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Cover Page Footnote

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ORIGINAL ARTICLE

Fractal Analysis of Subchondral Cyst at Mandibular Condyle Detected on Panoramic Radiograph in A Group of Thai Population

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ABSTRACT

Objectives: This study aimed to analyze subchondral cyst on the mandibular condyle using fractal dimension (FD) measurement on a panoramic radiograph. **Methods:** This retrospective study examined 15 patients aged 24 to 75 years who had undergone panoramic radiography and cone-beam computed tomography on both sides of the mandibular condyles, between January 2013 and November 2017, in the Oral and Maxillofacial Radiology Clinic, Dental Hospital, Mahidol University. These 15 patients, all of whom had a subchondral cyst on one side of the mandibular condyle, constituted both the study and control groups: the 15 affected sides constituted the study group, and the 15 unaffected sides constituted the control group. The FD of both groups was calculated by two investigators using ImageJ version 2.0x. **Results:** The average age of the subjects was 47.47 ± 15.99 years. The mean FD value was 1.306 ± 0.133 in the study group and 1.409 ± 0.858 in the control group. The FD values were significantly different between these groups (*p*-value 0.016). **Conclusion:** The FD values of mandibular condyle were lower in patients with subchondral cysts than in healthy patients. The fractal analysis provided clinicians with extra information regarding the condition of the subchondral cyst as an early sign of osteoarthritis on panoramic radiographs.

Key words: fractal dimension, mandibular condyle, panoramic radiograph, subchondral cyst

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INTRODUCTION

Patients with osteoarthritis (OA) sometimes experience cavitary lesions in subchondral bone. These lesions are generally referred to as subchondral cysts. According to new research, patients with subchondral cysts have more severe illness and inflammation, as well as a higher chance of joint replacement.[1] However, since cavitary lesions in subchondral bone may not have an epithelial coating and are not universally fluid-covered, the term subchondral cyst is inaccurate. Therefore, they are referred to as intra-osseous tumors or pseudo-cysts.[2,3] Subchondral cysts are made up of fibrous connective tissue that can contain fluid at first but eventually ossifies in later stages.[4]

Radiographically, subchondral cysts appear as well-defined radiolucent areas with sclerotic rims.[5] Panoramic radiography is becoming one of the diagnostic tools for assessing dental and maxillofacial structures. However, panoramic radiography has a very restricted value in the diagnosis of temporomandibular disorders (TMDs). Generally, aberrant morphological features found in panoramic imaging do not indicate TMDs. Meanwhile, the hard tissue in the temporomandibular joint (TMJ) can be evaluated using cone-beam computed tomography (CBCT). This imaging technique may detect changes such as osteophyte growth, degradation, subchondral cysts,

sclerosis, and flattening and narrowing of the joint space at different levels.[6]

In response to the limitations of panoramic radiography, some previous studies used the fractal analysis method to see the microarchitectural changes in bone structures. Fractal dimension (FD), which is expressed from fractal analysis, shows texture roughness, which is the repetitive pattern of grayscale configurations in the trabecular network. This method can be considered a reflection of trabecular bone microarchitecture when applied to see trabecular bone on radiographic images.[7, 8] Sindeaux et al. (2014) suggested that FD analysis might be considered an auxiliary tool to measure cortical bone, referring the patient for bone densitometry using a dual-energy X-ray absorptiometry exam.[9] Magat et al. (2019) found that FD analysis can be performed using a panoramic radiograph to evaluate the trabecular structure.[10]

This retrospective study, conducted on Thai subjects, aimed to analyze subchondral cyst on the mandibular condyle using FD analysis on a panoramic radiograph confirmed from CBCT images.

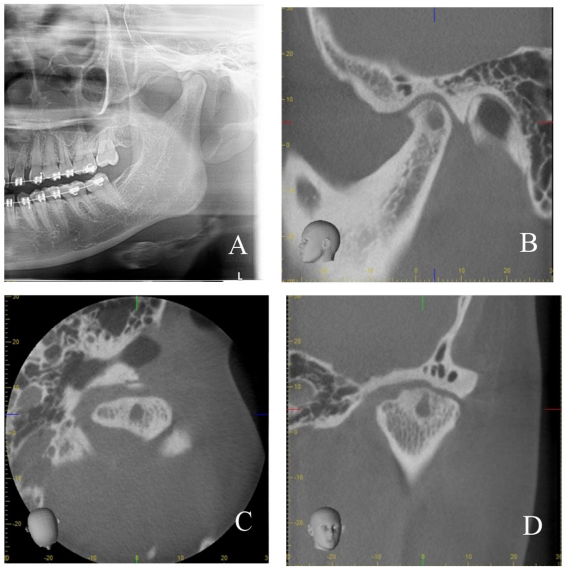

Figure 1. An example of a subchondral cyst on the left mandibular condyle. A) Cropped panoramic radiograph. B) Sagittal view. C) Axial view. D) Coronal view of CBCT images.

