The morphological analysis of root resorption of mandibular primary canines and their relationship with the position of successive permanent teeth using Micro-CT

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Abstract The aim of this study is to elucidate the root resorption of primary canines in relation to the development of successive permanent teeth and the change in the internal structure of the surrounding area. We observed the mandibles of the dry skulls of Indian children, using Micro-CT, and measured distance between the root surface of the primary canine and the bony crypt of canine. The bony crypts including successive canines were located immediately below the primary canine roots in the primary dentition stage. When the first molars reached the alveolar crest in addition to the primary dentition, the bony crypts moved in the distolingual direction, and showed inferior growth, resulting in compact bone resorption of the mandibular base. Root resorption of primary canines was observed on the distolingual surface with the advancing of the developing stages. After the central incisors reached the alveolar crest, it was quantitatively shown that the distance between the lingual surface of primary canine roots and canine bony crypts reduced.

Introduction The physiological root resorption of primary teeth is a peculiar phenomenon observed in teeth at the time of their replacement by successive permanent teeth1–4). In the treatment of primary teeth, the accurate evaluations of their state of root resorption and positional relationship with the successive permanent teeth are very important, and these evaluations are performed mainly by dental radiography. However, accurate evaluation of the state of root resorption on X-ray films is difficult, particularly in the part of primary incisors due to their labiolingual overlapping with successive permanent tooth germs.

The physiological root resorption of the primary incisors is characterized by the initiation of resorption on the lingual surface of the root since successive permanent tooth germs are located lingually to the primary teeth. Matsumoto et al.5) described that resorption rapidly extends to the labial surface when the length of root decreased to about 3/4. Haavikko6) reported that root resorption of the preceding primary teeth is initiated when the root of the successive permanent teeth begins to form, or 1/4 of root formation is completed.

However, there have been only a few studies on physiological root resorption of the primary teeth, and little is known about the resorption pattern and direction. Since the skulls of children are difficult to obtain, the relationship between root resorption of human primary teeth and successive permanent teeth
has been studied only by Saka\textsuperscript{7}, Saka \textit{et al.}\textsuperscript{8}, Kikuchi\textsuperscript{9}, Kitamura \textit{et al.}\textsuperscript{10}, Iida \textit{et al.}\textsuperscript{11} and Hiraide \textit{et al.}\textsuperscript{12}. Although there have been some reports on three-dimensional observation using X-ray CT\textsuperscript{13}, only second primary molars have been observed in those studies.

Therefore, we focused on the mandibular primary canines in this time and performed three-dimensional reconstruction with Micro-CT using dry skulls of children as specimens to elucidate the relationship between root resorption and successive permanent teeth. We observed the positional relationship between the mandibular primary canines and successive permanent teeth in each tooth eruption phase, and the change in the internal structure of the surrounding area.

**Materials and Methods**

1. **Observation of the positional relationship between the roots of primary canines and successive permanent canines in the dried skull specimens of children**

   Imaging of the mandibular primary canines was performed using Micro-CT, and the positional relationship between the roots of mandibular primary canines and successive permanent canines was observed.

   Sixteen mandibular specimens isolated from dry skulls of Indian children belong to our department without missing teeth, deformation and malalignment of the teeth, and carious teeth extending into dentin were used. These specimens were classified into four eruption phases with eruption reaching the alveolar crest as the standard, four specimens and eight sides (left and right side) from each stage were observed.

   Stage I: The mandible with primary central incisors to primary second molars reaching alveolar crests (primary dentition stage)

   Stage II: The mandible with first molars reaching alveolar crests, in addition to teeth in Stage I

   Stage III: The mandible with central incisors reaching alveolar crests, in addition to teeth in Stage II

   Stage IV: The mandible with lateral incisors reaching alveolar crests, in addition to teeth in Stage III (Table 1).

   Micro-CT (HMX225-ACTIS, TESCO) was used to observe the relationship between the mandibular primary canines and the bony crypt including tooth germs of canines.

   Radiographic conditions were a tube voltage of 100 kV and tube current of 90 \( \mu \)A, magnification was 3.53.

   Based on the obtained raw data, two-dimensional slice images were produced by the back projection method. For noise elimination and contrast adjustment in each slice image, photo retouch software (Photoshop 6.0, Adobe) was used.

   Three-dimensional reconstruction of the two-dimensional slice images was performed by volume rendering using three-dimensional reconstruction software (VG Studio Max, Nihon Visual Science). The relationship between the roots of the mandibular primary canines and the bony crypt including tooth germs of canines was observed by setting sections in the coronal, sagittal, and horizontal directions. A reference area was set in each plane, and divided into four sections. Among five observable planes, three planes in the middle were observed.

