Research Article

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# Evaluation of the Mechanical Stress on Root from Tooth Movement by Sliding Mechanics

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## ABSTRACT

**Background**: This finite element study was conducted to calculate the distribution of stresses on root surfaces when a orthodontic force of 2N was applied at different degrees namely 0 degree, 30 degree and 45 degree to the horizontal plane.

**Materials and Methods**: An in-vitro finite element method was used to construct a three-dimensional finite element model of a mandibular arch (without first premolars). Mechanical properties like Young's modulus of elasticity and Poisson's ratio were assigned to the model. To this model an orthodontic force was applied at various degrees on the crown of the tooth model. After the application of the forces initial stress on the root surface of mandibular anterior teeth was evaluated.

**Results:** The greatest amount of the maximum level of stress was found at the cervical margin of the PDL at all tooth roots, while the maximum stresses occurred at the root crest region of the canine among them. Bodily movement and tipping forces produce stress concentrated at the alveolar crest and not at the root apex

**Conclusion:** This 3-dimensional model is a useful example to investigate the biomechanics of dental movement analyzing the mechanical stress on root surfaces in response to orthodontic forces.

**Keywords:** Sliding, Stress, Mechanical forces, Finite element method.

## INTRODUCTION

Orthodontic space closure has always been a challenge for the orthodontist. Space closure using fixed appliances is usually accomplished using a variety of methods. Dental movement can be considered as one of the basic pillars of orthodontic tooth movement[1].Once force is applied to the tooth, stress is distributed instantly along the periodontal ligament and the root surfaces to achieve a state of equilibrium[2].Sliding mechanics, which causes bodily movement of the teeth along the arch wire[3], is a basic method for an orthodontist to close space at an extraction site. Different types of orthodontic force may produce different mechanical stresses at varying locations within the root. There has not

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been sufficient mechanical stress investigation so far concerning this connection between the optimum forces of sliding mechanics and orthodontic tooth movement[4].While using sliding mechanics, a force of 100-200gms has been recommended[5]. Currently, there are several methods to apply this force by the usage of elastic modules, elastic chains, NiTi open coil springs, Pletcher coil springs etc. However, the potential disadvantage of using elastic modules or elastic chains is the significant force decay over time and also the inability to determine the exact amount of force applied by the stretch of the elastics. Though NiTi coil springs have proven to rapidly close the extraction spaces due to the application of continuous forces, they have a definite disadvantage of being an expensive option[5, 6]. All of the above options have produced space closure of the order of 0.5- 1mm/ month.

Proffit advocated that optimum force levels for orthodontic tooth movement should be just high enough to stimulate cellular activity without completely occluding blood vessels in the periodontal ligament. If the applied force is great enough to totally occlude blood vessels and cut off the blood supply, a hyalinized avascular necrotic area is formed. This area must revascularize before the teeth start to move. These processes slow down the treatment progress and increases treatment time[7, 8]. The finite element method is a numerical method of analysis that provides the orthodontist with the quantitative data that can extend the understanding of the physiologic reactions that occur and thus allows the study of stress distribution in biological system[9, 1].Thus the purpose of this research is to create a realistic finite element model to calculate the stress in the dental root from orthodontic tooth movement by sliding mechanics and integrate these simulations into the planning of the therapy.

**Aims and Objectives:**

1. To create 3-dimensional finite element model of mandibular arch comprising of teeth, brackets and arch wire to calculate the stress profile in the dental root, periodontal ligament and alveolar bone.

2. To locate the areas of maximum compressive and tensile stresses.

3. To evaluate the stress distribution at the mesial and distal sides to ensure ideal bodily tooth movement.

4. To determine the areas with largest and least amount of displacement in the anterior mandibular teeth.

## MATERIALS AND METHODS

In this study a 3-dimensional finite element model of mandibular dental arch with brackets and arch wire without first premolar (due to extraction) was generated and used to calculate the stress in the dental root from orthodontic tooth movement by sliding mechanics and integrate these simulation into the planning of the therapy.

**Computational facilities used for the study:**

Hardware: A PC workstation having an Intel Core DUO processor with 8GB RAM, 500 GB secondary storage and graphic accelerator were used for the study.

Software: The software used for the geometric modelling was ANSYS 12.

