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Fractal Dimensions Analysis of Mandibular Cortical Thickness in Rheumatoid Arthritis Patients – A CBCT Study

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Abstract

Introduction

The fractal analysis involves examining the fractal properties of data and utilizes mathematical techniques to measure the complexity inherent in the geometric patterns of various objects. Rheumatoid arthritis (RA) is a chronic autoimmune condition that primarily impacts the joints but can also affect various other bodily systems, including the jaw. Individuals with RA are at an elevated risk for developing secondary osteoporosis due to both the disease itself and the treatments used. In mandibular bone, RA can cause a decrease in bone density, changes in the trabecular structures, and thinning of the cortical bone. Assessing bone structure and morphology, fractal dimensions analysis can provide additional information about the complexity of the bone structure, which can be useful in diagnosing and monitoring bone diseases, various counting algorithms in fractal analysis, including the box-counting method, are employed to examine trabecular patterns.

Materials And Methods

A single-centered prospective imaging study. 50 (25 Rheumatoid arthritis and 25 healthy patients). The patient is diagnosed with rheumatoid arthritis. Age group 30-70. CBCT images were obtained by using CS 9300 select (Carestream) with 85kv, 4.0mA, and 8.01s. The regions of interest (ROI) for CBCT imaging were selected in the mandibular region, specifically before the mental foramen, typically targeting the apical areas of teeth 33 and 43. The images were subsequently transferred to the FIJI (ImageJ) version 1.51 software (National Institutes of Health, Bethesda, MD; available at https://imagej.nih.gov/ij/download.html) for the calculation of fractal dimensions (FDs). SPSS 20.0 (SPSS, Chicago, IL) was used to perform all statistical analyses. This statistical test was chosen to compare the FD values between two groups: healthy individuals and patients with rheumatoid arthritis (RA). The Independent Samples t-test is used to compare the means of two separate groups to determine if there is a statistically significant difference between them. A comparison of variables within the group (left side/right side) was done using a paired t-test. Significance was defined as $p \leq 0.05$.

Results

The results demonstrated that RA patients had lower fractal dimension (FD) values than healthy individuals, indicating reduced bone complexity in RA patients. The fractal dimension values of the trabecular bone structure corroborate the hypothesis of the study, that there is a significantly differences in trabecular bone complexity in female RA patients than the healthy females.

Conclusion

The study's findings indicate that fractal dimension (FD) analysis of CBCT images can detect osteoporosis-related reductions in mandibular cortical thickness in patients with rheumatoid arthritis (RA). Further research is needed to validate the use of fractal analysis in clinical practice and to explore the potential clinical implications of this technique for the early detection and management of Rheumatoid arthritis diseases.

Keywords: Rheumatoid arthritis, Fractal analysis, CBCT, Image J, Mandibular cortical bone

Introduction

Rheumatoid arthritis (RA) is an autoimmune chronic disorder that affects the synovial joints, causing symptoms such as inflammation, discomfort, swelling, and progressive joint destruction (1). RA affects approximately 1% of the globally and is more common in women than men, with a ratio of about 3:1. It can occur at any age between the ages of 30 and 60. The prevalence of RA varies by geographic region and ethnicity, with higher rates observed in some populations (2). Rheumatoid arthritis (RA) not only affects peripheral joints but also has significant impacts on craniofacial structures, including the mandibular cortical bone and the temporomandibular joint (TMJ). These changes can lead to various complications, influencing both the function and the overall health of the oral cavity (3).

RA patients frequently exhibit reduced mandibular cortical thickness and increased porosity, indicative of osteoporosis and bone resorption. This can be attributed to both systemic inflammation and the use of corticosteroids in RA management, which can exacerbate bone loss (4). The thinning of the cortical bone and decreased bone mineral density increases the risk of mandibular fractures and erosions. These structural changes can compromise the stability and integrity of the mandible (5). Individuals with rheumatoid arthritis are particularly vulnerable to developing secondary osteoporosis. Alterations in bone structure can be key indicators for diagnosing osteoporosis in these patients (6).

A comprehensive assessment of the mandibular cortical bone in RA patients involves a combination of imaging modalities and quantitative analysis techniques. Panoramic radiography, CBCT, MRI, fractal dimension analysis, and DEXA all play crucial roles in diagnosing and monitoring bone changes. Early and accurate detection of mandibular bone involvement in RA is essential for timely intervention and management to prevent further complications and improve patient outcomes (7).

