ABSTRACT

Objective: To evaluate Stage III of the Begg technique using finite element method and to locate the center of rotation (Crot) during torquing and uprighting of the central incisor.

Materials and methods: The maxillary central incisor was subjected to a finite element study. Movement of the tooth along the z-axis (labio-lingual) and X-axis (mesiodistal) was noted. The Crot was located by finding the nodes which had zero displacement during the torquing and uprighting maneuvers. The location of Crot was also confirmed by the point of intersection of lines drawn along the long axis of the tooth between the initial and final positions after displacement.

Results: This study revealed that the location of the Crot was 6.59 mm from the incisal edge (between the bracket slot and the cervical margin) during torquing maneuvers and 17.31 mm (between the apex and the middle third of the root) while uprighting the tooth. This is suggestive of a lack in control of the position of the crown during the third stage of Begg technique.

Conclusion: Though the efficiency of torquing and uprighting in the Stage III of Begg technique was considered to be acceptable or satisfactory, it may be prudent to consider altering or effecting the Crot closer to the incisal edge for producing optimal result in Stage III.

Keywords: Center of rotation, Center of resistance, Stage III Begg, Finite element model, Uprighting, Torquing.

INTRODUCTION

The Begg technique is a standardized procedure that has been developed over years for the correction of malocclusion by simple tipping movements of tooth.1 There are three basic stages and each stage completes a definite part of the treatment that involves mechanical and technical changes in the appliance structure which require thorough knowledge of biomechanics and force systems.2

Stage I predominantly involves bite opening mechanisms,3,4 at the end of which an edge-to-edge bite is achieved. The second stage employs mechanisms to distally tip the crowns of the six anterior teeth in order to close the extraction spaces.1 This encompasses the principles of the differential force concept,5-7 whereby light forces-applied on the anterior teeth—will move them rapidly, without disturbing the anchor teeth. By the end of the second stage the incisor crowns are tipped palatally and the roots are labially placed.

In Stage III, all the axial inclinations of the teeth are corrected, and is successful only if the crown of the anterior teeth can be positioned in their appropriate axial inclination1,8,9 This involves purely root movements which require precise knowledge of the location of the center of rotation1,10 (Crot). Ideally it should be situated at the incisal edge, failing which the objectives of Stage I and II are lost.11

The complexities of the Stage III mechanics in Begg technique necessitate an analytical approach in studying and understanding the type of tooth movements involved.8 The finite element method (FEM) is a powerful computer simulation tool, which has been successfully applied to the mechanical study of stress and strain and solving problems in the mechanics of solids and structures.12 This makes it practical to elucidate the biomechanical components, such as displacements strain and stress included in the living structures from various external forces.13

The FEM has some distinct advantages over other methods of stress analysis which are as follows:

1. It is noninvasive.
2. It is able to model much more closely, the structures of irregular geometry, nonhomogenous material properties and overcomes difficulties inherent in conventional experimental methods.
It offers an ideal method of accurate modeling of the tooth periodontium system with its complicated three-dimensional geometry.  

4. It is possible to analytically apply various force systems at any point and in any direction.  

5. The study can be repeated as many times as required because reproducibility does not affect the material properties of the model. Unfortunately, thus far no studies have been conducted on Begg mechanics per se, especially using the FEM and there exists a great lacuna in the understanding of mechanisms involved in Stage III of the Begg technique. Hence, the need was felt to evaluate the Stage III of Begg technique using the FEM and to locate the Crot during torquing and uprighting of central incisor so as to achieve precise control of tooth movement.

**MATERIALS AND METHODS**

Finite element study of maxillary central incisor was done to locate the Crot during torquing. The procedure is as follows:

1. **Creation of geometric model:** A skull with maxillary central incisor was placed in the CT spiral scanner and serial cross-sections of 1 mm thickness were obtained. These tomographic sections (Fig. 1) were then traced in mat acetate tracing paper with utmost care so as not to distort the anatomy of the tooth cross-sections.

2. The traced images were then digitized by scanning them in a high resolution optical scanner and the scanned images were then converted to DXF (data exchange format) format using AutoCAD 2000.

3. The DXF format were then stacked vertically in a high end modeling software called Unigraphics, and manipulated to develop 3D models. The model was then refined and scaled down to that of the guide curves (Fig. 2) which are natural dimensions of the maxillary central incisor as mentioned by Wheeler. Variable periodontal ligament (PDL) widths (Table 1) were fed at different occluso-gingival levels derived from the previously published data.

4. **Mesh generation:** In this stage the geometric model is converted into the finite element model (Fig. 3). The geometric model is converted to initial graphics exchange specification (IGES) file, which is then fed into the finite element software (COSMOS/M 2.8). Here, the model is subdivided into smaller units called elements that are interconnected via nodes. The complete 3D finite element model of the tooth—PDL–alveolar bone system consisted of 2,205 nodal points and 1,932 elements (Fig. 4). The mechanical properties of each material, such as bone, PDL and tooth were taken from previously published values (Table 2).

5. Boundary conditions of the model were assigned at the top surface of the bone (representing palatal surface) and 4 mm from the incisal tip (bracket position).

