ORIGINAL PAPER

Effect of Image Resolution and Compression on Fractal Analysis of the Periapical Bone

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ABSTRACT

Introduction: Fractal dimension (FD) on periapical radiographs is used as a simple descriptor of the complex architecture of the trabecular bone surrounding the dentition. It is used on periapical and panoramic radiographs as a descriptor of the complex architecture of trabecular bone surrounding teeth. **Aim:** The aim of this study was to evaluate the effect of image resolution and different compression levels on fractal dimension of alveolar bone with images obtained using storage phosphor plate (SPP) system. **Methods:** Periapical images of premolar and molar teeth on both sides of three dry human mandibles were obtained with Digora Optime (Soredex Corp., Helsinki, Finland) SPP system. The SPPs were exposed equally and scanned immediately after exposure with standard, high and very high resolutions. All the images then were compressed and saved by degrees of 0%, 25%, 50%, 75% and 90%. FD was calculated using public domain software (ImageJ with FracLac plug-in) on two non-overlapping regions of interest (ROIs) on premolar and molar periapical bone areas of each radiograph using differential box-counting method. The ROIs on corresponding images were of the same size and position. FDs were compared using two-way ANOVA and Tukey–Kramer multiple comparison tests (p=0.05). **Results:** There was no significant difference in FD calculations in different levels of compression for all the resolutions. Images obtained with high resolution scans showed significantly lower variation in FD values compared to very high and standard resolutions for all compressions (p<0.0001). **Conclusion:** The high resolution demonstrated the lowest variation in FD values in all levels of compression which makes it the most reliable and consistent resolution for measuring the FD values. The level of compression does not make a significant difference in FD values for all the scan resolutions. Scanning resolution of SPPs should be carefully chosen when evaluating the change in FD of alveolar bone for various bone disorders.

Keywords: Fractal, Radiography, Digital Image analysis, Data compression.

1. INTRODUCTION

Fractal analysis (FA) is a method for describing complex shapes and structural patterns and is expressed numerically as Fractal dimension (FD). Fractal dimension on periapical radiographs is used as a simple descriptor of the complex architecture of the trabecular bone surrounding the dentition (1, 2). Fractal dimension (FD) calculation has become a popular computer analysis method to distinguish image textures. It is used on periapical and panoramic radiographs as a descriptor of the complex architecture of trabecular bone surrounding teeth (1, 3). This computer analysis method is even more practical on digital dental systems since digitization of film is no longer needed. In dentistry, FD calculation has been performed on non-standardized radiographs for assessment of dental implant sites (4), evaluation of root canal therapy (5), and detection of many systemic pathological conditions such as osteoporosis (6) and sickle cell anemia (7).

According to the results of early studies, FD calculations were considered to be unaffected by variations in film exposure, alignment, and region of interest (ROI) (8). Later, two other studies reported that FD is affected by the size, shape, and location of ROI (9, 10). Chen and Chen demonstrated significant change in fractal dimension with projection geometry (11). Pornprasertsuk et al. and Bollen et al. showed that different types of image receptors significantly affect estimates of FD (1, 12). In contrast, a recent study proved that variations in radiographic settings including kVp, mAs, and cone angulation have a minimal impact on the fractal dimension (13). A recent study by Pauwels et al. on CBCT images revealed that most bone structure parameters are not affected by the kV if the radiation dose is constant; however parameters dealing with the trabecular structure are heavily affected by the voxel size (14).

