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Original Article

Dentistry Section

A Fractal Dimension Analysis to Evaluate the Change in the Alveolar Osseous Structure of Mandibular Incisors after Orthodontic Treatment: A Retrospective Study

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ABSTRACT

Introduction: As bone traces tooth movement during orthodontic treatment, leading to biological response of the surrounding tissues of the teeth resulting in remodelling of the socket, favourable bone response is expected after incisor retraction. Orthodontic treatment causing changes in alveolar bone can be evaluated using Fractal dimension (FD) analysis, a mathematical method of information processing, where the input data is in the form of an image and generated information is displayed as numbers.

Aim: To evaluate changes in the trabecular structure of alveolar bone after incisor retraction in the mandibular symphysis region in adult patients using fractal analysis.

Materials and Methods: This retrospective study was conducted with digital Orthopantomogram (OPG) of 30 patients with class I and class II malocclusion with mandibular incisor protrusion treated with extraction and retraction of anterior teeth were taken with standard protocols at the three different periods, before orthodontic treatment (T0), before retraction (T1) and after retraction of anterior teeth (T2) included in the study. Regions of interest were located between the apices of mandibular incisors. FD was calculated using Image J software. Statistical Analysis was carried out by repeated Analysis of Variance (ANOVA) test and post-hoc test.

Results: Total of 30 cases were selected, out of which 15 were males and 15 females with the mean age of 21±2 years. FD values of the alveolar bone of mandibular incisors at T0 were 1.470±0.09 which reduced to 1.390±0.09 at T1 and to 1.350±0.08 at T2. This overall changes in FD values were significant (p-value=0.001).

Conclusion: Fractal dimension analysis demonstrate significant changes in bone trabeculation of the mandibular symphysis region before and after orthodontic treatment. It has valuable impact in the cases of fenestration, dehiscence's, and osteoporosis.

Keywords: Digital panoromic radiographs, Fractal geometry, Orthodontic tooth movement

INTRODUCTION

The soft tissue profiles of patients with bimaxillary protrusion are considered unaesthetic. These patients depict characteristics like dentoalveolar flaring of the maxillary and mandibular anterior teeth, which causes into protrusion of the lips and convexity of the face. To reduce the facial protrusion the treatment of choice includes extracting the four first premolars. Maximum stability is achieved when the incisors are positioned in the medullary portion of the alveolar bone and in good harmony with the labial and lingual musculature. Incisors when positioned in upright position on the basal bone improves the support around the root of incisors which leads to better periodontal conditions [1]

As bone traces tooth movement during orthodontic treatment leading to biological response of the surrounding tissues of the teeth resulting in remodelling of the socket, favourable bone response is expected after incisor retraction [1]. However, sometimes there may not be coherence with this rule. Mechanical forces which are exerted on the tooth are transmitted to the bone via the Periodontal Ligament (PDL) to produce orthodontic tooth movement. The biological response of these periodontal tissues to loads of mastication and orthodontic movement enables the supporting bone to adapt to changes in its mechanical environment. The PDL bone interface plays an integral component of mechanotransduction in normal occlusion and in orthodontic movement [2].

When the incisors are retracted the risk of adverse effect is present. Thus, this must be carefully monitored to avoid the iatrogenic effects. The chances of dehiscence are different for extraction and non extraction cases in relation to lower incisors [3]. It is therefore important to investigate biomechanical and structural reactions of the bone, the PDL, and the PDL-bone interface with external forces, to establish optimal force application in orthodontic tooth movement.

This change in alveolar bone during and after orthodontic treatment has been observed, but only few investigations [4] have dealt with the evaluation of quantitative bone quality of lower anterior teeth [3]. This change can be assessed using FD analysis, which is a mathematical method of information processing, where the data is uploaded in the form of an image and generated information is displayed as numbers [5].

