Root resorption of maxillary primary incisors in relation to position of successive permanent incisors by Micro-CT

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Abstract The aim of this study is to elucidate the root resorption of primary incisors in relation to the development of permanent incisors. We observed the maxillae of the dry skulls of Indian children, using Micro-CT, and measured distance between the root surface of the primary incisor and the bony crypt of the permanent incisor. The bony crypt of the maxillary permanent incisor, which was situated at the lingual side of the primary incisor, grew upward towards the mouth as the tooth eruption stage proceeded. Root resorption was clearly seen at the primary dentition stage, and it proceeded to from root surface towards root canal at the first molar eruption. With the advance of the stage, the distance between the root surface of the primary incisor and the bony crypt of the permanent incisor became shorter, especially the distance between the root of the primary lateral incisor and the bony crypt of the permanent central incisor did. By using Micro-CT, we could confirm more clearly that the growth of the bony crypt of the central permanent incisor deeply influence the progress of root resorption of the primary lateral incisor.

Key words Bony crypt, Dry skulls of Indian children, Maxillary primary incisors, Micro-CT, Root resorption

Introduction The physiological root resorption of the primary tooth is a phenomenon observed at the time of its replacement by the successive permanent tooth1–4). In the treatment of the primary tooth, the accurate evaluation of the state of the root resorption and of its positional relationship with the successive permanent tooth is important. This evaluation is usually performed by dental radiography, but it is difficult to do it accurately, especially about the primary incisor, because on dental X-ray films it overlaps labiolinguually with the successive permanent tooth.

It is characteristic of the primary incisor that root resorption is initiated on the lingual surface of the root. As the successive permanent incisor is located at the lingual side of the primary incisor on both maxilla and mandible, root resorption progresses from the lingual surface toward the root apex. Matsumoto et al.5) pointed out that resorption rapidly extends to the labial surface when the length of the root decreases to about 3/4. Haavikko6) reported that the root resorption of the preceding primary tooth is initiated, when the root of the successive permanent tooth begins to form, or 1/4 of the length

Received on September 19, 2007
Accepted on February 18, 2008
is formed, and that the root resorption of the maxillary primary incisor progresses in a particularly short period because of the rapidness of the growth of the successive permanent tooth.

There are, however, not so many studies on the physiological root resorption of primary incisors. It is mainly because specimens are difficult to obtain for the study. The relationship between the root resorption of human primary teeth and successive permanent teeth has only been studied by Saka\textsuperscript{7}) and Saka\textsuperscript{et al.}\textsuperscript{8}) about maxillary primary molars, by Kikuchi\textsuperscript{9}) and Kitamura\textsuperscript{et al.}\textsuperscript{10}) about mandibular primary molars, and by Iida\textsuperscript{et al.}\textsuperscript{11}) about mandibular primary incisors. A three-dimensional study by use of X-ray CT was made by Kamioka\textsuperscript{12}) about second primary molars.

In many of the previous studies, resin-embedded specimens of skulls were sectioned for the observation of the relationship between root of the primary tooth and the successive permanent tooth\textsuperscript{7–10}). But this method destroys valuable specimens, because we need to cut them to make thin pieces, so that observation is made only from one direction.

In this study, therefore, Micro-CT is used for the purpose of stereographic imaging. It enables us to reconstruct specimens three-dimensionally without destroying specimens. As observation is made from any direction, we can quantitatively analyze the changes in the positional relationship between the primary tooth and the successive permanent tooth, which occur with advance of the eruption stage.

**Materials and Methods**

1. **Observation of the positional relationship between the roots of the primary incisor and successive permanent incisor in dried skulls of children**

Sixteen maxillas of dry skulls of Indian children without dental defects, malocclusion, and dentin caries, which were stored in the autopsy department of Tokyo Dental College, were used as specimens for our study. They were classified into four eruption stages, according to which tooth reaches the alveolar crest.

Stage I: The maxilla with primary central and lateral incisors and first primary molars reaching alveolar crests

Stage II: The maxilla with primary canines reaching alveolar crests, in addition to teeth in Stage I

Stage III: The maxilla with primary second molars reaching alveolar crests, in addition to teeth in Stage II

Stage IV: The maxilla with first permanent molars reaching alveolar crests, in addition to teeth in Stage III (Table 1)

Then, the positional relationship between maxillary primary incisors and successive permanent incisors was observed by use of Micro-CT (Kashimura KSM-755), at the tube voltage of 65 kV and the tube current of 85 mA, and 500 image slices (16 bit) were obtained as raw data.

Based on them, two-dimensional slice images of the relation were produced by the Back Projection method, with the help of the simple multi-section reconstruction software (MultiBP, Image script). For the noise elimination and contrast adjustment in each slice image, photo retouch software (Photoshop 5.0, Adobe) was used.