Steps involved in the generation of finite element model

1. Construction of a geometric model

2. Conversion of geometric model to finite element model (Fig.1)

3. Material property data representation(Table.1)

4. Defining the boundary condition

5. Application of forces(Table.2)

6. Solving the system of linear algebraic equations

Table 1: Material Parameter's used in the Finite Element Model.

| Material | Young's modulus ($N/mm^2$) | Poisson's Ratio |
|---|---|---|
| Enamel | $8.41 \times 10^4$ | 0.33 |
| Dentin | $1.83 \times 10^4$ | 0.30 |
| Periodontal ligament | $6.90 \times 10^{-1}$ | 0.45 |
| Bone | $1.37 \times 10^4$ | 0.30 |
| Bracket | $2.0 \times 10^5$ | 0.30 |
| Wire | $2.0 \times 10^5$ | 0.30 |

Table 2: Force System Applied.

| Force Type | Force Magnitude | Direction |
|---|---|---|
| Sliding | 2 N | 0, 30 and 45 degree from the horizontal axis |

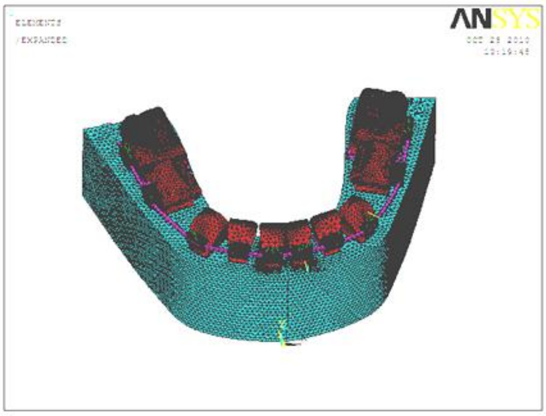


Fig 1: Element of lower teeth, wire, brackets and bone.

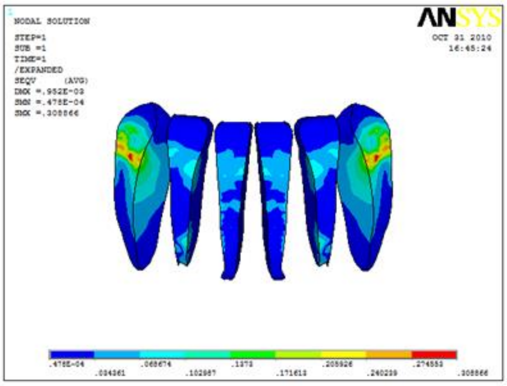


Fig 2: Stress distribution on the mandibular anterior teeth.

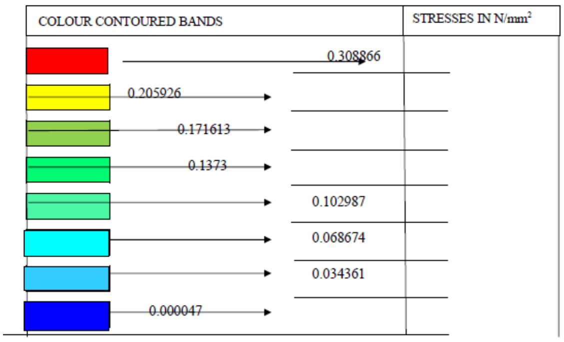


Fig 3: Stress distribution on the mandibular anterior teeth.

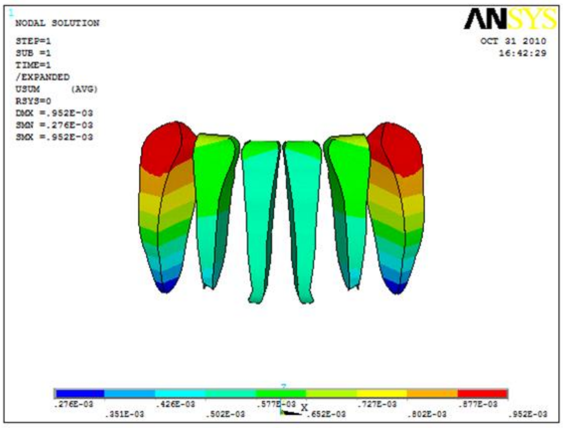


Fig 4: Displacement of the mandibular anterior teeth.

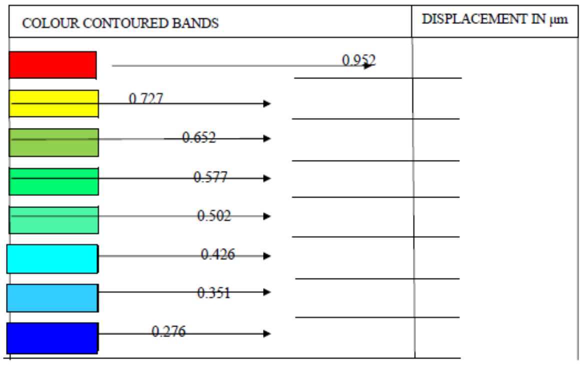


Fig 5: Displacement of the mandibular anterior teeth.