Fractal analysis is used to describe complex shapes and structural patterns and results are displayed numerically as FD values. Fractal analysis is the process of information processing, where the data is uploaded in the form of an image. The generated information is stored as numbers. The execution of this uploaded image processing requires a computer system. The quality of the standardised images becomes an important factor, as considerable compression ratio determines the effective image compression. Compressing an image reduces the amount of unwanted data from the image. The objective of quality measures is to imitate the rough quality of the decoded images. The signal-to-noise ratio is a quality measure which is frequently used to evaluate the deviation between an original and a coded image [5]. Fractal geometry of an object is a measure of its self-similarity. It is a method for illustrating complexity and thus computing morphologies that are generally irregular. Mandelbrot established the concept of "Fractal" to describe objects with "fractional" geometric dimensions. The fractal dimension of an

object works on its space-filling property, the more space the object occupies, higher is the FD [6].

No previous studies used this analysis to investigate the changes in trabecular bone patterns resulting from fixed orthodontic treatment. With plenty research along with recent reports suggests that FD analysis can successfully demonstrates changes in trabeculae [4,1,2]. Thus the study was aimed to evaluate changes in the trabecular structure of alveolar bone after incisor retraction in the mandibular symphysis region in adult patients using fractal analysis.

Objectives

- To evaluate the osseous structure before orthodontic treatment.
- To evaluate the osseous structure before retraction and after alignment and
- To evaluate the osseous structure after complete orthodontic treatment.

MATERIALS AND METHODS

This retrospective study was conducted in Department of Orthodontics and Dentofacial Orthopaedics of Bharati Vidyapeeth (Deemed to be) University Dental College and Hospital, Sangli, Maharashtra, India from April 2022 to August 2022. The data in the form of OPG was obtained from patients who underwent treatment from January 2020 and completed the treatment by April 2022. The study was started after approval by the Ethical Committee of Bharati Vidyapeeth Dental College and Hospital, Sangli, Maharashtra, India [BV(DU)CH&H/Sangli/IEC/ D-71/22].

Inclusion criteria:

Records of the patients with

- Fully erupted permanent dentition
- Symmetrical face
- Digital Panaromic Radiographs of patients with first premolar extraction in mandible
- Patients with age group 18-25 years with any gender.

Exclusion criteria:

Records of the patients with

- Non extraction cases
- Patients on anti-inflammatory drugs
- Patients with medical history of bone metabolism problem
- Patients with history of lower incisor trauma

Sample size calculation: GPower 3.1.0 software package was used to determine the number of individuals to include in the study, and power analysis was performed. Sample size calculation was based on the ability to detect significant differences at a α=0.05 error probability. According to the power analysis, a sample size of estimated was 30. Therefore, 30 patients were included who required lower first premolar extraction.

Care was taken that no subject had any general health issues or presented any co-morbidity. The samples were selected randomly out of which 15 were males and 15 were females. Samples selected for the study were native of Sangli, which is a part of Western Maharashtra of India.

Study Procedure

Records of the patients bonded with MBT 0.022 slot were selected for the study. The alignment was done till 19×25 stainless steel wire. After alignment the extraction of first premolars was advised. Retraction was done either with sliding or loop mechanics.

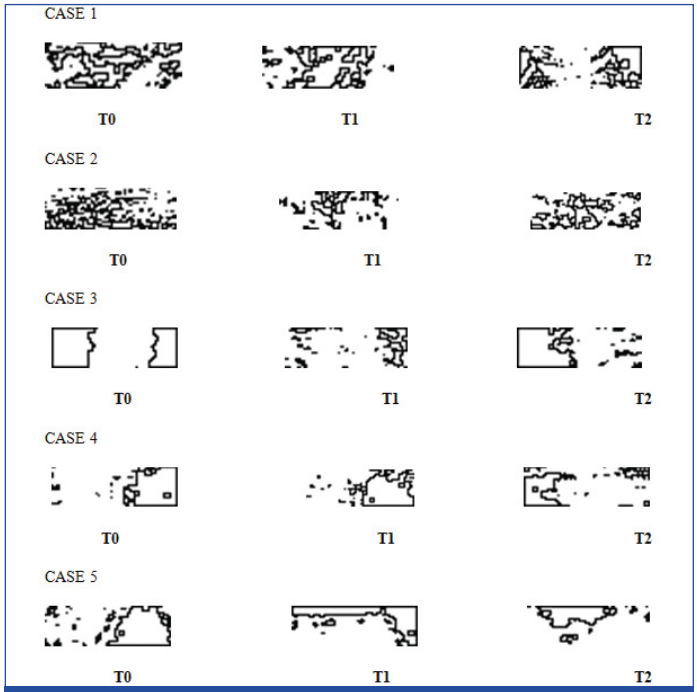
Cephalometric and digital panoramic radiographs of the patient were taken as (T0) i.e., before alignment, (T1) i.e., after alignment and before retraction and postorthodontic treatment (T2). The timeline for the radiograph T0 was the start of treatment, T1 was 6-8 months and T2 was 1.5-2 years.

