Original Article

Prediction of maxillary canine impaction using eruption pathway and angular measurement on panoramic radiographs

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ABSTRACT

Objectives: To compare the normal eruption pattern and angulation in impacted maxillary canines using panoramic radiographs to predict maxillary canine impaction.

Materials and Methods: Patients aged 6 to 15 years were classified into the normal eruption group (n = 229) and the impaction group (n = 191). At least two panoramic radiographs were taken in the normal eruption group during the eruption process of the maxillary canine. The growth pattern of the maxillary canine was analyzed using an XY coordinate system, with the tip of the maxillary lateral incisor as the origin and the tooth's long axis as the Y-axis and measurement of the relative position of the crown tip and angulation of the maxillary canine.

Results: The crown tips of normally erupted maxillary canines were intensively distributed along the distal surface of the maxillary lateral incisor, while those of impacted canines were widely distributed. The angulations of the normally erupted canines increased as eruption increased along the lateral incisor and then decreased at the cervical point of the lateral incisor. The angulations of the impacted canines were scattered, with no uniform pattern.

Conclusions: While using the normal eruption path of the maxillary canine and the pattern of change in angulation based on the distal surface of the maxillary lateral incisor, early intervention or regular follow-up is needed to prevent maxillary canine impaction. (*Angle Orthod.* 2022;92:18–26.)

KEY WORDS: Canine; Impaction; Panoramic radiograph; Eruption pathway; Prediction

INTRODUCTION

Ectopic eruption and impaction of permanent maxillary canines are common orthodontic problems. Impaction of permanent maxillary canines can result in complications, such as displacement of adjacent teeth and cystic changes, ankylosis, or infections.[1] Of these complications, root resorption of the adjacent incisors is the most common.[1,2]

To prevent irreversible, permanent damage such as root resorption, early detection or prediction of maxillary canine impaction is important to initiate timely orthodontic treatment with or without surgery.[3–5] Early detection of maxillary canine impaction can also decrease the duration, complexity, and cost of treatment. To prevent maxillary canine impaction and its complications, many studies[6,7] have been conducted to identify its cause and predictors.

Evaluation of maxillary canine impaction using panoramic or cephalometric radiographs with low radiation doses may be recommended.[8,9] Panoramic radiographs may be useful to acquire consecutive radiographic data, as they are frequently performed to evaluate caries, tooth eruption, impaction, and missing teeth in the early mixed dentition. However, because magnifications on panoramic radiographs differ based on factors such as the patient's head position,[10] panoramic radiographs have been used to determine

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the relative, and not the absolute, position of the maxillary canine with respect to other structures.[9,11] Diagnosis of canine impaction is limited because cumulative data from consecutive radiographs are not used for diagnosis; therefore, a panoramic radiograph taken at a single time point is used as the baseline. Identifying an eruption pathway and abnormal eruption using consecutive radiographic data may be more helpful in reaching a diagnosis in borderline patients than is using diagnostic data from a single time point. Coulter and Richardson[8] studied eruption pathways using lateral and posteroanterior radiographs. Although they demonstrated a normal eruption pathway, the study results were limited, as they could not be used to diagnose and predict the location of canines on frequent radiographs. Furthermore, there are limitations to using lateral and posteroanterior radiographs clinically, as those radiographs are not generally taken prior to the clinical diagnoses in orthodontic treatment. Therefore, it would be very useful clinically to evaluate the path of canine eruption using panoramic radiographs taken for preventive or therapeutic purposes in the early mixed dentition.

This study aimed to analyze the normal eruption pathway of canines, compared to impacted canines, using consecutive panoramic radiographs of maxillary canines, to use as a resource for ectopic eruption diagnoses. The specific aims were (1) to compare the locational distribution of the cusp tip of a normally erupting canine and an impacted canine by superimposing on the lateral incisor and (2) to compare the axial inclinations between the normally erupted canines and impacted canines by superimposing on the lateral incisor.

MATERIALS AND METHODS

Samples

Patients aged 6 to 15 years who visited Pusan National University Dental Hospital were included in this study. Panoramic radiographs (Planmeca, Helsinki, Finland) were consecutively taken to diagnose and confirm treatment progress.

The patients were divided into the normal eruption group ($n = 229$) and the impaction group ($n = 191$). In the normal group, the total number of maxillary canines was 458. In the impaction group, the total number of maxillary canines was 191.

The normal eruption group included patients (mean age: 9.5 ± 1.2 years; range, 6.8–15.5 years; 110 girls and 119 boys) whose maxillary canines erupted normally and who had at least two consecutive panoramic radiographs. Panoramic radiographs were taken 3.3 ± 1.2 (range, 2–6) times, on average, for periodic dental development evaluations.

