Biomechanical analysis of corticotomy

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We constructed a three-dimensional finite element model of the mandible, performed mechanical analysis at the time of corticotomy in the mandibular anterior segment, and evaluated tooth displacement and the stress distribution in the mandibular anterior teeth and anterior alveolar region. Based on computed tomographic (CT) data, a three-dimensional mandibular model was produced, and, using this model, we made the following three models: a model after extraction of the mandibular first premolars (control model) and models after horizontal corticotomy 2 mm below the tooth apices of the mandibular anterior teeth followed by vertical corticotomy only on the labial side (labial model) or on both the labial and lingual sides (labiolingual model).

In the control model, stress in the alveolar region below the root apex was the greatest for the central incisors and decreased distally. After corticotomy, stress decreased in the body of the bone below the corticotomy line. This tendency was more marked after bilateral vertical labiolingual corticotomy. In the region above the osteotomy line, stress was greatest in the labiolingual model, followed in order by the labial and control models. Concerning stress distribution in the 6 mandibular anterior teeth, although no marked difference was observed in the coronal labial area between the labiolingual and labial models, stress at 1/3 the distance from the root apex as well as at the root apex was elevated in the labiolingual model. Displacement on the incisal margin was marked in the labiolingual model.

Our results suggest that corticotomy is useful for tooth movement because the continuity of cortical bone is interrupted, resulting in the concentration of orthodontic forces. These forces were dispersed to the surrounding bone and on the teeth, while the stress was concentrated in the surrounding alveolar region. We found that in addition, corticotomy on both the labial and lingual sides, as opposed to only on the labial side, may be more effective. (J Osaka Dent Univ 2013; 47: 171-178)

Key words: Corticotomy; Three-dimensional finite method; mandible

INTRODUCTION

With a general increase in the demand for orthodontia in recent years, there has been a marked increase in adults seeking treatment. When orthodontic treatment is done on adults, malocclusion is often more severe, the amount of tooth movement is greater, and the tissue reaction to orthodontic forces is decreased. In addition, there may be periodontal disease, defects in teeth which are a fixation source, and the presence of prostheses. Thus, compared with patients during the growth and development stage, adults present various problems in orthodontic treatment, as well as other issues such as social and treatment time constraints. Therefore, corticotomy is sometimes done to reduce the treatment time in patients for whom tooth movement is orthodontically difficult.

This technique, in which only cortical bone is reduced, is minimally invasive, and preserves blood flow in the bone marrow, only slightly affecting the teeth, and, therefore, has been clinically used and
confirmed to be useful. However, there have been only a few studies on this technique using biomechanical analysis. In this study, we constructed three-dimensional finite element models, performed mechanical analysis at the time of corticotomy in the mandibular anterior segment, and evaluated tooth displacement, as well as the stress distribution in the anterior teeth and anterior alveolar region.

**MATERIALS AND METHODS**

**Defining the mandibular model**

CT Data on the mandible of healthy adults was obtained using a CT system (Bright Speed, GE Medical System, New York, USA) in the Central Imaging Laboratory of Osaka Dental University Hospital at a tube voltage of 120 kV and a tube current of 120 mA with a slice thickness of 0.625 mm. The data was input to Mechanical Finder version 6.1 (Research Center of Computational Mechanics, Tokyo, Japan). Outlines of bone image areas were extracted using thresholding of each CT image. For outline extraction, the external shape of the mandible, consisting of enamel, dentin, cortical bone, and cancellous bone, was obtained utilizing the higher CT value in bone than in its surrounding areas. Revisions in details were manually added based on CT images (Fig. 1 A).

**Production of corticotomy models**

The element size of the mandible was set at 1.0 mm, and that of the tooth at 0.5 mm using the oct-tree method. A mesh was generated by controlling the element size according to shape factors, and mandibular models after corticotomy were produced. In this mandibular model, the bilateral mandibular first premolars were not selected in the computer operations. This was considered a model after extraction of these premolars (control model) (Fig. 1 B).