In this regard, 3D imaging techniques are particularly valuable. CBCT, in particular, is advantageous due to its lower cost, minimal radiation exposure, and high-quality resolution for complex tissues. (8). The mentioned benefits are particularly useful in identifying the precise extent of a lesion. Nevertheless, unlike CT scans, which utilize Hounsfield units to detail the internal structure of lesions, CBCT relies on grayscale values for radiodensity quantification, making this specific analysis challenging (9). Conducting a detailed quantitative analysis of bone architecture instead of a qualitative assessment can be particularly beneficial in this context.

The trabeculae within cancellous bone exhibit a vast array of shapes and sizes, characterized by their mathematical complexity. Analyzing these structures, known as fractals, can enhance diagnostic processes. Fractal analysis (FA) and fractal dimension (FD) evaluate the complexity of trabecular structures by using a non-integer ratio or index (10).

This study aims to assess the mandibular cortical thickness between Rheumatoid arthritis (RA) patients and healthy controls using cone beam computed tomography (CBCT). To compare the mandibular cortical bone thickness in rheumatoid arthritis (RA) patients using fractal dimensions analysis of cone beam computed tomography images (CBCT).

Materials And Methods

This prospective imaging study received approval from the Institutional Review Board with the approval number IHEC/SDC/OMED-2105/23/112. A sample size of 25 RA patients and 25 healthy controls is sufficient to detect a moderate effect size in mandibular cortical bone measurements with 80% power with a 95% confidence interval.

The inclusion criteria are as follows: Confirmed rheumatoid arthritis diagnosis under medications including corticosteroids (e.g., prednisone), disease-modifying antirheumatic drugs (DMARDs), or biologics. It is important to document the type, dosage, and duration of medication use to evaluate its impact on bone health. Aged between 30 and 70 years. The exclusion criteria are as follows: Distorted images of CBCT. Patients with a history of other bone diseases (e.g., osteoporosis, Paget's disease). Patients with a history of jaw trauma or surgery.

This study will employ a cross-sectional observational design to investigate the changes in mandibular cortical thickness and its fractal dimensions in patients with RA compared to healthy controls. The CS 9600 scanner from Carestream Dental was used to obtain CBCT images, with exposure settings tailored to each patient's age and physique. The images, collected in DICOM format, required settings between 90-110 kVp and 8-10 mA, ensuring optimal image quality and patient safety.

To perform fractal analysis on CBCT images, will be utilizing ImageJ (FIJI) software tools that can extract the patterns and structure of interest from the image data. The selected region of interest (ROI) for the CBCT images focused on the mandibular region below the lower canine tooth apex on both the right and left sides (Figure 1). This approach was used to avoid overlapping with critical anatomical structures such as the mental foramen, genisapophyses, and high-stress regions around the premolars and molars, ensuring clearer and more accurate imaging results. All the slices were saved in JPEG format. The images were then transferred to the ImageJ (FIJI) version 1.51 program program (National Institutes of Health, Bethesda, MD @; https://imagej.nih.gov/ij/download.html) to calculate the FDs.

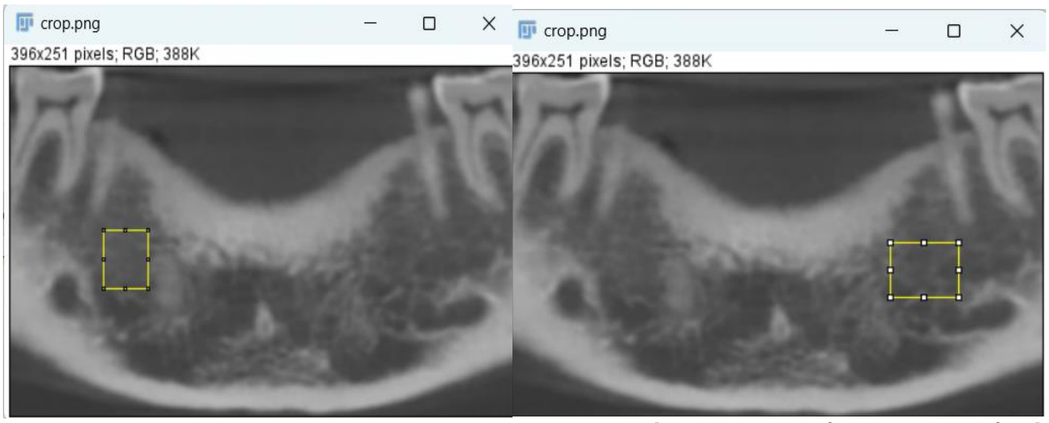


Figure 1: The area region of interest (ROI) for the CBCT images is concentrated on the mandibular region beneath the apex of the lower canine tooth on both the right and left sides.

