Original Article

Impact of orthodontic forced eruption timing on root development of impacted maxillary canines: a linear and volumetric analysis using cone-beam computed tomography images

Ye-Hyun Lee[a]; Na-Young Chang[b]; Jong-Moon Chae[c]

ABSTRACT

Objectives: To evaluate root development after forced eruption of impacted maxillary canines before or after complete root development of the contralateral canine.

Materials and Methods: A total of 50 patients (21 male, 29 female; mean age: 12.4 years) with unilateral impaction of maxillary canines were classified to "Immature group" with incomplete root development of the contralateral canine or "Mature group" with complete root development of the contralateral canine. Volume, total length, crown length, root length, and root/crown ratio (R/C) of the impacted canine and the contralateral canine were measured in the posttreatment cone-beam computed tomography images.

Results: In the immature group, total length and root length of impacted canines were 0.68 mm and 0.51 mm shorter than contralateral canines, respectively ($P < .05$). In the mature group, volume, total length, root length, and R/C of impacted canines were 37.90 mm^3, 2.43 mm, 2.53 mm, and 0.26 smaller, respectively, than contralateral canines ($P < .001$). Crown length also showed a statistically significant difference between impacted canines and contralateral canines ($P < .05$). When differences between impacted canines and contralateral canines were compared between the immature and mature groups, all variables showed statistically significant differences, with the mean difference in total length and root length being 1.75 mm and 2.02 mm larger, respectively, in the mature group, ($P < .001$).

Conclusions: Regardless of treatment timing, total length and root length of impacted canines were shorter than those of contralateral canines. Forced eruption of the impacted canine undertaken before root development of the contralateral canine showed better root development in both linear and volumetric measurements. (*Angle Orthod*. 2025;00:000–000.)

KEY WORDS: Impacted maxillary canine; Root development; Cone-beam computed tomography images

INTRODUCTION

Canines are the cornerstones of the dental arch, having the longest and strongest roots, with a crucial role of canine guidance and esthetics, especially in the maxillary arch.[1] However, maxillary canines show the highest rate of impaction[2–5] after third molars, especially due to their relatively late eruption time.[6]

For impacted teeth, possible treatment options include extraction, surgical repositioning, and forced eruption, which involves surgical exposure followed by orthodontic traction of the impacted tooth, with the objective being to move it into its ideal position.[7] Because of its importance, it is preferred for the impacted maxillary canines to be treated ideally.

Regarding timing of intervention, Dekel et al.[8] emphasized the importance of beginning orthodontic traction

[a] Resident, Department of Orthodontics, School of Dentistry, University of Wonkwang, Iksan, South Korea.

[b] Professor and Chair, Department of Orthodontics, School of Dentistry, University of Wonkwang, Wonkwang Dental Research Institute, Iksan, Korea.

[c] Professor, Department of Orthodontics, School of Dentistry, University of Wonkwang, Wonkwang Dental Research Institute, Iksan, Korea; and Visiting Scholar, Postgraduate Orthodontic Program, Arizona School of Dentistry & Oral Health, A. T. Still University, Mesa, AZ, USA.

Corresponding author: Dr Na-Young Chang, Department of Orthodontics, School of Dentistry, Wonkwang University, Wonkwang Dental Research Institute, Daejeon Dental Hospital, 77 Doonsan-ro, Seo-Gu, Daejeon 35233, South Korea
(e-mail: esther0705@hanmail.net)

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Table 1. Summary of Patient Characteristics

	Immature Group		Mature Group		Total	
Age (y)	Mean	10.79	Mean	14.67	Mean	12.42
	Range	8–13	Range	11–25	Range	8–25
Gender (N)	Male	14	Male	7	21	50
	Female	15	Female	14	29	

prior to root development of the apical third of the impacted canine to induce normal development without anatomical restrictions. Many previous studies reported development of roots after orthodontic traction in cases which initiated traction when there was root development potential. Shi et al.[9] suggested that early traction of immature teeth can fully utilize the growth potential of the root. Similar results were reported by Mavragani et al.,[10] showing an advantage of incompletely developed roots on posttreatment root length.

