



Influence of phosphor plate–based radiographic image specifications on fractal analysis of alveolar bone

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Objective. The aim of this study was to evaluate the influence of spatial resolution, bit depth, and enhancement filters on the fractal dimension (FD) of photostimulable phosphor (PSP) plate–based intraoral radiographic images of alveolar bone.

Study Design. Periapical radiographs were obtained using PSP plates, which were scanned at 2 spatial resolutions: 1270 dpi and 2000 dpi. All images were subjected to 3 enhancement filters—Perio, Endo, and Fine—and exported in 8 and 16 bits. A region-of-interest was selected on alveolar bone and the FD value was calculated. The multiway analysis of variance test followed by the post hoc Tukey test compared the FD values between the different groups ($\alpha = 0.05$).

Results. No significant difference was observed in FD values between the 8- and 16-bit images. Except for the Perio filter, FD values were significantly higher for images at 1270 dpi. FD values were significantly higher for the Perio filter, followed by the Endo filter, and the Fine filter. The FD values of the Fine filter did not differ significantly from the original image.

Conclusions. Fractal analysis of alveolar bone obtained from PSP plate–based intraoral radiographic images is influenced by spatial resolution and some digital enhancement filters; therefore, for FD comparison purposes, images should have the same specifications. (Oral Surg Oral Med Oral Pathol Oral Radiol 2019;128:418–423)

Fractal analysis (FA) is an objective and quantitative method to express the complexity of structures, numerically represented as the fractal dimension (FD); higher FD values indicate greater complexity, and vice versa.¹⁻³ Numerous studies in different fields of science, such as engineering,⁴ physics,⁵ and geophysics, have used FA.⁶ In dentistry, FA has been used in the evaluation of the radiographic aspects of trabecular bone architecture.⁷⁻⁹

FA of trabecular bone can reveal information that is not often visible to the naked eye and may contribute to greater diagnostic accuracy,^{3,8} for instance, structural patterns as an indicator of bone strength.¹⁰ However, the correlation between FD values with different clinical conditions, such as temporomandibular disorders and osteoarthritic alterations,³ hyperparathyroidism,¹¹ osteogenesis imperfecta,¹² osteoporosis,^{1,13,14} suture maturation, and implant insertion torque,^{2,15} remains controversial. It is not clear yet whether the differences observed in FD values among similar studies represent actual changes in bone structure or limitations of the analysis as a result of lack of standardization of image specifications and calculation methods.⁷

Because FD is obtained from a digital image, the final value may be influenced by many factors that have not yet been considered in previous scientific

studies. Among the most important are spatial resolution, bit depth, and image enhancement condition. *Spatial resolution*, also referred to as *sharpness* or *blurriness*, represents the capability of an image to distinguish between 2 objects; thus, different spatial resolutions could possibly alter the limits of the medullary space and bone trabeculae, affecting the apparent trabecular thickness and, consequently, the calculation of FD.¹⁶ *Bit depth* indicates the capability of a digital image to depict structures of very similar physical properties with the most accurate gray level; considering that image binarization is an essential step during FA, it is important to assess whether bit depth affects thresholding for that purpose. *Digital image enhancement* is a postprocessing collection of methods that operate on an image with the aim of enhancing particular features, such as edges and contrast, to increase diagnostic accuracy.

Considering the potential contribution of FA in the diagnostic process, the aim of this study was to evaluate the influence of spatial resolution, bit depth, and enhancement filters of photostimulable phosphor (PSP) plate–based intraoral radiographic images on the FD of alveolar bone.

Statement of Clinical Relevance

Fractal dimension analysis can add information on bone structure when evaluating diseases but presents limitations not studied before. This study shows that standardization of digital radiographic image specifications is important in the fractal dimension analysis of alveolar bone.

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Received for publication Feb 25, 2019; returned for revision May 20, 2019; accepted for publication Jun 23, 2019.

