ORIGINAL ARTICLE

# Fractal Dimension Approach for Quantitative Analysis Radiograph in Periapical Inflammation: A Systematic Review

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## ABSTRACT

**Background and Objective.** Periapical inflammation on visual interpretation, especially in conditions of early inflammation, is very dependent on visual acuity. Visual ability can only detect if the inflammatory condition in the periapical area is more than 30%. This study reviewed the use of fractal dimension (FD) for quantitative assessment radiographs in periapical inflammation.

**Methods.** The search was performed using PubMed, Web of Science, and Scopus databases. The inclusion criteria were clinical research, the area was in the periapical inflammation, used the periapical radiograph, measured the fractal dimension in human bone, the article studies were in the English language. There was no restriction for publication date.

**Results.** Five articles were found in which fractal dimension was applied for the assessment of periapical lesions visually indiscernible in radiographs, for evaluation of apical inflammation, for imaging diagnosis of the periapical lesion, for analysis of trabecular bone, and for analysis of trabecular bone structure around the bone of periapical inflammation. Various sizes and sites of the regions of interest were used to evaluate the bone structure of periapical inflammation with fractal dimension.

**Conclusion.** Fractal dimension in Dentistry has been widely applied to the study of images. Periapical radiographs were the most frequently used. The Image J software and the fractal analysis method were extensively adopted in the studies reviewed herein. Further studies are encouraged to improve the use of fractal dimension in assessing quantitative radiographs in periapical inflammation.

*Keywords: fractal dimension, periapical inflammation, dental radiograph*

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## INTRODUCTION

Periapical inflammatory lesions are one of the most common pathological lesions that occur in the alveolar tissue. This is caused by the presence of pulpal necrosis, and the emergence of inflammatory mediators that diffuse through the apical foramen to the surrounding tissue of the tooth. The World Health Organization does not classify periapical lesions specifically, but a study has classified periapical radiolucent lesions as periapical abscess, acute apical periodontitis, periapical cyst, chronic apical periodontitis, and granuloma.[1–4]

The apical inflammatory lesion is one of the protective actions of the host response, the alveolar bone around the apical tooth will be destroyed due to this protection. One of the key indicators of an apical lesion is bone destruction.

The gradual loss of bone defects due to a destructive response is often used as a clinical indicator and assesses the inflammation process of alveolar inflammatory lesions.[5–10]

Fractal analysis is a technique for evaluating complex and irregular bone structures mathematically. The quantitative yield of this technique is known as a fractal dimension (FD). In 1875, Du Bois Reymond proposed a continuous function concept for the first time, then researchers refined and utilized fractal dimensions. Mandelbrot presented information about the set of mathematical functions used to represent complex geometric structures, which led to the consolidation of the term "fractals". This fractal analysis technique differs from traditional geometry in that it is used to analyze similar structures at different scales. The fractal analysis actually can assess physical form both temporally and spatially, and has an infinitely repeating pattern.[11–16]

Fractal dimension analysis has been adopted in the medical field because it can be widely used in image examination. In dentistry, dimensional fractals are used to evaluate the pattern of the jawbones on dental radiographs. Researchers who are assessing bone mineral density (BMD) have also profited from this method for quantitatively assessing trabecular bone. In recent years, however, the fractal approach has been utilized in a number of research investigating radiograph patterns of trabecular bone inflammation.[13,17–20] Bone density changes are the most reliable radiographic indicator of the progression or remission of periapical inflammation. Early change detection is a crucial aspect of determining the efficacy of treatment and managing a patient. In traditional radiography, a periapical lesion must undergo a 30% change in mineralization before it can be noticed by the human eye.[21–25]

