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Fractal Analysis of Periapical Bone from Lossy Compressed Radiographs: A Comparison of Two Lossy Compression Methods

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Abstract The aim of the study was to evaluate the effect of two lossy image compression methods on fractal dimension (FD) calculation. Ten periapical images of the posterior teeth with no restorations or previous root canal therapy were obtained using storage phosphor plates and were saved in TIF format. Then, all images were compressed with lossy JPEG and JPEG2000 compression methods at five compression levels, i.e., 90, 70, 50, 30, and 10. Compressed file sizes from all images and compression ratios were calculated. On each image, two regions of interest (ROIs) containing healthy trabecular bone in the posterior periapical area were selected. The FD of each ROI on the original and compressed images was calculated using differential box counting method. Both image compression and analysis were performed by a public domain software. Altogether, the FD of 220 ROIs was calculated. FDs were compared using ANOVA and Dunnett tests. The FD decreased gradually with compression level. A statistically significant decrease of the FD values was found for JPEG 10, JPEG2000 10, and JPEG2000 30 compression levels ($p<0.05$). At comparable file sizes, the JPEG induced a smaller FD difference. In conclusion, lossy compressed images with appropriate compression level may be used for FD calculation.

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Introduction

A fractal analysis is a method for quantitative evaluation of complex geometric structures that exhibit patterns throughout the image. The complexity of the structure is represented by a single number, the fractal dimension (FD), which is calculated with a computer algorithm.[1] In medical radiology, the FD calculation is used to enhance the diagnosis of osteoporosis[2] or breast cancer.[3] In dental radiology, the FD calculation was used to evaluate and quantify a trabecular bone structure for the detection of bone changes associated with periapical periodontitis,[4,5] periodontal disease,[6] bone surgery,[7] and systemic diseases.[8,9] Several methods for FD calculation were proposed, with box counting method[10] being the most often used in dental radiology.[4]

Due to the benefits of digital radiography,[11] its use in dentistry is increasing, further facilitating the application of fractal analysis as images are readily available in digital format. However, storage and communication of digital images still remain a challenge.[12] Hardware requirements for picture archival and communication systems can be efficiently reduced by utilization of lossy image compression.[13] Two standardized lossy compression methods, namely JPEG[14] and JPEG2000[15] are widely accepted in dental radiography.[16] They offer considerably higher compression ratios compared to lossless compression, but on the cost of image information loss, adjusted by compression level. It is of utmost importance, that diagnostic accuracy of image is preserved. Therefore, to maximize file size reduction, the highest amount of image information loss that is still preserving diagnostic accuracy should be determined and applied. Unfortunately, the amount of acceptable image information loss cannot be universally recommended as it is rather task specific.[13] In dental radiology, the compression ratio (CR) between 1:6.5 [17] and 1:28[18] was reported acceptable for visual interpretation.

Due to the concerns regarding diagnostic accuracy, the use of lossy compression is generally discouraged for computer-aided image evaluation methods, as they are more sensitive and consequently supposed to be more susceptible to compression-induced information loss. In contrast to this general belief, the accuracy of one computer-aided method, namely digital subtraction radiography (DSR) was not affected by lossy compression with CR of 1:7.[19] This was explained by the fact that a slight lossy image compression performs as a noise reduction filter. Fractal analysis, in comparison to DSR, was reported to be a more robust computer-aided image analysis method, insensible to variations in film exposure, limited image geometry variations and sizes and positions of region of interest (ROI).[1,20] However, the effect of lossy image compression on FD calculation has not been evaluated yet.

Therefore, the aim of the study was to evaluate the effect of two standard lossy image compression methods on FD calculation and to determine the highest acceptable degree of information loss, still preserving the diagnostic accuracy of FD calculation.

Materials and Methods

Radiographic Technique

Dry human mandibles, containing premolars and molars at least on one side, with no restorations or previous root canal therapy were selected. Specimens were radiographed with storage phosphor plates (SPP) of Digora® Optime (Soredex Corporation, Helsinki, Finland) system to ensure the absence of periapical pathology. Ten mandibles meeting the criteria were used in the study. An optical bench was used to standardize the projection geometry. Size 2 (31× 41 mm) blue SPPs were exposed at a focus receptor distance of 25 cm with a Gendex Oralix DC (Gendex Dental Systems, Milan, Italy) dental X-ray unit operating at 60 kVp, 7 mA, and 1.5 mm Al equivalent filtration. The image plates were exposed for 0.12 s and scanned immediately after exposure in the Digora® Optime scanner with a matrix size of 620×476 pixels and resolution of 400 dpi. The acquired images were saved uncompressed in TIF format with Digora for Windows software (Soredex Corporation, Helsinki, Finland).