Fractal Analysis (Fa) Procedure

Image J software analyses the images to evaluate the possibilities of changes in the trabecular pattern of the area of interest. The following steps were followed: I) Create a duplicate of the region of interest (ROI) image to ensure the original remains unchanged for reference. II) Apply a Gaussian blur with a radius of 33 pixels. This acts as a low filter. III) Subtract the blurred image from the original image. This step highlights the finer details by removing the broader variations in density. IV) Add the computed constant to each pixel in the resulting subtracted image. This operation adjusts the pixel values so that the average intensity of the resulting image is approximately 128. V) Convert the normalized image into a binary format, where the image is reduced to black and white pixels. VI) Erode the binary image. This morphological operation reduces the objects in the image by setting each pixel to the minimum value within its neighborhood. VII) Dilate the eroded image, which expands the objects by setting each pixel to the maximum value within its 3x3 neighborhood. VIII) Invert the binary image, swapping the black and white pixels. IX) Apply a skeletonization process to reduce the objects in the binary image to a single-pixel-wide skeleton, retaining the essential structure of the trabeculae while removing extraneous edges (Figure 2).

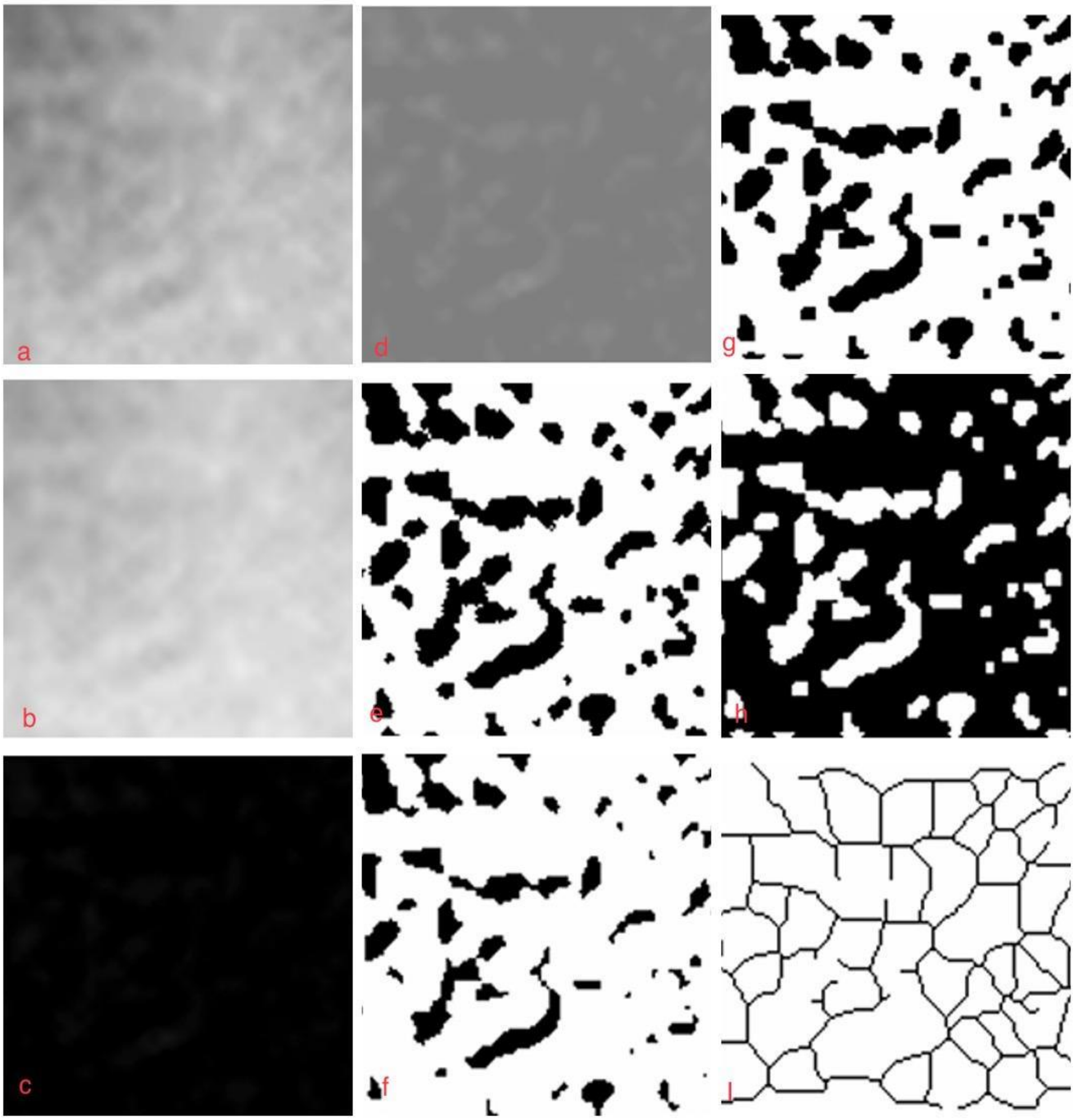


Figure 2: Image J software analyses the images (a. original image, b. Blur image using Gaussian blur with a radius of 33, c. Subtract the background image, d. Add the value of 128, e. convert image into Binary image, f. Eroded the binary image, g. Dilate the eroded image, h. Invert the binary image, i. skeletonization image).

The images were skeletonized to reduce the structures to single-pixel-wide lines, representing the essential features of the trabecular pattern. The Fractal Box Counter plugin in ImageJ was utilized to conduct the box-counting analysis. This method involves overlaying a grid of boxes of varying sizes (C2, C3, C4, C6, C8, C12, C16, C32, and C64) on the skeletonized image and counting the number of boxes that contain part of the skeleton. A plot was created with the logarithm of the box size on the x-axis and the logarithm of the box count on the y-axis. The slope of the resulting line provides the fractal dimension (FD) (Figure 3).