However, most previous studies were based on linear analysis, comparing root lengths between impacted and naturally erupted teeth. To evaluate the amount of dental structure loss, a volumetric analysis is needed. The recent advent of cone-beam computed tomography (CBCT) has made this task more accessible. CBCT provides 3-dimensional images with anatomic accuracy, allowing the evaluation of root structure both qualitatively and quantitatively.[11,12] According to Ponder et al.,[13] CBCT scans can be useful in accurate quantification of root defects.

Root/crown ratio is another variable that could be used to evaluate root resorption or, in this case, the lack of root development. It is classified as the anatomical or clinical root/crown ratio. The reference lines for crown length and root length measurement are set, respectively, at the cementoenamel junction (CEJ) and alveolar bone level.[14] Root/crown ratio has been an essential criterion for making decisions of implant and dental crown placement, especially for patients with compromised periodontal tissues.[15,16]

Until recently, no previous studies have directly compared root development between different timing of forced eruption procedures. The aim of this study was to evaluate root development after forced eruption of impacted canines before or after complete root development of the contralateral canine.

MATERIALS AND METHODS

Patient Selection

A total of 50 patients (21 male, 29 female; mean age: 12.4 years) with unilateral impaction of the maxillary canine were included in this retrospective study. Table 1 shows a summary of patient characteristics. All patients received orthodontic treatment including forced eruption (closed-technique) of the impacted canine at the Department of Orthodontics at Wonkwang University Daejeon Dental Hospital in Daejeon, South Korea. Approval of the Institutional Review Board of Wonkwang University Daejeon Dental Hospital was obtained to conduct the study (Approved April 24, 2023; IRB: W2304/008-001).

Inclusion criteria were: (1) unilateral impaction of a maxillary canine with natural eruption of the contralateral canine; (2) impacted canine treated with forced eruption procedure-closed technique; (3) pretreatment panoramic radiograph and posttreatment CBCT images available; and (4) canines without significant dilaceration.

Patients were classified into two groups by the root development of the contralateral canine shown on the pretreatment panoramic radiograph. Patients with incomplete root development of the contralateral canine were classified as "Immature group" and patients with complete root development of the contralateral canine were classified as "Mature group," according to Nolla's stages of root development.[17] The contralateral canines showed stages 7–9 in the immature group and stage 10 in the mature group.

The immature group consisted of 29 patients (14 male, 15 female) with a mean age of 10.79 years (range: 8–13 years), whereas the mature group consisted of 21 patients (7 male, 14 female) with a mean age of 14.6 years (range: 11–25 years).

Measurement of the Variables

The pretreatment radiographs were taken using PCH-2500 (Vatech, Hwaseong, Korea) with the setting of 73 kVp, 10.0 mA for adults and 67 kVp, 8.0 mA for children and adolescents.

Posttreatment CBCT images were taken using the Green 21 (Vatech Korea, Seoul, Korea) with the setting of 106 kVp, 4.5 mA. The scanning time was 18 seconds, with the field of view of 210×190 mm^2, voxel size $0.3 \times 0.3 \times 0.3$ mm^3. Digital Imaging and Communications in Medicine (DICOM) data were attained and applied to Mimics Research 21.0 software (Materialise NV, Belgium). A mask was created using a customized threshold for each patient and the canines were separated from the adjacent tissues by deleting the surrounding bone, periodontal ligament (PDL), and soft tissues on the mask in all slices of the axial, coronal, and sagittal views.[18,19] The pulp tissues were included in the canine masks to minimize errors in volume evaluation.[20] The volume of the canine masks were calculated by the software in cubic millimeters (Figure 1).[21]

Linear measurements were conducted on the plane created by setting three points; cusp tip, root apex, and