   Three directions were set up as a reference area. In the coronal direction, from the plane which is perpendicular to the mandibular base edge, and connects the mesioincisal and distoincisal angles of primary canines to the widest contour point of labial and lingual cervical lines (Fig. 1-A). In the sagittal direction, from the plane which is perpendicular to the mandibular base edge, and connects the cusp tip of the canine and the widest contour point of the lingual cervical line to the mesioincisal and distoincisal angles of the primary canines (Fig. 1-B). In the horizontal direction, the area which is parallel to the mandibular base edge, and from the labial alveolar crest of the primary canines to the upper margin of the mental (Fig. 1-C).

   Observation was performed from the labial side in the coronal direction, distal side in the sagittal
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2. Measurement of the distance between the root surface and bony crypt

To clarify the relationship between the roots of the mandibular primary canines and the bony crypts of successive permanent teeth observed on Micro-CT images, the shortest distance between the root surface and bony crypt was measured. Measurement was carried out in the horizontal direction in the
range of the bony crypt.

The mean value and the standard deviation were calculated by the statistical method. Differences in the mean value between the dentition stages were analyzed by Tukey’s t-test ($P<0.05$), statistical analysis software (Statmate III, Atms) was used.

Results

1. Observation of the positional relationship between the roots of primary canines and successive permanent canines in the dried skull specimens of children

1) Stage I (Fig. 2).

a. Coronal direction

The bony crypts of canines were located immediately below the root of the primary canines labially, centrally, and linguually (A-1, 2, 3). The compact bone around the bony crypt was thick, and round in shape (A-1, 2).

b. Sagittal direction

The roots of primary canines were incomplete (B-2). Although the bony crypts of canines were observed on the lingual side near the root apex of the primary canines in the upper area, and in the middle of the root labiolingually in the lower area, they were leaning toward the labial side at the median height of the mandible (B-1, 2, 3). The mesial part of the bony crypt overlapped that of the lateral incisor. Lateral incisors were observed in the upper part of the lingual side and canines were observed in the mid-lower part (B-3).

c. Horizontal direction

The root of primary canines was located on the labial side (C-1, 2, 3) and the parts of canine bony crypts were observed in the upper part (C-1).
shape of the bony crypts was triangular in the middle (C-2, 3).

2) Stage II (Fig. 3)
   a. Coronal direction
   The bony crypts located immediately below the primary canine roots in Stage I were located in the same area in the upper part, but distal growth was observed in the lower area (A-1, 2, 3). The shape of the bony crypts became oval due to superoinferior growth (A-1, 2, 3). On the lingual side, primary canine roots and the distal part of the bony crypts of the lateral incisors were adjacent (A-3).
   b. Sagittal direction
   The roots of primary canines which were incomplete at Stage I were complete at this stage (B-2). The bony crypts of the canines were located in the same area as in Stage I in the upper, middle, and lower areas (B-1, 2, 3). The mesial part of the canine bony crypt overlapped that of the lateral incisor, and they were located even closer than in Stage I (B-3).
   c. Horizontal direction
   In the upper area, the distal part of the bony crypt of the lateral incisor was adjacent to the lingual side of the primary canine roots (C-1). In the lower area, the shape of the canine bony crypt changed to oval due to mesiodistal growth (C-3).

3) Stage III (Fig. 4)
   a. Coronal direction
   The bony crypts of the canines located immediately below the primary canines in the upper area, and distally in the lower area in Stage II grew further distally against the primary canines (A-1, 2, 3). They also grew markedly superoinferiorly,
and were adjacent to the distal part of the primary canine roots (A-1, 2, 3). Resorption in the compact bone of the mandibular base adjacent to the lower part of the bony crypt was observed (A-2, 3).

b. Sagittal direction
The bony crypt of the canines showed labiolingual growth distally, centrally, and mesially, and covered a large proportion of the mid-lower mandible (B-1, 2, 3). The lingual side of the primary canine roots showed resorption in the central area (B-2). Resorption in the compact bone of the mandibular base adjacent to the lower part of the bony crypt was observed, as well as in the coronal direction (B-1, 2, 3).

c. Horizontal direction
The canine bony crypts were located on the distolingual side of the primary canine roots in the upper, central, and lower areas (C-1, 2, 3). The resorption of the distolingual surface of the roots was significant in the lower area (C-3).

4) Stage IV (Fig. 5)
a. Coronal direction
The canine bony crypts were located distal to the primary canines, as was observed at Stage III (A-1, 2, 3). Significant growth of the canine bony crypts in the superoinferior direction was observed and part of the canine roots was formed (A-1, 2, 3). In the central area, resorption in the distal surface of the primary canines was observed (A-2). The compact bone of the mandibular base adjacent to the lower part of the bony crypt showed further resorption (A-1, 2, 3).

b. Sagittal direction
The canine bony crypts showed further growth compared with Stage III and an oval shape,
accounting for the majority of the mandible (B-1, 2, 3).

c. Horizontal direction
In the upper area, the canine bony crypts were located on the lingual side of the primary canine roots (C-1). In the central and upper areas, the canine bony crypts surrounded primary canine roots, showing marked labiolingual growth (C-2, 3). Root resorption of the primary canines was observed (C-1, 2, 3).