Digital dental systems have wide range of technical specifications and many of them provide options to acquire images at different resolutions. For storage phosphor systems (SPP), the resolution is mainly determined by the speed of the scanning process. A slower scan increases spatial resolution and generates images with smaller radiographic details that can be observed (15). Baksi and Fidler evaluated the effect of image resolution and exposure time of digital radiographs on the FD of the periapical bone and found that FD shows significant changes with image resolution and exposure time. FDs of images obtained from higher resolution images were significantly higher compared to FDs obtained from lower resolution images (3). They also demonstrated that FD values of images obtained with 0.05 seconds of exposure were significantly higher than images obtained with 0.12 seconds exposure time (3). Moreover, storage and communication of digital images has always been a challenge. Hardware requirements for picture archival and communication systems can be efficiently reduced by utilization of image compression (16). Baksi and Fidler, also evaluated the effect of lossy image compressions on FD calculation. The results of this study indicate that the fractal dimension is not affected by lossy image, namely to JPEG and JPEG 2000 at approximate compression ratio of 1:30 (17).

2. AIM

Given the controversies in the previous studies regarding the effects of image parameters on the FD values, the aim of this study was to evaluate the effect of image resolution on FD of periapical bone on images obtained using a storage phosphor plate (SPP) system, and also to assess the effect of different compression values on FD calculation and to determine the highest acceptable degree of information loss, still preserving the diagnostic accuracy of FD calculation.

3. METHODS

Radiographic technique: Three dry human mandibles, containing the full arch teeth with no restorations or previous root canal therapy were selected. Six posterior mandible segments, two sides on each dry mandible, were used in the study. Each side was marked with two 1 mm pieces of Gutta-Percha in two different locations of the periapical area not overlapping the roots to determine identical region of interests (ROI). The mandibles were fixed in their position using Sil-Tech polyvinylsiloxane putty impression material (Ivoclar Vivadent Inc., Amherst, New York, USA) and the dental x-ray unit was fixed by using a holder in order to standardize projection geometry.

Specimens were radiographed with size 2 (31×41 mm) storage phosphor plates of ScanX (Air Techniques Inc. Melville, New York, USA). A Planmeca (Planmeca USA, Inc. Roselle, IL, USA) dental X-ray unit was operating at 60 kVp, 6 mA in a source-receptor distance of 25 cm. Image plates were exposed and scanned immediately after exposure using a ScanX (Air Techniques Inc. Melville, New York, USA) in three resolutions of "Standard", "High" and "Very High", respectively. In total, 18 images were obtained and saved in uncompressed TIF, BMP and JPEG formats with ScanX for Windows software (Air Techniques Inc. Melville, New York, USA). Each JPEG image then was compressed and saved at five levels of 0% (the original image), 25%, 50%, 75% and 90% using ImageJ software (http://rsbweb.nih.gov/ij).

Fractal dimension calculation: As mentioned above, on each image, two areas were marked using Gutta-Percha in periapical trabecular bone not overlapping roots or periodontal space. The ROIs were all of the same length and height of 125 mm x 75 mm respectively extending identically from the marked areas. FD of all ROIs was calculated with public domain ImageJ software and FracLac plug-in (http://rsbweb.nih.gov/ij/plugins/fraclac/FLHelp/Introduction.htm), which is implementing a differential box-counting method (18), developed for analysis of grayscale images.

The fractal value of x-ray images was determined at 5 levels of compression (0%, 25%, 50%, 75%, and 90%) and 3 levels of resolution (Standard, High Resolution, and Very High Resolution), to determine if either compression or resolution, or perhaps the interaction of compression and resolution, had an effect on the measurement of fractal value. Because it was expected that the fractal values would vary by mandible due to a difference in bone densities, and that fractal values may also vary by side of the mandible, x-ray images were collected for three different mandibles, with one image per side (left, right), for a total of six images per each combination of compression and resolution. Fractal values were calculated at two locations per image to obtain a measure of variation in fractal value within each image, resulting in a total of 6x3x5x2 = 180 fractal values. The measured locations were in exactly the same spot regardless of compression level or resolution. The random effects portion of the model accounted for variance not contributed