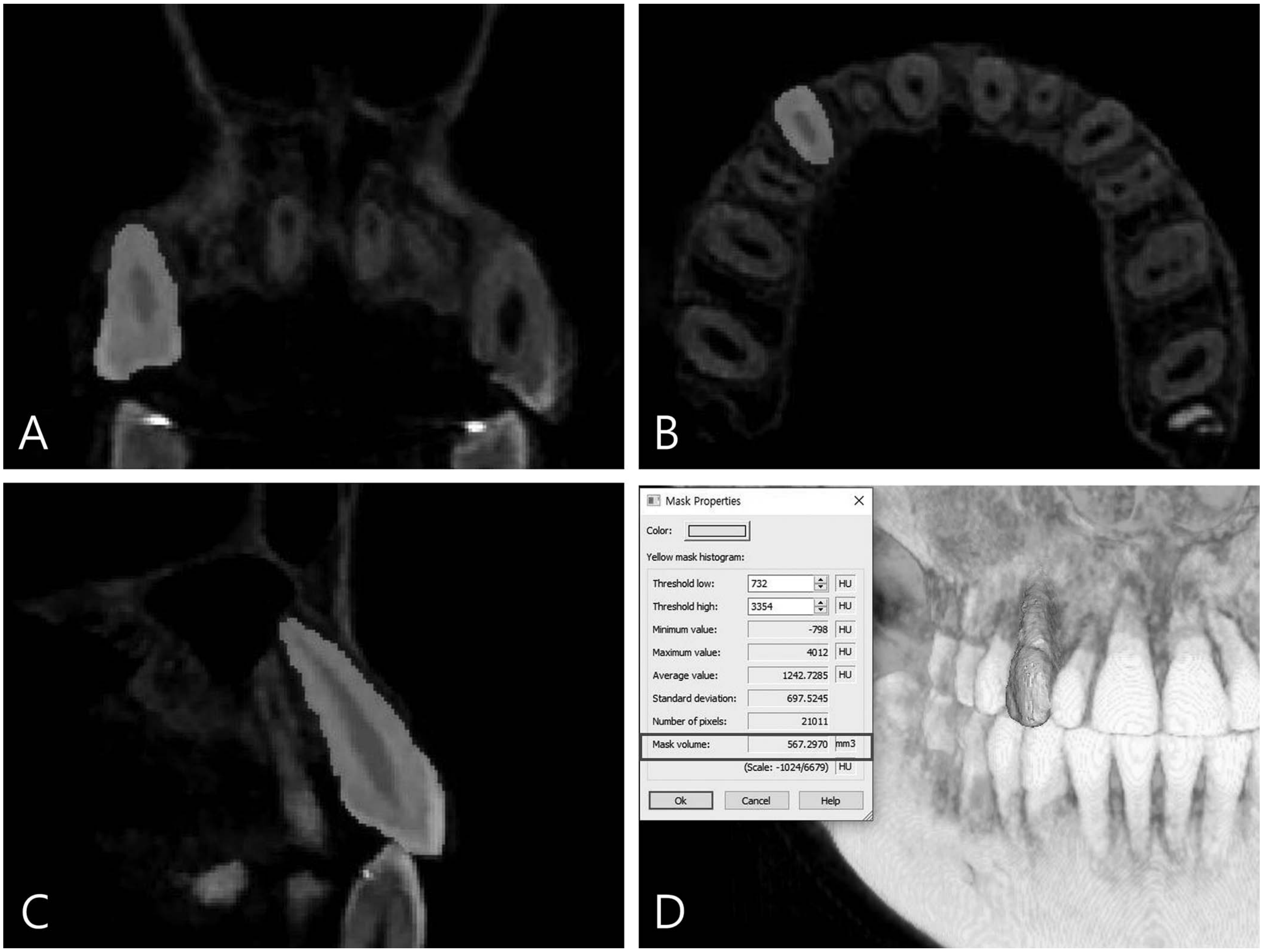

Figure 1. Masking on Mimics software and volumetric measurement of the canine: (A) Mask of the maxillary right canine seen in Coronal view; (B) Axial view; (C) Sagittal view; (D) 3D preview of the mask in CBCT reconstruction view and mask volume shown in cubic millimeters on mask properties.

the most prominent point of the labial surface of the canine, in the axial view at the CEJ level. Total length of the canine was measured from the cusp tip to the root apex, and this line of measurement was also considered as the long axis. The labial and lingual CEJ was detected and connected, defining the border of the crown and the root. Crown length was measured from the cusp tip along the defined long axis, until it met the connected line (Figures 2 and 3). Root length was calculated by subtracting the crown length from the total length. Root/crown ratio (R/C) was also calculated by the values obtained. Definitions of terms and measurement variables are shown in Table 2.