Image Compression

Images were compressed with a public domain IrfanView software[21] with two lossy compression methods. The first, JPEG (JP) compression method is based on discrete cosine transformation of image tiles and discarding frequency information,[14] while the second, the JPEG2000 (J2) compression method is utilizing the discrete wavelet transformation and converts an image into series of wavelets.[19] Images were compressed for both compression methods at five different compression levels (CL) of 90, 70, 50, 30, and 10. A CL, sometimes referred to as quality factor, is a value from a scale from 100 to 1, where a higher number means a lower amount of image information loss. The average file sizes and compression ratio of compressed images were calculated for each CL and compression method.

Fractal Dimension Calculation

On each original image, two nonoverlapping rectangular ROIs were selected in periapical trabecular bone not including roots or periodontal space. The positions and sizes of ROIs were determined according to the size and shape of the periapical region[22] resulting in sizes ranging between 3.77 and 118.15 mm^2. Position and size of each ROI in original and corresponding compressed images was identical. In total, FD was calculated on 220 ROIs (20 ROIs×11 image types—original +2×5 compressed) with public domain Image J software[23] and FracLac plug-in,[24] implementing a differential box counting method.[10] The maximum box size was 45% of each ROI and ranged from 5 to 57 pixels, depending on the ROI size; the minimum box size was always two and the box series was linear. These parameters were independent from compression level and method. The FD of each ROI was determined as the mean of four calculations inside the ROI. For every combination of compression method and CL the mean FD was calculated. For comparison of the two compression methods, a plot depicting the relationship between the compressed file size and induced FD difference was created, as compression scales of different compression methods does not represent the same amount of information loss.[16]

Statistical Analysis

The fractal dimensions of ROIs from the original and compressed images were compared using ANOVA ($p<0.05$). Post hoc pairwise comparisons between FDs from the original and compressed images were made with the Dunnett test ($p<0.05$).

Results

Image Compression

With decreasing CL from 90 to 10, the amount of image information loss increases. This results in image alteration, which is ranges from noise reduction and blurring to introduction of artifacts and finally image degradation (Fig. 1). Concurrently, a file size is reduced (Fig. 2) with smaller file sizes for J2 at all compression levels ($p<0.01$).

Fractal Dimension at Different Compression Levels

In general, FD decreased with decreasing CL from 90 to 10 for both compression methods. A decrease in FD was more pronounced for the J2 compression method (Fig. 3) at all compression levels. There was no statistically significant difference in the FDs of the original images and images compressed with CL 90 to CL 30 for JP ($p>0.05$), while for J2, there was no statistically significant difference in the FDs for CL 90 to CL 50 ($p>0.05$) (Fig. 3). This results in a CR of 1:31 and 1:35 for JP and J2, respectively. At CL 10, the mean FD for JP and J2 was nearly the same, i.e., 2.40 and 2.39, respectively. At comparable file sizes down to 10 kB, JP induced a slightly less FD difference than J2 compression method (Fig. 4). Below this file size, an opposite relationship was found. The same FD difference of −0.036 was achieved at 9.7 kB with JP 30 and 13.8 kB with J2 70 compression method (Fig. 4). For both compression methods, the standard deviation increased with the reduction of CL (Fig. 4).

Discussion

The results of this study indicate that fractal analysis seems to be insensible to lossy image compression, namely to JPEG and JPEG 2000 at approximate compression ratio of 1:30. This result confirms the robustness of fractal analysis, as previously reported to be insensible to variations in film exposure, image geometry, and size and position of ROI. [1,20] Certainly, there is a limit in the acceptable amount of information loss, as found to be the CL 30 and CL 50 for JPEG and JPEG2000, respectively. With the use of lossy compression, high-frequency image content is lost first and as the compression level decreases, lower frequencies in image content are progressively reduced. Visually, this was represented as noise reduction at the beginning, then the image becomes progressively blurred, and finally compression artifacts become apparent, as it is clearly depicted in Fig. 3. Concurrently, the image complexity is progressively reduced resulting in the reduction of FD. Together with the loss of information, the file size reduces, which is the primary aim of lossy compression. At the abovementioned limits of information loss for FD calculation, a considerable file size reduction was achieved, i.e., a CR of 1:31 and 1:35 for JP and J2, respectively.

