabeculae and therefore reduces their ability to describe the bone architecture \((20)\). In the studies by Law et al \((23)\) and Tosoni et al \((7)\) in which PI analysis was found to be superior to FD analysis, panoramic radiographs were used for the calculation of FD. In one of the studies, digitized conventional films were used, which may also have an impact on image resolution and accordingly on the FD analysis \((23)\). Moreover, a different method for FD calculation other than the box-counting method was used. Differences in image receptors, calculation methods, and type of images may explain the variance between the results of these studies and ours.

We found that FD analysis was able to distinguish between areas with and without demineralization as well as between different demineralization patterns caused by different acid exposure periods. Moreover, FD analysis was capable of detecting changes in trabecular pattern earlier than the PI measurements. Calculation of the FD is an inexpensive method with fewer limitations than other quantitative methods such as PI measurements or subtraction radiography \((23)\). The necessity of using a reference standard in each image for normalization of exposure variations is the most important limitation of PI analysis. Subtraction radiography is technique sensitive and requires specialized equipment \((25)\).

FD analysis in periapical radiographs has been used as a simple descriptor of the complex architecture of the cancellous bone surrounding the dentition \((20)\). Variations in radiographic settings, including tube potential and irradiation geometry, have minimal impact on the FD, supporting its use in studies that use periapical radiography to determine bone quality in health and disease \((12, 26, 27)\). Thus, it may be used as a quantitative and objective method in detecting early changes of periapical trabecular pattern \((8, 13, 14)\).

Although FD analysis appears to be relatively insensitive to variations in film exposure and alignment, the effect of the location of the ROI on FD calculations is controversial \((26, 27)\). In 2 consecutive studies by the same group of researchers it was first reported that the placement of the ROI may not be crucial \((26)\). Two years later, however, they suggested that the same ROI must be identified when doing comparisons over time. We placed our ROIs exactly at the same location before and after acid application. If one cannot say that FD values from different ROI locations are the same, then the technique requires earlier radiographs for comparison, particularly for longitudinal studies. Similarities between FD for different ROIs in the same patient have not yet been determined. Until further research has established that FD is not dependent on the placement of the ROI, it may be wise to use identical ROIs in comparative studies.

Bone density changes are the most consistent feature of progression or resolution of periapical inflammation present in radiographs. Early detection of change is an important step in the assessment of treatment efficacy and patient management \((1)\). However, in conventional radiography approximately 30% change in mineralization is necessary for a periapical lesion to be detected by the human visual system \((28)\). In addition, the quality of radiographs, acquisition geometry, subjectivity of evaluation process, and presence of anatomic noise are well-known disadvantages resulting in interpretation errors.

The introduction of cone-beam computed tomography (CBCT) has demonstrated important advantages over conventional intraoral radiographs for the diagnosis of endodontic pathology. A previous clinical study found that limited CBCT detected 62% more lesions than periapical radiography \((3)\). Bornstein et al \((29)\) found that 26% of roots with periapical lesions, as detected in limited CBCT images, were not diagnosed in periapical radiographs. Nevertheless, it was also proved that we usually tend to miss at least 30% of lesions in the jaws with respect to different areas in the maxillary bones. Subtle pathologies may be difficult for the human eye to discern because of the low signal-to-noise ratio of the image \((either 2-dimensional [2D] or 3-dimensional [3D])\) and/or different image parts, but if the image has a significant spatial extent, they are characterized by low and/or high frequencies in the specimen, which are well revealed by many image analysis methods \((25)\).

In other words, the hidden diagnostic information in the image may only be revealed by texture analysis. One of the most recommended analysis methods to

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<tr>
<th>Acid duration</th>
<th>FD ± SD</th>
<th>PI ± SD</th>
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<tbody>
<tr>
<td>No acid</td>
<td>1.19 ± 0.089</td>
<td>134.9 ± 14.27</td>
</tr>
<tr>
<td>30 minutes</td>
<td>1.33 ± 0.125*</td>
<td>127.5 ± 18.63</td>
</tr>
<tr>
<td>60 minutes</td>
<td>1.90 ± 0.06*</td>
<td>104.7 ± 18.76*</td>
</tr>
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*Significant difference compared with no acid.
reveal the density changes in the trabecular bone associated with a periapical lesion in its early stages was the measurement of changes in the pixel/voxel values (densitometric measurements) (14). However, voxel values from CBCT are arbitrary gray values without Hounsfield unit (HU) calibration that do not allow an absolute bone quality evaluation similar to that performed with HU in medical CT (30). Thus, this imaging modality does not allow reliable and accurate bone quality assessment when focusing on the inherent radiographic density information that is otherwise expressed by HU (31). Most CBCT units deliver considerably higher doses than a periapical image (32), and financial costs are higher (33). In addition, interpreting either the 2D or 3D digital image continues to be more of a subjective exercise than an objective one (34). At this point, using a quantitative and objective method such as fractal analysis can be of help in detecting early changes of periapical trabecular pattern.

In dental radiology, FD calculation was used to evaluate and quantify trabecular bone structure for detection of bone changes associated with periapical periodontitis (8, 14), periodontal disease (35), bone surgery (11), and systemic diseases (7, 12). The comparable performance of the fractal analysis by using intraoral radiographs as compared with advanced imaging modalities in regard to the bone quality evaluation illustrates that there may be a potential for fractal analysis to become a method for standard clinical jaw bone quality assessment.

According to our results, radiographically invisible demineralizations of periapical bone can be better detected by FD analysis than by PI analysis. It should be remembered that this study used images of single-rooted mandibular premolars obtained under strict conditions. If further clinical studies support the results of this in vitro evaluation for all areas of the jaws, FD calculation could be recommended as a quantitative and objective method for the detection of clinically suspicious early periapical lesions whenever earlier obtained radiographs are available for comparison.

Acknowledgments

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References