Measurements were performed by 1 investigator (L.Y.H.). Measurements of 20 random patients were repeated after 10 days for intra-examiner reliability analysis. The investigator had no information on the side of impaction throughout measurements.

Statistical Analysis

Measurement data were recorded in Microsoft Excel 2021, and were analyzed using SPSS software (version 20.0, 171, IBM, Chicago).

Values of the impacted canines and contralateral canines were compared in the immature group and the mature group. In the immature group, paired *t*-test was used for the values total length, crown length, root length and volume, and Wilcoxon signed-rank test was used for R/C. For the mature group, paired *t*-test was used for the values total length, root length, R/C, whereas Wilcoxon signed-rank test was used for crown length and volume.

To compare between the immature and mature groups, independent *t*-test was used to evaluate the difference between the impacted canine and contralateral canine for total length and root length, and Mann-Whitney *U* test was used for the difference of crown length, R/C, and volume.

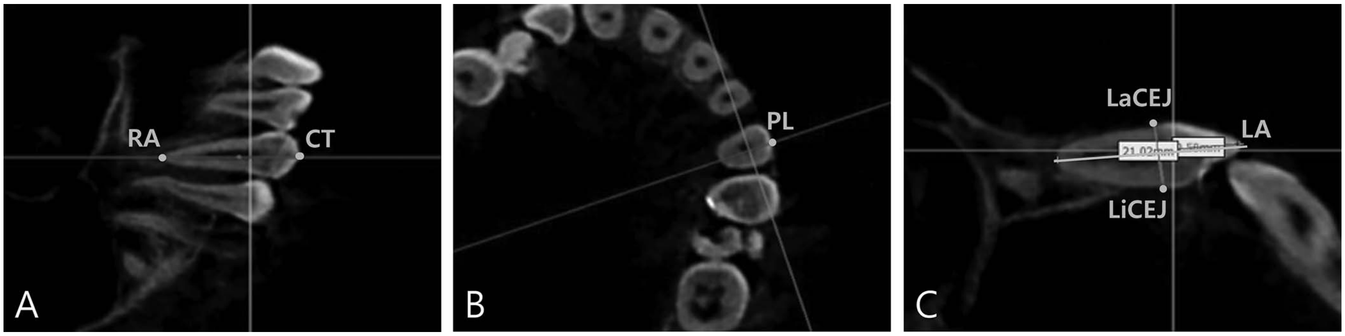

Figure 2. Reference points and lines used to measure the variables: (A) View that includes both AT and CT; (B) Axial view at CEJ level; (C) View from the plane defined by AT, CT, and PL. *RA*, root apex; CT indicates cusp tip; PL, most prominent point of the labial surface; LA, long axis (orange line); LaCEJ, labial CEJ; LiCEJ, lingual CEJ.

RESULTS

Reliability

Two sets of measurements conducted 10 days apart showed no significant differences by paired *t*-tests ($P > .05$). The intraclass correlation coefficients showed a range of 0.967 to 0.993, indicating excellent intraexaminer reliability.[22]

Linear and Volumetric Measurements of the Immature Group

Table 3 shows mean values of linear and volumetric measurements of impacted canines and contralateral canines of patients having initiated forced eruption before the completion of root development of the contralateral canine. The mean total length and root length of impacted canines were significantly shorter than contralateral canines by 0.68 mm and 0.51 mm, respectively ($P < .05$). Crown length did not show a statistically significant difference. R/C showed a statistically significant difference ($P < .05$). Mean volume was 12.97 mm^3 smaller in the impacted canines but the difference was not statistically significant.