A comparison of our results with other studies is not possible as this is the first study evaluating the effect of lossy image compression on FD calculation. In general, due to the absence of normative data, fractal dimension at various conditions/pathologies and for various image types could only be evaluated as relative measurements. The limit of detection with fractal analysis method was reported only by Southard et al. It was stated that at optimal beam angulation a 5.7% decalcification of maxillary alveolar bone was the limit of detection with fractal analysis.[25] According to the results obtained, a significant difference in FD values as compared to the originals was found at CL 30 and CL 10 for JPEG2000 and only at CL 10 for JPEG. The FD of the compressed images for JPEG and JPEG2000 at CL 10 demonstrated respectively 0.10 and 0.11 lower values than the FD of their originals and therefore approximately 4.4% difference. On the other hand, the FD of images compressed with JPEG2000 at CL 30 was 0.07 lower than the original FD resulting in a 3% difference as calculated by the differential box counting method.

Originally, a box counting method for FD calculation was developed for the analysis of binary images. As radiographs are grayscale images, they should be converted to binary images before fractal analysis was performed. The process precisely described by White et al.[26] has several steps and is time consuming. To facilitate the fractal analysis in various application fields employing grayscale images, a modification of box counting method, namely differential box counting method was proposed.[27] It was proven that the differential box counting method not only has a more precise estimated value of fractal dimension, but also consumes less computational time than the so-called traditional box counting method.[28] In biomedicine, it has been used in ultrasonography for the characterization of salivary gland tumors.[29] In dental radiology, this is the first time this method has been used.

The efficient reduction of file size with lossy image compression requires applying the highest degree of information loss yet still preserving the diagnostic value of the image, resulting in the smallest possible file size. The determination of a more efficient compression method could be simply done with the comparison of compressed file sizes obtained at the same compression level. In our study, file sizes were smaller for JPEG2000 as compared to JPEG compression method at the same compression level, indicating that JPEG2000 is a more efficient compression method. It should be emphasized that this would be an erroneous approach as compression scales are different and even same compression methods do not have a standard-