The impaction group included patients (mean age: 12.1 ± 2.2 years; range, 8.2–18.7 years; 120 girls and 71 boys) with both unilateral and bilateral maxillary canine impaction and who had at least one panoramic radiograph, without distinction between palatal and buccal impaction. Panoramic radiographs were taken 1.2 ± 0.38 (range, 1–2) times, on average, before the intervention. In patients with unilateral impaction, only the impacted tooth was used for the study. This study was reviewed and approved by the institutional review board of Pusan National University Dental Hospital (PNUDH-2013015).

X, Y, Z Coordinates for Landmarks

Images were converted from DICOM to BMP file format for labeling the landmarks of interest. Using the converted image, an XY coordinate system was established. The following coordinates were obtained for analysis: the tip of the lateral incisor (defined as the meeting point between the long axis and the incisal edge of the lateral incisor); the apex; the tip of the canine (defined as the sharpest point of the canine); and the cervical point (defined as the point at which the long axis of the dental pulp meets the cervical line) (Figure 1). The analysis was based on the right side of the maxilla, while analysis of the left side was performed through mirror inversion.

Superimposition for Canine Position

MATLAB (MathWorks, Natick, Mass) was used to establish the tip of the maxillary lateral incisor as the origin and its cervical point as coordinates (0,1) through rotation and isotropic scaling and then superimposition (Figure 2). The coordinates obtained after superimposition are demonstrated in Figure 3.

The kernel density estimation was used to better understand the locational distribution of canines after superimposition and demonstrated canine location in both groups.

Principal component analysis (PCA) was performed for comparative analysis of the location of the tips of normal and impacted canines. Tips of the canines in two-dimensional (2D) space were linearly transformed as a principal component (PC1). Considering PC1 as an axis, the locational distribution of the tips of the canines were compared using an independent *t*-test ($P < .05$).

Finally, the inclination was measured on the Y-axis after superimposition, and the measured inclination angles of the normal eruption and impaction groups were compared.[12]

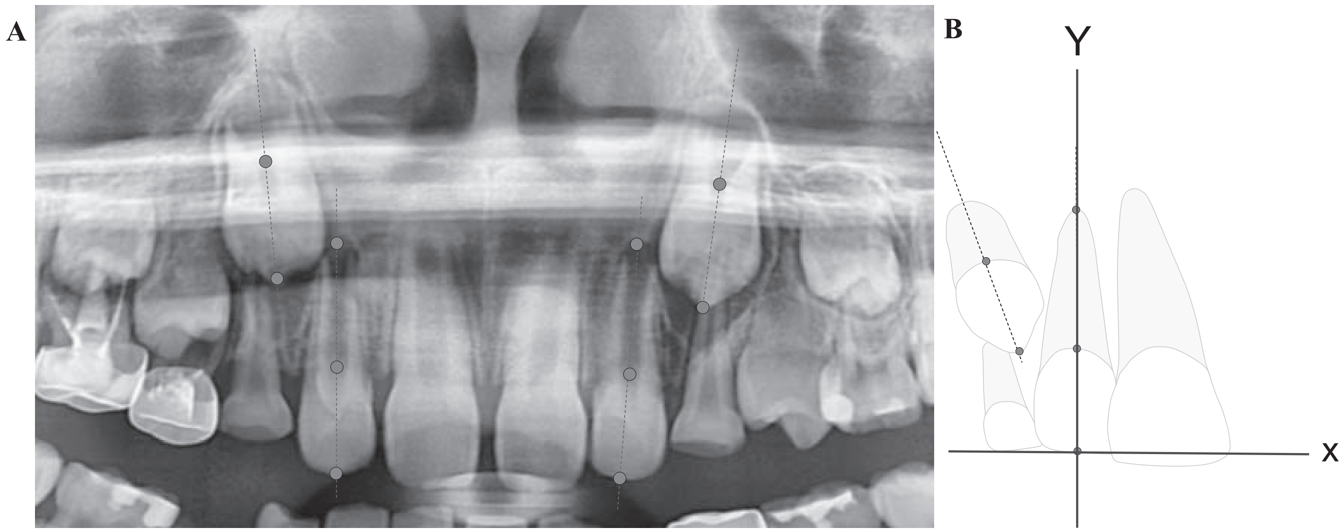


Figure 1. (A) Panoramic radiograph showing the lateral incisor tip (incisal edge), cervical, and apex; and canine tip and cervical point. (B) XY coordinate system.