Three osteotomy sites, which were either 2 mm above or 2 mm below the root apex, were compared. The osteotomy 2 mm below the root apex was found most beneficial. Therefore, for the corticotomy, horizontal osteotomy was performed 2 mm below the root apex in the labial cortical bone, and vertical osteotomy was performed only on the labial side (hereafter referred to as the labial model) or on both labial and lingual sides (the labiobuccal model). The external shape of the corticotomy models was formed by reducing the cortical bone in the alveolar osteotomy area. The width of the corticotomy was assumed to be that using a fissure bur with a tip width of 1 mm (Fig. 1 C).

The control model consisted of 139,833 tangent points and 733,015 elements, the labial model of 139,760 tangent points and 729,688 elements, and the labiobuccal model of 140,198 tangent points and 730,570 elements. Orthodontic appliances were not
included because that would make computations beyond the capacity of the computer.

**Determination of the physical properties of the mandible and teeth**

**Young’s module**

Young’s module (E) of each solid element was calculated from the CT value using formulas (1) and (2) below. There is a proportional relationship between the CT value (V_\text{CT}) and bone density (\rho), as shown in formula (1). In this formula, a and b were determined by simultaneous imaging of a bone mineral phantom [Ca_10(PO_4)_6(OH)_2].

Young’s module was calculated using formula (2) below on the reports by Carter et al. and Akiyama et al. It was 6,000 for enamel, 1,400 for dentin, 1,100 for cortical bone, and 250 for cancellous bone. In this study, the strain rate (\epsilon) was set at 0.01.

\begin{align*}
(1) \quad \rho &= a \cdot V_{\text{CT}} + b \\
(2) \quad E &= 3790.4 \ell O^{0.3} \rho^{0.3}
\end{align*}

The concentration of each element was determined as follows. Since tetrahedral tetra elements were used in the finite element model in this study, we determined the central point of the element and 4 points on each line, which connect the central point and each apex and is divided into 5 equal parts (a total of 17 points). Since each point is always present in the voxel range, the concentration in each point is determined based on the voxel values for the surrounding 8 points and distances from them. This procedure was performed for all 17 points, and the concentration of an element was determined from the mean value.

**Poisson’s ratio**

Poisson’s ratio was determined as 0.4 based on the report by Van Buskirk et al.

**Loading and constraint**

The labial surfaces of the bilateral mandibular first molars were completely constrained. Orthodontic loading force (1 N) was applied to the central area of the labial surface of the crown of the 6 mandibular anterior teeth in the posterior direction in parallel to the mandibular occlusal plane.

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**Measurement sites of the alveolar region and teeth**

Equivalent stress was analyzed at six points below the corticotomy line (A-F, Fig. 2) and at six points above (a-f, Fig. 3). In addition, equivalent stress was analyzed at the labial coronal sites (1-6), 1/3 of the distance from the root apex (7-12), and at the root apex (13-18, Fig. 4).

**Measurement of tooth displacement**

Displacement on the incisal margin was measured in each of the 6 mandibular anterior teeth.

**RESULTS**

Equivalent stress distribution in the alveolar region below the corticotomy line (Figs. 5 and 6, Table 1)
In the control model, equivalent stress was between $13.4 \times 10^{-3}$ and $28.4 \times 10^{-3}$ kgf/mm, being higher at measurement points C and D in the alveolar region for the central incisors ($28.4 \times 10^{-3}$ and $24.2 \times 10^{-3}$ kgf/mm, respectively) than at other measurement points. In the labial model, equivalent stress was between $10.2 \times 10^{-3}$ and $13.5 \times 10^{-3}$ kgf/mm, while in the labiolingual model, it was between $5.42 \times 10^{-4}$ and $9.04 \times 10^{-4}$ kgf/mm. Equivalent stress was similar among measurement points A-F in these models. However at each point it was lower in the labiolingual model than in the labial mode.