METHODS

This was a retrospective study of 15 subjects: men and women aged 24 and above who had undergone panoramic and CBCT radiography on both sides of the TMJ in the Oral and Maxillofacial Radiology Clinic, Dental Hospital, Mahidol University, Thailand, between January 2013 and November 2017. The panoramic and CBCT radiographs were taken within six months of one another so that the progression of the subchondral cyst would not result in a difference in radiographic appearance between the panoramic and CBCT radiographs. The 15 subjects, all of whom had a subchondral cyst on one side of the mandibular condyle, constituted both the study and control groups: the 15 affected sides constituted the study group, and the 15 unaffected sides constituted the control group. Two oral and maxillofacial radiologists with 16 years of experience and a master's student in oral and maxillofacial radiology chose and confirmed the subjects whose CBCT indicated subchondral cyst (Figure 1). There was no congenital TMJ disease, osteoporosis, or surgical treatment for TMJ in any of the subjects.

The clinical protocol was approved by the Institutional Review Board of the Faculty of Dentistry and the Faculty of Pharmacy at Mahidol University (COA.No.MU-DT/PY-IRB 2021/065.1607). Patient demographic information, including age and gender, was recorded. The dates on which the panoramic radiograph and CBCT images were taken were noted. The panoramic radiographs were obtained from CS9000c (Carestream Health Inc., Rochester, NY) using exposing factors of 70–72 kV, 10–12 mA, and 15 seconds. These radiographs were exported in tag image file format (TIFF) from Trophy software for FD analysis. The investigators compared the panoramic and CBCT radiographs that could give the appearance of the subchondral cyst on the mandibular condyle.

Fractal dimension analysis

The panoramic radiograph was cropped in the same region after being imported into ImageJ software (National Institutes of Health, Bethesda, Maryland, USA) for FD analysis. The region of interest (ROI) of 60 x 60 pixels was manually selected on the trabecular bone of the condylar head and placed at the highest location without superimposition over the cortical bone and outside the pterygoid fovea at the condylar head for the study group and the same area of normal trabecular bones for the control group (Figure 2). The ROIs were cropped and transferred to ImageJ 2.0x. Thereafter, the transferred images were processed using the method described by White and Rudolph et al.[11] The ROI was duplicated and then blurred with a Gaussian filter (kernel size = 30) to remove the fine medium-scale variations in image brightness. The blurred image was subtracted from the original image and added 128 at each pixel location. Then, the resultant image was converted to binary with a threshold at the gray value of 128. The segmented objects approximated the subchondral bone of the TMJ. The binary image was eroded and dilated once to reduce the noise before skeletonization. The image was then skeletonized and used for fractal analysis (Figure 3). The FD value of the skeletonized image was calculated with ImageJ 2.0x using the box-counting function. The image was covered by a square grid of equally sized tiles, and the

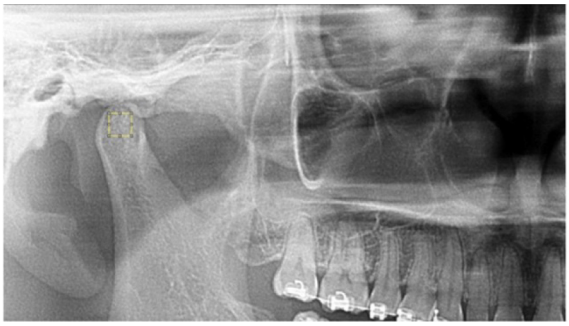

Figure 2. ROI 60 × 60 pixels (yellow square) of the right mandibular condyle on the cropped panoramic radiograph.

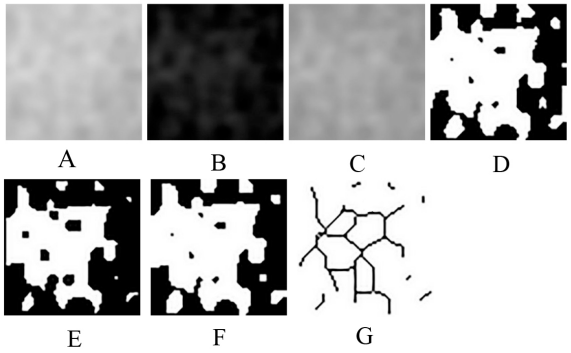

Figure 3. Steps of fractal dimension analysis. A) Gaussian blur. B) Subtraction of the region of interest from the background. C) Addition of 128 gray value to each pixel location. D) Binarization. E) Erosion. F) Dilatation. G) Skeletonization.