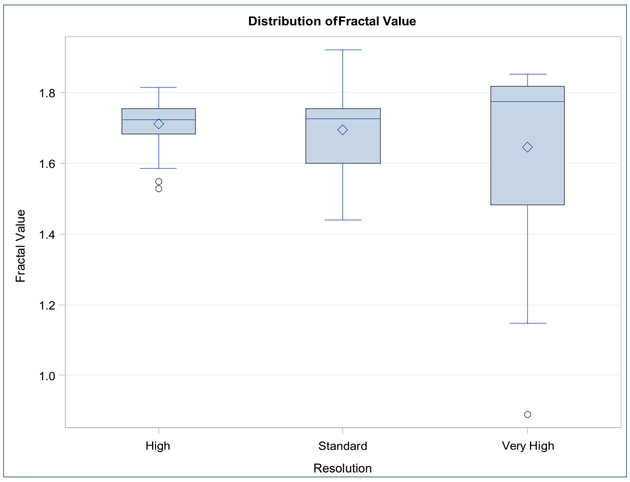

Figure 1. Box Plots of Fractal Value Data, by Resolution.

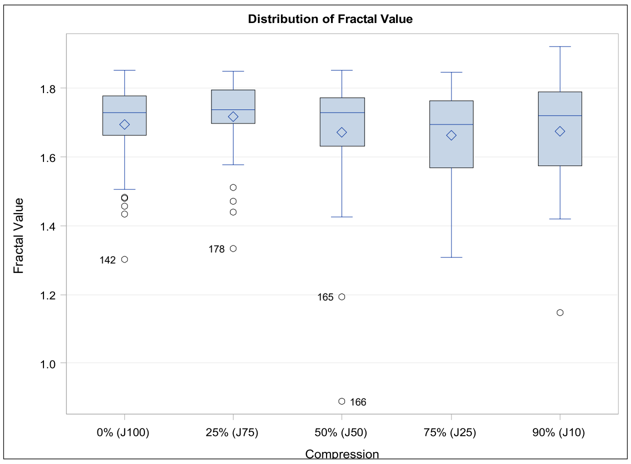

Figure 2. Box Plots of Fractal Value Data, by Level of Compression.

by either compression or resolution. In essence, the mandible, side, and location of mandible acted as blocking factors that did not interact with either the compression or resolution factors.

Statistical analysis: The data were analyzed using an Analysis of Variance (ANOVA) model with both fixed effects (compression and resolution) and random effects (mandible, side nested within mandible, location nested within side). The SAS statistical package (SAS Institute Inc., Cary NC), version 9.4, was used to generate results.

4. RESULTS

The image resolution of a SPP system is determined by its scanning speed. The slower the scan speed (longer the scan time), the higher the resolution. The ScanX device provides three resolutions, named "standard", "High Resolution" and "Very High Resolution", their pixel size is 50μ, 29μ and 21μ respectively.

The median FD was found for very high resolution (Table 1 and 2) (Figure 1 and 2). A mathematical simulation study conducted by Veenland et al. confirms this finding with showing that more details are portrayed as resolution of the image increases (19). Similar results were obtained from the Baksi and Fidler study (3) which indicated that FD values increased with increasing the resolution of the scan and also by Bollen et al. (1) in their study comparing the FD difference using periapical and panoramic images. While increasing spatial resolution enables observing smaller details, it results in higher level of noise in the resultant images (20). Baksi and Fidler stated in their study that the higher FD values of the higher resolution images are partially correlated to the higher amount of noise resulting from increased resolution (3). The present study confirmed the results of Baksi and Fidler, that the higher the resolution the higher the FD values, and the possible correlation to the higher amount of noise (Figure 1).

However, Levene's test for equality of variances ($p<0.0001$) indicates a statistical difference in variance among the three resolutions. It is clear that the high resolution images show less variation in the FD amounts compared to standard and very high resolutions, generating the most consistent and reliable FD calculation.

The exposure parameters used in this study are identical to what is used in dental clinic on a regular basis, the increase of exposure time/milliamperage might reduce the noise level on images scanned with very high resolution and show lower variation but this does not warrant an increase in patient exposure.