Linear and Volumetric Measurements of the Mature Group

Table 4 shows mean values of the measurements of patients having initiated forced eruption after the completion of root development of the contralateral canine. The mean total length and root length of impacted canines were 2.43 mm and 2.53 mm shorter than contralateral canines, respectively. The difference was highly significant for both variables ($P < .001$). Crown length showed a statistically significant difference ($P < .05$) between impacted canines and contralateral canines. R/C was 0.26 mm smaller in impacted canines and was highly significant ($P < .001$). Volume showed a highly significant difference with the mean volume 37.90 mm^3 smaller in the impacted canines ($P < .001$).

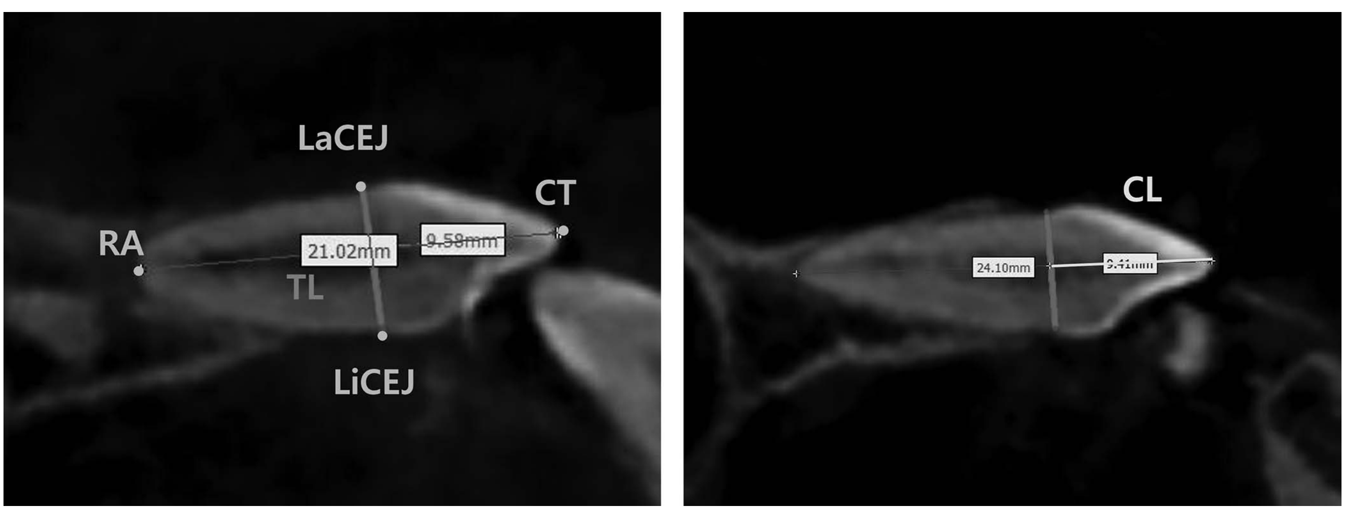

Figure 3. Linear Measurements: (A) Impacted canine; (B) Contralateral canine. TL indicates total length (green line; the line connecting RA and CT); CL, crown length (yellow line; the distance from CT to the line connecting LaCEJ and LiCEJ).

Table 2. Definitions of Variables Used in this Study

Variable	Definition
Total length (TL)	Distance from cusp tip to root apex
Crown length (CL)	Distance from cusp tip along the long axis to the line connecting the labial and lingual CEJ
Root length (RL)	Subtraction of crown length from total length
Root/crown ratio (R/C)	Ratio of root length to crown length
Volume (Vol)	Mask volume measured in mm^3
diff	Differences between the impacted canine and contralateral canine (Impacted canine - Contralateral canine)

Comparison between Immature Group and Mature Group

Table 5 shows a comparison between the immature and mature groups in differences between the impacted canines and contralateral canines for each of the variables. All variables showed statistically significant differences. The mean differences in total length and root length between impacted canines and contralateral canines were 1.75 mm and 2.02 mm larger, respectively ($P < .001$), in the mature group. The difference in R/C was 0.23 larger, and the difference in volume was 24.93 mm^3 larger, in the mature group.