Based on the two-dimensional images, the three-dimensional reconstruction was performed by the Volume Rendering method, with the help of the three-dimensional reconstruction software (AVS, KGT Inc.). And we observed the images of coronal, sagittal, and horizontal direction.
In the coronal direction, perpendicular to the Frankfort plane, the area from the line connecting the incisal margins of the primary right and left central incisors, to the line connecting the disto-incisal angles of the primary right and left lateral incisors, was divided into three equal portions and was observed from the lingual direction. In the sagittal direction, the area from the median plane to the distoincisal angle of the primary right lateral incisor was divided into four equal portions and was observed from the distal direction on the labial side. In the horizontal direction, parallel to the Frankfort plane, the area from the labial alveolar crest of the primary central incisors to the deepest point (subspinale) between the anterior nasal spine and alveolar process was divided into four equal portions and observed from below.

2. Measurement of the distance between the root surface and bony crypt
Based on the images obtained by use of Micro-CT, the shortest distance between the root surface of the maxillary primary incisor and the bony crypt of the successive permanent incisor was measured on the slice images of horizontal direction (Fig. 1).

The mean value and the standard deviation were calculated by the statistical method. Differences in the mean value among the dentition stages were analyzed by Tukey’s q-test \((P<0.05)\) and the distances between the roots of primary lateral incisors and the bony crypts of incisors were analyzed by t-test \((P<0.05)\), statistical analysis software (Statmate III, Atms) was used.

Results
1. Observation of the positional relationship between the roots of the primary incisor and successive permanent incisor in dried skulls of children
These pictures were taken from the coronal direction (A1–A4: from lingual to labial), from the sagittal...
direction (B1–B5: from distal to median plane) and from the horizontal direction (C1–C5: from below to above).

1) Stage I
a. Coronal direction
The root of the primary central incisor was complete (Fig. 2 A1, A2), but that of the primary lateral incisor was not (Fig. 2 A1–A4). The superior margin of the bony crypt of the central incisor was located on the inferior margin of the bottom of the nasal cavity (Fig. 2 A1–A4). The bony crypt of the lateral incisor was located distolingual to the root of the primary lateral incisor (Fig. 2 A4).

b. Sagittal direction
The inferior margin of the bony crypt of the central incisor was located on the level with 1/2 of the root of the primary central incisor, near the median area (Fig. 2 B5) and the distoincisal angle of the primary central incisor (Fig. 2 B3), but it was observed close to the alveolar crest and the root in the middle area of the lingual side of the primary central incisor (Fig. 2 B4), showing unclear border between the bony crypt and the alveolar bone proper. A bony crypt of the lateral incisor was observed near the root apex of the primary lateral incisor (Fig. 2 B2). However, in the distoincisal angle of the primary lateral incisor (Fig. 2 B1), the bony crypt was unclear.

c. Horizontal direction
The bony crypt of the primary central incisor became larger from the inferior area toward the superior area, showing an increase in the labiolingual width, and it was also close to the mesiolingual area of the root of the primary lateral incisor (Fig. 2 C3–C5). On the lingual side of the root of the primary central incisor, from the middle area to the root apex, the border between the bony crypt and the alveolar bone proper was partly unclear (Fig. 2 C2–C5). The bony crypt of the lateral incisor was located almost in parallel to the central incisor in the inferior area (Fig. 2 C2, C3) but it became more lingual side toward the
2) Stage II
   a. Coronal direction
   The root of the primary lateral incisor was incomplete in Stage I but was almost complete in this stage (Fig. 3 A2). The bony crypt of the central incisor showed superoinferior growth in this stage (Fig. 3 A3, A4), compared with that in Stage I.
   b. Sagittal direction
   The bony crypt of the lateral incisor was located near the root apex just like in Stage I, but slightly increased in size (Fig. 3 B2). The root of the primary lateral incisor completed to its apex (Fig. 3 B2).
   c. Horizontal direction
   In the lingual area of the root of the primary central incisor, the border between the bony crypt and the proper alveolar bone was unclear in this Stage (Fig. 3 C2–C5). The root of the primary lateral incisor was closer to the distal area of the bony crypt of the central incisor than to the bony crypt of the lateral incisor, as the successive permanent tooth was located lingually (Fig. 3 C4, C5).

3) Stage III
   a. Coronal direction
   The bony crypt of the central incisor grew further mesiodistally, resulting in resorption of the mesial surface of the root of the primary lateral incisor (Fig. 4 A4).
   b. Sagittal direction
   The bony crypt of the central incisor grew, resulting in resorption near the root apex of the primary central incisor (Fig. 4 B4). On the distal side of the lateral incisor, the inside of the maxilla showed a complicated form as was observed (Fig. 4 B1).
   c. Horizontal direction
   At the level of the alveolar crest of the primary central incisor, cortical bone resorption on the
lingual side of the primary central incisor, this was caused by the growth of the central incisor (Fig. 4 C1). The lingual area of the root of the primary central incisor was close to the crown of the central incisor (Fig. 4 C2–C5) and showed resorption near the root apex (Fig. 4 C4).

