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Stress Distribution in Maxillary Anterior Region during En masse Intrusion of Six Anterior Teeth: A Finite Element Analysis

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ABSTRACT

Introduction: A true intrusion was considered difficult until recently but work of many clinicians has laid this controversy to rest. Effects of en masse intrusion have been studied only clinically till now. The aim of this study was to analyse stress distribution in alveolar bone, periodontal membrane, and the roots of six maxillary anterior teeth during their en masse intrusion by applying 45 grams of force per side by using finite element method.

Methodology: In this study, a three-dimensional CT scan of six maxillary anterior teeth was taken. A finite element model of six maxillary anterior teeth was simulated. On this model, vertical intrusive force of 90 grams (45 gm/side) was applied to determine the stress distribution along the roots, periodontal ligament, and the surrounding bone of teeth.

Results: We observed that the stress in our model was concentrated at apex of the roots. The maximum amount of stress was at apex of the central incisors followed by canines and then lateral incisors. In periodontal ligament (PDL) more amount of stress was seen at the apex of central incisors. Among teeth, PDL, and bone, the maximum amount of stress was observed in bone.

Conclusion: It is concluded that stresses on dental systems in our modelling study are in normative range. This stress can be taken up by the roots and the surrounding tissues without causing any deleterious effect.

INTRODUCTION

Orthodontics has evolved over the years from an empirical art to a definitive science. In recent years, greater emphasis has been placed on the understanding of the exact mechanical and biological systems that govern the force needed to produce tooth movement.

Deep overbite is a common feature of many malocclusions. One of the objectives of orthodontic treatment is to establish a normal overbite. Intrusion of maxillary anterior teeth is required very often to reduce incisor exposure, in patients with increased lower facial height. A great controversy among the proponents of the different treatment modalities has been reported.[1]

Until recently true intrusion, which refers to the apical movement of the geometric centre of the root (centroid) in respect to the occlusal plane or a plane based on the long axis of the tooth, was considered difficult[2], but work of many clinicians has laid this controversy to rest. This has necessitated the understanding of intrusion mechanics, which forms the chief component of bite opening where the amount of incisor exposure is of major concern.

A precise force system must be developed for true intrusion. The force applied earlier was light (10-20 grams)[3,4], but now with absolute anchorage from implants, 45 grams of force per side can be applied to have en masse intrusion of the six anterior teeth. According to literature, the application of external forces to the teeth to produce orthodontic tooth movement carries some calculated risks. One of these is irreversible root resorption.[5] Different types of orthodontic tooth movement may produce different mechanical stresses at varying locations within the root. In vivo measurement of stress is difficult at best. The response of the periodontium to these forces has mainly been studied in animals, using histological techniques. But even with the techniques used, it has not been possible to study the internal stresses developed in the periodontium.

The amount of stresses that are produced by applying 45 grams of force/side in the anterior region has to be evaluated. One of the recent and advanced ways to study these stresses is by generating a model representing the structures to be investigated and studying the reaction of this model to applied forces. Of the various methods propounded to assess the force systems precisely, the finite element method is the most significant. As we all know, oral cavity consists of various complex structures with a very limited accessibility. Due to this, most biomechanical research of the oral environment has been performed in vitro. Finite Element Analysis (FEA) is a modern tool for numerical stress analysis, with an advantage of being applicable to solids of irregular geometry that contain heterogeneous material properties.[6] Finite Element Analysis (FEA) has been widely used through numerical analysis that has been successfully applied in many engineering and bio-engineering areas since the 1960s.[7] It has now become a useful technique for stress strain analysis in both biological and mechanical systems. This method makes it possible to analytically apply various force systems at any point and in any direction and also quantitatively assess the distribution of such forces through the wire and related structures. The aim of this study was to analyze stress distribution in alveolar bone, periodontal membrane and the roots of six maxillary anterior teeth during their en masse intrusion by applying 45 grams of force per side by using finite element method.

