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Radiologic assessment of bone healing after orthognathic surgery using fractal analysis

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ABSTRACT

Purpose : To evaluate the radiographic change of operation sites after orthognathic surgery using the digital image processing and fractal analysis.

Materials and Methods : A series of panoramic radiographs of thirty-five randomly selected patients who had undergone mandibular orthognathic surgery (bilateral sagittal split ramus osteotomy) without clinical complication for osseous healing, were taken. The panoramic radiographs of each selected patient were taken at pre-operation (stage 0), 1 or 2 days after operation (stage 1), 1 month after operation (stage 2), 6 months after operation (stage 3), and 12 months after operation (stage 4). The radiographs were digitized at 600 dpi, 8 bit, and 256 gray levels. The region of interest, centered on the bony gap area of the operation site, was selected and the fractal dimension was calculated by using the tile-counting method. The mean values and standard deviations of fractal dimension for each stage were calculated and the differences among stage 0, 1, 2, 3, and 4 were evaluated through repeated measures of the ANOVA and paired t-test.

Results : The mean values and standard deviations of the fractal dimensions obtained from stage 0, 1, 2, 3, and 4 were 1.658 ± 0.048, 1.580 ± 0.050, 1.607 ± 0.046, 1.624 ± 0.049, and 1.641 ± 0.061, respectively. The fractal dimensions from stage 1 to stage 4 were shown to have a tendency to increase ($p < 0.05$).

Conclusion : The tendency of the fractal dimesion to increase relative to healing time may be a useful means of evaluating post-operative bony healing of the osteotomy site. (***Korean J Oral Maxillofac Radiol 2002; 32 : 201-6***)

KEY WORDS : image processing, computer-assisted; fractals; osteotomy; wound healing

The assessment of the osseous healing after orthognathic surgery was usually performed via clinical sign. Though the histologic or the physiologic changes of the patients undergone orthognathic surgery have been thoroughly assessed by many researchers, the radiographic changes have not been. Radiologists as well as surgeons have some difficulties to interpret the radiographic changes after the orthognathic surgery because in the early stage such as 1 or 2 month (s) the radiographic density change at osteotomy site is not remarkable.

Texture in images consists of aggregates of many small elements of patterns. Traditional methods of texture analysis can be broadly classified into two main categories: statistical and structural.[1] Recently, the measures of self-similarity such as fractal dimension have been used as texture analysis. The fractal dimension is a concept which has, since the work of Mandelbrot,[2] become widely used in image analysis. Several authors have applied the fractal dimension for the characterization,[3,4] segmentation of structures,[5] or for object recognition.[6] Some researchers[7] have revealed that fractal analysis of dental radiographs was shown to be independent, to some extents, of imaging conditions such as angle between X-ray collimator. Other[8] stated that only under restricted condition, fractal analysis was valid for evaluation. The purpose of this study is to evaluate the radiographic changes on operation sites through the digital image processing and fractal analysis.

Materials and Methods

1. Fractal analysis

1) Collection of radiographs

The patients who had mandibular prognathism and under-

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went orthognathic surgery at Seoul National University Dental Hospital from January 1996 to December 1999 were randomly selected. The operation method was bilateral sagittal split ramus osteotomy (BSSRO) and mandibular setback with bicortical screw fixation technique. We had taken the panoramic view with scheduled program; 1 week before operation (stage 0), 1 or 2 days after operation (stage 1), 1 month after operation (stage 2), 6 months after operation (stage 3), and 12 months after operation (stage 4) (Fig. 1A, B).

2) Selection of radiographs

Total 35 patients were selected. The number of panoramic radiographs of stage 1, 2, and 3 was 35, respectively, and the number of radiographs of stage 4 was 10. The operation was done on both sides of mandible, so we selected two regions of interest (ROIs) in each radiograph.