4) Stage IV
a. Coronal direction
The germ of the central incisor mesiodistally overlapped with that of the lateral incisor (Fig. 5 A3, A4).
b. Sagittal direction
The bony crypts of the central and lateral incisors were observed nearly at similar levels in the distal area of the central incisor (Fig. 5 B3). These crypts were close to the roots of the preceding primary teeth, and root resorption was observed (Fig. 5 B2, B4).
c. Horizontal direction
Root resorption of both primary central and lateral incisors was observed (Fig. 5 C2–C5). In particular, the right primary central incisor showed resorption extending to the root canal (Fig. 5 C2–C4). In the superior area, the central incisor showed a marked mesiodistal growth, resulting in lingual shift of the lateral incisor (Fig. 5 C4, C5). The root resorption of the primary lateral incisor was more markedly affected by the adjacent permanent central incisor than by the successive permanent lateral incisor, and the mesial surface showed more advanced resorption than the lingual surface (Fig. 5 C3, C4).

2. Measurement of the distance between the root surface and bony crypt
The shortest distance between the root surface and bony crypt was measured.
1) Measurement of the distance between the root surface of primary central incisors and bony crypt of central incisors (Table 2 and Fig. 6).
The mean distance in Stage I was 1.05 mm, the
maximum 1.55 mm, and the minimum 0.00 mm. The mean distance in Stage II was 0.78 mm, the maximum 1.21 mm, and the minimum 0.00 mm. The mean distance in Stage III was 0.33 mm, the maximum 0.52 mm, and the minimum 0.00 mm. The mean distance in Stage IV was 0.11 mm, the maximum 0.21 mm, and the minimum 0.00 mm.

Significant differences were observed between Stage I and Stage III, IV, between Stage II and Stage IV and between Stage III and Stage IV.

Table 2. The shortest distances between the root of primary incisors and the bony crypt of successive permanent teeth (mm)

<table>
<thead>
<tr>
<th>Teeth</th>
<th>Stage I</th>
<th></th>
<th></th>
<th>Stage II</th>
<th></th>
<th></th>
<th>Stage III</th>
<th></th>
<th></th>
<th>Stage IV</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>p.c.i</td>
<td>1.05</td>
<td>0.22</td>
<td>1.55</td>
<td>0.00</td>
<td>0.78</td>
<td>0.20</td>
<td>1.21</td>
<td>0.00</td>
<td>0.33</td>
<td>0.08</td>
<td>0.52</td>
</tr>
<tr>
<td>p.l.i</td>
<td>1.48</td>
<td>0.35</td>
<td>2.42</td>
<td>0.32</td>
<td>1.33</td>
<td>0.30</td>
<td>2.34</td>
<td>0.33</td>
<td>0.90</td>
<td>0.17</td>
<td>1.79</td>
</tr>
</tbody>
</table>

p.c.i: primary central incisor, p.l.i: primary lateral incisor, S.D.: standard deviation

2) Measurement of the distance between the root surface of primary lateral incisors and bony crypt of lateral incisors (Table 2 and Fig. 7).

The mean distance in Stage I was 1.48 mm, the maximum 2.42 mm, and the minimum 0.32 mm. The mean distance in Stage II was 1.33 mm, the maximum 2.34 mm, and the minimum 0.33 mm. The mean distance in Stage III was 0.90 mm, the maximum 1.79 mm, and the minimum 0.00 mm. The mean distance in Stage IV was 0.49 mm, the maximum 0.87 mm, and the minimum 0.00 mm.

Significant differences were observed between Stage I and Stage III, IV, between Stage II and Stage IV and between Stage III and Stage IV.
3) Measurement of the distance between the root surface of primary lateral incisors and bony crypt of central incisors (Table 3 and Fig. 7).

The mean distance in Stage I was 0.78 mm, the maximum 1.37 mm, and the minimum 0.00 mm. The mean distance in Stage II was 0.51 mm, the maximum 0.94 mm, and the minimum 0.00 mm. The mean distance in Stage III was 0.20 mm, the maximum 0.58 mm, and the minimum 0.00 mm. The mean distance in Stage IV was 0.07 mm, the maximum 0.16 mm, and the minimum 0.00 mm.

Significant differences were observed between Stage I and Stage II, III, IV and between Stage II and Stage III, IV.