6. Now the three-dimensionally modeled central incisor was oriented such that the mesiodistal plane was represented by X-axis, the vertical plane represented by Y-axis and labiolingual plane represented by Z-axis. Seventy-five grams of torquing force was applied at 4 mm from the
The Location of the Center of Rotation of the Maxillary Central Incisor during Stage III of the Begg Technique

The Journal of Indian Orthodontic Society, October-December 2012;46(4):183-187

bracket slot in the labiolingual direction, uprighting force was applied in the mesiodistal direction and the run static command was activated to calculate the nodal displacements and determine the Crot.

RESULTS

After applying the predetermined torquing and uprighting forces, the following observations were made:

1. Movement of the tooth along the Z-axis (labiolingual) was noticed. More of positive movement was observed in the root and less of negative movement was observed in the crown, indicating that the root movement was more in the palatal direction and the crown movement was less in the labial direction (Fig. 5) (Table 3).

2. Simultaneously the movement of the crown and the root along the X-axis (mesiodistal) was also observed (Fig. 6). Displacement characteristics were measured in five different regions of the tooth (incisal tip, 4 mm from the incisal tip, cervical margin of the tooth, middle of the root, apex of the root) in both X- and Z-axes. The Crot was located

---

Table 1: Variable Pdl widths at different occluso-gingival levels from the alveolar crest

<table>
<thead>
<tr>
<th>Distance from the alveolar crest (mm)</th>
<th>Distal (mm)</th>
<th>Lingual (mm)</th>
<th>Mesial (mm)</th>
<th>Labial (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.0</td>
<td>0.20</td>
<td>0.25</td>
<td>0.22</td>
<td>0.25</td>
</tr>
<tr>
<td>10.5</td>
<td>0.18</td>
<td>0.22</td>
<td>0.20</td>
<td>0.22</td>
</tr>
<tr>
<td>8.0</td>
<td>0.15</td>
<td>0.20</td>
<td>0.17</td>
<td>0.20</td>
</tr>
<tr>
<td>6.5</td>
<td>0.14</td>
<td>0.18</td>
<td>0.16</td>
<td>0.18</td>
</tr>
<tr>
<td>5.0</td>
<td>0.15</td>
<td>0.20</td>
<td>0.17</td>
<td>0.20</td>
</tr>
<tr>
<td>2.5</td>
<td>0.18</td>
<td>0.22</td>
<td>0.20</td>
<td>0.22</td>
</tr>
<tr>
<td>0.0</td>
<td>0.19</td>
<td>0.24</td>
<td>0.21</td>
<td>0.24</td>
</tr>
</tbody>
</table>

---

Table 2: Mechanical properties for the tooth, Pdl and alveolar bone

<table>
<thead>
<tr>
<th>Material</th>
<th>Young’s modulus (Kg/mm²)</th>
<th>Poisson’s ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tooth</td>
<td>2.0 × 10³</td>
<td>0.15</td>
</tr>
<tr>
<td>Pdl</td>
<td>6.8 × 10⁻²</td>
<td>0.49</td>
</tr>
<tr>
<td>Alveolar bone</td>
<td>1.4 × 10⁻³</td>
<td>0.15</td>
</tr>
</tbody>
</table>

---

Table 3: Nodal displacements that were observed in various regions of tooth

<table>
<thead>
<tr>
<th>Node</th>
<th>X-axis</th>
<th>Y-axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incisal tip</td>
<td>0.0007483900</td>
<td>-6.2203 E⁻⁰⁵</td>
</tr>
<tr>
<td>Bracket slot</td>
<td>0.0005089200</td>
<td>-5.6715 E⁻⁰⁷</td>
</tr>
<tr>
<td>Cervical margin</td>
<td>0.0002694500</td>
<td>6.1068 E⁻⁰⁵</td>
</tr>
<tr>
<td>Center of the root</td>
<td>2.9970 E⁻⁰⁵</td>
<td>0.0001227000</td>
</tr>
<tr>
<td>Apex of the root</td>
<td>-0.0002094900</td>
<td>0.0001843400</td>
</tr>
</tbody>
</table>

---

Fig. 4: Finite element model showing nodes between elements

Fig. 5: 3D model after finite element analysis. Arrow showing crot during torquing

Fig. 6: 3D model after finite element analysis. Arrow showing Crot during uprighting
by finding those nodes that had zero displacement\textsuperscript{20} during the torquing and uprighting movements. The location of Crot was further confirmed by the point of intersection of the lines drawn along the long axis of the tooth between the initial and final positions after displacement.\textsuperscript{21}

During torquing the Crot was found to be at 6.59 mm from the incisal edge (between the cervical margin and the bracket slot) and during uprighting the Crot was found to be at 17.31 mm from the incisal edge (between the apex and the middle third of the root).

**DISCUSSION**

The location of the center of resistance (Cres) and Crot is of vital importance in tooth movement.\textsuperscript{22} It is important to determine the location of Crot of a tooth to better understand the nature of their displacement characteristics when subject to various force levels.\textsuperscript{23,24} The Crot can be at any point on or off a tooth and the ratio between the net moment and the net force (m/f ratio) on a tooth with reference to the Cres determines the Crot.