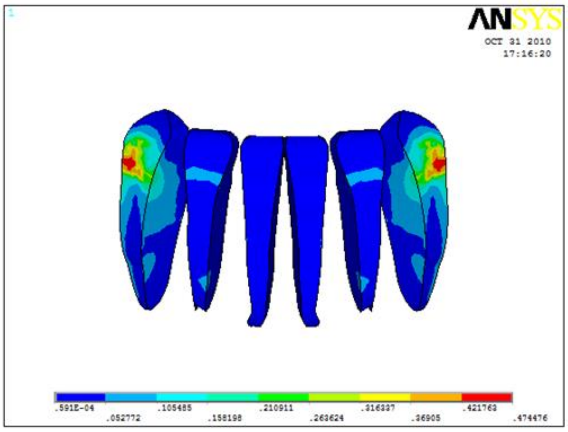


Fig 6: Stress distribution on the mandibular anterior teeth.

**AT 30 DEGREE**

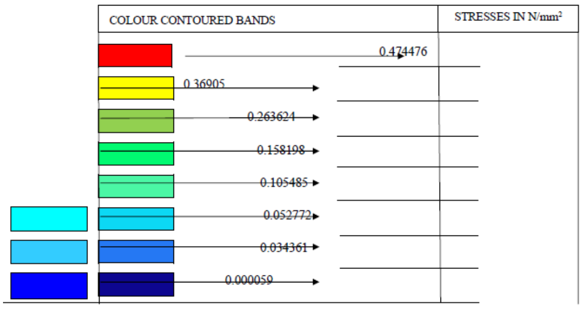


Fig 7: Stress distribution on the mandibular anterior teeth.

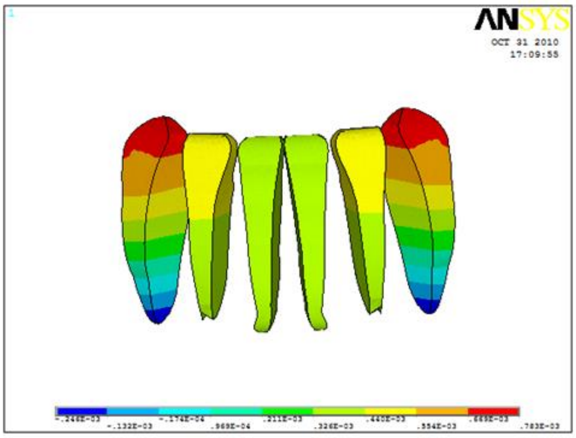


Fig 8: Displacement of the mandibular anterior teeth.

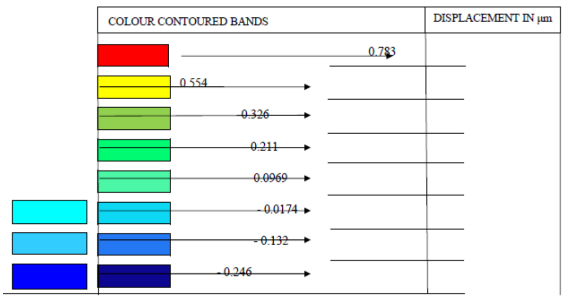


Fig 9: Displacement of the mandibular anterior teeth.

**AT 45 DEGREE**

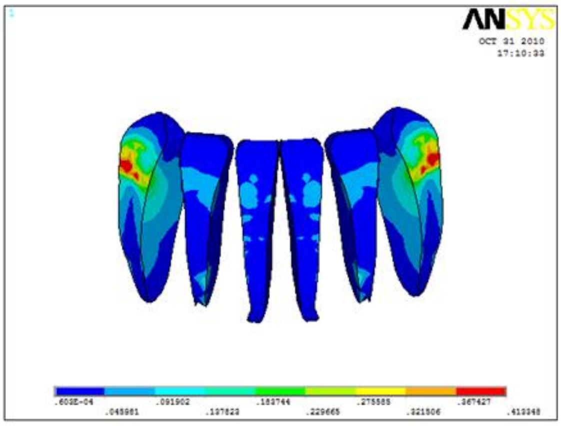


Fig 10: Stress distribution on the mandibular anterior teeth.

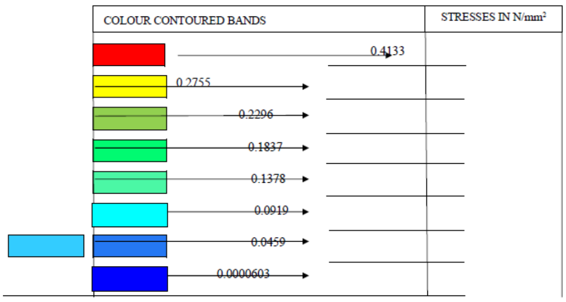


Fig 11: Stress distribution on the mandibular anterior teeth.

