

Factors affecting forced eruption duration of impacted and labially displaced canines

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Introduction: Patients with impacted maxillary canines typically endure long treatment time, and reliable pretreatment estimates of orthodontic treatment duration would be beneficial to patients and clinicians. The purpose of this study was to identify factors that affect the duration of forced eruption for impacted maxillary canines.

Methods: Data from treatment records and radiographic scans of 27 patients with 29 impacted and labially displaced maxillary canines (25 unilateral, 2 bilateral) were collected. The patients underwent surgical and orthodontic interventions to bring the canine into the dental arch. Linear and angular measurements between the cusp tip and various reference planes were made on 3-dimensional images. Measurements associated with dental follicle, bone density, and canine root length were also obtained. Data were analyzed using simple linear regression and stepwise regression analysis. **Results:** A total of 29 treated canines moved into the arch over a period of 13.0 ± 8.3 months (range, 5-33 months). Simple regression analysis showed that the only significant factor, with duration of traction as the dependent factor, was pretreatment inclination of the canines toward the midsagittal plane; stepwise regression analysis indicated a strong direct correlation between the duration of traction and this factor. The other variables were not significantly associated with the duration of traction. **Conclusions:** The inclination of canines toward the midsagittal plane was found to be a reliable predictor of the duration of forced eruption for impacted maxillary canines. (Am J Orthod Dentofacial Orthop 2019;156:808-17)

The maxillary canine is the second most commonly impacted tooth, after the third molar, with an incidence ranging from 0.8% to 2.8%, depending on the population examined.¹ An impacted canine requires complex therapeutic management, which can be considered successful only if forced eruption and the subsequent alignment lead the tooth to the correct position in the dental arch.² Forced eruption for impacted

maxillary canines typically necessitates surgical and orthodontic intervention to bring the canine into the dental arch successfully.

Variations in buccopalatal, vertical, and anteroposterior locations of impaction define treatment complexity and duration.³ Reliable pretreatment estimates of orthodontic treatment duration would be helpful in the decision-making process for patients with impacted canines and in providing accurate information to the patient.⁴

Several variables have been proposed to predict the duration of forced eruption: age, number of impacted canines, pretreatment radiographic variables in panoramic radiographs, indices calculated from cone beam computed tomography (CBCT).^{2,4-16} In terms of age, Zuccati et al,⁴ Stewart et al,⁵ and Zhang et al⁶ reported that treatment time was dependent on the patient's age. However, Becker and Chaushu⁷ reported that the duration of treating the overall malocclusion of adults and young patients did not materially differ. Regarding the number of impacted maxillary canines, Stewart et al⁵ suggested that patients with bilateral impaction required more time for treatment than did patients

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with unilateral impaction. Nieri et al² also reported that bilateral occurrence of impaction determines a longer duration of treatment.

Pretreatment radiographic variables in panoramic radiographs are associated with the duration of orthodontic traction. The pretreatment radiographic features, such as angle, distance, and sector of impaction, suggested by Ericson and Kuroi^{8,9} have been demonstrated to predict the durations of orthodontic traction and comprehensive orthodontic treatment to reposition impacted teeth.^{2,10,11} Stewart et al⁵ and Zucconi et al⁴ reported that canines with cusp tips farther from the occlusal plane required longer treatment. Bazargani et al¹² suggested that the initial position of the canine, the distance between the canine cusp tip and the occlusal plane, and the inclination of the canine on panoramic radiographs were significantly associated with treatment duration. Fleming et al¹³ and Dubovska et al¹⁴ reported that the horizontal position of the canine is a factor that significantly affects the treatment duration.

With the recent advancements of CBCT imaging, a practitioner has access to an abundance of information regarding impaction.¹⁵ Kau et al¹⁶ calculated the “KPG” index by adding the scores assigned to the cusp tip and root tip in the 3 planes of space on CBCT panoramic and axial sections. San Martín et al¹⁵ suggested the KPG index as an estimate of the treatment time necessary to successfully bring an impacted canine into the arch, but the KPG index cannot be confirmed as an accurate means of estimating treatment time.

From CBCT data, software enables multiplanar and 3-dimensional (3D) reconstructions for the assessment of impaction. Although the duration of forced eruption is primarily estimated using 3D assessment, other critical factors include the presence or absence of a dental follicle, size and volume of the dental follicle, quality of bone covering the tooth, and overall stage of canine root development. These factors can be assessed using secondary reconstructions.