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2212-4403/\$-see front matter

<https://doi.org/10.1016/j.oooo.2019.06.011>

MATERIALS AND METHODS

Radiographic acquisition

After approval of the project by the local institutional research ethics committee (protocol #88145018100005418), 10 dry human mandibles were selected. Five repeated periapical radiographs were obtained using the paralleling technique from 20 posterior anatomic regions (2 from each mandible) with the aid of an acrylic device that allowed for standardized positioning. A 24-mm-thick acrylic plate was placed between the radiation source and the mandible to simulate soft tissue attenuation (Figure 1).

All radiographic images were obtained using the same size 2 photostimulable phosphor (PSP) plate from the VistaScan digital radiographic system (Dürr Dental, Beitigheim-Bissingen, Germany) and the FOCUS dental X-ray unit (Instrumentarium, Tuusula, Finland), adjusted to operate at 70 kVp, 7 mA, an exposure time of 0.16 second, and a focus-receptor distance of 30 cm.

Each radiographic image was obtained in duplicate so that the PSP plates could be scanned at 2 spatial resolutions—1270 dpi (25 lp/mm) and 2000 dpi (40 lp/mm)—using the DBSWIN software (Dürr Dental, Beitigheim-Bissingen, Germany). Each resulting image was subjected to 3 digital image enhancement filters—Perio, Endo, and Fine—and exported in TIFF (tagged image file format) at 2 bit depths: 8 and 16. No other software-related image manipulation, such as adjustment of brightness, contrast, or gamma, was performed. This methodologic design resulted in 16 evaluation conditions (Figure 2)—2 spatial resolutions \times 2 bit depths \times 4 enhancement conditions (original + 3 filters)—with a total of 1600 radiographic images (16 evaluation conditions \times 20 anatomic regions \times 5 repetitions).



Fig. 1. Photograph of the acrylic apparatus used to ensure reproducible radiographic exposure geometry with the image receptor, mandible, and X-ray source positioned according to the paralleling technique.

Fractal analysis

A square region of interest (ROI) of 240×240 pixels was selected in the 1270 dpi images and of 377×377 pixels in the 2000 dpi images on alveolar trabecular bone, avoiding anatomic structures such as the periodontal ligament space, dental roots, and mandibular canal. Figure 3 shows the histograms of the ROI in the different groups. The ROIs of the same anatomic region were positioned in the same place in all images by using the Macro function of the ImageJ software (Figure 4). Each ROI, after being binarized and outlined (Figure 5), had the FD value calculated with use of the differential box-counting method implemented by Sarkar and Chaudhuri,¹⁷ using the ImageJ/Fiji software (version 2.0.0), a public domain software developed by the National Institutes of Health, coupled with the FracLac plug-in (<https://imagej.nih.gov/ij/plugins/fraclac/fraclac.html>). The maximum box size was adjusted at 45% of the ROI size, the minimum box size was 2 pixels, and the box series was linear.¹⁸ Binarization is a process that converts an image to black and white based on a specific threshold. In the present study, the threshold (T) was automatically calculated as follows: $T = (\text{average background} + \text{average objects}) \div 2$, having the medullary space as the background and the bone trabeculae as the objects. Additionally, the outline process contours the pixels of the structures of a binary image (<https://imagej.nih.gov/ij/docs/menus/process.html>).

Statistical analysis

Using SPSS software version 24.0 (SPSS Inc., Chicago, IL), a multiway analysis of variance, followed by the post hoc Tukey test, was performed to assess the effects of the different conditions of spatial resolution, bit depth, and digital image enhancement and their interactions on FD values. The level of significance was established at 5% ($\alpha = 0.05$).