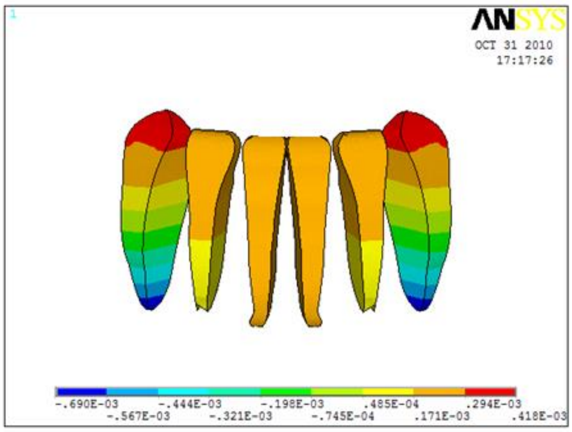


Fig 12: Displacement of the mandibular anterior teeth.

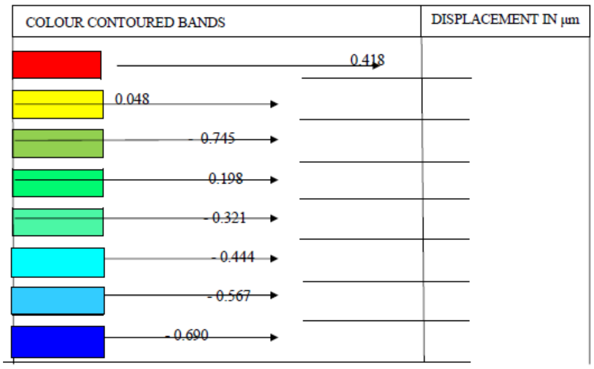


Fig 13: Displacement of the mandibular anterior teeth.

## RESULTS

Stress distribution on the roots of mandibular teeth on application of orthodontic force loadings was analyzed using FEM.

### AT $0^0$ OF HOROZONTAL LEVEL

In the case of linguo-labialy directed force of 2 N at 0 degree of horizontal level, the maximum level of stress was found at the cervical margin of the PDL of all the tooth root which was 0.3088N/mm$^2$ for cervical margin (Fig. 2 & 3). In the presence of the same load, the top of tooth crown showed the largest amount of displacement (0.952µm) (Fig. 4 & 05).

### AT $30^0$ OF HOROZONTAL LEVEL

In the case of linguo-labialy directed force at 30 degree of horizontal level, the maximum stress on the root occurred during tipping, 0.4744 N/mm$^2$ for cervical margin (Fig.06 & 07). The top of tooth crown showed the largest amount of displacement (0.783 µm)(Fig. 08 & 09). The PDL underwent tensile stress along the root surface and the sub-apical level experienced compression.

### AT $45^0$ OF HORIZONTAL LEVEL

In the case of linguo-labialy directed forces at 45 degree of horizontal level, the stress was mainly concentrated at the neck of the tooth, decreasing uniformly to the apex and crown. The maximum stress on the root was 0.4133 N/mm$^2$ for cervical margin (Fig. 10 & 11). The top of tooth crown showed the largest amount of displacement (0.418 µm)(Fig. 12 & 13). The stress distribution on the mesial and distal sides showed almost symmetrical behaviors, the maximum compressive stress was localized mesially and the maximum tensile stress distally.

## DISCUSSION

Many methods have been used in the past to study the relationship between well known force systems and the distribution of stress/ strain on the teeth and its supporting tissues. Some of them are the Strain Gauge Technique, Laser Holographic Interferometry technique, Photoelasto plastic method, Maxwell displacement current technique (MDC), Berthelot tube method, Thermovision method, Quantum isoenthalpic – isotension method, etc.Sliding mechanics is an effective method of controlled space closure and has been widely accepted by orthodontists. It is of great importance in orthodontics to identify the optimum sliding forces to trigger tooth movement at the highest possible speed without damaging the tooth, periodontal ligament and bone. The orthodontic forces are largely determined by the manner in which the mechanical stresses are transferred from the orthodontic appliance to the surrounding structures.

