Stress Appraisal with Simulation of *en masse* Absolute Intrusion of Maxillary Anteriors deploying Strategic Mini-implant Locations: A Finite Element Analysis

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ABSTRACT

One of the major challenges of fixed clinical orthodontics is the correction of deep overbite. Mini screw implants are ideally suited for absolute intrusion because they make it possible to apply light continuous forces of known magnitudes without producing any reciprocal reactionary effect on posterior teeth. The purpose of this FEM study was to evaluate and compare the stresses generated in maxillary anterior region during absolute *en masse* intrusion of six maxillary teeth using mini-implants at strategic locations.

**Materials and methods:** Finite element model was generated using FEM software ANSYS and, on the same model, two different analyses were carried out for two groups with different points of force application as Group I consisted of two bilateral implants for *en masse* intrusion of maxillary anteriors and Group II consisted of a single mid implant.

**Results:** Soft and hard bones showed significantly high stress distribution in Group I as compared to Group II. The total tooth deformation was found to be more with single point of force application which produced oblique force vectors.

**Conclusion:** Stresses on the teeth are higher and distributed more evenly, when the point of force application is bilateral rather than a single source. Bilateral implants generate less stresses which are evenly distributed with minimum detrimental effect on the teeth during absolute intrusion.

**Keywords:** Absolute intrusion, Finite element analysis, Mini-implants, Stress appraisal.

INTRODUCTION

One of the major challenges of orthodontic treatment is the correction of deep overbite. In most instances, this correction is produced by the extrusion of posterior teeth, or a combination of anterior intrusion along with posterior extrusion, which is undesirable in vertical growers.1 In such cases, absolute intrusion or true intrusion of the anteriors is desired, especially when there is excessive incisal display with extruded incisors. Orthodontic tooth movement has always been limited to action-reaction reciprocal force mechanics for anchorage control.2

Mini-screw implants (MSIs) used as fixed anchorage devices give orthodontists increased potential for versatile mechanotherapy resulting in favorable treatment outcome. Perhaps most importantly, they help to reduce patient compliance during treatment, like use of headgears for anchorage preservation. MSIs are especially well suited for intruding teeth because they make it possible to apply light continuous forces of known magnitudes without producing any reactionary reciprocal effect on posterior teeth. Better control of the forces could diminish apical root resorption often associated with intrusive movements.

High stresses and prolonged treatment time may lead to apical root resorption which has gained considerable attention recently because of medicolegal considerations. Loss of the apical root material is unpredictable and, when extending into the dentin, irreversible. Extensive postorthodontic root resorption compromises the benefits of an otherwise successful orthodontic treatment. Distinct points of force application may result in different areas of root resorption.

The first descriptive finite element analysis (FEA) study of orthodontic tooth displacement and stress magnitudes was conducted by Tanne et al.3 FEM has been used successfully to model the application of forces to single-tooth systems. Alveolar bone loss was shown to lower the center of resistance of the tooth and alter the stress patterns on the root. Similar changes were observed in altering root length. FEM was also
used to show that areas of bone remodeling in vitro corresponded with the same areas in vivo.

MATERIALS AND METHODS

For the study, finite element model was generated. This model was the replica of adult human maxilla. The model consisted of periodontal ligament, alveolar bone and all the teeth except the first premolars and third molars. The bracket system simulated was MBT extraction series bracket system from 3M Unitek (0.22 slot) and the archwire was of $21 \times 25$ stainless steel consisting of two attachments between lateral incisors and canines bilaterally.

A three-dimensional (3D) quantitative analysis requires some mathematical method, making use of a model accurate both in anatomy and physical characteristics and along with the use of a computer, which has become an indispensable aid as far as 3D analyses are concerned.

Steps involved in construction of finite element model are as follows:

1. Construction of the geometric model
2. Conversion of the geometric model to a finite element model
3. Material property data representation
4. Defining the boundary condition
5. Loading configuration

1. Construction of the geometric model: Mathematical model 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 3D CT scan of adult maxilla was taken. The software used for geometric modeling was ANSYS Workbench 11.

2. Conversion of geometric model to finite element model: This geometric model was converted into finite element model. The finite element modeling is the representative of geometry in terms of finite number of elements and nodes. This process is called discretization. The main idea behind discretization is to improve the accuracy of the results (Table 1).

3. Material property data representation: 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 derived by Mc Guiness and were also used in finite element studies done by Tanne K. These materials properties were the average values reported in literature (Table 2).

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 are fixed in all directions to avoid free body movement of the tooth.

5. Loading configuration: Two different points of force applications were used and categorized in two groups as follows:

- **Group I:** Point of force application was from the bilateral implants to the attachment on the wire ($21 \times 25$ SS) between the lateral incisor and canine on the either side (Fig. 1).
- **Group II:** In this group, the point of force application was from the single mid implant to the attachment on the wire ($21 \times 25$ SS) between the lateral incisor and canine on the either side (Fig. 2).