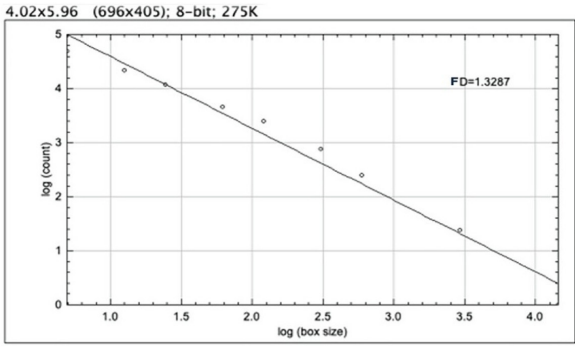

Figure 4. Calculation of fractal dimension.

number of tiles referring to the trabecular bone was counted. The widths of the square boxes were 2, 3, 4, 6, 8, 12, 16, 32, and 64 pixels. Subsequently, the number of counted tiles was plotted against the total number of tiles in a double logarithmic scale, and the FD value was calculated from the slope of the line fitted on the data points (Figure 4).

Statistical analysis

Fractal analysis on panoramic with subchondral cyst on CBCT radiograph was conducted by two investigators in the same condition, and the same investigators repeated the measurements after two weeks. Data were entered and analyzed using the Statistical Package for the Social Sciences (SPSS) 26 (IBM, Chicago, IL, USA). Descriptive statistics were used to define the distribution of the mean age and sex of the subjects. Intra-examiner and inter-examiner reliability tests were evaluated using the intraclass correlation coefficient (ICC). Thereafter, statistical analysis for data distribution was assessed using the Shapiro–Wilk test. Subsequently, statistical analysis of the difference in FD value between subchondral cyst on the mandibular condyle and normal trabecular bone on panoramic radiograph was evaluated by independent t-test. The p-value of <0.05 with a 95% confidence interval was considered statistically significant.

Table 1. Distribution of sample

Case No.	Sex	Age	Right Mandibular Condyle	Left Mandibular Condyle
1.	F	59	Normal	Subchondral cyst
2.	F	24	Normal	Subchondral cyst
3.	F	75	Subchondral cyst	Normal
4.	M	30	Subchondral cyst	Normal
5.	F	53	Normal	Subchondral cyst
6.	F	26	Subchondral cyst	Normal
7.	F	55	Subchondral cyst	Normal
8.	F	54	Subchondral cyst	Normal
9.	F	58	Subchondral cyst	Normal
10.	M	67	Normal	Subchondral cyst
11.	M	55	Normal	Subchondral cyst
12.	F	33	Subchondral cyst	Normal
13.	F	37	Subchondral cyst	Normal
14.	F	30	Subchondral cyst	Normal
15.	F	56	Subchondral cyst	Normal

F: Female; M: Male

RESULTS

Fifteen radiographs from 15 patients aged 24 to 75 years, who had undergone panoramic and CBCT radiography on both sides of the TMJ between January 2013 and November 2017, were selected according to the inclusion and exclusion criteria. Of the 15 subjects, 12 were women, and 3 were men. The subjects' mean age was 47.47 ± 15.99 years. Table 1 presents the subjects' ages, sexes, and subchondral cyst locations.

Intra-examiner and inter-examiner reliability tests were conducted using the intraclass correlation coefficient (ICC) test, which was measured from 15 panoramic radiographs. The measurement was done separately at two different times (intra-examiner) and by two

Table 2. Reliability test value*

Test	Observation	ICC value
Intra-examiner	Study group	0.975**
	Control group	0.808***
Inter-examiner	Study group	0.776***
	Control group	0.931**

ICC: intraclass correlation coefficient
* ICC test
** Excellent reliability
*** Good reliability

Table 3. Statistical analysis of the FD values of subchondral cyst on the left and right mandibular condyles*

Group	n	Mean FD	p
Left TMJ	5	1.351 ± 0.169	0.373**
Right TMJ	10	1.283 ± 0.115	

FD: fractal dimension; TMJ: temporomandibular joint
* Independent t-test
** Statistically not different (p > 0.05)

Table 4. Statistical analysis of the FD values of subchondral cyst and normal trabecular bone*

Group	n	FD	p
Subchondral cyst	15	1.306 ± 0.133	0.016**
Normal trabecular bone	15	1.409 ± 0.858	

FD: fractal dimension
* Independent t-test
** Statistically different (p < 0.05)

investigators (inter-examiner). This was done to assess whether there was agreement between the investigators at different times and to avoid hesitation with the same method. Table 2 presents the value of the reliability tests; the results showed excellent reliability in the intra-examiner test of the study group (0.975) and the inter-examiner test of the control group (0.931). Meanwhile, the results showed good reliability in the intra-examiner test of the study group (0.808) and the inter-examiner test of the control group (0.776).