This study investigated the stress pattern in the dental root from sliding mechanics in the mandibular arch by means of the finite element method.To carry out the analysis the mandibular arch (without first premolar) with its supporting structures was considered. These teeth were considered as they undergo the most detailed teeth movement by sliding mechanics. It was found that when the orthodontic forces used was 2 N, the maximum compressive stress was localized mesially, the maximum tensile stress distally and the stress distribution at the mesial and distal sides showed almost symmetrical behaviors, which is ideal to ensure the bodily orthodontic tooth movement by sliding mechanics.The Finite Element model of the mandibular dental arch with sliding mechanic orthodontic appliance consists of 2, 34,268 elements, 50,923 nodes and 3 degrees of freedom. This new model allows a much more detailed depiction of the dental roots and orthodontic appliance and can be used for the analysis of the stress distribution of sliding mechanics in space-closing under different loading conditions. With the development of implant anchorage, orthodontic force at 30 and 45 degree from the horizontal axis became more and more common in space-closing by sliding mechanics. Clinically, orthodontic forces at 30 and 45 degrees have been traditionally suspected in some cases of root resorption. Analysis of the mechanical stress on roots after horizontal loading at 0, 30 and 45 degree in our study showed that the cervical third of the mandibular teeth root supported greater part of loadings of stress magnitude and distribution. The highest stress concentration in the roots was localized at the cervical margin in all the three conditions and the stress distribution was less concentrated at the apical region, which are in agreement with some previous studies. The results of the present study indicated that there was the same risk of root resorption after horizontal loading at 0, 30 and 45 degree. This finding is clinically useful when an orthodontist chooses implants as anchorage for sliding mechanics to close dental arch space.

Ping, Jing, Zhou and Hui[10] reported that when orthodontic forces were applied to the tooth, the stress was mainly concentrated at the neck of the tooth decreasing uniformly to the apex and crown. The highest stress on the root was 0.621 $N/mm^2$ for cervical margin of the canine, and 0.114 $N/mm^2$ for apical region of the canine. The top of canine crown showed the largest amount of displacement (2.417 µm). When compared with our study the stress patterns were found to be similar. The stress value of 0.4744 $N/mm^2$ was found to be less in our study when compared to the above study which was 0.621$N/mm^2$. But the displacement in our study also decreased by 0.95 µm when compared to the above study which was 2.417 µm.This maybe due to the difference in finite element tooth model.

Cobo J et al [11]determined the stresses during tooth movement with diverse degrees of bone loss. Mandibular canine with a labiolingual force of 100 gms displayed a progressive increase in stress in the labial and lingual zones of the tooth, periodontal ligament and alveolar bone when the bone height was reduced. The result showed that the distribution of stresses is seen at the cervical margin which is similar with our study.

RudolphJD et al[12]showedthat the bodily movement and tipping forces concentrate forces at the alveolar crest, not at the apex, which is similar to our study.

Geramy[13] analysed six 3-D finite element models of a human maxillary central incisor. The models were of the same configuration except for the alveolar bone height. The results showed that alveolar bone loss caused increased stress production under the same load compared with healthy bone support (without alveolar bone resorption). Tipping movements resulted in an increased level of stress at the cervical margin of the PDM in all sampling points and at all stages of alveolar bone loss. The result showed that the stress concentration was at cervical margin of the PDM which is similar with our study.

Melsen[14]showed that there was a marked variation in the stress distribution from cervix to apex, where the maximum stress was on the cervix which shows a similar pattern to our study.

The finite element analysis was used for this study because it has the following advantages:

- It is a noninvasive technique
- Soft tissues like the periodontal ligament can be generated.
- The actual physical properties of the materials involved can be simulated. Thus this method is the nearest one that could possibly get to simulating the vital human tissues in vitro.
- The actual stress experienced at any given point can be measured.
- The actual displacement of the tooth can be visualized.
- Reproducibility does not affect the physical properties of the involved materials and the study can be repeated as many times as the operator wants.

## CONCLUSION

- The 3-dimentional FEM model is useful in analyzing the mechanical stress on root surfaces in response to orthodontic forces.
- At 0 degree of horizontal level, the greatest amount orthe maximum level of stress was found at the cervical margin of the PDL at all tooth roots. The maximum stress at the sub-

apical level was approximately 45 percent of the cervical stress.

- At 30 degree of horizontal level, the maximum stresses occurred at the root crest region of the canine, the highest stress on the root occurred during tipping. The maximum stress at the sub-apical level was approximately 20 percent of the cervical stress.

- At 45 degree of horizontal level, the stress was mainly concentrated at the neck of the tooth, decreasing uniformly to the apex and crown. The highest stress on the root was at the cervical margin of the canine.

Finally, it can be concluded that this tri-dimensional model is a useful example to investigate the biomechanism of dental movement, keeping in mind that it is more valid as a qualitative study.

## CONFLICTS OF INTEREST

The authors declare they have no potential conflict of interests regarding this article.

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