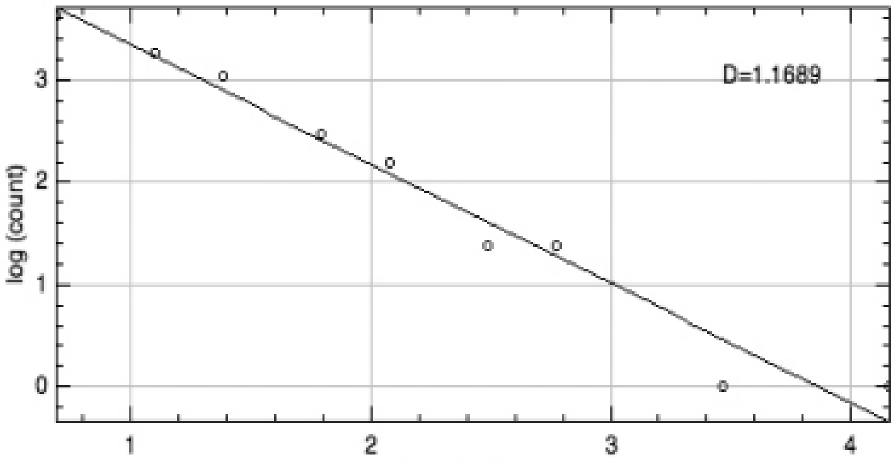


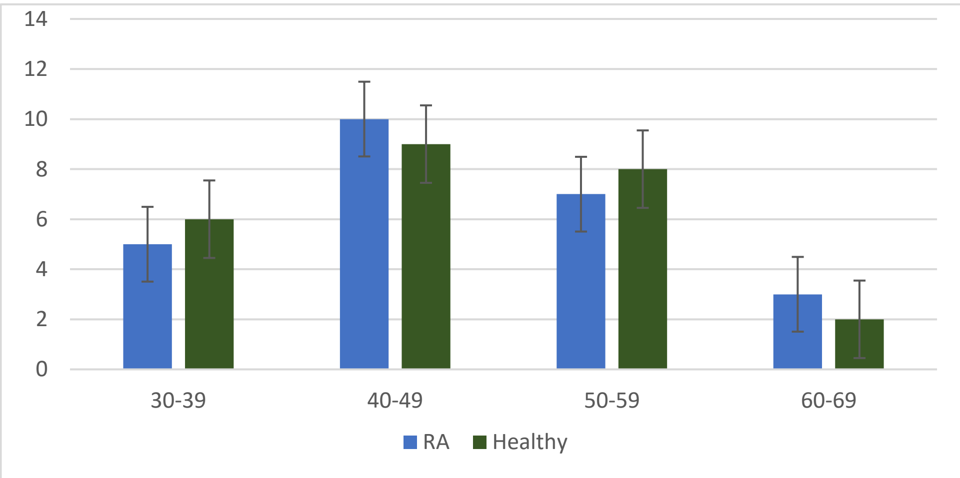
Figure 3: ImageJ was used to perform the box-counting.

Statistical Analysis

SPSS 20.0 (SPSS, Chicago, IL) was used to perform all statistical analyses. This statistical test was chosen to compare the FD values between two groups: healthy individuals and patients with rheumatoid arthritis (RA). The Independent Samples t-test is used to compare the means of two separate groups to determine if there is a statistically significant difference between them. A comparison of variables within the group (left side/right side) was done using a paired t-test. Significance was defined as $p \leq 0.05$.

Results