3) Digitized image and selection of ROI

All radiographs were digitized at 600 dpi, 8 bit, 256 gray level on an AGFA Arcus II scanner (AGFA Inc., USA). For each patient, the digitized images for each stage were overlapped on Adobe Photoshop program (v5.02, Adobe systems, USA). We selected ROIs (200 × 200 pixel size) on overlapped images in bony gap. Because of the possibility of alterations due to dental root and fixation screws, ROIs were chosen at remote sites from the dentition and the screws. The selected ROIs were separated for each stage and saved as files on personel computer (Fig. 2).

4) Image processing

Using Scion image program (v4.02, Scion Corp., USA) which was IBM PC version of NIH image software, we characterized morphologic feature on the selected ROI.[9, 10] In order to remove large-scale variations in brightness of the image due to differences in thickness of the object and radiation exposure, the ROI was blurred using a Gaussian filter (kernel size = 30 × 30). This step removed all fine and medium scale structure and retained only large variations in density. The blurred image was then subtracted from the original image and 128 was added to the result at each pixel location. This generated an image with a mean value of approximately 128 regardless of initial intensity of the image. This image was then made binary, thresholding on a brightness value of 128, thus segmenting the image into components that radiographically approximate the bone pattern. The resultant image was eroded and dilated once to reduce noise. This image was finally skeletonized and used in the next step (Fig. 3A, B).

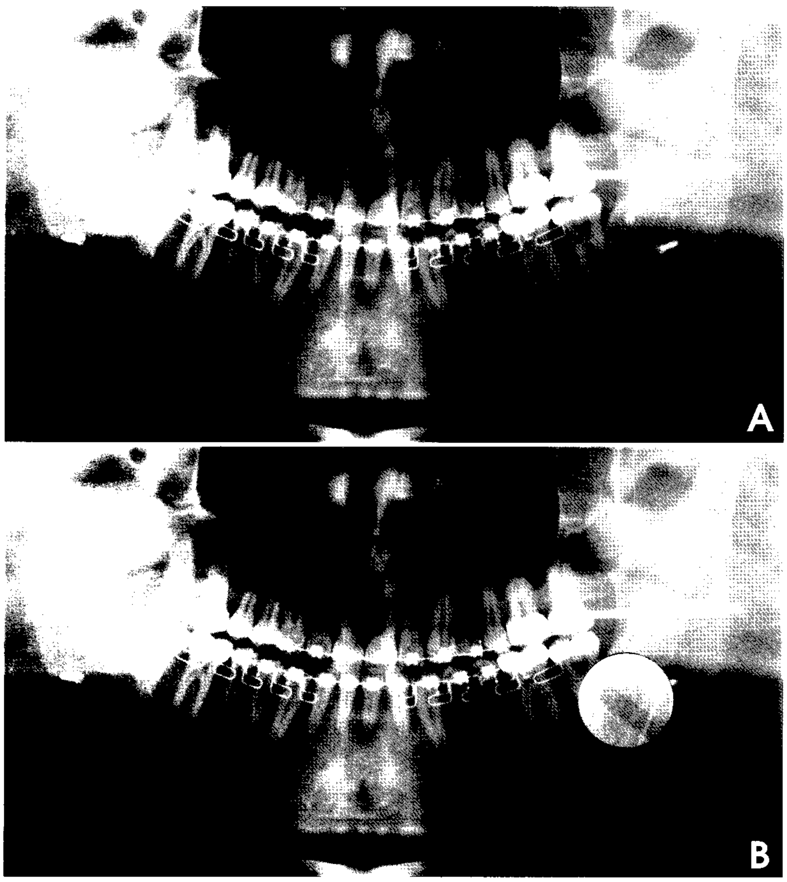

Fig. 1. A. Example of panoramic radiographs after BSSRO. Bony gap is seen on both sides of mandible. B. Bright round area shows an analyzed site in this study.