Location of the Crot has been studied over the years with numerous model systems; these studies include analytical models, direct measurement \textit{in vivo},\textsuperscript{25} photoelastic technique,\textsuperscript{21} strain gauge technique,\textsuperscript{26} laser reflection technique\textsuperscript{27} and holographic method,\textsuperscript{23} etc.

Although these model systems have provided some insight into the displacement characteristics of the tooth to apply forces, these studies have obvious limitations, such as:

1. The root morphology of the tooth has been approximated to a parabola, cone or a wedge, tending to produce differing results.
2. Such studies used synthetic substances to simulate the periodontal ligament that did not have physical properties comparable to that of the periodontal ligament.\textsuperscript{27}
3. The experimental apparatus used to measure the force and displacement was very invasive and they themselves have a mechanical inertia during deflection, so these things affected the accuracy of the result.\textsuperscript{23}
4. Experimental studies of force displacement characteristics of teeth have yielded low predictive capability because most of these experiments employed forces that produced three-dimensional displacements of tooth and yet the tooth displacements were measured along one axis only.\textsuperscript{23}

To overcome these disadvantages and pitfalls, FEM was chosen for this study. The essence of this method is that a continuous solid (such as tooth) that is acted upon by predetermined forces is idealized into an assemblage of separate finite regions or elements. These are then considered to be interconnected at specific points called nodes on their common boundaries.\textsuperscript{13}

In the Begg technique, more complex movements are encountered in the third stage, such as torquing and uprighting.\textsuperscript{9} Several clinicians have refined and modified this technique to prevent excessive uncontrolled tipping and to achieve better finishing with this appliance.\textsuperscript{7} Consequently modern Begg aims for controlled tipping, in turn reducing the necessity for torquing in the later stage.\textsuperscript{28}

The maxillary incisors are usually the only teeth which require complex torquing and uprighting forces simultaneously. Hence, the central incisor was chosen for this study. In addition, the forces employed in Stage III of the Begg technique have displacement characteristics in all three-dimensions, so a three-dimensional tooth displacement study was undertaken.

The Crot was determined by observing the area where the nodes suffered very negligible or zero displacement.\textsuperscript{20} The area of zero displacement in the Z-axis (labiobuccal direction) was considered to be the Crot for torquing movement and the area where the nodes had zero displacement in the X-axis (mesiodistal direction) was considered to be the Crot during uprighting movement of the central incisor. The intersection point, drawn along the long axis between the initial and the final position of the tooth after displacement confirmed our findings.\textsuperscript{20,21}

In this study, the location of the Crot during torquing was found to be at 6.59 mm from the incisal edge (between bracket slot and the cervical margin). This was confirmed from the area where the nodal displacements were virtually zero and further the nodal displacements above this area had positive movement suggestive of palatal root movement and below this area had negative displacement indicating labial crown movement (Fig. 5). While during uprighting, the location of Crot was found to be at 17.31 mm from the incisal edge (between the apex and middle third of the root; Fig. 6).

The result obtained were concordant with the study conducted by Hurd and Nikolai\textsuperscript{29} Albeit a two-dimensional study, it revealed the fact that the Crot during Stage III maneuvers does not lie on the incisal edge or at the bracket height but more apical to the bracket level. In this study, the reason why there is a shift in the Crot more occlusally (2.61 mm below the alveolar crest level) than that reported by Hurd and Nikolai (within alveolar crest level) might be because of the variance in the sensitivity and accuracy of plotting between two-dimensional and three-dimensional models.\textsuperscript{23}

These findings clearly outline the difficulties experienced during Stage III of the Begg technique with emphasis on torquing of the root because of the inability to locate the Crot at the incisal edge (indicated by the labial movement of the coronal portion of the central incisor; pure torquing movements on the other hand would require zero labial movement of the crown). The present location of the Crot 6.59 mm apical to the incisal edge explains the tendency for labial flaring\textsuperscript{6} of the anteriors and the opening up of the extraction spaces,\textsuperscript{11} the commonly associated side effects seen during the Stage III. These results validate the need for over correction at the end of Stage II, which has been advocated by many authors;\textsuperscript{30} subsequently giving a leeway to the flaring of the anterior that is commonly seen during Stage III.
The above study reveals that though the efficacy of torquing and uprighting in the Stage III of Begg technique was considered to be acceptable or satisfactory, it may be prudent to consider altering or effecting the Crot closer to the incisal edge for producing optimal result in Stage III.

CONCLUSION

The present study revealed that the location of the Crot was 6.59 mm from the incisal edge (between the bracket slot and the cervical margin) during torquing maneuvers and 17.31 mm (between the apex and the middle third of the root) while uprighting the tooth, suggestive of a lack in control of the position of the crown during the third stage.

It may be presumptuous to conclude that the location of the Crot during Stage III is more apical to the bracket slot. Therefore, more studies in the future are warranted in mechanics involving modern Begg, to further improve upon the technique.

REFERENCES