In dental clinical practice, radiographic pictures are frequently ordered as supplementary examinations. Methods such as fractal dimension, which objectively assess changes in bone patterns caused by treatment progression or a disease, are essential for clinical and scientific research.[26,27] According to research articles by Elif Sogur et al., FD analysis is more effective than pixel intensity analysis for detecting undetectable demineralizations of periapical bone radiographically. Fractal dimension may be suggested as an objective and quantitative method for identifying early periapical lesions. According to research articles by Kurşun-Çakmak et al., examining the bone microarchitecture using fractal dimension has been proven to be effective.[21,28] We aim to present a study that describes the application of fractal dimension as a quantitative assessment for periapical inflammation in this systematic review. However, no review summarizes the evidence of fractal dimension approach for periapical inflammation has been conducted thus far. This subject review would be helpful to the dentist regarding the application of fractal dimensions in dentistry. Therefore, the purpose of this systematic review was to present studies that describe the utility and applicability of fractal dimension as a tool for bone structures evaluation in dental radiographs and to demonstrate the procedures and outcomes of the included articles.

## METHODS

This systematic review was prepared based on the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) with PICO. Electronic searches were done using PubMed, ProQuest, ScienceDirect, Google Scholar, and Scopus databases until the end of September 2022 with Boolean search use - periapical inflammation AND fractal dimension AND quantitative analysis.

### Identification of Studies

We only included researches published in English. There was no publication date restriction.

### Eligibility Criteria

Original research article about dental radiographic analysis using fractal dimensions as an evaluation tool. Articles on fractal dimension application other than dentistry, literature review, and case report were excluded. Studies conducted on bone models, animals, and studies in other materials were also excluded.

### Data Extraction and Items

Data were extracted by the two review investigators using a predesigned data form independently. The following information were taken from each study: last name of the first author, publication year, subject, ROI, and the main results regarding fractal dimension.

### Study Selection

Two reviewers evaluated each article's title and abstract in the first screening to match the eligibility criteria. The full texts of the publications were obtained, along with titles and abstracts that provided enough details for inclusion and exclusion determinations. The retrieved full texts were assessed again, this time taking into account the identical eligibility criteria as the previous screening. They were also included if they met the eligibility requirements. Disagreements among review investigators during the research selection were settled by conversation until an agreement was reached. If there is no agreement, the two reviewers consulted third and fourth review researchers (senior lecturers of Oral and Maxillofacial Radiology), to reach a final decision regarding the inclusion or exclusion of articles.

## RESULTS

We found 227 articles from the search engine (PubMed, ProQuest, Scopus, Google Scholar) and there were 87 articles that matched the initial screening. After we assessed the eligibility of the full text articles, we found eight articles that meet the inclusion criteria, but three were excluded because the inflammation was not in the periapical area (Figure 1). Table 1 shows the five articles included in this study. The limitations of all the included articles are: did not provide

the detailed step of fractal dimension measurement and did not provide any explanation about the risk of bias.

One article about fractal dimension in assessing periapical area was published in 2009.[29] Most articles were published after 2012. Various sample sizes were employed in the included studies. The sample sizes ranged from 20 radiographs for the smallest number to 6000 for the biggest number. Each study used different ROI size but most of the studies used square ROIs.

## DISCUSSION

This systematic review illustrates the fractal dimension used in evaluating the periapical lesion. Radiographic examination is necessary for the treatment of periapical pathology. The detection and evaluation of the site and periapical lesions extent are essential for treatment planning, maintenance treatments, and prognosis. In dentistry, the application of fractal dimension analysis has increased significantly in the last year. Trabecular bone quantification is essential, and dental imaging such as periapical radiographs is preferred in several dental specialties. Practitioners have access to an easy handling and free software, such as ImageJ, which enables them to analyze quantitative assessment in their patients' radiographs.[21,30–32]