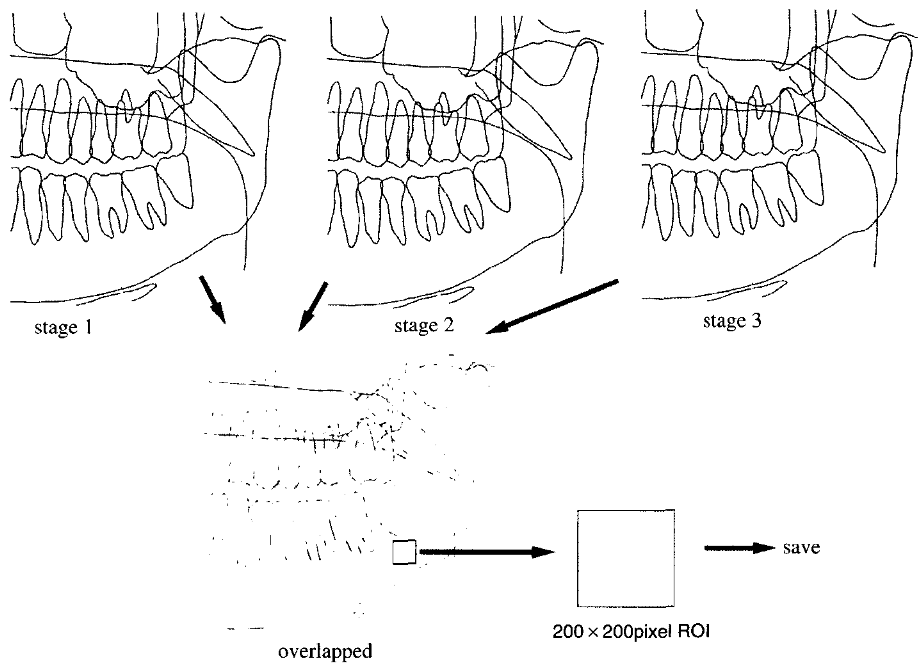

Fig. 2. Schematic diagram of selection of ROI. ROI was selected centered on bony gap area of overlapped image.

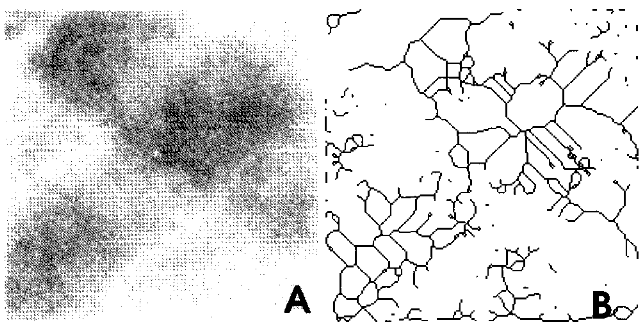

Fig. 3. A. Example of selected ROI. 200 × 200 pixel sized ROI was selected. B. Skeletonized image was acquired by dilation and erosion in ROI.

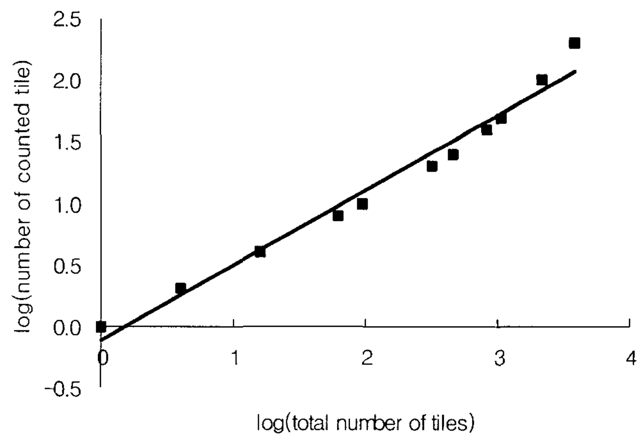

Fig. 4. Example of double logarithmic plot. Fractal dimension is the gradient of the line.