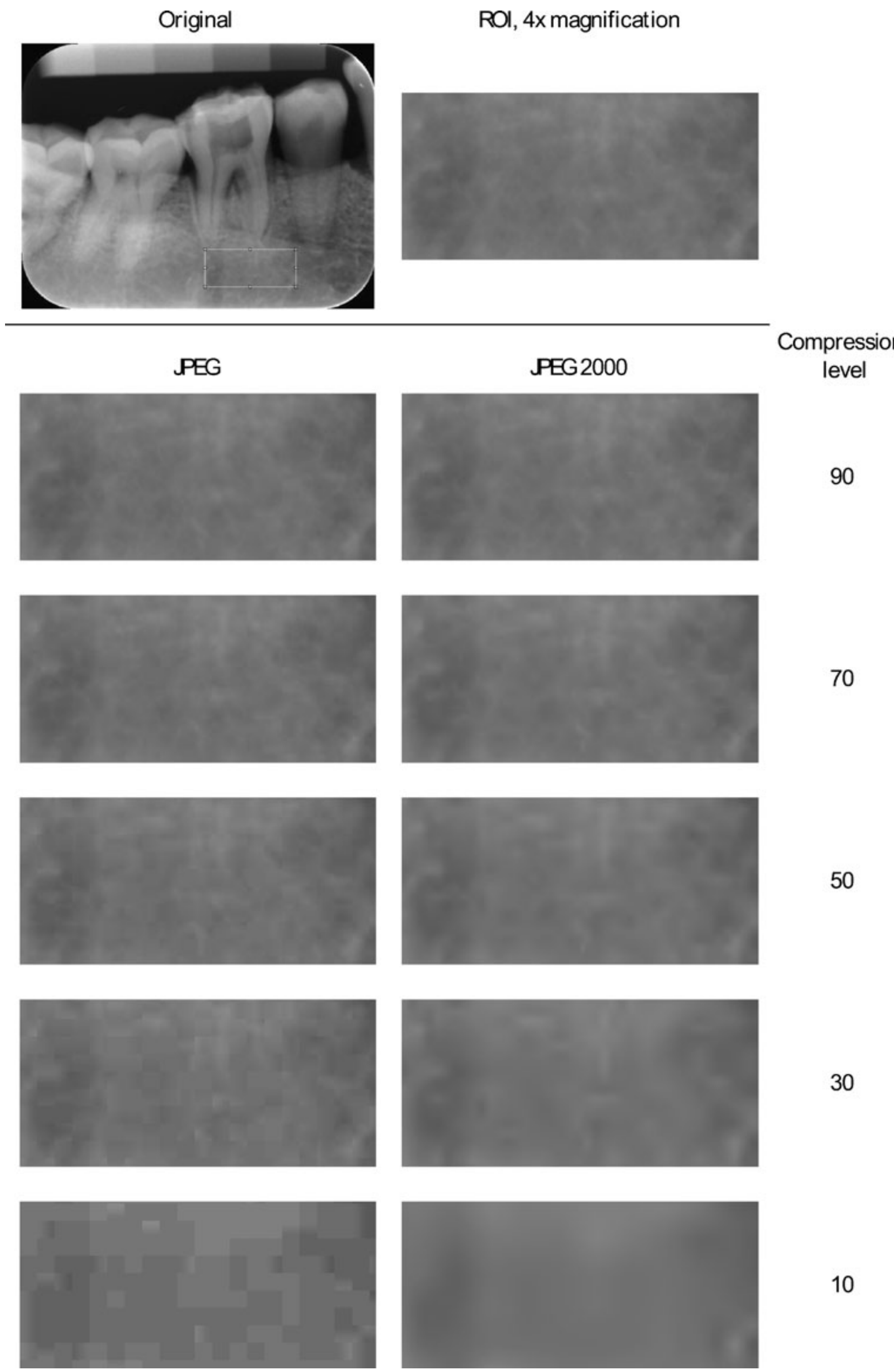

Fig. 1 Example of original image with marked ROI and 4× magnified ROIs of original image and compressed images, which were compressed with JPEG and JPEG2000 compression method at compression level 90, 70, 50, 30, and 10

ized compression scale.[16] In this study, at compression levels above 30, the JPEG2000 compression method obviously induced more image information loss at the same compression level, resulting in smaller file size and bigger FD difference. A truly more efficient compression method would need to exhibit either the same FD difference at a smaller file size or a smaller FD difference at the same file size. For the correct comparison of the efficiency of compression methods, a plot was generated to reveal the relationship between a compressed file size and induced FD difference. This comparison demonstrated that JPEG performed slightly better than JPEG2000, i.e., induced less FD difference at the same file size, although JPEG2000 is a newer method. However, this difference would be negligi-

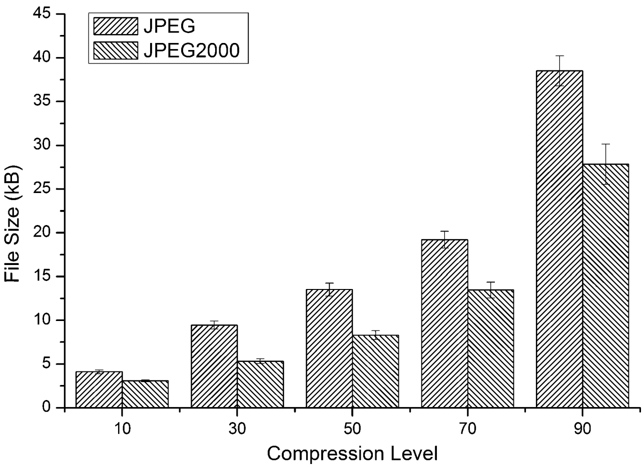

Fig. 2 Mean file sizes at different compression levels for both compression methods

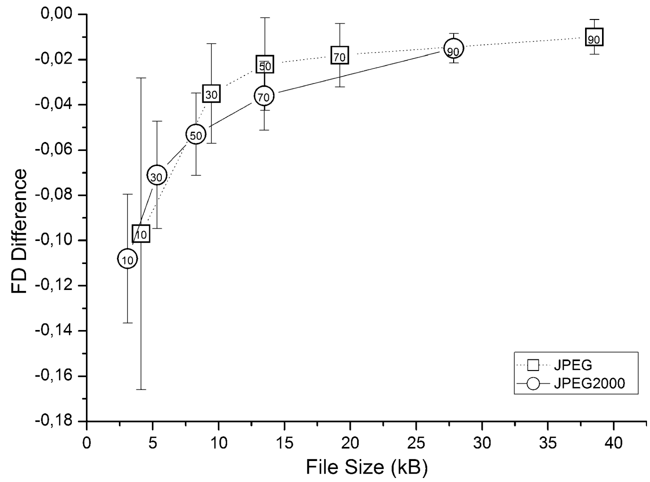

Fig. 4 Fractal dimension difference and file sizes at different compression levels

ble in the clinical setting. Similar results were reported in a study evaluating the effect of both lossy compression methods in DSR.[19]