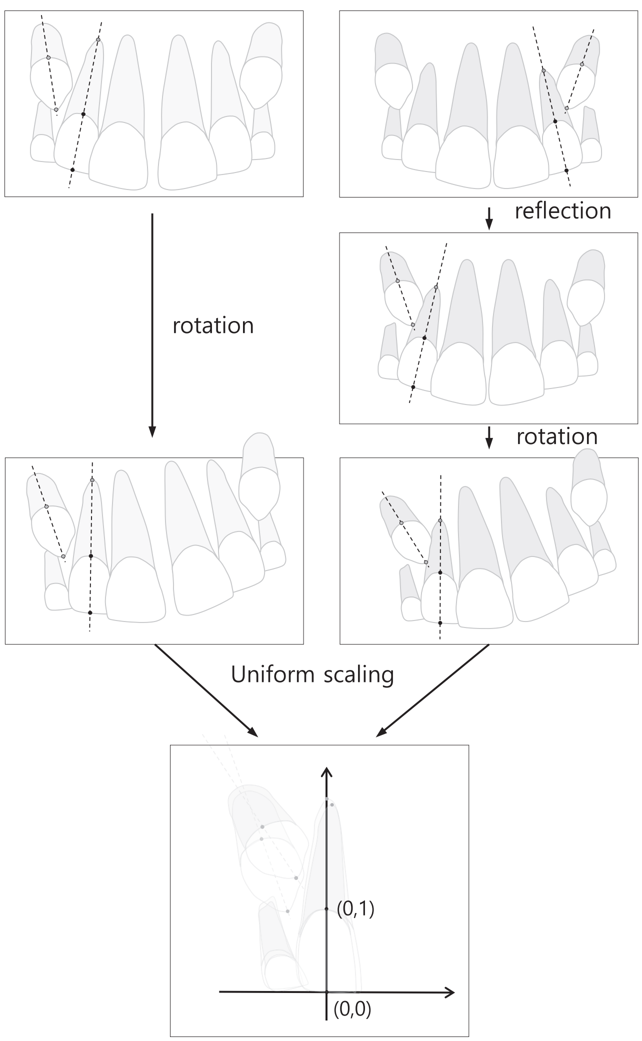


Figure 2. The workflow of superimposition.

RESULTS

Comparison After Superimposition Between Normally Erupted and Impacted Canine Tip Positions

Figures 3 and 4 show the results of the superimposition, preceded by rotation and isotropic scaling of the cervical point of maxillary lateral incisors to align with coordinates (0,1), with the lateral incisor tip (intersection of long axis and the incisal edge) as the origin. The cusp tips of normally erupted canines were distributed along the distal surface of the maxillary lateral incisor. However, those of the impacted canines showed a mesial and distal distribution in relation to the axis of the maxillary lateral incisor (Figure 3). As shown in Figure 3C, in some cases the cusp tips of the impacted canines overlapped those of the normally erupted canines. Kernel density estimation also demonstrated a clear difference in the distribution of canine cusp tips between the two groups (Figure 4).

The locational distribution of the canine tips in each group in relation to the PC1 as the central axis, according to the results from the principal component analysis to analyze comparatively the location of the tips of normally erupted and impacted canines, is shown in Figure 5. There was a statistically significant difference in the distribution of canine tips between the two groups ($P < .05$). The 95% confidence interval (CI) was –0.205 to 0.205 and –0.42 to 1.66 for the eruption and impaction groups, respectively.

Comparison of Canine Angulations Between the Normally Erupted and Impacted Canine Groups

Based on the long axis of the lateral incisor, the average value of the inclination of the maxillary canine