**Table 1** Equivalent stress distribution in the alveolar region below the corticotomy line

<table>
<thead>
<tr>
<th>Measurement site</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>13.4</td>
<td>16.2</td>
<td>28.4</td>
<td>24.2</td>
<td>19.8</td>
<td>14.7</td>
</tr>
<tr>
<td>Labial</td>
<td>11.2</td>
<td>13.5</td>
<td>11.7</td>
<td>10.2</td>
<td>11.1</td>
<td>12.1</td>
</tr>
<tr>
<td>Labiolingual</td>
<td>5.65</td>
<td>5.42</td>
<td>9.04</td>
<td>7.29</td>
<td>5.51</td>
<td>6.36</td>
</tr>
</tbody>
</table>

($\times 10^{-3}$ kgf/mm$^3$)

**Table 2** Equivalent stress distribution in the alveolar region above the corticotomy line

<table>
<thead>
<tr>
<th>Measurement site</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.34</td>
<td>2.42</td>
<td>2.22</td>
<td>2.96</td>
<td>1.99</td>
<td>1.72</td>
</tr>
<tr>
<td>Labial</td>
<td>1.61</td>
<td>3.63</td>
<td>2.73</td>
<td>3.13</td>
<td>3.45</td>
<td>1.88</td>
</tr>
<tr>
<td>Labiolingual</td>
<td>2.73</td>
<td>4.32</td>
<td>5.09</td>
<td>4.27</td>
<td>4.25</td>
<td>2.05</td>
</tr>
</tbody>
</table>

($\times 10^{-4}$ kgf/mm$^3$)

In the control model, equivalent stress was between $13.4 \times 10^{-3}$ and $28.4 \times 10^{-3}$ kgf/mm, being higher at measurement points C and D in the alveolar region for the central incisors ($28.4 \times 10^{-3}$ and $24.2 \times 10^{-3}$ kgf/mm, respectively) than at other measurement points. In the labial model, equivalent stress was between $10.2 \times 10^{-3}$ and $13.5 \times 10^{-3}$ kgf/mm, while in the labiolingual model, it was between $5.42 \times 10^{-4}$ and $9.04 \times 10^{-4}$ kgf/mm. Equivalent stress was similar among measurement points A-F in these models. However at each point it was lower in the labiolingual model than in the labial mode.

**Fig. 5** Equivalent stress distribution in the alveolar region of the control model (A), the labial model (B), and the labiolingual model (C).

**Fig. 6** Equivalent stress distribution in the alveolar region below the corticotomy line.

**Fig. 7** Equivalent stress distribution in the alveolar region above the corticotomy line.
model, followed by the labial model, while the labiolingual model showed the greatest stress.

**Equivalent stress distribution in the teeth (Fig. 8)**
In the control model, equivalent stress in the labial cervical sites (1–6) (Figs. 4 and 8, Table 3) was between $1.75 \times 10^{-3}$ and $4.67 \times 10^{-3}$ kgf/mm, being elevated at measurement point 4, the left central incisor ($4.67 \times 10^{-3}$ kgf/mm), and decreasing distally. In the labial model, it was between $1.86 \times 10^{-3}$ and $5.59 \times 10^{-3}$ kgf/mm, while in the labiolingual model it was between $2.17 \times 10^{-3}$ and $5.75 \times 10^{-3}$ kgf/mm. In both groups, equivalent stress was elevated at measurement points 3 and 4, and decreased distally, showing a tendency similar to that in the control group. No marked difference was observed between the labial and labiolingual models. In addition, at measurement points 1, 2 and 6, no marked difference was observed among the three groups.

In the control model, equivalent stress at 1/3 the distance from the root apex (7–12, Fig. 10, Table 4) was between $0.62 \times 10^{-3}$ and $2.43 \times 10^{-3}$ kgf/mm. In the labial model, it was between $1.25 \times 10^{-3}$ and $2.54 \times 10^{-3}$ kgf/mm, while in the labiolingual model it was between $1.81 \times 10^{-3}$ and $3.85 \times 10^{-3}$ kgf/mm. The labiolingual model showed elevated stress at all measurement points.