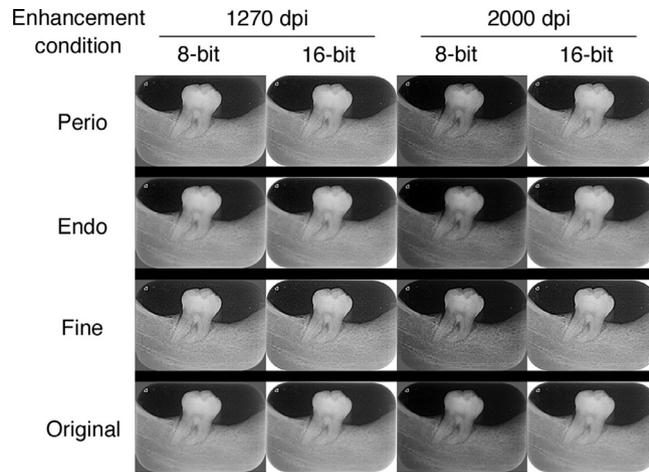


Fig. 2. Representative radiographic images under different conditions of spatial resolution, bit depth, and image enhancement.

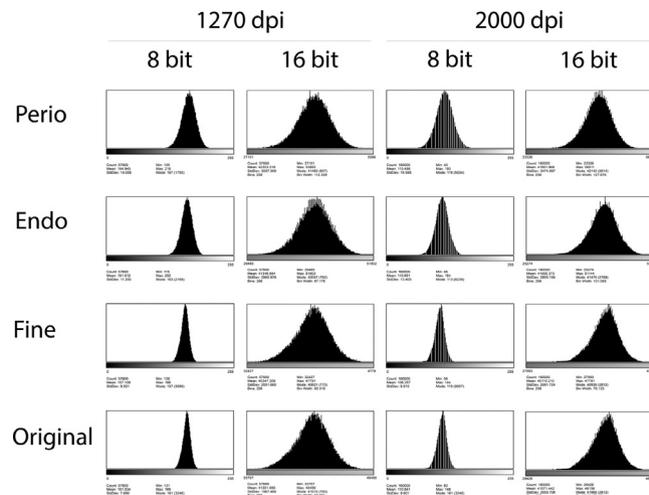


Fig. 3. Histograms of the regions of interest (ROIs) of the radiographic images under different conditions of spatial resolution, bit depth, and image enhancement.

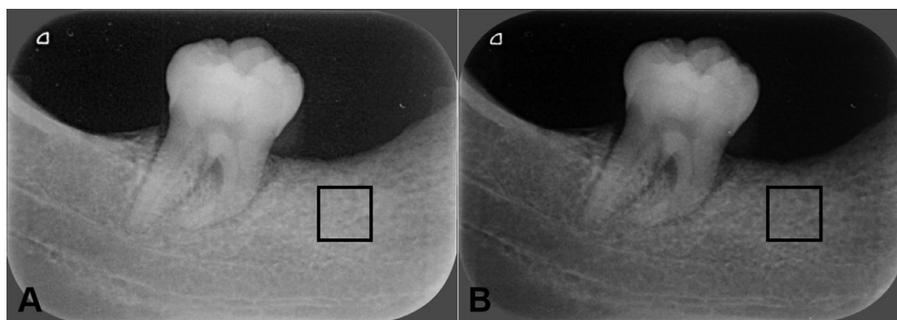


Fig. 4. Radiographic images at different spatial resolutions with the region of interest (black-outlined square) positioned on the same anatomic region. A, 1270 dpi. B, 2000 dpi.

RESULTS

Table I shows FD mean values of images under different conditions of spatial resolution, bit depth, and digital image enhancement. With regard to spatial resolution, FD values

were significantly higher for images at 1270 dpi compared with those at 2000 dpi ($P \leq .05$), except for the Perio filter. No statistically significant differences were observed in FD values between the 8- and 16-bit images ($P > .05$).