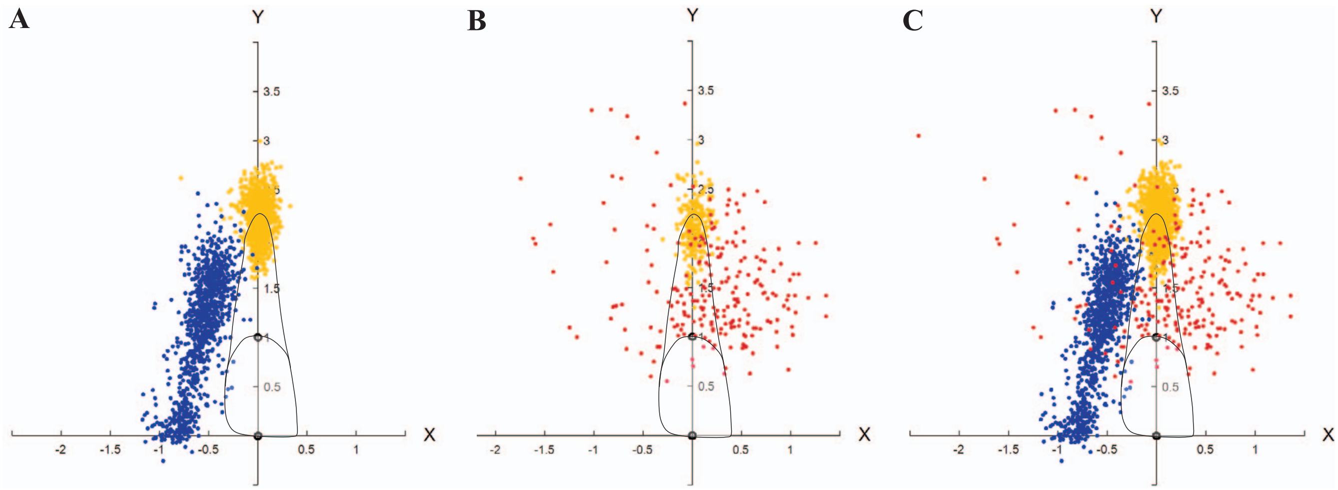


Figure 3. Crown coordinates of canines obtained after superimposition. Normal canines (A), impacted canines (B), and normal and impacted canines (C). Canine coordinates obtained after superimposition. A scale indicating tip–cervical point of lateral incisors as "1" was used. Blue dot: cusp tip location of normal canines; red dot: cusp tip location of impacted canines; yellow dot: apical position of the lateral incisors; and ○: tip and cervical points of lateral incisors.

was 9.12 (95% CI: −5.40–23.61) in the normal eruption group and 30.35 (95% CI: −17.95–78.65) in the impaction group. The inclination of the normally erupted canines was approximately between −10° and −30° and demonstrated similar eruption pathways, whereas the impacted canines deviated from the normal range of inclination in most cases and had varied eruption pathways (Figure 6). The inclination was considered 0° when the long axis of the canine was parallel to that of the lateral incisor. It was positive when the root of the canine was inclined to the distal of the lateral incisor relative to the tooth axis of the lateral incisor and negative when the root of the canine was inclined to the mesial of the lateral incisor. In the normal eruption group, it was observed that when the canine was closer to the lateral incisor, the greater was its axial inclination toward the lateral incisor. The further the canine was from the lateral incisor, the greater the axial inclination toward the first premolar. In general, as the tooth erupted toward the occlusal plane, the angle of inclination changed along the axis of the lateral incisor. However, there was a relative lack of alignment in the axial direction of the impaction group.

The normal eruption group demonstrated an increase in canine inclination as the tooth erupted along the lateral incisor, followed by a decrease in inclination as it reached the cervical point of the lateral incisor (near coordinate 1). However, the impaction group demonstrated a scattered distribution in inclination, with no pattern (Figures 6 and 7).

DISCUSSION

Several reports[13–16] have already revealed a correlation between the lateral incisors and canine eruption. However, a longitudinal study to investigate canine eruption pathways is still needed to plan effective intervention.

Unfortunately, it is difficult to monitor the eruption pathway of maxillary canines because the inclination, size, and location of adjacent lateral incisors vary.[17] In this study, geometric morphometrics was adopted to produce shape information, with the forms under comparison scaled to an equivalent size beforehand.[18] The isotropic registration was used to eliminate variations of the lateral incisor. PCA reduced the dimension of canine positions.

Concerning the distribution probability of the canine based on the primary principal axis, most erupting canine crowns were distributed within a narrow range around the PC1 axis along the adjacent incisor. Hence, it may be concluded that the normal eruption pathway of maxillary canines can be determined in accordance with the location of the lateral incisors. This can then be used as an evaluation tool for additional examination when a tooth deviates from the normal range, with the assumption that there may be indications for impaction. However, although rare, maxillary canines on a normal eruption pathway can erupt ectopically. Thus, periodic evaluation is necessary even if the maxillary canines have a normal eruption pathway.

With isotropic registration of the erupting canine tips with the lateral incisor, it is noteworthy that the normal eruption tended to follow the adjacent lateral incisor distal aspect, not the shortest route to the occlusal plane. Most of the erupting canine tips were located between the crown and apex of the lateral incisors, which introduced guidance. On the other hand, impacted canine tips were irregularly distributed,