A normality test was used to evaluate whether the data distribution was normal. The Shapiro–Wilk test results indicated that the FD value of subchondral cyst and normal trabecular bone was normally distributed (FD of subchondral cyst, $p = 0.419$; FD of normal trabecular bone, $p = 0.110$; $P > 0.05$).

A statistical analysis of the FD values of the subchondral cyst condition showed non-significance between the left and right sides of the mandibular condyles. Table 3 shows that the left side had a mean FD of 1.351 ± 0.169 and the right side had a mean FD of 1.283 ± 0.115 ($p > 0.05$). To evaluate the difference between the FD value of subchondral cyst on the mandibular condyle and normal trabecular bone, this study used an independent t-test. The independent t-test showed significance in FD between subchondral cyst (1.306 ± 0.133) and normal trabecular bone (1.409 ± 0.858) on the mandibular condyle ($p < 0.05$; Table 4). Therefore, a precise conclusion can be stated regarding changes in FD with subchondral cyst; namely, subchondral cyst had a lesser bone complexity.

DISCUSSION

The study sample comprised 15 radiographs from 15 patients aged 24 to 75 years, of whom 12 were women and 3 were men. These 15 patients, all of whom had a subchondral cyst on one side of the mandibular condyle, constituted both the study and control groups: the 15 affected sides constituted the study group, and the 15 unaffected sides constituted the control group. It could be speculated that the women—due to estrogen and progesterone, which are responsible for immunologic response—were more prone to developing temporomandibular joint osteoarthritis (TMJOA) following the progression of joint laxity as a result of the increase in TMJ fibrocartilage catabolism caused by estrogen.[12,13] The subjects' average age was 47.47 ± 15.99 years, which was compatible with the theory that the fibrocartilage structure of the mandibular condyle is gradually replaced by fibrous tissue as age progresses. This gradual replacement leads to a decreased adaptive capacity to resist mechanical loading, and it is a risk factor for OA.[13,14]

The results of this study might contribute to the development of a method that uses fractal analysis on panoramic radiographs. The FD value of subchondral cyst on the mandibular condyle was measured using box counting, which was commonly used in the literature. The box-counting dimension was most typically used in natural fractals. Selecting the ROI in the area of trabecular bone on panoramic was critical to determining subchondral cyst in the mandibular condyle area. A previous study by Arsan et al. used 84 × 84 pixels of ROI to cover the cortical and subchondral bones of the mandibular condyle.[15] However, in the present study, smaller standardized ROIs (60 × 60 pixel squares) were used to avoid superimposition over the cortical bone, and they were placed at the highest location of the mandibular condyle.

In this study, the mean value of the study group's FD (1.306 ± 0.133) was lower than that of the control group (1.409 ± 0.858). This finding was compatible with findings from some previous studies that suggested that the FD value of the mandibular condyle was lower in patients with degenerative joint disease than in healthy patient.[15-17] Kayipmaz et al. showed similar results to the present study's results. They compared FD values from CBCT radiographs between patients with TMJOA and

healthy patients; the results showed that patients with TMJOA had significantly lower FD values than healthy patients.[14] Yesiltepe et al. evaluated the bone structure at the TMJ in patients with rheumatoid arthritis, using fractal analysis from CBCT images. They found a significant difference in the FD value of bone structure between patients with rheumatoid arthritis and healthy patients.[16] The results of the present study were also consistent with Gümüssoy et al.'s results. They found that as the grade of bone degeneration increased, FD values decreased. The patients with severe erosive on the mandibular condyle underwent greater loss of complexity of trabecular architecture than patients with normal condyle.[17] Arsan et al. found that the mean FD of the study group with TMDs was lower than the mean FD of the healthy patients in the control group.[15] The study group's FD value might be related to the higher severity of degenerative alteration in trabecular bone caused by the subchondral cyst. This result revealed that osteoarthritic alteration was conveyed to the subchondral bone and affected the condyle's trabecular architecture. Moreover, this result demonstrated that subchondral cyst had distinctive trabecular architecture, with less complexity and a smoother appearance.

The present study had some limitations. First, the number of subjects was limited. Some data should be excluded from the subjects because of the interval time of more than 6 months between panoramic and CBCT radiographs. This study needed a further study with an adequate sample size to find the base value of the FD value of subchondral cyst on the mandibular condyle, which could increase the efficiency of fractal analysis as a diagnostic tool to detect osteoarthritis.

CONCLUSION

In conclusion, lower fractal dimension values reflected reduced complexity, which represented alterations in the trabecular structure of the mandibular condyle in patients with subchondral cyst. The fractal analysis of the panoramic radiograph also showed alterations in the trabecular structure that were previously undetectable to the human eye. As a result, during a routine radiographic examination, the fractal analysis provided clinicians with extra information regarding the condition of the subchondral cyst as an early sign of osteoarthritis on panoramic radiographs, which enhanced diagnostic efficiency.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest regarding the authorship and/or publication of this article.

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