The most common application of irreversible compression in radiology is teleradiology, while another application is to reduce the storage and bandwidth requirements required to deliver images to clinicians.[30] Teleradiology has a particular benefit from irreversible compression due to the low bandwidth connections most homes have. Although technologies like cable modems and digital subscriber lines have increased bandwidth substantially, the need for compression seems to remain particularly due to the massive amounts of data generated by cone beam computed tomography scanners. Lossy compression methods were not recommended and may not be needed for primary image storage because of the present day availability of very large sized mass storages. However, it

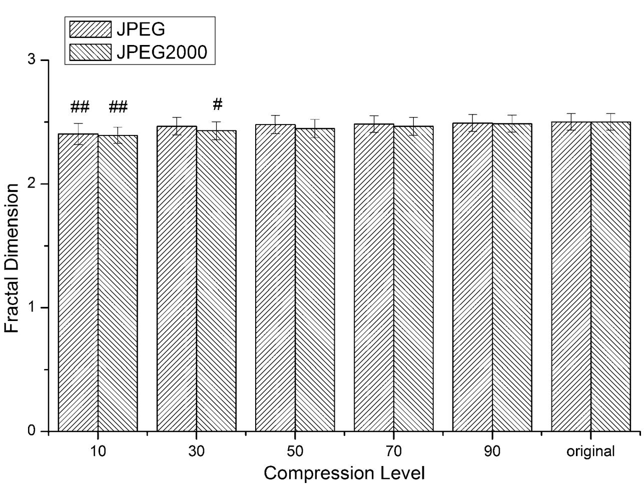

Fig. 3 Mean fractal dimension at different compression levels compared to FD on original images. #, $p<0.05$; ##, $p<0.01$

becomes an obligation because of the critical issue of dental/medical imaging applications to transmit and display the archived images promptly when requested.

The greatest concern in using lossy compression for dental/medical images is that subtle findings would be lost in the compressed image, which may not be always true. Subtle findings may be difficult for the human eye to discern due to the low contrast of the image, but if the image has a significant spatial extent, they are characterized by low frequencies in the spectral domain, which are well preserved by many compression methods.[31] Information belonging to subtle pathologies such as a thin fracture line or faint periapical radiolucency that may not be perceivable by the naked eye in the compressed image may be uncovered by image analysis techniques. In other words, the hidden diagnostic information in the compressed image may be revealed. At this point, the importance of testing the vulnerability of various image analysis techniques to different compression methods becomes evident. It is necessary for radiologists to be equally familiar with image compression techniques and effects of various image analyses techniques on compressed images. Such an evaluation using dental images was previously done to test the effect of JPEG and JPEG2000 compression methods on subtraction radiography.[19,32]

The lack of medicolegal standards is a significant difficulty for the widespread use of irreversible compression for diagnosis. Yet, it was stated that compression was not essentially different from any other step in the imaging chain (creation and presentation).[13] There is increasing evidence that some forms of irreversible compression can be used with no measurable degradation in diagnostic value.[13] This issue is of particular importance for clinical setting.

Conclusions

This study confirms that FD calculation is a robust method, which can be readily performed on lossy compressed images. The JPEG compression method performed only slightly better than JPEG2000 since it showed less FD difference at the same compressed file size down to JPEG 30 CL. However, the difference between the two methods was small and it may be negligible in a clinical setting. Nevertheless, the question of the acceptable loss of information for detecting changes in bone structure using fractal analysis requires further studies, including studies on artificially generated test fractals, in which the fractal dimension may be computed analytically.