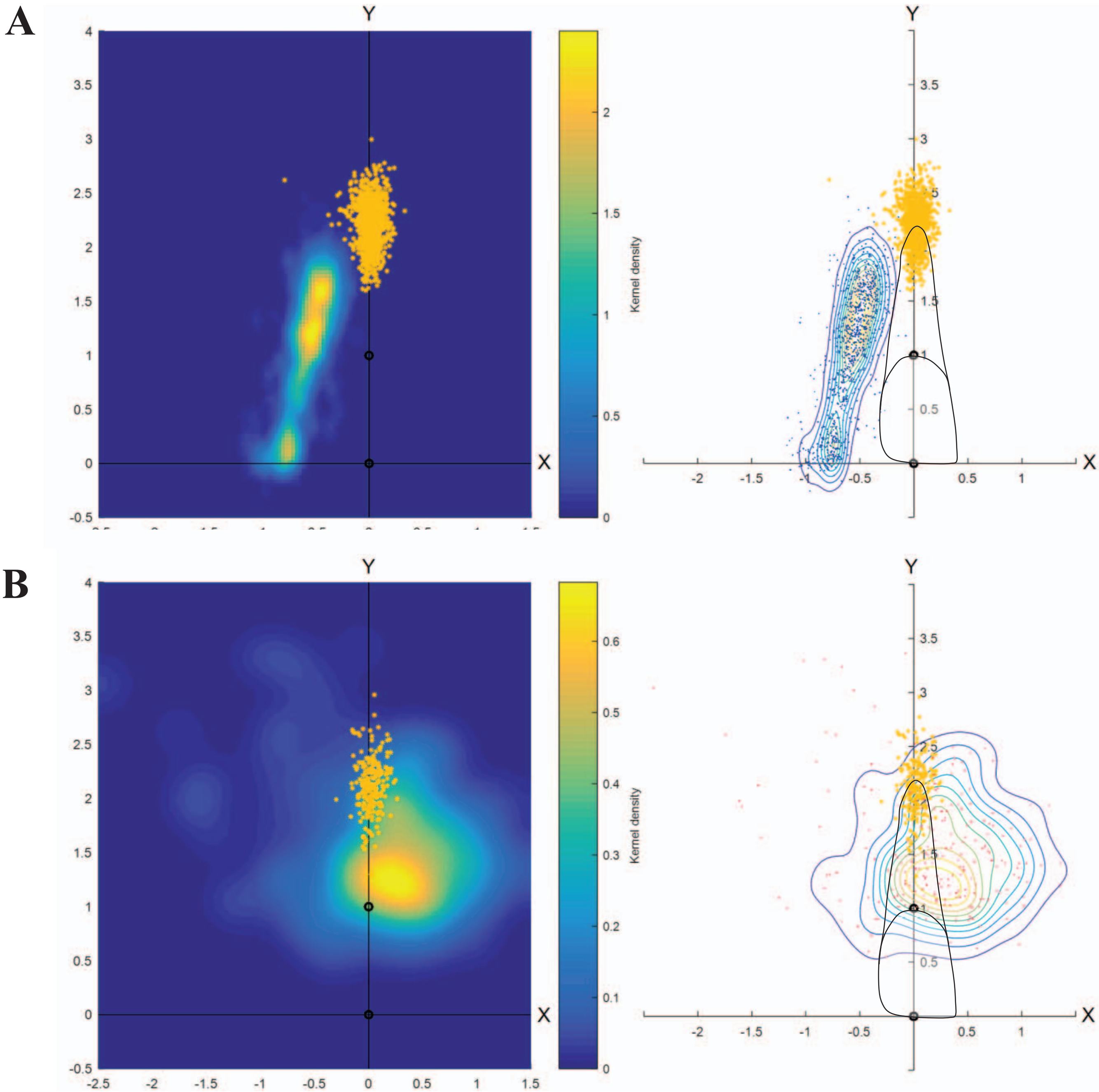


Figure 4. Kernel density estimation of canine cusp tips. Normal canines (A) and impacted canines (B). Blue dot: cusp tip location of normal canines; red dot: cusp tip location of impacted canines; yellow dot; apical position of lateral incisors; and ○: tip and cervical points of lateral incisors.

showing a weak relationship to the adjacent lateral incisors. These findings were in support of the guidance theory, which claims that movement occurs via the distal aspect of adjacent incisor, thus guiding the canine into a more favorable position in the arch.[19,20]

The current study indicated that crown inclinations in impacted canines deviated from the range of inclination observed in normally erupted canines. In agreement with previous findings[13] on the relationship between the lateral incisor and canine inclinations, the crown inclination of normally erupted canines was between −10° and −30°. As demonstrated in Figure 8, the maxillary canines initially erupted with increasing inclination until they reached the maximal point of the lateral incisors (near 1.4 times higher than the lateral incisors' anatomical crown), followed by a gradual decrease. The impaction group, in contrast, showed a