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**Fig. 8** Equivalent stress distribution in the teeth of the control model (A), the labial model (B), and the labiolingual model (C).

**Fig. 9** Equivalent stress distribution at the labial cervical sites.

**Fig. 10** Equivalent stress distribution at 1/3 the distance from the root apex.

**Table 3** Equivalent stress distribution at the labial cervical sites

<table>
<thead>
<tr>
<th>Measurement site</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.75</td>
<td>3.27</td>
<td>3.55</td>
<td>4.67</td>
<td>4.32</td>
<td>2.3</td>
</tr>
<tr>
<td>Labial</td>
<td>1.86</td>
<td>3.43</td>
<td>5.59</td>
<td>5.57</td>
<td>5.07</td>
<td>2.4</td>
</tr>
<tr>
<td>Labiolingual</td>
<td>2.17</td>
<td>3.74</td>
<td>5.73</td>
<td>5.75</td>
<td>5.12</td>
<td>2.55</td>
</tr>
</tbody>
</table>

$(\times 10^{-3}$ kgf/mm$^2$)

**Table 4** Equivalent stress distribution at 1/3 the distance from the root apex

<table>
<thead>
<tr>
<th>Measurement site</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.43</td>
<td>2.43</td>
<td>2.05</td>
<td>1.76</td>
<td>1.25</td>
<td>0.62</td>
</tr>
<tr>
<td>Labial</td>
<td>1.15</td>
<td>2.6</td>
<td>2.36</td>
<td>2.47</td>
<td>2.54</td>
<td>1.32</td>
</tr>
<tr>
<td>Labiolingual</td>
<td>2.07</td>
<td>3.75</td>
<td>3.9</td>
<td>3.45</td>
<td>3.85</td>
<td>1.81</td>
</tr>
</tbody>
</table>

$(\times 10^{-3}$ kgf/mm$^2$)
In the control model, equivalent stress at the root apex (13–18, Fig. 11, Table 5) was between \(0.41 \times 10^{-3}\) and \(1.27 \times 10^{-3}\) kgf/mm. In the labial model, it was between \(0.45 \times 10^{-3}\) and \(2.02 \times 10^{-3}\) kgf/mm while in

the labiobuccal model it was between \(1.11 \times 10^{-3}\) and \(3.84 \times 10^{-3}\) kgf/mm. No difference was observed at measurement points 13 and 18 between the control and the labial models. At the other measurement points (14–17), the controls showed the lowest stress, followed by the labial model, and the labiobuccal model in that order, which showed elevated stress at every measurement point.

**Tooth displacement** (Figs. 12 and 13, Table 6)

Tooth displacement was between \(1.16 \times 10^{-4}\) and \(2.02 \times 10^{-4}\) mm in the controls, between \(1.48 \times 10^{-4}\) and \(3.06 \times 10^{-4}\) mm in the labial model, and between \(2.36 \times 10^{-4}\) and \(5.23 \times 10^{-4}\) mm in the labiobuccal model. In each group, the amount of displacement was the greatest for the central incisors and decreased distally. In each tooth, the amount of displacement was small in the control model, and greatest in the labiobuccal model.

**DISCUSSION**

In recent years, there has been an increase in people receiving orthodontic treatment, not only school children in the growth stage, but also adults. Orthodontic treatment in adults has special issues, including, malalignment, tooth defects, and periodontal disease, as well as social and time constraints. In 1959,
Köle reported that corticotomy could reduce the orthodontic treatment period. He noted that corticotomy has the advantages of shortening of the orthodontic treatment period by increasing the speed of tooth movement by reducing the resistance of the cortical bone, increasing bone metabolism, and preventing relapse due to hardening of the alveolar region after osseous healing, compared with the preoperative state.7

This technique, in which only cortical bone is cut, is minimally invasive and preserves blood flow in the bone marrow, only slightly affecting the teeth. This method has been frequently used in clinical practice and many clinical cases have been reported. However, there have been only a few studies in which biomechanical and three-dimensional analysis of this technique have been performed. It is mainly applied to the maxilla and relatively rarely done in the mandible. Therefore, using a three-dimensional finite element model after corticotomy in the mandibular anterior segment, we applied a distalizing load to these teeth, and evaluated tooth displacement, as well as the equivalent pressure distribution in the anterior teeth and anterior alveolar region.