Each of the two group categories consisted of 50 patients. The mean age along with the standard deviations is provided. The bar graph displaying the age includes error bars (Graph 1).



Graph 1 The bar graph depicts the age distribution of patients included in the study

The selected samples for the analysis illustrate the distribution of genders. (Table *1*).

Groups	**Male**	**Female**	**Total**
RA Patients	10	15	25

Control groups	12	13	25

TABLE 1: Gender distribution of the samples.

The bar graph below presents the fractal values graphically.

Groups	Gender	Mean ± SD	p-value
RA Patients	Male	1.65 ± 0.14	0.002
	Female	1.69 ± 0.13	
Control Groups	Male	1.86 ± 0.11	0.001
	Female	1.90 ± 0.11	

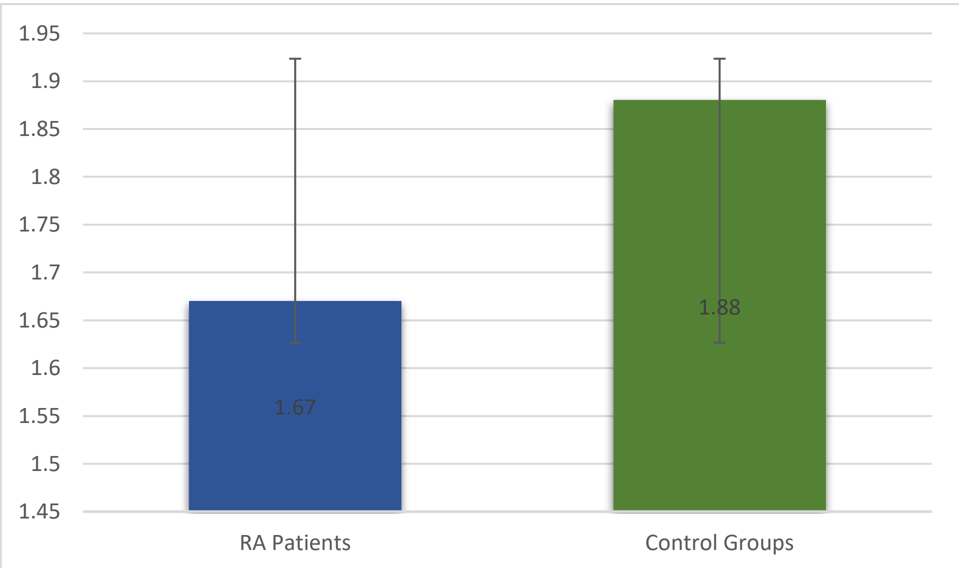
Table 2: Fractal Dimension Values by Gender

Comparison of fractal dimension values between the groups.