**Discussion**

Several studies in our department have shown that maxillary bony crypts change in size, shape, and position, as the tooth eruption stage progresses\(^7,8,13,14\). Kawashima\(^13\), who studied positional changes of maxillary bony crypts, reports that, in a primary dentition stage, the central incisor is closer to the labial side, and the lateral incisor to the lingual side in the anteroposterior direction; the central incisor is superior to the lateral incisor in the superoinferior direction; and the mesial half of the lateral incisor overlaps with the central incisor in the mesiodistal direction. He also shows that these anteroposterior and superoinferior positional relationships remain clear until the early mixed dentition stage (the stage after primary dentition at which the first molar and the central incisor erupt) and that they subsequently change to linear arrangements.

Those findings are similar to ours, but the overlapping of the distal area of bony crypts of central incisors with the mesial area of the root of primary lateral incisor is made clearer in our study, Micro-CT, as it enables us to obtain the three-dimensional images of teeth observed from three different directions. Especially the image observed from a horizontal direction is detailed and the distance between the bony crypt of the permanent incisor and the root of the primary incisor can be accurately measured.

In our study, the root resorption from the lingual surface of the primary central incisor is affected by the successive permanent central incisor. It starts and progresses earlier than the root resorption of the primary lateral incisor, as the results of measurement of the distance prove it. These findings are consistent with a previous report on mandibular incisors\(^11\).

The root resorption of the primary lateral incisor has been reported to be affected by the bony crypt of the successive permanent lateral incisor in a horizontal direction, as well as by that of the mandibular central incisor in a coronal direction\(^11\). However, our observation of the maxilla shows that it is more markedly affected by the bony crypt of the central incisor than by that of the lateral incisor. And the results of measurement show that the root of the primary lateral incisor is closer to the bony crypt of the central incisor than to that of the successive lateral incisor.

In the maxilla, the successive permanent tooth is larger than it in the mandible, and the tooth arrangement is more intricate, due to the inadequate jaw growth. The lateral incisor is located lingual to the central incisor, and the distal area of the central incisor approaches to the mesial surface of the primary lateral incisor. Therefore, the influence of the central incisor on the root resorption of the primary lateral incisor is more prominent in the maxilla than in the mandible.

These results elucidated the sequence of the root resorption of the primary lateral incisor. First occurs mesial resorption, due to the influence of the bony crypt of the central incisor. Subsequently, the bony crypt of the lateral incisor, which is located more distolingually, grows in the mesial direction, with advancement of the eruption stage, and its distance to the root of the primary lateral incisor decreases.

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**Table 3** The shortest distances between the root of primary lateral incisors and the bony crypt of central incisors (mm)

<table>
<thead>
<tr>
<th></th>
<th>Stage I</th>
<th></th>
<th>Stage II</th>
<th></th>
<th>Stage III</th>
<th></th>
<th>Stage IV</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.78</td>
<td>S.D.</td>
<td>0.15</td>
<td>Max.</td>
<td>1.37</td>
<td>Min.</td>
<td>0.00</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>0.51</td>
<td>S.D.</td>
<td>0.09</td>
<td>Max.</td>
<td>0.94</td>
<td>Min.</td>
<td>0.00</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>0.20</td>
<td>S.D.</td>
<td>0.06</td>
<td>Max.</td>
<td>0.58</td>
<td>Min.</td>
<td>0.00</td>
<td>Mean</td>
</tr>
</tbody>
</table>

S.D.: standard deviation
Resulting resorption on the lingual side shortens the length of the root, and the primary lateral incisor comes to its shedding.

Conclusions

We classified 16 dry maxilla of Indian children stored in the autopsy department of Tokyo Dental College into four stages according to the eruption state of primary teeth and first molar, and observed them using Micro-CT.

1. Observation of the positional relationship between the roots of the primary incisor and successive permanent incisor in dried skulls of children

The bony crypts of the central and lateral incisors overlapped with the lingual side of the preceding primary teeth, grew with advancement in the eruption stage, and became close to the roots of the primary teeth from their half level to the apex, resulting in root resorption.

When the first molars reached the alveolar crest in addition to the primary dentition (Stage IV), progression of the root resorption of the primary central incisor and resorption extending to the root canal were observed.

The root resorption of the primary lateral incisor was initiated on the mesial surface due to growth of the bony crypt of the adjacent central incisor.

2. Measurement of the distance between the root surface and bony crypt

To clarify the relationship between the roots of the maxillary primary incisors and the bony crypts of successive permanent teeth observed on images obtained using Micro-CT, the distance between the root surface and bony crypt was measured.

With progression in the tooth eruption stage, the distance between the lingual surfaces of the roots of the primary central and lateral incisors and the bony crypts decreased. The primary lateral incisor was closer to the bony crypt of the central incisor than that of the lateral incisor.

Acknowledgments

We would like to thank our staff for all their advice and valuable suggestions.

References