5) Calculating the fractal dimension

We calculated the fractal dimension of the skeletonized image to determine the morphologic changes of the selected ROI for each stage. The tile-counting method[11,12] was used by the following steps. The image was covered by a square grid of equally sized tiles. All tiles containing at least one black pixel were counted. Same procedure was repeated at each side length of tiles (200, 100, 50, 25, 20, 10, 8, 5, 4, 2, 1). The resulting number of counted tiles was drawn against the total number of tiles in a double logarithmic plot. The plotted points would approximately lie on a straight line (Fig. 4). Its slope represented the tile counting fractal dimension. All of the above procedures were performed by the custom-made functions programmed with macro language of Scion image (Fig. 5).

6) Statistical analysis

Mean values and standard deviations of fractal dimension for each stage were calculated. Repeated measures of ANOVA were then used to determine whether the values of fractal dimensions were statistically different. Due to the lack of number of subjects for stage 4, only paired t-test was performed to compare with the mean value of stage 3.

2. Inter-rater agreement test

Seventy osteotomy sites of 35 patients' radiographs selected

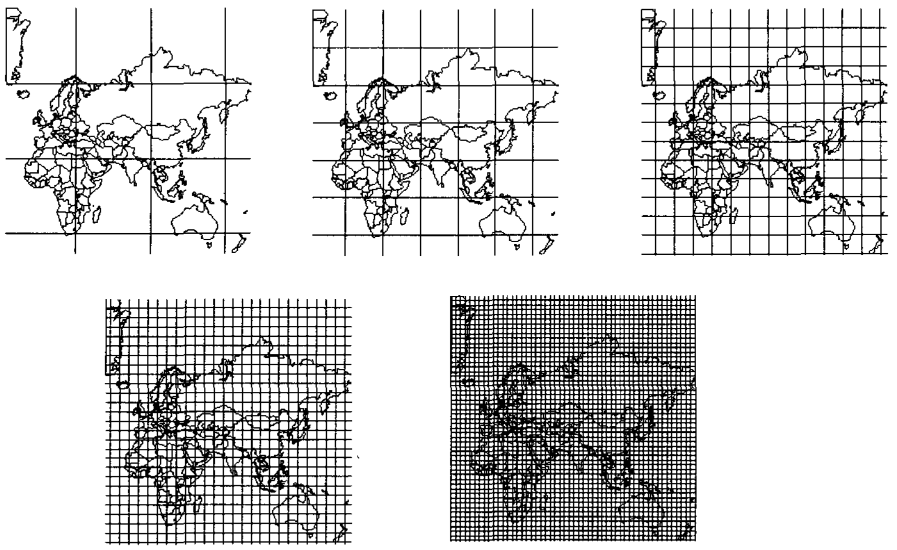

Fig. 5. Examples of square grids of equally sized tiles to use the tile-counting method is seen.

Table 1. Fractal dimensions of each stage on mandibular operated sites

Stage	Fractal dimension (mean ± SD)
Stage 0	1.658 ± 0.048
Stage 1	1.580 ± 0.050
Stage 2	1.607 ± 0.046
Stage 3	1.624 ± 0.049
Stage 4	1.641 ± 0.061

stage 0: preoperation, stage 1: 1 or 2 days after operation, stage 2: 1 month after operation, stage 3: 6 months after operation, stage 4: 12 months after operation.

Table 2. The changes of fractal dimension between each stage

Stage	0 to 1	1 to 2	2 to 3	3 to 4	0 to 4
D	Decrease*	Increase*	Increase**	Increase	Decrease

Data among stage 0, 1, 2, and 3 was statistically different by repeated measures of ANOVA ($p < 0.01$). D: fractal dimension, stage 0: preoperation, stage 1: 1 or 2 days after operation, stage 2: 1 month after operation, stage 3: 6 months after operation, stage 4: 12 months after operation.
*: $p < 0.01$ (paired t-test), **: $p < 0.05$ (paired t-test).