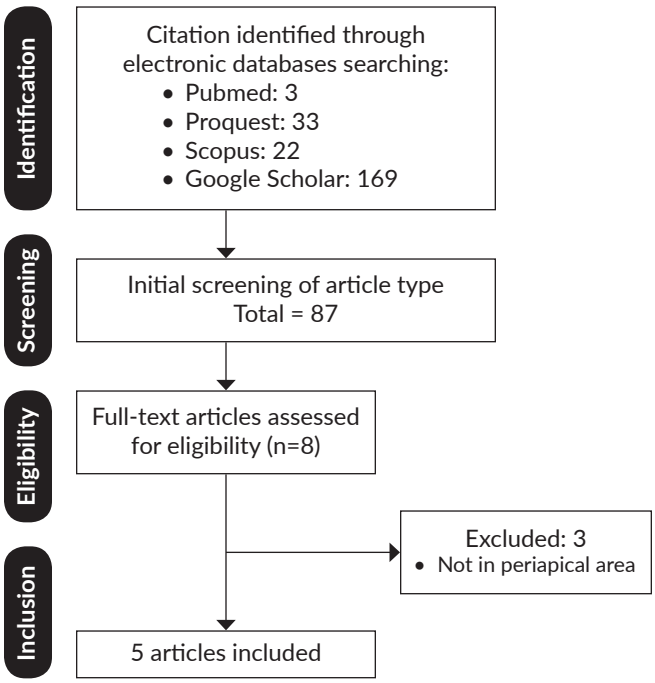


**Figure 1.** The study selection process flowchart.

Fractals can be calculated from digitized image. However, these images must be preprocessed. White and Rudolph described a computer algorithm that analyzes medical images to determine the trabecular bone morphologic properties.[21] In their work, the authors described the standardization methods of image required to emphasize trabecular bone. ImageJ, which may be accessed at https://imagej.nih.gov/ij/, was utilized. To prevent deviations, high-resolution and compressed pictures were preserved after image acquisition. Cropping the regions of interest (ROI), duplicating the ROI, and removing large-scale brightness changes with a gaussian blurred filter (sigma = 35 pixels, kernel size = 3333) comprised the sequence. This process also included the ROI elimination from the original image, the insertion of 128 grey values to each pixel position, binary image, erosion, dilation, inversion, and skeletonization.[8,9] Following image processing, a number of techniques for fractal dimension computation can be used, including surface area of triangular prism, power spectral density, intensity difference scaling, the blanket method, and the variogram. The most utilized method was the box-counting algorithm, which was deemed to be easily reachable. Fractal dimension is a mathematical instrument that enables the radiologist to forecast the bone tissue quality. The development of digital image technology is a high-precision image modality that can provide access to high-quality images so that they can be used to evaluate bone microarchitecture quantitatively.[33–37]

**Table 1.** Main Findings of the Included Articles

| Study and Location | Subject | ROI | Outcome |
|---|---|---|---|
| ***Y.Y. Yu, et al. (2009), Washington, USA*** | 38 digitized periapical radiograph | 128 X 128 pixels | The fractal dimension decreases significantly in reactive bone following a successful treatment of root canal. |
| ***C.C. Huang et al. (2012), Taipei, Taiwan*** | 26 digital radiograph periapical | 400 X 400 pixels | The FD values of apical lesion area were significantly decreased after 1 year of root canal treatment. |
| ***Maha Eshak Amir, et al. (2012), Michigan, USA*** | 600 digitized periapical radiograph | 100 X 100 pixels | Fractal dimensional analysis is a useful technique. It is utilized to analyze the structure of trabecular bone.<br>The normal trabecular pattern in healthy patients has a fractal dimension of about 1.5 in the maxilla and mandible region. |
| ***Elif Sogur, et al. (2013), Turkey*** | 56 periapical radiograph | 100 X 60 pixels | Fractal dimension analysis can detect invisible periapical bone demineralizations radiographically better more than pixel intensity analysis. Fractal dimension calculation can be used as a technique for early periapical lesion detection. |
| ***S.S. Saeed, et al. (2019), Iraq*** | 20 periapical radiograph | 22 X 16 pixels | The fractal dimension could be suggested as an objective and quantitative approach for clinically suspicious periapical lesions detection. |