The aim of this study was to identify factors that can affect the duration of forced eruption for impacted maxillary canines. This study included factors other than those analyzed in previous studies because wider knowledge of factors that may affect the duration of orthodontic treatment in patients with displaced maxillary canines would be beneficial to both orthodontist and their patients.¹²

MATERIALS AND METHODS

The records of 27 patients treated surgically and orthodontically to align 29 impacted maxillary canines

(25 unilateral, 2 bilateral) from 2009 to 2016 were reviewed. The patients were aged 9–22 years (mean age, 12.5 ± 2.9 years). The research was approved by the institutional review board for ethical issues (institutional review board number: W1724/001-001).

The inclusion criteria were (1) impacted and labially displaced maxillary canines unilaterally or bilaterally treated using forced eruption with fixed orthodontic appliances; (2) presence of pretreatment panoramic radiographs and both pre- and posttreatment CBCT; (3) all treatment completed; and (4) complete treatment records. Patients with impacted teeth other than the maxillary canines, ankylosed canines, dilacerated canines, craniofacial syndrome, limited field of view on CBCT, and the presence of mechanical obstacles to eruption, such as supernumerary teeth, tumors, or odontomas, were excluded.

The patients had been referred from the department of orthodontics for surgical exposure of impacted maxillary canines. All patients underwent a closed-flap surgical procedure followed by orthodontic traction.

After local anesthesia, a vestibular and vertical incision was performed at the level of the impacted maxillary canine. The mucoperiosteum was then dissected off the bone. The bony covering was removed with a round bur, and the dental follicular tissue was removed from the surface of the enamel. Further soft tissue and/or bone removal was performed to enhance the forced eruption of the canine. An orthodontic bracket was bonded, and orthodontic traction force was applied after 7 days.

Data, including age, sex, and tooth number, were documented. Radiography included orthopantomography, CBCT before surgical exposure, and CBCT after forced eruption. Panoramic images were obtained using Planmeca ProMax (Planmeca Oy, Helsinki, Finland). The dental CBCT scanner used in this study was the Asahi Alphard 3030 (Belmont Takara, Kyoto, Japan) with settings of 80 kV, 5 mA, and exposure time of 17 seconds. CBCT data were converted using Simplant Pro 2011 software (Materialise, Leuven, Belgium) and assessed. The following variables were recorded: Three parameters were assessed for each maxillary canine dental follicle: (1) Presence of a dental follicle around the crown of the canine, indicated by radiolucency around the crown of the canine on the preoperative panoramic image. (2) Size of the dental follicle, called Radio2D (mm) in this study, indicated by the largest distance from the crown of the canine to the periphery of the follicle on the preoperative panoramic image. (3) Dental follicle volume, called Radio3D (mm³) in this study, as measured on preoperative CBCT using manual segmentation in Simplant software, as follows:

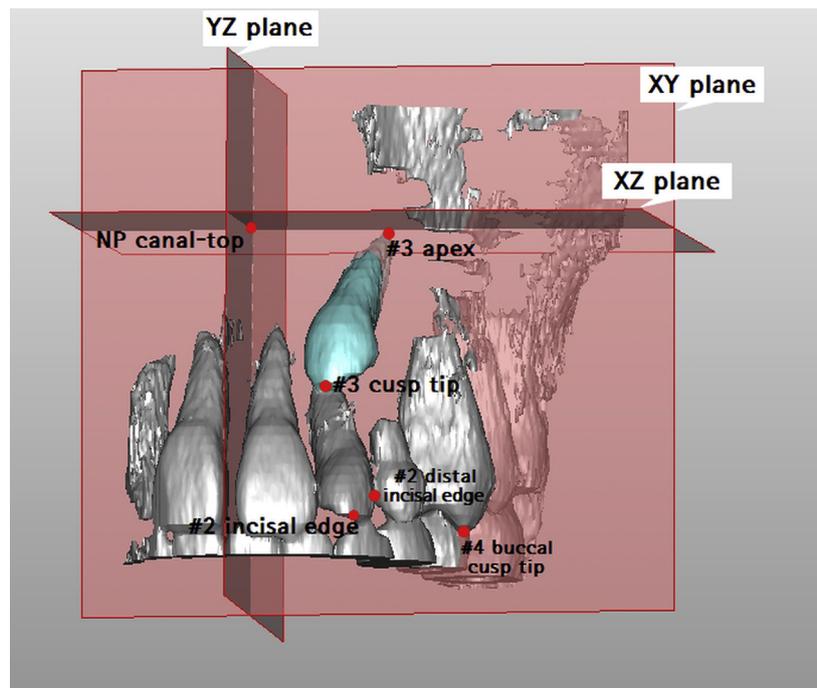


Fig 1. Three-dimensional computed tomography reconstruction image of an impacted maxillary canine.