Groups	Fractal dimensions value	p-value
RA Patients	1.67 ± 0.14	<0.001
Control Groups	1.88 ± 0.11	<0.001

TABLE 4: Comparison of fractal dimension values between the groups

The bar graph below presents the graphical representation of the fractal values



Graph 2: the control group had a higher fractal dimension

values than Rheumatoid arthritis (RA) patients

An Independent t-test is done to compare the fractal dimension values between RA patients and healthy controls. A paired t-test was done to compare within-group differences, such as between male and female patients. Rheumatoid arthritis patients (both male and female) have significantly lower fractal dimension values compared to healthy controls, suggesting poorer bone quality. There is a gender-based difference in fractal dimension values within RA patients, with males showing slightly lower values than females. The significant differences identified by the ANOVA and further clarified by Tukey's HSD test underscore the impact of rheumatoid arthritis on bone structure and the need for tailored management strategies based on gender.

Discussion

Rheumatoid arthritis (RA) is a chronic autoimmune disorder characterized by inflammation and erosion of joints (11). Rheumatoid arthritis (RA) is more prevalent among females than males and is primarily seen in the elderly population. This study found that RA patients have significantly lower fractal dimensions of mandibular cortical thickness compared to healthy controls. This suggests that the mandibular bone structure in RA patients is more disorganized and less complex compared to healthy individuals. To compare the FD values, demographic parameters were analyzed. Fractal analysis (FA) is a mathematical technique used to quantify the metric properties of complex, irregular structures, such as the trabeculae found in cancellous bone. This method involves transforming irregular shapes into approximate geometric forms using specialized software. Subsequently, the dimensions of these geometric forms are calculated and expressed as fractal dimension (FD) values (12). Yesiltepe et al. studied CBCT images of 10 females RA patients and evaluated the FD values for trabecular bone structures, rheumatoid arthritis patients had lower fractal dimension values than healthy patients for each side (13).

While some studies suggest a correlation between increasing fractal dimensions (FD) and greater structural complexity, there is no universal agreement on this matter. Variations in fractal dimension values are often attributed to anatomical differences, diverse methodologies used to calculate FD, and the specific areas of the alveolar bone that are examined. Identifying the appropriate criteria for selecting regions of interest and the methods for capturing two-dimensional images is essential. Contrary to our findings, other researchers, including Hau et al., have observed that FD values may rise in patients with conditions that induce osteoporotic changes in bone structure (14).

Fractal analysis has been widely applied in the medical field and is becoming more prevalent in dental specialties. It is particularly used to examine bone trabecular patterns, especially for evaluating trabecular structures in osteoporosis cases. This method provides a more accessible and standardized approach to assessing bone mineral density (15). While fractal analysis has been widely reported using panoramic radiographs, fewer studies focus on cone-beam computed tomography (CBCT). The high-resolution images provided by CBCT enable precise evaluation of bone quality. Previous studies suggest that comparing orthopantomographic radiographs with CBCT results in more accurate fractal analysis values, akin to those derived from bone mineral density assessments using dual-energy X-ray absorptiometry (16).

A CBCT study examining bone trabecular patterns using fractal dimension (FD) and fractal analysis (FA) in odontogenic cysts has identified significant variations in trabecular parameters across different types of cysts. These results could have important implications for the diagnosis, treatment, and prognosis of odontogenic cysts (17). From this study. The significant reduction in FD values in RA patients suggests that rheumatoid arthritis adversely affects the trabecular structure of the mandibular bone. This reduction in fractal dimension reflects a loss of complexity and structural integrity of the bone, and the study also revealed significant gender-based differences in FD values within RA patients. Male RA patients had lower FD values compared to females.

While the study provides valuable insights, it is not without limitations. The relatively small sample size may limit the generalizability of the finding Although the study offers valuable insights, it has some limitations. The relatively small sample size may restrict the generalizability of the results. Additionally, longitudinal studies would be beneficial to assess the progression of bone changes over time and the impact of various treatments on bone quality. Future studies should focus on controlling these variables to offer a more complete understanding of the connection between RA and the quality of mandibular bone.

Conclusion

In conclusion, this study highlights the significant impact of rheumatoid arthritis on mandibular cortical bone quality, as evidenced by reduced fractal dimensions in RA patients. The findings underscore the importance of regular bone health assessments in RA patients and suggest that FD analysis using CBCT could be a valuable tool in clinical practice. Addressing the bone health of RA patients, particularly those at higher risk, could improve patient outcomes and reduce the incidence of fractures and other complications associated with bone deterioration.