METHODS

A three-dimensional (3-D) quantitative analysis requires some mathematical method, making use of a model accurate both in anatomy and physical characteristics, and alongwith the use of a computer, which has become an indispensable aid as far as 3-D analyses are concerned. All these are available in the branch of engineering through the use of finite element method (FEM) of analysis. This involves the subdivision of the structure under consideration into a number of finite sections or elements. These elements are connected at intersections called nodes. A complex structure may contain many elements, which can be arranged in two or three dimensional in layers, rather like bricks in a wall.

Steps involved in the finite element model:

1. Construction of the geometric model: The aim was to produce a mathematical model, which represented the biological properties of the teeth and the periodontium. This was represented in terms of points (grids), lines, surfaces (patterns) and volume (hyper-patches). In this study, a 3-D CT scan of six maxillary anterior teeth was taken. The dimensions in this method were similar to the dimensions and morphology found in Wheeler's text book. As the thickness of the periodontal ligament is not same all over, an average thickness of 0.25 mm was assumed and generated around the model of the root. The normal apico-gingival height of the alveolar bone was considered as 14 mm. The software used for geometric modeling was ABAQUS.
2. Conversion of geometric model to finite element model: This geometric model was converted into finite element model. Type of element - Quadrilateral.
3. Material property: The different structures involved in this study include teeth, the periodontal ligament and alveolar bone. Each structure has specific material property. The material properties used here were used in finite element studies done by Tanne K.[8] These material properties were the average values reported in literature.
4. Defining the boundary condition: The boundary conditions were defined to simulate how the model was constrained and to prevent it from free body motion. The nodes attached to the area of the outer surface of the bone were fixed in all directions to avoid free body movement of the tooth.
5. Application of force: Single vertical intrusive force was applied from two points; the points of force application were implants which were placed between the roots of lateral incisors and the canines. 45 grams of force per side (90 grams total) was applied from implants to hooks which were placed on the wire (21×25 stainless steel) between lateral incisors and canine.
6. Evaluation of stress distribution: Stresses (N/mm^2) were calculated and presented as different colours, which represented different stress levels. Red colour column of spectrum indicated maximum principal stresses and the following colours like orange, yellow, green, and blue represented reducing level of stress

Table 1: Stress distribution in maxillary anterior region during en masse intrusion of six anterior teeth

Area	Force applied 90 grams (45 grams/side)					
	Right maxillary canine	Right maxillary lateral incisor	Right maxillary central incisor	Left maxillary central incisor	Left maxillary lateral incisor	Left maxillary canine
Tooth	0.0093	0.0023	0.025	0.025	0.0022	0.0093
PDL	0.0056	0.0037	0.013	0.013	0.0037.	0.0056
Bone	0.05	0.043	0.050	0.050	0.043	0.05

PDL: Peridontal ligament

with blue color representing the lowest level of stress. Then the analysis was carried out.

RESULTS

The result of an analysis is called post processing. The analysis was done to check stress distribution along the roots, periodontal ligament, and the surrounding bone after applying intrusive force of 45 grams per side on the six maxillary anterior teeth. The data regarding stress distribution on each tooth is shown in table 1. The stresses on roots were identical on right and left teeth varying from 0.0093 to 0.025 with greater stress on central incisors. Similarly, stress on periodontal ligament (PDL) and bone were also maximum on the central incisors. Thus, central incisors have the highest levels of stress as shown in figure 1.

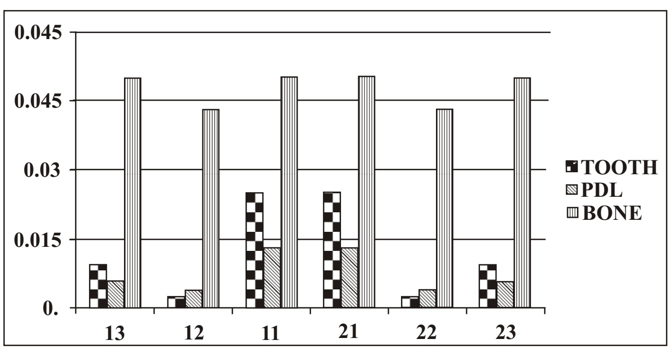

Figure 1: Multiple bar diagram representing stress distribution in maxillary anterior region during en masse intrusion of six anterior teeth.