Dental Panoramic Radiographs (DPRs) were measured using Image J version 1.3 software. Image J is a Java-based image-processing program, and it was preferred to use Image J to process DPRs. Customised software designed by White and Rudolph was used for FD analysis by means of the box counting method [7].

The Region Of Interest (ROI) was the mandibular symphysis region i.e below the mandibular all four incisors with the range of 60×20-pixel size. Tagged Image File Formats (TIFFs) were made from the DPRs of the patients in the groups because of their high resolution. [Table/Fig-1]. This standardisation helped to extract the same region from all the panoramic radiographs. Due to varying thicknesses of bone and overlying soft tissues, Gaussian blur was used to distract brightness differences. The resulting image was then subtracted from the original image. 128 gray value was added to each pixel location to distinguish bone marrow spaces and trabeculae. FD values were calculated after applying binary, erode, dilate, invert, and skeletonising processes [Table/Fig-2,3]. Increase in the FD values shows good trabecular pattern whereas decrease in the FD value shows alveolar bone loss [8].

[Table/Fig-1]: ROI of Mandibular symphysis region.

[Table/Fig-2]: a) Original panoramic radiograph; b) Binary image; c) Binary image converted to outline image.



[Table/Fig-3]: Fractal images.
T0=Fractal image before orthodontic treatment of mandibular symphysis region (ROI) from OPG
T1= Fractal image after alignment and levelling of mandibular symphysis region (ROI) from OPG
T2= Fractal image after orthodontic treatment of mandibular symphysis region (ROI) from OPG

STATISTICAL ANALYSIS

The statistical analysis was calculated by Statistical Package for Social Sciences software version 23.0. Comparison of change in FD analysis values from T0 to T2 was calculated by repeated measure ANOVA test. And Pairwise (intergroup) comparison of FD values was calculated by post-hoc test.

RESULTS

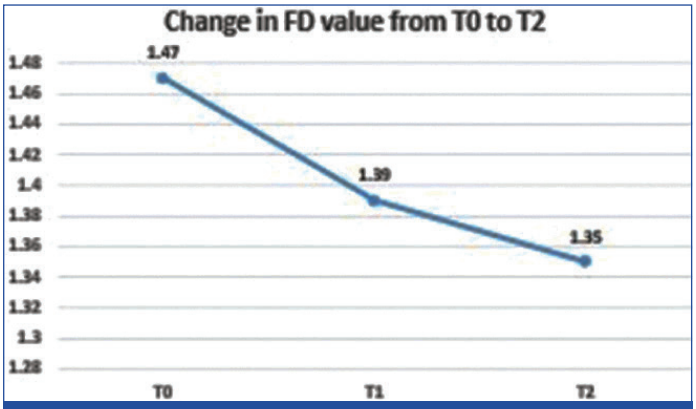
The mean age of study population was 21±2 years of any gender. FD values of the alveolar bone of mandibular incisors at T0 were 1.470±0.09 which reduced to 1.390±0.09 at T1 and to 1.350±0.08 at T2 [Table/Fig-4]. The change in the trabecular pattern of bone was significant throughout the orthodontic treatment in extraction cases [Table/Fig-5,6].

Time	Mean	Std. Deviation	F value	p-value
T0	1.47	0.09	41.564	0.001*
T1	1.39	0.09		
T2	1.35	0.08		

[Table/Fig-4]: Comparison of change in FD analysis values from T0 to T2.
Repeated measure ANOVA test; *indicates significant difference at p-value ≤0.05

Pair	Difference	p-value
T0-T1	0.08	0.001*
T0-T2	0.12	0.001*
T1-T2	0.04	0.001*

[Table/Fig-5]: Pairwise (intergroup) comparison of FD values.
Multiple comparison adjustment using least significant difference test; *indicates significant difference at p≤0.05 [post-hoc test]



[Table/Fig-6]: Change in FD value from T0 to T2.