References

1. Jolley L, Majumdar S, Kapila S: Technical factors in fractal analysis of periapical radiographs. Dento-Maxillo-Facial Radiol 35:393–397, 2006
2. Lee RL, Dacre JE, James MF: Image processing assessment of femoral osteopenia. J Digit Imaging 10:218–221, 1997
3. Sankar D, Thomas T: A new fast fractal modeling approach for the detection of microcalcifications in mammograms. J Digit Imaging 23:538–546, 2010
4. Chen SK, Oviir T, Lin CH, Leu LJ, Cho BH, Hollender L: Digital imaging analysis with mathematical morphology and fractal dimension for evaluation of periapical lesions following endodontic treatment. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 100:467–472, 2005
5. Yu YY, et al: Fractal dimension analysis of periapical reactive bone in response to root canal treatment. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 107:283–288, 2009
6. Updike SX, Nowzari H: Fractal analysis of dental radiographs to detect periodontitis-induced trabecular changes. J Periodontal Res 43:658–664, 2008
7. Heo MS, et al: Fractal analysis of mandibular bony healing after orthognathic surgery. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 94:763–767, 2002
8. Bollen AM, Taguchi A, Hujoel PP, Hollender LG: Fractal dimension on dental radiographs. Dento-Maxillo-Facial Radiol 30:270–275, 2001
9. Ergun S, Saracoglu A, Guneri P, Ozpinar B: Application of fractal analysis in hyperparathyroidism. Dento-Maxillo-Facial Radiol 38:281–288, 2009
10. Majumdar S, Weinstein RS, Prasad RR: Application of fractal geometry techniques to the study of trabecular bone. Med Phys 20:1611–1619, 1993
11. Miles DA, Razzano MR: The future of digital imaging in dentistry. Dent Clin North Am 44:427–438, 2000
12. Wenzel A, Moystad A: Work flow with digital intraoral radiography: a systematic review. Acta Odontol Scand 68:106–114, 2010
13. Erickson BJ: Irreversible compression of medical images. J Digit Imaging 15:5–14, 2002
14. Wallace GK: The JPEG still picture compression picture standard. Commun Assoc Computing Machinery 34:30–44, 1991
15. ISO/IEC JTC 1/SC 29/WG 1 IIF: Information technology—JPEG 2000 image coding system: Core coding system [WG 1 N 1890], September 2000
16. Fidler A, Likar B, Skaleric U: Lossy JPEG compression: easy to compress, hard to compare. Dento-Maxillo-Facial Radiol 35:67–73, 2006
17. Siragusa M, McDonnell DJ: Indirect digital images: limit of image compression for diagnosis in endodontics. Int Endod J 35:991–995, 2002
18. Koenig L, Parks E, Analoui M, Eckert G: The impact of image compression on diagnostic quality of digital images for detection of chemically-induced periapical lesions. Dento-Maxillo-Facial Radiol 33:37–43, 2004
19. Fidler A, Likar B, Pernus F, Skaleric U: Comparative evaluation of JPEG and JPEG2000 compression in quantitative digital subtraction radiography. Dento-Maxillo-Facial Radiol 31:379–384, 2002
20. Shrout MK, Potter BJ, Hildebolt CF: The effect of image variations on fractal dimension calculations. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 84:96–100, 1997
21. Irfanview (2010) http://www.irfanview.com/. Accessed 18 Dec 2010
22. Shrout MK, Roberson B, Potter BJ, Mailhot JM, Hildebolt CF: A comparison of 2 patient populations using fractal analysis. J Periodontol 69:9–13, 1998
23. ImageJ (2010) http://rsbweb.nih.gov/ij/. Accessed 18 Dec 2010
24. FracLac (2010) http://rsbweb.nih.gov/ij/plugins/fraclac/fraclac.html. Accessed 18 Dec 2010
25. Southard TE, Southard KA: Detection of simulated osteoporosis in maxillae using radiographic texture analysis. IEEE Trans Biomed Eng 43:123–132, 1996
26. White SC, Rudolph DJ: Alterations of the trabecular pattern of the jaws in patients with osteoporosis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 88:628–635, 1999
27. Sarkar N, Chaudhuri BB: An efficient differential box-counting approach to compute fractal dimension of image. IEEE Trans Syst Man Cybern 24:115–120, 1994
28. Liu S: An improved differential box-counting approach to compute fractal dimension of gray-level image: In: Yu F, Yue G, Chen Z, Zhang J Eds. Proceedings of the International Symposium on Information Science and Engineering; 2008 Dec 20–22; Shanghai, China. IEEE, Los Alamitos, pp 303–306
29. Chikui T, Tokumori K, Yoshiura K, Oobu K, Nakamura S, Nakamura K: Sonographic texture characterization of salivary gland tumors by fractal analyses. Ultrasound Med Biol 31:1297–1304, 2005
30. Erickson BJ, Ryan WJ, Gehring DG, Beebe C: Image display for clinicians on medical record workstations. J Digit Imaging 10:38–40, 1997
31. Persons K, Palisson P, Manduca A, Erickson BJ, Savcenko V: An analytical look at the effects of compression on medical images. J Digit Imaging 10:60–66, 1997
32. Gegler A, Mahl C, Fontanella V: Reproducibility of and file format effect on digital subtraction radiography of simulated external root resorptions. Dento-Maxillo-Facial Radiol 35:10–13, 2006