2. Measurement of the distance between the root surface and bony crypt
The shortest distance between the root surface of primary canine and bony crypt of canine was measured (Fig. 6) (Table 2).

The mean distance in Stage I was 1.37 mm, the maximum 1.78 mm, and the minimum 0.00 mm. The mean distance in Stage II was 1.20 mm, the maximum 1.61 mm, and the minimum 0.00 mm. The mean distance in Stage III was 0.68 mm, the maximum 1.03 mm, and the minimum 0.00 mm. The mean distance in Stage IV was 0.22 mm, the maximum 0.48 mm, and the minimum 0.00 mm.

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

Discussion
1. Observation of the positional relationship between the roots of primary canines and successive permanent canines in the dried skull specimens of children
Bony crypts have been considered an important factor along with successive permanent tooth germs in the root resorption of primary teeth. Therefore, we observed the positional relationship between the roots of mandibular primary canines and the bony crypts of successive canines. Previous studies in our department have shown changes in the size, shape, and position of mandibular bony crypts with changes in the tooth eruption phase.\(^{9-11,14-16}\).

Nishimura\(^{14}\) reported the change in position of the bony crypts of mandibular canines. According to his reports, bony crypts which were located on the labial side in the lower area in the primary dentition stage show growth and lingual movement.
in the lower margin, followed by growth in the upper margin. The shape of bony crypts changes from round to oval due to the vertical growth\(^{15}\). Tanaka\(^{16}\) described the growth and positional change of permanent tooth germs. He reported that canine tooth germs grow superiorly between the primary dentition stage and eruption of the first molars, followed by inferior growth in the eruption of central incisors. The inferior growth of canine bony crypts as well as superior growth, and compact bone resorption inside of the base of mandible observed in the present study were peculiar findings in this area. This is considered to be due to the fact that not only canine bony crypts are located in the lower area, but also that inferior growth of the bony crypts is inevitable as well as superior growth because canines are the longest in all kind of teeth.

In addition, the position of the canine bony crypts located immediately below the primary canine roots in the primary dentition period is shifted towards the distal side along with the tooth eruption phase. In previous studies targeting other parts of the mandible, no mesiodistal positional change of the bony crypts was observed. This is also considered to be due to the fact that long canines require vertical space.

Therefore, root resorption of the primary canines is not affected when the bony crypts are located immediately below the incomplete roots, and starts being affected after the bony crypts move toward the distolingual side. Although the distal part of the bony crypts of adjacent lateral incisors is close to the mesial surface of the primary canine roots, it showed no influence on root resorption. Therefore, it was considered that root resorption starts on the distolingual surface.

2. Measurement of the distance between the root surface and bony crypt
Using Micro-CT, three-dimensional reconstruction images could be observed, and changes in the positional relationship between the primary teeth and successive permanent teeth with advancement of the eruption phase could be quantitatively analyzed.

Therefore, to clarify the relationship between the roots of the mandibular primary canines and the bony crypts of canines observed on images obtained using Micro-CT, the distance between the root surface and bony crypt was measured.

The measurements in the present study showed that the distance between the canine bony crypts and roots reduced after Stage II. This result quantitatively showed that the canine bony crypts initially move in the distal direction, followed by the root resorption by moving closer to the distolingual surface of the primary canines.

Conclusion
We classified 16 dry mandible of Indian children stored in the department of Anatomy in Tokyo Dental College into four stages according to the eruption state of primary and permanent teeth, and observed the relationship between the root of primary canines and successive permanent teeth using Micro-CT.

1. Observation of the positional relationship between the roots of primary canines and successive permanent canines in the dried skull specimens of children
In the primary dentition stage (Stage I), the bony crypts including successive canines were located immediately below the primary canine roots.

When the first molars reached the alveolar crest in addition to the primary dentition (Stage II), the bony crypts moved in the distolingual direction, and showed inferior growth, resulting in compact bone resorption of the mandibular base.

When the central incisors reached the alveolar crest in addition to Stage II (Stage III), root resorption of primary canines was observed on the distolingual surface.

2. Measurement of the distance between the root surface and bony crypt
After the first molars the central incisors reached the alveolar crest in addition to the primary dentition (Stage III), it was quantitatively shown that the distance between the lingual surface of primary canine roots and canine bony crypts reduced.

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References