<table>
<thead>
<tr>
<th>Table 1: Number of elements and nodes</th>
<th>No. of nodes</th>
<th>No. of elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tooth</td>
<td>5635</td>
<td>5181</td>
</tr>
<tr>
<td>PDL</td>
<td>8202</td>
<td>7428</td>
</tr>
<tr>
<td>Bone</td>
<td>7648</td>
<td>7234</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2: Material properties</th>
<th>Young’s modulus (N/mm²)</th>
<th>Poisson’s ratio</th>
</tr>
</thead>
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<tr>
<td>Tooth</td>
<td>20300</td>
<td>0.30</td>
</tr>
<tr>
<td>PDL</td>
<td>0.667</td>
<td>0.49</td>
</tr>
<tr>
<td>Alveolar bone</td>
<td>13700</td>
<td>0.38</td>
</tr>
</tbody>
</table>
RESULTS

Group I

The stress generated during absolute intrusion in the soft bone around the right canine, LI and CI were found to be 2.927e to 2 Mpa, 2.857e to 2 Mpa and 1.045e to 2 Mpa respectively, and in the left canine, LI and CI were found to be 2.694e to 2 Mpa, 2.126e to 2 Mpa and 1.074e to 2 Mpa respectively (Graph 1 and Fig. 3).

The stress generated in the hard bone around the right canine, LI and CI were 0.2923 Mpa, 0.4993 Mpa and 2.199e to 2 Mpa respectively and, on left canine, LI and CI were found to be 0.3526 Mpa, 0.4223 Mpa and 1.056e to 2 Mpa respectively (Graph 2 and Fig. 4).

The total tooth deformation with right and left canine, LI and CI were of 2.306e to 3 mm, 2.588e to 3 mm, 2.639e to 3 mm, 2.331e to 3 mm, 2.598e to 3 mm and 2.657e to 3 mm respectively (Graph 3 and Fig. 5).

Group II

The stress generated during absolute intrusion in the soft bone around the right canine, LI and CI were found to be 2.009e to 2 Mpa, 2.865e to 2 Mpa and 1.530e to 2 Mpa respectively and, in
the left canine, LI and CI were found to be 1.516e to 2 Mpa, 2.099e to 2 Mpa and 1.270e to 2 Mpa respectively (Graph 1 and Fig. 6).

The stress generated in the hard bone around the right canine, LI and CI were 0.1399 Mpa, 0.3207 Mpa and 0.1597 Mpa respectively and, on left canine, LI and CI were found to be 0.1485 Mpa, 0.2571 Mpa and 0.1128 Mpa respectively (Graph 2 and Fig. 7).

The total tooth deformation with right and left canine, LI and CI were of 2.004e to 3 mm, 2.287e to 3 mm, 2.317e to 3 mm, 2.039e to 3 mm, 2.309e to 3 mm and 2.371e to 3 mm respectively (Graph 3 and Fig. 8).

DISCUSSION

The finite element method (FEM) enables the investigation of biomechanical issues involved in orthodontic treatment. FEM has many advantages over other methods (such as the photoelastic method) highlighted by the ability to include heterogeneity of tooth material and irregularity of the tooth contour in the model design and the relative ease with which loads can be applied at different directions and magnitudes for a more complete analysis. In this study, the finite element model was constructed to observe and evaluate the stress generated in the soft bone and the hard bone and the teeth deformation using ANSYS workbench 11 finite element analysis software. This model encompasses the tooth, the alveolar bone and the periodontal ligament. Optimum intrusive forces recommended by Burstone were applied to simulate the effect of intrusive forces on the teeth and surrounding structures.

OBSERVATIONS

- When the stress distribution and total teeth deformation were compared between Groups I and II, it was observed that the Group I had less total teeth deformation than Group II, but the values were not significant.
- When the stress levels on the soft bone were observed in Group I and Group II, higher levels of stress distribution in the soft bone of Group I was seen.
- As the stress levels on the hard bone were observed in Group I and Group II, it was found that the Group II showed higher levels of stress distribution on hard bone than in the Group I.

The pattern of stress distribution observed here can be attributed to the direction and point of force application in Group I which was from the bilateral implants to the attachment on the wire between the lateral incisor and the canine which produced more forces in axial direction, i.e. parallel to the long axis of the teeth. Whereas, in Group II, the point of force application was from the mid implant to the attachment on the wire between the lateral incisor and the canine bilaterally which produced more forces in the oblique direction than in the axial direction to the long axis of the teeth. This is supported by the study done in 2001 by Rudolph et al which states that different force vectors create different stress throughout the root.

Our study showed variable stress distribution on the teeth, soft bone and hard bone. The stresses in the apical areas of all the teeth showed significantly lesser amount of stress compared to the crown areas as the analysis shows the stresses generated at the initial time of force application and not over a period of time, as the amount of intrusion and the duration is significantly correlated to the amount of stress generated at the apices to initiate apical root resorption. The range of stresses exerted by the blood in the capillary vessels (0.0026 N/mm²) helps us to predict the onset of bone remodelling.

Research shows that comprehensive orthodontic treatment causes increased incidence and severity of root resorption, especially when the treatment is carried out over a prolonged period of time and heavy forces are particularly harmful. Heavy force application produces more significant orthodontically induced inflammatory root resorption than light force.

CONCLUSION

Among all the orthodontic moments, intrusion is the most detrimental in orthodontics. It is well established that these forces generate stress which cause changes on the tooth structure and the surrounding periodontium.
The finite element method is highly precise technique used to analyze structural stresses. Over the years, finite element method has been used successfully in orthodontics to simulate various orthodontic tooth moments and stress distribution patterns. Stresses on the teeth are less and distributed more evenly, when the point of force application is bilateral rather than a single source where the direction of forces are oblique. Different force vectors create variable stress throughout the tooth. Hence, use of bilateral implants are more efficient and less detrimental for the teeth during absolute intrusion of the maxillary anterior teeth.

REFERENCES