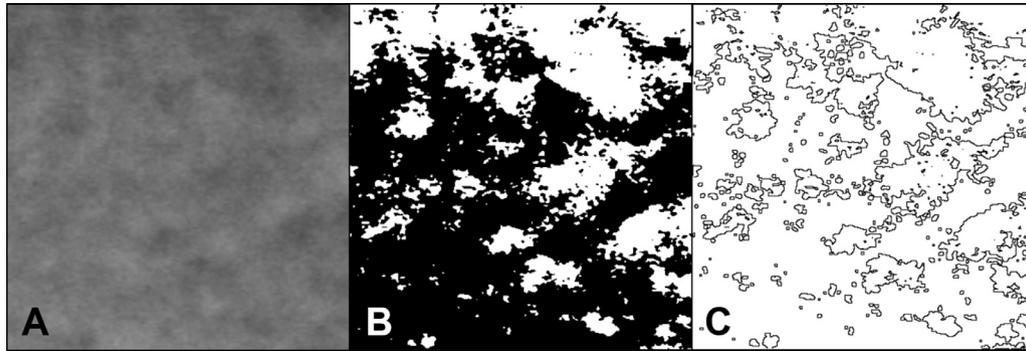


Fig. 5. Resulting cropped region of interest after digital processing for fractal analysis. **A**, Original. **B**, Binarized. **C**, Outlined.

Table I. Mean values (standard deviation) of fractal dimension (FD) values according to spatial resolution, bit depth, and image enhancement condition

Bit depth	Enhancement condition	Spatial resolution	
		1270 dpi	2000 dpi
8-bit	Perio	1.75 (0.02)*	1.75 (0.03)
	Endo	1.71 (0.02) ^{†‡}	1.68 (0.04)
	Fine	1.65 (0.05) [†]	1.57 (0.06)
	Original image	1.64 (0.06) [†]	1.56 (0.07)
16-bit	Perio	1.75 (0.02)*	1.76 (0.03)
	Endo	1.72 (0.02) ^{†‡}	1.68 (0.04)
	Fine	1.65 (0.05) [†]	1.57 (0.06)
	Original image	1.64 (0.06) [†]	1.57 (0.08)

*Significantly greater than other enhancement conditions.
[†]Significantly greater than 2000 dpi for the same enhancement condition and bit depth.
[‡]Significantly lower than the Perio filter and greater than the Fine filter and original image. Bit depth did not produce significant differences ($P > .05$).

With regard to the digital enhancement conditions, FD values were significantly higher for the Perio filter, followed by the Endo filter, and the Fine filter ($P \leq .05$). The FD values of the Fine filter did not differ significantly from the original image ($P > .05$).

DISCUSSION

FD is an objective measurement to describe the architectural complexity of bone tissue, including shapes and structural patterns. Previous studies have produced controversial results of this analysis for different diagnostic tasks; however, most of them did not follow a strictly standardized method. Geraets and van der Stelt¹³ stated that all stages in the “analytic chain” of FA have an impact in the assessment of bone, but they were mainly referring to the wide range of methods and their variations. Analog radiographic systems have been extensively replaced by digital systems by various manufacturers and present different features and varying specifications in the production of images. This

adds even more stages to the FA chain and poses extra challenges for image standardization before FA.

Higher spatial resolution produces images of greater sharpness at an increased file size. In the present study, except for the Perio filter, lower spatial resolution (1270 vs 2000 dpi) resulted in significantly higher FD values. The authors believe that this can be explained by the fact that larger pixels (lower spatial resolution) at bordering areas, such as the interface of the trabecular bone with the medullary space, assume an intermediate gray level that may lead to increased trabecular thickness after binarization. This hypothesis is supported by the fact that reduced trabecular thickness has been associated with increased FD values.¹⁶ Future studies should more closely investigate the effect of different binarization methods on FD values. The influence of spatial resolution on FA was also observed by Baksi and Fidler¹⁸; however, in contrast to the present study, higher spatial resolution led to increased FD values. This difference can possibly be explained by the fact that in Baksi and Fidler’s study,¹⁸ much lower spatial resolutions (397 and 651 dpi) were used compared with those in the present study (1270 and 2000 dpi), which may have resulted in loss of information regarding trabecular bone. Considering the lack of a gold standard for FA, further studies making use of a wide range of spatial resolutions are recommended to detect any potential correlation with FD values.