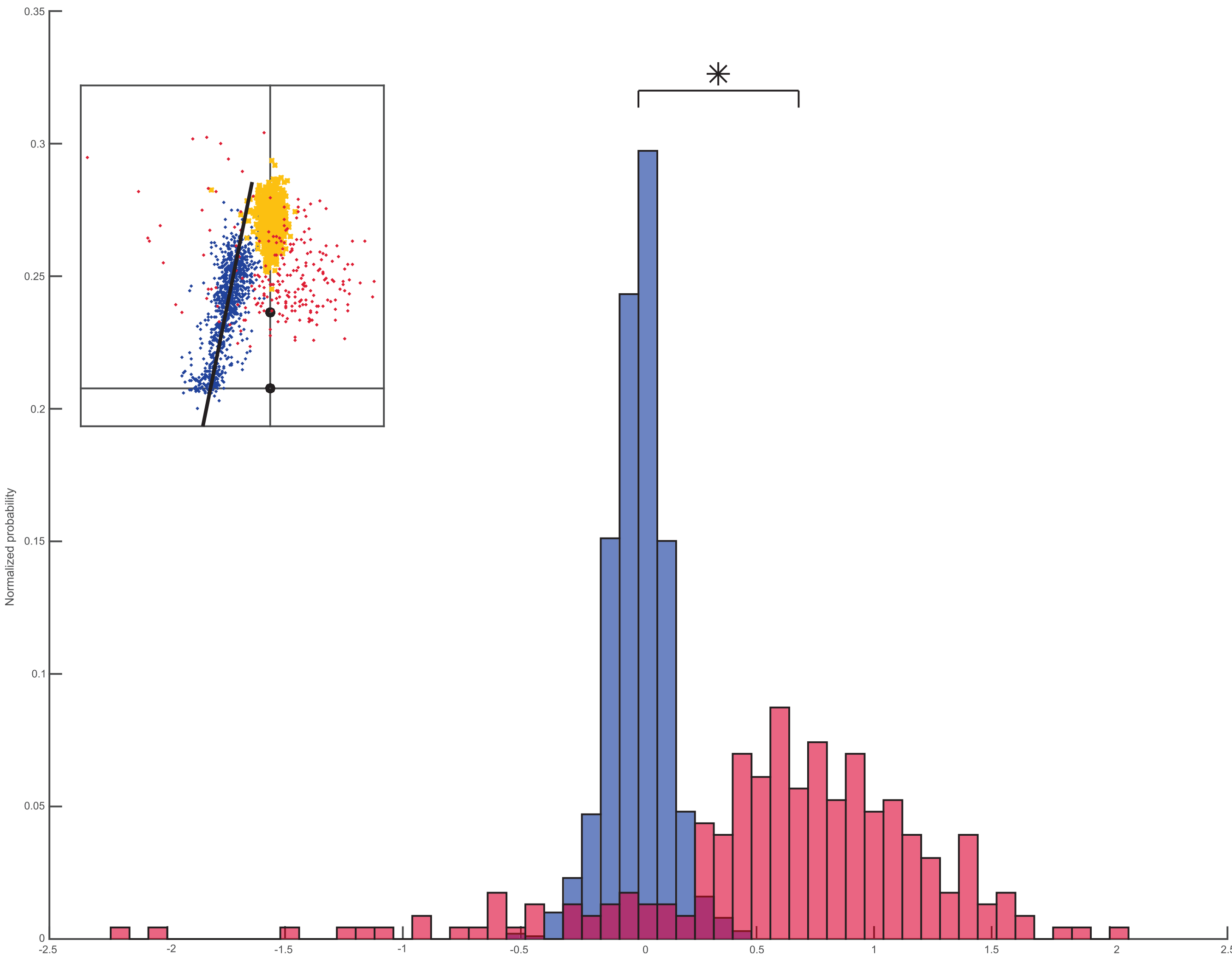


Figure 5. Distribution of canine cusp tips in relation to the lateral incisors as the central axis. The probability distribution of normal and impacted canines was obtained from rotation of the principal axis through principal component analysis.

scattered distribution of the canine inclination, with no pattern.

Considering the angle of the lateral incisor in relation to eruption of the canine, it is possible to interpret this finding in line with the schematic diagram in Figure 8. At an X-axis value under 1.4, the cusp of the canine surpassed the cervical point of the lateral incisor; that is, the axis of the lateral incisor inclined toward the canine as the cusp of the canine pushed on the root of the lateral incisor. Although the inclination of the canine appears to be increasing on the graph, it is believed that if the X-axis is <1.4 (that is, if the canine cusp surpassed the cervical point at the lateral incisor), (1) the eruption direction of the canine shifted toward the occlusal plane and (2) the inclination of the lateral incisor increased simultaneously. This would be the time when the "ugly duckling" stage shows improvement. It is speculated that the combination of the two phenomena gradually alleviates the canine inclination (Figure 8).

These results were supportive of the findings of Broadbent,[21] which indicated that any contact during the eruption of the crown of the maxillary canine led to lateral displacement from the root tip of the lateral incisor. In the current study, the angle of the canine crown shifted from a mesial position in the early stages of eruption to a more vertical position, consistent with the findings of Fernández et al.[17]

The current study results suggest that periodic panoramic radiographic observations and preventive treatment are needed for canine eruption that demonstrates a deviation from the normal pathway. Accurate understanding of the normal eruption range obtained from evaluating maxillary canine crown inclinations based on the long axis of lateral incisors and periodic examination after deviations from the normal range, assuming a high potential for impaction, are necessary.