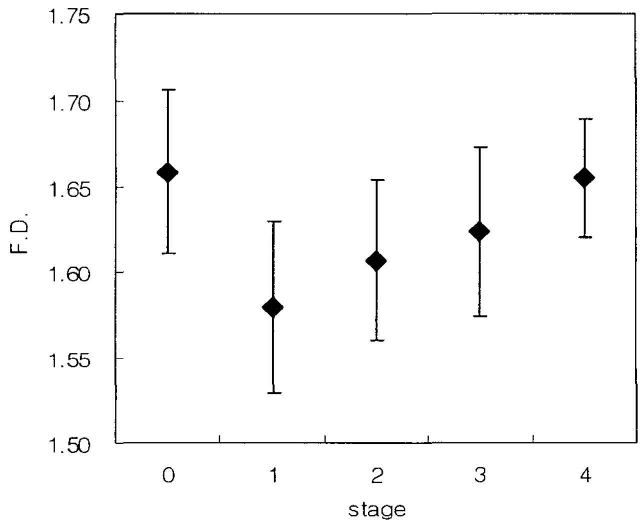

Fig. 6. Diagrammatic presentation of mean values of fractal dimension for each stages (n = 70 except for stage 4). Error bar means the standard deviation. stage 0: preoperation, stage 1: 1 or 2 days after operation, stage 2: 1 month after operation, stage 3: 6 months after operation, stage 4: 12 months after operation

as the above were used to measure the agreement between raters. The two radiographs, or stage 1 and 2, of each patient were interpreted on a light view box by three dentists, respectively. They were asked to assess the bone density changes on a 3-point scale (where −1 = Bone density decreased, 0 = No change, +1 = Bone density increased). A descriptive analysis of the score was then performed by Cohen's kappa (κ) which was used to evaluate the inter-rater agreement where poor is $\kappa < 0.20$, fair is $\kappa = 0.21$-0.40, moderate is $\kappa = 0.41$-0.60 and good is $\kappa > 0.60$.

All the procedures concerned with statistical analysis were performed with the SPSS (v9.0, SPSS Inc. USA) program.

Results

1. Fractal analysis

Table 1 shows the mean value and standard deviation of the fractal dimension of the stages. Because of the large number of subjects, we did not list all the values of fractal dimension of each images. The mean values of the fractal dimensions for stage 0, 1, 2, and 3 were statistically different (repeated measures of ANOVA, $p < 0.01$), and comparison between each stages by paired t-test was significantly different. In case of

Table 3. Interpretation of bone density in stage 2 compared with stage 3

Score	Rater 1	Rater 2	Rater 3
−1	4	3	2
0	37	39	44
+1	29	28	24

−1: Bone density decreased, 0: No change, +1: Bone density increased

Table 4. Inter-rater agreement (Cohen's kappa)

	Rater	Rater	Rater
	1 vs 2	1 vs 3	2 vs 3
κ	0.309*	0.646*	0.078

*: $p<0.01$, poor: $\kappa<0.20$, fair: $\kappa=0.21$-0.40, moderate: $\kappa=0.41$-0.60, good: $\kappa>0.60$.

stage 3 and 4, the difference was not significant by paired t-test ($p>0.05$, Fig. 6, Table 2).

2. Inter-rater agreement

Table 3 and 4 shows the result of inter-rater agreement test using Cohen's kappa values. Rater 1 was compared with rater 2 and with rater 3, and rater 2 with rater 3. Some disagreement exists between raters.

Discussion

The BSSRO is perhaps the most commonly performed mandibular osteotomy. The large area of bony contact remaining after setback facilitates osseous union. Some authors[13,14] researched the histologic changes on osteotomy site of mandible or on the fracture of long bones, however, there has been no method for radiologic evaluation of osteotomy site. When evaluating the healing of osteotomy sites, most surgeons have been dependent on clinical signs. Radiologists also have no method to determine the osseous healing process. Thanks to the development of digital image processing technique, some detailed image patterns which have been undistinguishable with naked eyes became analyzable. The radiographs are also evaluated by various method. The fractal dimension is one of them.