DISCUSSION

This study examined the trabecular architecture on DPRs. DPRs are used in general dental practice to diagnose dental diseases like periapical lesions, to locate the position of impacted teeth, positions of third molars etc. and in Orthodontics, it is used to assess bony trabecular pattern, growth status, orthodontically induced root resorption and root formation. In addition, they better visualise the bone density and the trabecular pattern [9]. Therefore to visualise the changes in bony trabeculae pattern, DPRs of 30 patients were taken pretreatment, midtreatment that is before retraction and postretraction and these digital panoramic radiographs were examined by fractal analysis. The result showed statistically significant changes in the bony trabeculae of mandible in region of incisors due to the retraction. There is presence of bone loss during orthodontic treatment. There are several methods to estimate the alveolar bone density from dental radiographs, but fractal analysis is an inexpensive and readily available method [9]. The trabecular bone depicts branching pattern that exhibits fractal properties which shows self-similarity and lack of well-defined scale. Because of this phenomenon, the measurement of FD can be used to determine trabecular complexity and bone structure [5].

In many cases excessive lingual retraction of the incisors is needed to reach the objectives of treatment, and the extent of alveolar bone remodelling that occurs in response to this type of movement may vary with each patient. When the area for movement is limited, excessive force will cause the tooth to touch the cortical plate of the alveolus, leading to resorption of the cortical bone and exposure of the root [1]. Moving the incisors this way leads to alveolar bone loss, and there is disagreement about whether the remodelling capacity of the alveolar bone can compensate for the bone loss in every case.

According to the study conducted by Krishna UN et al., there is risk of adverse effects on bone during retraction of anteriors after extraction of premolars. Higher orthodontic forces might overload the periodontal tissues and can lead to negative effect which might hinder the tooth movement. Care must be taken during retraction to avoid any iatrogenic effect on bone [10]. Sarikaya S et al., concluded from there study that during retraction of anterior teeth, long-term consequences of alveolar bone losses and some dehiscences are present [1].

In 2005 Wagle N et al., suggested that orthodontic appliance produce mechanical stress which leads to change in FD of the PDL-bone interface, which is directly proportional to the magnitude of force applied [2]. It is concluded from the study by Bollen AM et al., in 2001 that even if fractal analysis is a method for describing complex shapes and structural patterns, panoramic radiographs can be used as a possible alternative for the measurement of FD to periapical radiographs [11]. Study done by Yodthong N, et al., in 2013 concluded that rate of tooth movement, change in inclination, and extent of intrusion are significant factors that may influence alveolar bone thickness during upper incisor retraction, which is almost in coherence with the result of present study [8].

In this study, with the help of Image J software, we can assess the bone structure in three-dimensional view for a two-dimensional object. FD analysis uses a mathematical method to measure the complex structures such as trabecular bone and can be applied to DPR. Only few previous studies used FD analysis to investigate the changes in trabecular bone patterns resulting from orthodontic treatment [1,2]. FD analysis is one of the recent non invasive tools which can be used to demonstrates changes in the bony trabeculae [4].

Limitation(s)

Although previous studies have reported high reliability of FD analysis with OPG still it is beneficial to conduct future studies using three-dimensional images system for more detailed structure and radiation safety. The other major limitation of this study was limited sample size. Also, the cases with symphysial micro implants could not be used to access the trabecular pattern of that region.

CONCLUSION(S)

Thus, this study concludes that there was change in the trabecular pattern at the mandibular symphysis region on retraction of the anterior teeth. These results indicate that when mandibular incisors are retracted, the risk of adverse effects may be present. The long-term consequences of these alveolar bone losses are unknown. It has valuable impact in the cases of fenestration, dehiscence's, and osteoporosis. New alveolar bone formation may be expected after months, but the risks should be disclosed to the patients, and great care should be used when retracting mandibular incisors. Very light forces and long-term activations to allow the alveolar bone to adapt may be useful in this regard to avoid any negative iatrogenic effects. This study concludes that FD analysis is the most cost-effective method to study the bone trabecular patterns of two-dimensional images.

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