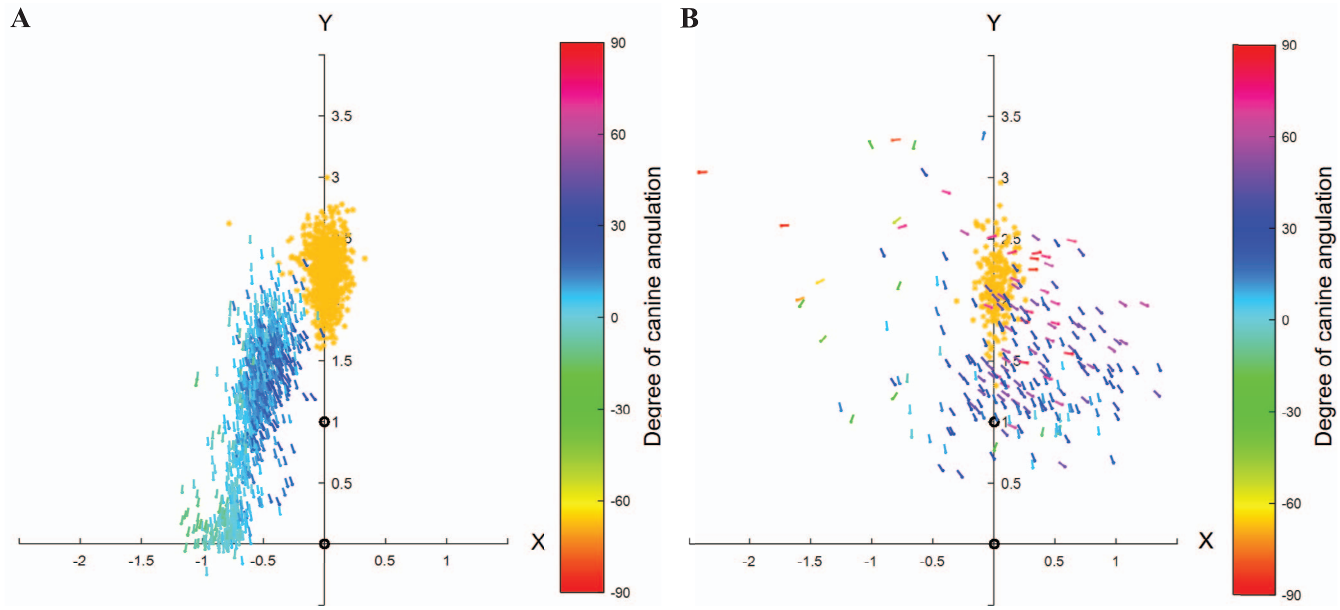
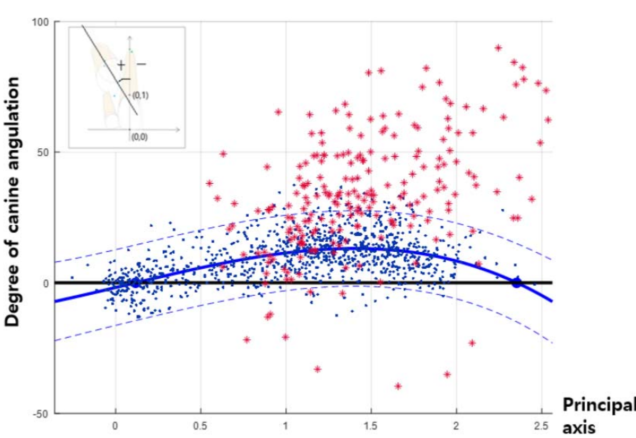


Figure 6. Crown inclination of normal canines (A) and impacted canines (B). Canine coordinates and angle of inclination were obtained after superimposition based on the maxillary lateral incisors. –30° is green; +30° is blue; and +90° is red.

When the relative location and crown inclination of the canine are not within the normal eruption range, impaction can occur, and the canine should be carefully observed.

This study has some limitations. The design was longitudinal and used panoramic radiographs. Patients in the impaction group were older than those in the normal eruption group. The researchers faced challenges in obtaining ethical approval for performing a longitudinal clinical study on impacted teeth. However, the eruption pathway and distribution of canines were identified, and the results may be useful in the diagnosis and screening of impacted teeth. As this study was limited to a 2D analysis, future studies are needed to identify 2D and three-dimensional eruption pathways through the simultaneous use of cone-beam computed tomography and panoramic radiographs.



$$y = -2.9417x^3 + 0.6526x^2 + 15.5321x - 1.8330$$

Figure 7. Distribution of crown inclinations of normal and impacted canines. The normal eruption group demonstrated an increase in canine inclination as the tooth erupted along the lateral incisor, followed by a decrease as it reached the cervical point of the lateral incisor (near coordinate 1). However, the impaction group demonstrated a scattered distribution in inclination, with no pattern.