In the field of oral and maxillofacial radiology, digitized image processing is mostly used for periapical radiographs and computed tomography. Digital subtraction radiography is a typical example. In the digital subtraction radiography, some softwares are used to precisely overlap the two images taken at time interval. It was verified that slight directional change of X-ray beam projection did not affect the subtraction[15] if adequate algorithm was applied. In case of this study, overlapping procedure identical with subtraction radiography could not be applied because panoramic radiographs had various distortions and morphologic changes if they were taken after orthognathic surgery.

Some researchers[7,16] have revealed that fractal analysis of radiograph was independent, to some extents, of imaging conditions. Others[17,18] reported that because the fractal dimension was severely affected by many factors such as noise produced in the course of image obtaining and processing studies on the fractal dimension of bone should be carefully designed to obtain more conclusive results. Basically if the morphologic pattern is similar to each other, fractal dimension will be similar. We applied a part of procedures proposed by White et al.[10] to this study. The procedures discard broad variations in density, reduced the noise and characterized a certain bone morphologic pattern such as trabecule. Though the panoramic radiographs for each stage of one patient were not overlapped precisely, the analysis of this study can be valid due to such properties as independency of imaging conditions, similar result by morphologic similarity of fractal dimension mentioned above.

The studies on the natural objects using fractal geometry technique have shown that true self-similarity was rarely observed in nature.[19] The limitations in the techniques used for analyzing fractals often lead to erroneous conclusions concerning the properties of subjects.

If the fractal concepts are applied on an average or statistical basis, these can be valid for natural objects.[20] Various methods for fractal analysis have been presented. The tile counting method also called Mosaic amalgation method is one of them. In the tile counting method, a succession of square grids of increasing edge length is superimposed on the image to be analysed. It can be shown that the total number M of tiles covering the black pixel is related to the edge length S as: $M(S)=k \cdot S^{-D}$. Therefore, when $\log(M(S))$ is plotted against $\log(S)$, a straight line is obtained with slope β. Then fractal dimension $D=-\beta$ with $1<D<2$. As the D increases, we can expect the complexity of an image to increase. We can also expect that the homogeneousness of an image will affect the resultant D. If the homogeneousness and the complexity of an image formed by some elements such as trabecular pattern increase together, the fractal dimension would be increased.

Ellis et al.[13] reported that the BSSRO could heal by direct or indirect bone formation depending on the rigidity of the fixation and that medullary space was not filled with connective tissue callus, but filled with mature bone after 6 weeks. In this study, all osteotomy sites are fixed with rigid fixation devices such as bicortical screws and some bone formation may be represented as morphological changes on radiographs. Mean values of fractal dimension during 6 months after operation were significantly different and increased. This made us expect that the morphologic patterns of selected ROIs had a certain tendency of change. It maybe an increase of homogeneousness and complexity.

Mean value of fractal dimension of stage 4 does not show significant difference from that of stage 3. It was maybe due to the little trabecular morphological change of osteotomy sites in this period.

In order to verify the possibility that radiologists or surgeons could practically determine the changes between radiographs of stage 1 and 2, inter-rater agreement test was done. The level of agreement ranged from poor to good ($\kappa = 0.078 - 0.646$). This result means that there were no reliable agreement among three observers who joined in the test and consequently interpretation of radiographs taken at immediate post operation and 1 month after operation was difficult. Additionally, it was not necessary to verify the ability to discriminate changes between the other stages except for between stage 1 and 2 because one could easily discriminate those and almost all the subjects could be interpreted as increase of radiographic density at osteotomy site.

In this study, it seems possible to use the fractal analysis to evaluate osseous healing at osteotomy site. If some strict conditions such as selection of ROI, image processing including the reduction of noise are satisfied like this study, the application of fractal analysis to individual case is expected to be a reliable and effective method to interpret the osseous healing on radiographs. The osseous healing process after BSSRO gives us the good material of various bone density. We suppose that this result could apply to evaluate the bone density such like osteogenic state or osteoporosis, considering that fractal dimensions between stage 0, 1, 2, and 3 are significantly different.

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