Finite element model was constructed (Figure 2) and showed that the stress was concentrated at the apex of the roots, with the maximum amount of stress at the apex of the central incisors followed by canines and then lateral incisors confirming the findings in table 1. We also observed that in the PDL, maximum stress was observed at the apex of central incisors followed by canines and lateral incisors as shown in figure 3.

We also constructed a model of the teeth, PDL, and bone to evaluate level of stress at specific sites in them. The maximum amount of stress was observed in the bone. The bone around the apex of central incisors and canine showed almost similar amount of stress distribution (Figure 4).

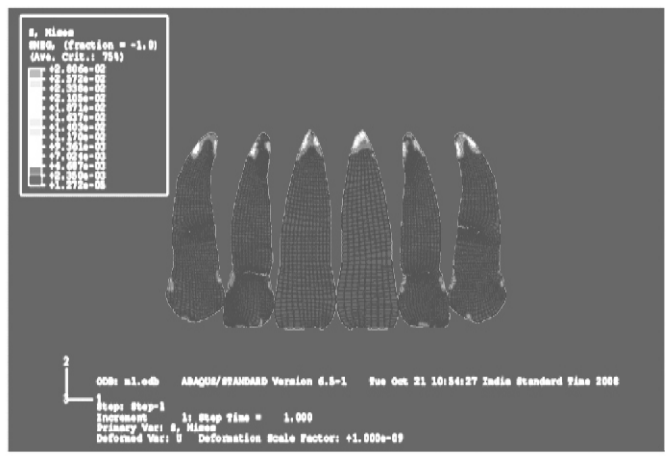

Figure 2: Finite element model of stress distribution at root apices of six maxillary anterior teeth.

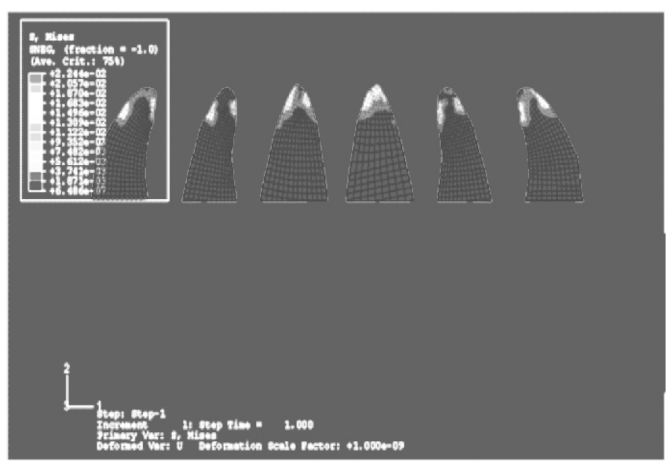

Figure 3: Finite element model of stress distribution at PDL of six maxillary anterior teeth.

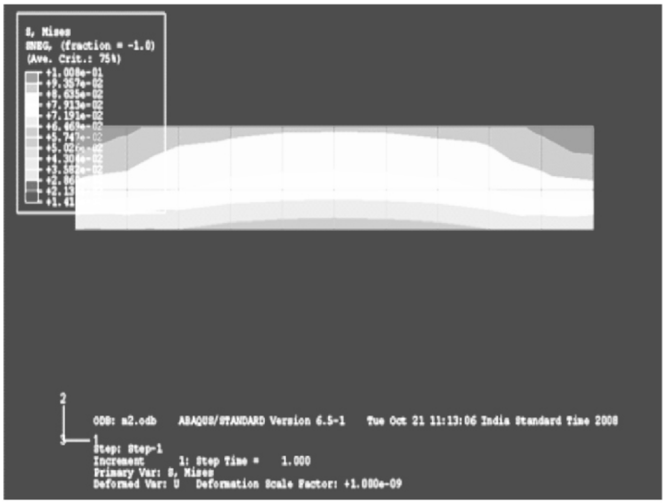

Figure 4: Finite element model of stress distribution at bone around six maxillary anterior teeth.