References

1. Firestein, G. S., & McInnes, I. B. (2017). Immunopathogenesis of Rheumatoid Arthritis. *Immunity*, 46(2), 183-196.
2. Alamanos, Y., Voulgari, P. V., & Drosos, A. A. (2006). Incidence and prevalence of rheumatoid arthritis, based on the 1987 American College of Rheumatology criteria: a systematic review. *Seminars in Arthritis and Rheumatism*, 36(3), 182-188.
3. Guo Q, Wang Y, Xu D, Nossent J, Pavlos NJ, Xu J. Rheumatoid arthritis: Pathological mechanisms and modern pharmacologic therapies. Bone Res 2018;6:15.
4. Gamsiz-Isik, H., Kansu, O., Ozbek, M., & Orhan, K. (2012). Mandibular cortical bone in patients with rheumatoid arthritis. *DentoMaxilloFacial Radiology*, 41(4), 307-312.
5. Koyama, Y., & Sasaki, Y. (2013). Fractal dimension analysis of mandibular cortical bone on panoramic radiographs in relation to bone mineral density and vertebral fractures in postmenopausal women. *Clinical Oral Investigations*, 17(5), 1725-1730.
6. Sanchez-Molina D, Velazquez-Ameijide J, Quintana V, Arregui-Dalmases C, Crandall JR, Subit D, *et al.* Fractal dimension and mechanical properties of human cortical bone. Med Eng Phys 2013;35:576-82.
7. Geraets, W. G., van der Stelt, P. F., Netelenbos, J. C., & Elders, P. J. (2007). A new method for automatic recognition of the mandibular cortex on panoramic radiographs for osteoporosis screening. *DentoMaxilloFacial Radiology*, 36(8), 488-492.
8. Banik S, Banik S, Shaikh MH, Sadat SA, Mallick PC: Keratocystic odontogenic tumor and its radiological diagnosis by 3-dimensional cone beam computed tomography (CBCT). Update Dent Coll J. 2011, 1:10-3.
9. Barngkgei I, Al Haffar I, Khattab R: Osteoporosis prediction from the mandible using cone-beam computed tomography. Imaging Sci Dent. 2014, 44:263-71. 10.5624/isd.2014.44.4.263
10. Kato CN, Barra SG, Tavares NP, Amaral TM, Brasileiro CB, Mesquita RA, Abreu LG: Use of fractal analysis in dental images: a systematic review. Dentomaxillofac Radiol. 2020, 49:20180457. 10.1259/dmfr.20180457
11. Paget SA, Gibofsky A, Beary JF. Romatolojiveklinikortopedi El Kitabı. 4th ed. İstanbul: Nobel TıpKitapevleri; 2004.
12. Kato CN, Barra SG, Tavares NP, Amaral TM, Brasileiro CB, Mesquita RA, Abreu LG: Use of fractal analysis in dental images: a systematic review. Dentomaxillofac Radiol. 2020, 49:20180457. 10.1259/dmfr.20180457
13. Yeşiltepe S, Yılmaz AB, Kurtuldu E, Sarıca I. Fracatal analysis of temporomandibular joint trabecular bone structure in patients with rheumatoid arthritis on cone beam computed tomography images.
14. Hua, Y., Nackaerts, O., Duyck, J., Maes, F. and Jacobs, R. (2009) Bone Quality Assessment Based on Cone Beam Computed Tomography Imaging. Clinical Oral Implants Research, 20, 767-771.

15. Kavitha MS, An SY, An CH, et al.: Texture analysis of mandibular cortical bone on digital dental panoramic radiographs for the diagnosis of osteoporosis in Korean women. Oral Surg Oral Med Oral Pathol Oral Radiol. 2015, 119:346-56. 10.1016/j.oooo.2014.11.009

16. Güngör E, Yildirim D, Çevik R: Evaluation of osteoporosis in jaw bones using cone beam CT and dual-energy X-ray absorptiometry. J Oral Sci. 2016, 58:185-94. 10.2334/josnusd.15-0609

17. Murugesan I, Kumar Vadivel J, Ramalingam K (February 19, 2024) Bone Trabecular Pattern Analysis in Odontogenic Cysts Using Cone Beam Computed Tomography: A Clinical Retrospective Study. Cureus 16(2): e54452. DOI 10.7759/cureus.54452