DISCUSSION

The immature group and mature group were compared to assess the impact of treatment timing of forced eruption on the root development of impacted canines. Whereas many studies compared root length between impacted and naturally erupted canines, none showed a direct comparison between immature and mature impacted canines.

Patients were classified according to the contralateral canine root development observed in pretreatment panoramic radiographs. Since impacted canines commonly show abnormal positions along with varying angulations, it is difficult to evaluate the root development potential of impacted canines. Dekel et al.[8] reported that root development was inhibited in impacted teeth that had their roots positioned close to adjacent anatomical structures, including the cortical bone of the maxillary sinus and palatal plane.[4] Therefore, to evaluate the growth potential of canine roots, the canine on the contralateral side was used for comparison. This data would also help in clinical situations to predict treatment outcomes, using panoramic radiographs taken prior to treatment.

Total length and root length of impacted canines was significantly shorter than contralateral canines in both groups, with a greater level of significance in the mature group. Differences in total length and differences in root length between the immature group and the mature group were compared, demonstrating a highly significant difference. This indicated that, although impaction and a forced eruption procedure may lead to a shorter total length and root length of the canine, orthodontic traction undertaken before full maturation of the contralateral canine demonstrates a better outcome.

The findings of this study were in agreement with a previous study by Dekel et al.,[8] which showed shorter lengths of buccally impacted canines (1.3 mm) and palatally impacted canines (0.9 mm), compared to contralateral canines measured in CBCT scans. A CBCT study by Rizzatto et al.[23] also reported 3.22 mm shorter roots in impacted maxillary central incisors.

Another CBCT study by Shi et al.[9] compared the root length of impacted maxillary central incisors and contralateral central incisors after closed eruption treatment when the teeth were immature. The root of the impacted immature maxillary central incisor developed to reach the same length as the contralateral side. In contrast, the current study did not demonstrate equal root lengths between impacted and contralateral maxillary canines. However, there is some agreement in that traction of immature teeth showed an advantage of better expressing their developmental potential.

Crown length between impacted canines and contralateral canines showed no statistically significant difference in the immature group, which was in agreement with a study by Kim et al.[24] However, the mature group did show a statistically significant difference. In a study by Rizzatto et al.,[23] the crown length of impacted maxillary central incisors was significantly shorter by 0.56 mm compared to contralateral maxillary central incisors ($P < .001$). Hettiarachchi et al.[25] also reported similar results showing 0.45 mm shorter crown lengths in palatally impacted

Table 3. Linear and Volumetric Measurements of Immature Group[a]

	IC			CC			
Measurements	Mean	SD	Range	Mean	SD	Range	*P*
TL (mm)[b]	24.18	2.54	19.14–27.96	24.86	2.60	18.17–28.82	.004*
CL (mm)[b]	10.21	0.73	8.97–11.73	10.37	0.79	8.85–11.97	.091
RL (mm)[b]	13.97	2.27	9.90–18.12	14.48	2.43	7.18–18.98	.012*
R/C[b]	1.37	0.23	0.98–1.92	1.40	0.25	0.65–1.97	.030*
Vol (mm^3)[c]	629	106	425–815	642	114	446–823	.051

[a] TL, total length; CL, crown length; RL, root length; R/C, root/crown ratio; Vol, volume.
* $P < .05$; ** $P < .001$. [b] Paired *t*-test and [c] Wilcoxon signed-rank test were performed.