DISCUSSION

“Do no Harm” is an age old saying. As health professionals, our aim should be minimizing any risk that could be caused by our treatment to the patient. Unfortunately, this is not always possible in clinical practice. Despite using the best treatment mechanics, we unintentionally inflict some damage to periodontium and the surrounding bone. None the less we must strive to at least “Do minimum Harm”. To attain it, there should be thorough knowledge of biomechanics and the manner in which the tooth and its supporting structures react to forces.

Conventionally, when intrusion of anterior teeth is required only four teeth are involved; the en masse intrusion of six anterior teeth is very difficult in terms of vertical anchorage. For intrusion of six anterior teeth, incisor intrusion is done first followed by separate canine intrusion. However, introduction of mini implants, have proven to be a useful addition to the orthodontist's armamentarium for control of anchorage, and has gained enormous credibility in the clinical management of various orthodontic tooth movements.

A very light force of 15-20 grams per tooth is recommended for intrusion.[9,10] It has been documented that the use of heavier force will not increase the rate of intrusion, instead it may lead to root resorption.[11] In the present study, enmasse intrusion of all the six teeth was attempted, therefore the intrusive force applied was 45 grams per side. The forces were provided by a pre-stretched elastic chain, extending from implants placed between the roots of maxillary lateral incisors and canines to crimpable hooks in the wire, between lateral incisors and canines.

In the present study, the stress distribution at the apex of root of central incisor was seen to be 0.025 N/mm^2. A similar study was done in which an intrusive movement caused a stress concentration at the sub apical and apical levels. The stress produced at sub apical and apical region were 0.026 and 0.029 N/mm^2.[2,3,10]

A finite element study done to analyze stress in the periodontal ligament when subjected to vertical orthodontic forces suggested 100 $gram/cm^2$ (0.01N/mm^2) as the ideal stress range in the periodontal ligament to move teeth, on the basis that this preserves the vascularity of the periodontal ligament, and avoids or at least minimizes the phenomenon of hyalinization that can slow up tooth movement considerably.[12]

This study has suggested that the stress in the periodontal ligament produced under the loading of 90 grams of force (45 grams/ side) is well below the upper level of the range proposed as optimal by previous researchers, with only central incisor being an exception with stress of 0.013 N/mm^2.

In the clinical part of this study it was noticed that during en masse intrusion of all the six teeth, both the canines were intruded more than the centrals and laterals. Besides, canine exhibited intrusion much before the incisors, and as a result a mild bowing was noticed. This FEM study was done to see if enmasse intrusion of six anterior teeth produced any deleterious effect on the teeth and surrounding structures. According to this study, enmasse intrusion applying intrusive force of 90 grams (45 grams/ side) can be carried out successfully without causing harmful effects on the roots, periodontal ligament and the bone of patients.

CONCLUSION

This research gains added importance with the increased number of adult patients requiring true intrusion. This study showed that on applying a vertical intrusive force of 45 grams per side on six maxillary anterior teeth from an implant placed between the roots of lateral incisors and canines the stresses that were generated were:

1. Concentrated at the apex of the roots, with the maximum amount of stress at the apex of the central incisors followed by canines and then lateral incisors.

2. Out of teeth, periodontal ligament, and bone more amount of stress was seen in bone. The bone around the apex of central incisors and canine showed almost similar amount of stress distribution. Thus, it can be concluded that the stresses generated in this study are within the normal range which can be taken up by the roots and the surrounding tissues without causing any deleterious effect. Therefore, intrusion with the help of implants, applying 45 grams of force per side on the six maxillary anterior teeth is a favorable and time saving procedure for correction of deep bite in patients requiring true intrusion without harming the roots or the surrounding structures.

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