The quantity of information included in an image is determined by the number and size of the pixels, as well as the number of greyscale tones available in radiographs. The fractal dimension applied to statistically quantify complicated geometric structures. In general, the larger the dimension, the more intricate the shape. The structure's complexity is quantified by a single number, which is determined using an algorithm. Several methods for calculating fractal dimensions have been presented, with the box-counting approach ias the most used in dental radiology. Box-counting algorithm is commonly used to characterize the trabecular pattern by counting the contact between bone marrow and trabecular bone. Additionally, the approach evaluates the boundary between bone marrow and trabecular bone; a higher box counting score suggests a more complicated structure.[24,36–40]

The periapical lesion exhibits fractal behavior, which can be thought of as a quantitative assessment of the periapical area. Due to the fact that this method can only be utilized on a limited portion of the radiolucent area being measured, it is difficult to apply it to the task of quantifying a whole radiolucent lesion. In spite of these limitations, fractal analysis has been demonstrated to be capable of identifying early alterations of trabecular pattern on a periapical radiograph. Bone tissue fractal analysis has been developed as a technology that is accurate, affordable, and readily available. The FD value, which measures a structure's porosity and skeletal properties, may indicate structural changes in cancellous bone during inflammation and inflammation process. The increased demineralization and decreased bone density in chronic periapical abscesses and cysts lead to an increase in fractal dimensions. An abrupt change in density may be seen in radiographic images due to the fine loss of trabecular structure that can result from demineralization, which in turn cause changes in the fractal dimension. In other words, an increase in fractal dimension could arise as a result of an increase in the roughness of the image, which would be a reflection of the architectural disarray caused by demineralization of the trabecular network.[13,21,24,30,41]

Finding a precise threshold value for the extraction of bone structure proved tough to accomplish. When a high threshold value is used, it is possible that skeletal pieces that have a low pixel intensity will not be included. Due to the fact that bony structures can be considered to be skeletal, a low threshold value might include the marrow gaps. The threshold approach is unable to differentiate between trabecular bone and other tissues that have a high pixel value. As a result, the skeleton approach was adopted. This method has been put to use in the process of extracting the distinctive pattern of trabecular bone from digital photographs in order to get over these restrictions. A gray-scale histogram can be effectively used to filter the most local maximums of the image, which represents a trabecular pattern, in the skeleton process that is based on mathematical morphology. This is done in order to maximize processing speed. After using the skeleton method, the background's intensity was reduced to zero, which made it possible to differentiate the trabecular pattern from the rest of the image. Following that, the value zero can be categorically employed as a threshold in order to differentiate trabecular pattern from other tissues.[27,29,37,42–44]

Anatomical variations, differences in the techniques used to collect two-dimensional bone scans, methodologies for measuring fractal dimension, and/or differences in regions of interest to be quantified account for the variety of results. This should be a consideration in the future research related to fractal dimension measurements.

This systematic review strongly recommends that future research clarifies the standard methodology used in the analysis of fractal dimensions and allows comparisons among other methods. The description of the analytical research should also include the type, resolution, and size of the images, as well as the shape, size, and location of the ROI. According to most of the studies that have been done with the box counting method proposed by White and Rudolph and ImageJ software, before suggesting consistent results, further studies are suggested to increase knowledge about the parameters that can directly affect fractal dimensional analysis.

## CONCLUSION

Fractal dimension in dentistry has been widely applied to the study of images. Periapical radiographs were the most frequently used. The periapical lesion exhibits fractal behavior, which can be thought of as a quantitative assessment of the periapical area. The ImageJ software and the fractal analysis method were extensively adopted in the studies reviewed herein. Further studies are encouraged to improve the use of fractal dimension in assessing quantitative radiographs in periapical inflammation.

### Statement of Authorship

All authors certified fulfillment of ICMJE authorship criteria.

### Author Disclosure

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