Table 4. Linear and Volumetric Measurements of Mature Group[a]

Measurements	IC			CC			
	Mean	SD	Range	Mean	SD	Range	*P*
TL (mm)[b]	22.38	2.36	18.73–28.12	24.81	2.43	21.21–29.06	0.000**
CL (mm)[c]	10.13	0.97	8.25–11.50	10.03	0.81	8.30–11.32	.016*
RL (mm)[b]	12.25	1.85	9.22–16.69	14.78	2.08	10.87–18.63	0.000**
R/C[b]	1.21	0.18	0.85–1.51	1.48	0.20	1.03–1.79	0.000**
Vol (mm^3)[c]	589	107	442–798	627	106	463–802	0.000**

[a] TL, total length; CL, crown length; RL, root length; R/C, root/crown ratio; Vol, volume.
* $P < .05$; ** $P < .001$. [b] Paired *t*-test and [c] Wilcoxon signed-rank test were performed.

canines compared to the unimpacted canines of age and gender matched patients ($P < .05$).

Despite the differences in crown length of the mature group, which also acted to influence R/C measures, the results of R/C showed the same pattern as total length and root length in both groups. Mean difference in R/C was −0.03 for the immature group and −0.26 for the mature group. This implies that late traction of the impacted canine may lead to lesser root development of 25% of the crown length on average. In the results of a study conducted by Hettiarachchi et al.[25], crown-root ratio converted to root/crown ratio was 1.30 for palatally impacted canines and 1.69 for the control group, with a difference of −0.39.

Calculations of root/crown ratio could provide a more precise evaluation of the impact of root length on an individual tooth. Many studies have evaluated the effect of forced eruption on the total length or the root length, but the R/C ratio was overlooked. Differences in crown length suggested by previous studies[16,18] and results of the current study for the mature group indicated a different influence, thus, different severity, of the same amount of root length reduced for each tooth.

Volume of tooth measured using CBCT scans provides a quantitative evaluation of the tooth structure. In the immature group, there was no significant difference between impacted canines and contralateral canines, whereas the mature group showed a highly significant difference. There was also a statistically significant difference when groups were compared directly, indicating that early traction of the impacted canine could allow more root development as measured by volume. Although root development potential was not considered, Dekel et al.[8] measured smaller volumes of palatally impacted canines (27 mm^3, $P = .010$), indicating that orthodontic traction should be done prior to root development of the apical third.

Decreased root lengths mainly occur due to restrictions during root development and resorption of roots that were properly developed. It is uncertain whether the differences in length and volume of impacted canines in the mature group were due to lack of root development or the progression of root resorption. However, the fact that an earlier forced eruption procedure can produce more favorable results in terms of prognosis and tooth structure remains clear.

The limitations of this study included the small sample size, especially of the mature group. Some samples were excluded mainly due to severe root dilacerations, which could distort linear measurements and cause failure of forced eruption, leading to extraction of the impacted tooth.

CONCLUSIONS

- Regardless of treatment timing, total length and root length was shorter for the impacted canines, compared to the contralateral canines.
- Forced eruption undertaken before maturation of the contralateral canine showed better results for root development in linear and volumetric measurements.
- Root/crown ratio could provide a more precise evaluation of the impact of reduced root length for each tooth, compared to total length or root length.

Table 5. Differences in Measurements Between Impacted and Contralateral Canines in Immature and Mature Groups[a]

Measurements	Immature Group			Mature Group			Difference Between Groups	*P*
	Mean	SD	*P*	Mean	SD	*P*		
diff TL (mm)[b]	−0.68	1.15	.004*	−2.43	1.37	< .001**	1.75	0.000**
diff CL (mm)[c]	−0.17	0.52	.091	0.1	0.39	.016*	−0.27	.020*
diff RL (mm)[b]	−0.51	1.02	.012*	−2.53	1.19	< .001**	2.02	0.000**
diff R/C[c]	−0.03	0.12	.030*	−0.26	0.11	< .001**	0.23	0.000**
diff Vol (mm^3)[c]	−12.97	34.25	.051	−37.9	41.73	< .001**	24.93	.014*

[a] diff indicates difference between the impacted canine and the contralateral canine; (-) indicates impacted canine < contralateral canine; TL, total length; CL, crown length; RL, root length; R/C, root/crown ratio; Vol, volume.
* $P < .05$; ** $P < .001$. [b] Independent *t*-test and [c] Mann-Whitney *U* test were performed.

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