CONCLUSIONS

- Normal eruption of the maxillary canine proceeds along the distal surface of the maxillary lateral incisor, with a gradual increase in the angulation, which then decreases as the canine nears the cervical area of the maxillary lateral incisor, and there is a tendency to straighten. The accuracy of prediction is limited because, in some cases, the position of the crown tip of the impacted maxillary canine overlaps the expected pathway of the crown tip of the normally erupting maxillary canine.
- The possibility of maxillary canine impaction is high if the canine tip deviates from the normal eruption path of the maxillary canine, based on panoramic radiography.
- If the eruption of the maxillary canine is deviant from the normal range or angulation with respect to the lateral incisor, further examination or periodic observation might be required to prevent impaction.

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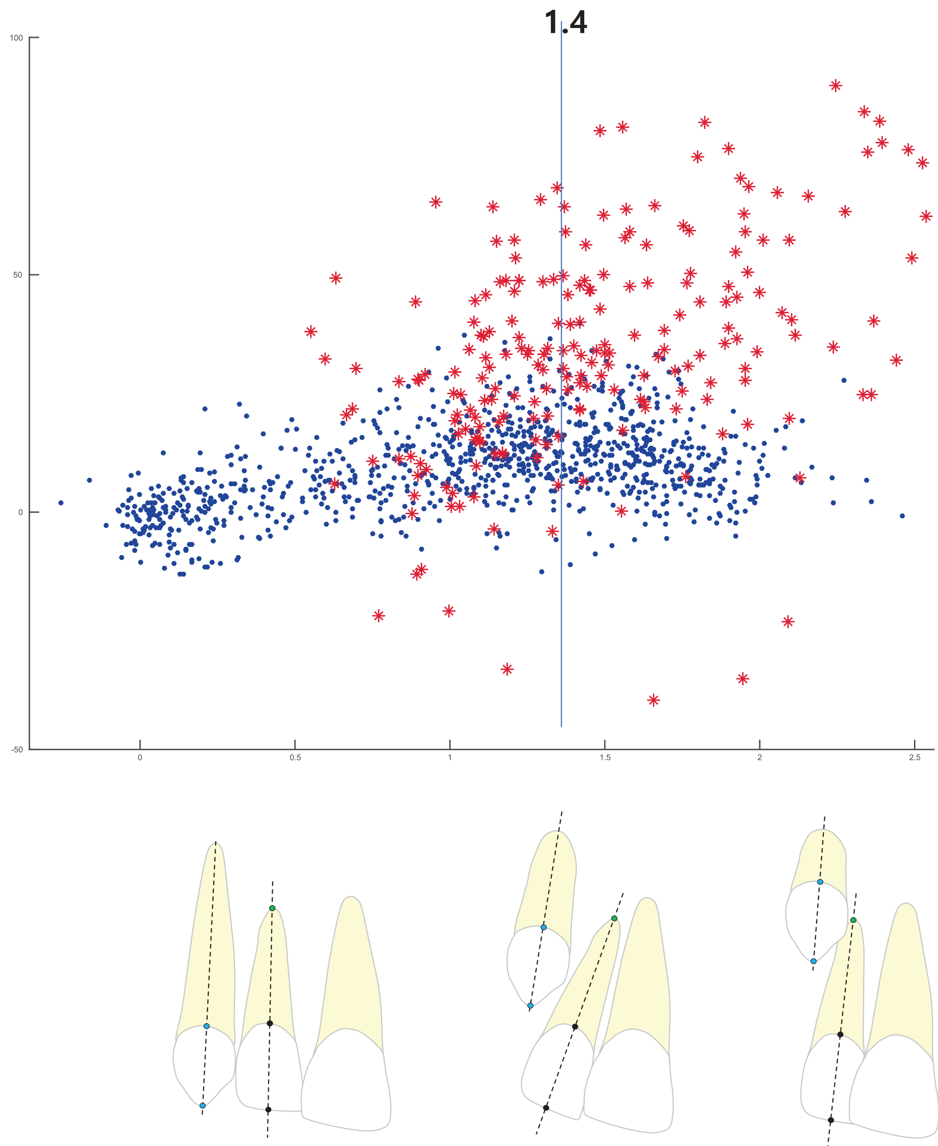

Figure 8. Schematic distribution of crown inclinations of normally erupted and impacted canines and the relationship between the corresponding location of maxillary canines and lateral incisors. The angle between the long axis of the lateral incisor and canine tooth axis (line connecting cusp–cervical point).

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