**Experimental methods**

Since Turneret al.8 first put the finite element method to practically use in the design of airplanes in 1956, this method has been applied in many fields. It allows the accurate observation of phenomena for which it is difficult to obtain experimental data.10 Although there have been mechanical studies on orthodontic tooth movement using the strain gauge method11 and laser hologyraphy,12 approximation of the in vivo anatomical morphology of the teeth and alveolus has been difficult using these methods. With advances in personal computers in recent years, it has become possible to increase the number of tangent points and elements, and to produce models more similar to the in vivo state. In this study, we produced a three-dimensional model of the teeth and mandible based on CT data, and, from this model, produced corticotomy models. As a result, we were able to produce models with markedly increased elements and tangent points.

**Equivalent stress distribution in the alveolar region**

In the control model, we found that equivalent stress in the alveolar region below the root apices was the greatest for the central incisor and decreased distally. With corticotomy, the equivalent stress decreased in the body of the bone below the corticotomy line. This tendency was more marked after bilateral labiolingual corticotomy. Above the corticotomy line, equivalent stress was the greatest at each measurement point in the labiobuccal model, followed in order by the labial and control models. Motohashi13 performed corticotomy of the maxillary anterior segment as a mass, followed by analysis using the three-dimensional finite element method, and reported that the stress transmitted by cortical bone was not transmitted to the area posterior to the corticotomy area due to stress interference by cancellous bone in the corticotomy area, suggesting high tooth movement efficiency. Yoshikawa14 also performed mechanical analysis after maxillary corticotomy using the strain gauge method, and reported that force dispersion to the cranial suture became difficult after corticotomy, which was effective for posterior movement in the alveolar region of the anterior teeth. In the mandibular model in this study, because the corticotomy interrupted the continuity of cortical bone below the root apex, the orthodontic force applied to the teeth may have been concentrated on bone around the teeth.

**Equivalent stress distribution in the teeth**

Equivalent stress distribution in the 6 anterior teeth was measured in the labial region of the crown, at 1/3 the distance from the root apex, which is considered to be the center of rotation, and at the root apex. On the labial side of the crown, although there was no marked difference between the labiobuccal and labial models, stress was elevated at all measurement sites in the labiobuccal corticotomy model. These findings suggest that corticotomy results in direct orthodontic force on the teeth as well as concentrated stress on the alveolar bone, and is advantageous for tooth movement.
Amount of tooth displacement
Tooth displacement at the incisal margin was increased in the labiolingual model. This may correlate with the stress distribution in the alveolar region and the teeth. Displacement was the most marked in the central incisors and decreased distally. This may have been the result of application of distalizing orthodontic force applied along the vertical axis of the center of the crown. In clinical practice, attention should be paid to the direction of orthodontic force.

These results showed that corticotomY is also useful for tooth movement in the anterior segment of the mandible, because the continuity of cortical bone is interrupted, resulting in the concentration of orthodontic force, which is generally dispersed to the surrounding bone, on the teeth, and concentration of stress in the alveolar region around the teeth. In addition, corticotomY performed on both the labial and lingual sides was more effective than that performed on the labial side alone.

CONCLUSION
Our results suggest that corticotomY is useful for tooth movement because the continuity of cortical bone is interrupted, resulting in the concentration of orthodontic forces. These forces were dispersed to the surrounding bone and on the teeth, while the stress was concentrated in the surrounding alveolar region. We found that in addition, corticotomY on both the labial and lingual sides, as opposed to only on the labial side, may be more effective.

REFERENCES