The diamond near the center of each box in Figures 2 and 3 is the mean fractal value, the horizontal line within each box is the median, and the lower and upper lines of each box are the 25th and 75th

Source	df	Sum of Squares	Mean Square	F-value	p-value
Model	25	0.9302	0.0372	1.89	0.011
Mandible	2	0.5337	0.2668	22.99	0.015
Side of Mandible (source of Mandible Error)	3	0.0348	0.0116	1.21	0.383
Location on Side (source of Side Error)	6	0.0574	0.0096	0.48	0.819
Compression	4	0.0664	0.0166	5.26	0.0015
Resolution	2	0.1404	0.0702	3.56	0.031
Compression*Resolution	8	0.0975	0.0122	0.62	0.762
Error	154	3.0394	0.0197		

Table 1. ANOVA table for Fractal Value (All Resolutions Considered) (R^2 = 0.234).

Source	df	Sum of Squares	Mean Square	F-value	p-value
Model	15	0.1354	0.0090	3.43	0.0007
Mandible	2	0.0014	0.0007	0.26	0.7747
Side of Mandible (source of Mandible Error)	3	0.0283	0.0094	3.58	0.0211
Location on Side (source of Side Error)	6	0.0505	0.0084	3.20	0.0108
Compression	4	0.0553	0.0138	0.84	0.0015
Error	44	0.1158	0.0026		

Table 2. ANOVA table for High Resolution (All Compressions Considered) (R2 = 0.539).

percentiles respectively (also known as the interquartile range, IQR). The whiskers represent the smallest and largest fractal values, up to a factor of 1.5 times the IQR, and circles outside the whiskers are considered outliers. The height of the box is slightly larger than one standard deviation.

5. DISCUSSION

Regarding the image compression, only one study has been done in the past to investigate the effect of lossy compression on the fractal values of the periapical images (17). The aforementioned study, which is done by the same group of authors Baksi and Fidler, indicates that fractal analysis is insensible to lossy image compression, namely to JPEG and JPEG 2000 at approximate compression ratio of 1:30. The present study found small difference in variation among the different levels of JPEG compression, for the three different resolutions, and therefore confirmed the same results. This result also confirms the robustness of fractal analysis, as previously reported to be insensitive to variations in film exposure, image geometry, and size and position of ROI (8,13). According to Baksi and Fidler study, there is a limit in the acceptable amount of information loss, as found to be the compression level 30 and compression level 50 for JPEG and JPEG2000, respectively (17). Tukey's HSD test indicated that compression levels J100, J75, and J50 produce a fractal value mean that is larger than the other two compression levels, and Levene's test ($p=0.0032$) indicates that the variance of those three levels is smaller; however, although there is a statistically measurable difference in means, from a practical point of view, the difference in mean fractal value between the lower and higher compression levels showed to be relatively small.

Due to multiple advantages, digital imaging is getting more popular among practitioners. Consequently, the need for archiving space and electronic transmission speed for referrals has increased. Large hard drives can be purchased for a reasonable price solving the issue of storage; however, transmission speeds, though constantly improving, are still limited. Compressed images, to remarkably small size files, do not appear to degrade the diagnostic ability of the images and influence the ability for fractal dimension calculation; this will simplify the task of image transmission for administrative purposes or teleradiology.

6. CONCLUSIONS

The overall conclusion of the analysis is that, for optimizing fractal value, the High Resolution setting is superior because of its low variation. Within the High Resolution setting, compression levels of 50% or less are superior to higher levels of compression, but if storage space is an important consideration, the higher levels of compression do not cause a substantial change in fractal value.

- **Author's contribution:** Each author gave substantial contribution to the conception or design of the work and in the acquisition, analysis and interpretation of data for the work. Each author had role in drafting the work and revising it critically for important intellectual content. Each author gave final approval of the version to be published and they agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.
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