In the present study, the bit depths tested did not significantly affect the FD values, which suggests that 8-bit images are adequate to analyze the complexity of alveolar trabecular bone; the gray scale of a radiographic image does not rely only on bit depth but also on the physical properties of the radiographed tissue.¹⁹⁻²¹ To the best of our knowledge, no other study has assessed the effects of bit depth in FA. Studies comparing different bit depths of digital radiographic systems for diverse diagnostic tasks concluded that higher values led to better differentiation of structures¹⁹⁻²¹; however, these studies made use of subjective analyses, such as sensitivity and

specificity, and evaluated different structures, such as teeth and dental materials.

Radiographic systems currently on the market offer an extensive number of digital enhancement filters.²²⁻²⁴ This is beneficial because it increases the possibility of image enhancement but is fairly limiting because filters are software specific—that is, they are not standardized. The methodology of the current study included filters from DBSWin software (Perio, Endo, and Fine), that we subjectively considered appropriate for the assessment of alveolar trabecular bone. Irrespective of spatial resolution and bit depth, the Perio filter had the highest FD values, followed by the Endo filter, and the Fine filter, which did not differ from the original nonfiltered image. This reveals that some enhancement filters adjust the radiographic gray scale in a way that affects FD values. Interestingly, all image enhancement filters used in this study are categorized as high-pass filters, which increases the sharpness of the radiographic image.^{23,24} In a recent study, it was observed that the Perio filter increases the participation of high frequencies while decreasing the participation of low frequencies by 90%, the Endo filter by 80%, and the Fine filter by 50%.²³ Thus, it is possible to observe that FD values increase linearly when sharpness is increased and smoothing is decreased.

In a previous study, the Perio and Endo filters increased image noise of bone, but the same did not occur with the Fine filter.²⁴ Because FD is sensitive to image noise,²⁵ we believe that the noise from the images with the Perio and Endo filters might have added different information to the image texture to significantly increase the FD values. Furthermore, increased sharpness from filters has been shown to increase image noise and affect spatial resolution, either by improving or degrading the ability to detect detail in the radiographic image.²⁶ Considering that the Perio filter led to the highest sharpness, this exacerbated sharpness must have greatly increased the noise to the point of reducing the ability to detect details in the image with higher spatial resolution. This may explain the fact that the Perio was the only filter that did not differ significantly between the 2 spatial resolutions used: 1270 and 2000 dpi ($P > .05$). Although we found some differences between the enhancement filters, no conclusion could be drawn regarding their effects on diagnostic accuracy.

The present methodology made use of a digital tool (Macro function) from the ImageJ software to ensure that the ROIs were exactly at the same location/position on repeat radiographic images of the same anatomic region. However, it should be mentioned that even when making use of an apparatus to keep the same geometric alignment, we detected an unavoidable minimal shift of the images because the PSP plate became slightly loose in the cassette during scanning.

Despite this limiting condition, the standard deviation (SD) of the FD values of the repeat radiographic images ranged from 0.02 to 0.08 (coefficient of variation between 1% and 5%), indicating no substantial influence on our results. Furthermore, such limitation represents the clinical scenario. All 20 ROIs were intentionally selected in the posterior region, away from sclerotic areas and lesions, which may have resulted in a similar bone pattern and contributed to the observed low overall SD values.

Our findings contribute to the scientific literature by demonstrating the importance of maintaining the same image specifications for FA. Any further study on this topic should consider this in depth. As new technologies are developed and deployed, new studies are needed to verify if the outcomes from obsolete systems are still valid and if different radiographic systems with different postprocessing algorithms provide the same results.

CONCLUSIONS

FA is influenced by spatial resolution and by some digital enhancement filters of PSP plate-based intraoral radiographic images of alveolar bone. Therefore, the same image specifications and processing conditions should be used for FD comparison purposes.

PRESENTATION

The present results were submitted for oral presentation of area 7 at the 36th annual meeting of the Brazilian division of the International Association for Dental Research (SBPqO-IADR) in September 2019.

FUNDING

Financial support was provided by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, Brasil (CAPES) (Finance code 001).

ACKNOWLEDGMENT

We wish to gratefully acknowledge the help from Dr. Victor Emanuel Armini Caldas for reviewing the manuscript.

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