- Open the CT images for measurement using Simplant software
- Set the range of Hounsfield unit values as -700 to 225
- Manually draw the boundary of radiolucency around the canine on each axial, coronal, and sagittal plane
- Segment the area of radiolucency around the canine
- Measure the volume of the area using the software's built-in tool

Radio2D (mm) and Radio3D (mm^3) comprise all canines with and without dental follicles. Radio2D_m (mm) and Radio3D_m (mm^3) include only canines with dental follicles. Therefore, in case of canines without dental follicles, Radio2D (mm) and Radio3D (mm^3), are 0.

The distance from the canine cusp tip to the XY, YZ, and XZ planes was observed on the preoperative CBCT and measured using Simplant software (Fig 1). Reference lines were created to assess these locations. The YZ plane passes through the point anterior nasal spine and the

line nasopalatine (NP) canal and refers to the midsagittal plane. The NP canal is the line between the superior foramina of the nasopalatine canal and the incisive foramen. The XY plane passes through the point superior foramina of the nasopalatine canal and the normal to inferior border line of the nasal floor and refers to the coronal plane. The XZ plane passes through the point superior foramina of the NP canal and is normal to the XY and YZ planes and refers to the axial plane.

CBCT data were converted using Simplant software and a tool in Simplant software was used to measure the average bone density. The region of interest (ROI) was determined as the area corresponding to the central area of cancellous bone above the impacted canine in axial section. Using a distance measuring tool in the software, an effort was made to set the ROI halfway buccolingually and mesiodistally of the bone. ROI was set to $1 \text{ mm} \times 1 \text{ mm}$ and measured in Hounsfield units.

The distance between the canine cusp tip before surgical exposure and after forced eruption (Distance3_mov) was calculated as follows:

$$\text{Distance3_mov} = \sqrt{(\text{Distance3_YZ} - \text{Post} - \text{Distance3_YZ})^2 + (\text{Distance3_XY} - \text{Post} - \text{Distance3_XY})^2 + (\text{Distance3_XZ} - \text{Post} - \text{Distance3_XZ})^2}$$

Table 1. Description of each of the study variables

Variables (scale)	Descriptions
RadioYN	Presence or absence of a dental follicle around the crown of the canine, indicated by radiolucency around the crown of the canine in orthopantomography and computed tomography
Age (y)	Age at date of the surgical exposure
Radio2D (mm)	Size of the dental follicle that is the greatest distance from the crown of the canine to the periphery of the follicle measured in orthopantomography before surgical exposure
Radio2D_m (mm)	Radio2D only in the group with dental follicles
Radio3D (mm ³)	Dental follicle volume measured in computed tomography before surgical exposure
Radio3D_m (mm ³)	Radio3D only in the group with dental follicles
Distance3_YZ (mm)	Distance from the canine cusp tip to the YZ plane [*] before surgical exposure
Distance3_XY (mm)	Distance from the canine cusp tip to the XY plane [†] before surgical exposure
Distance3_XZ (mm)	Distance from the canine cusp tip to the XZ plane [‡] before surgical exposure
Distance2_YZ (mm)	Distance from the distal incisor edge of the lateral incisor to the YZ plane before surgical exposure of the canine
Distance2_XY (mm)	Distance from the distal incisor edge of the lateral incisor to the XY plane before surgical exposure of the canine
Distance2_XZ (mm)	Distance from the distal incisor edge of the lateral incisor to the XZ plane before surgical exposure of the canine
Distance4_YZ (mm)	Distance from the buccal cusp tip of the first premolar to the YZ plane before surgical exposure of the canine
Distance4_XY (mm)	Distance from the buccal cusp tip of the first premolar to the XY plane before surgical exposure of the canine
Distance4_XZ (mm)	Distance from the buccal cusp tip of the first premolar to the XZ plane before surgical exposure of the canine
Angle3_YZ (°)	Angle between the long axis of the canine and the YZ plane before surgical exposure. Long axis of the canine is the line between the canine apex and the canine cusp tip.
Angle3_XY (°)	Angle between the long axis of the canine and the XY plane before surgical exposure
Angle3_XZ (°)	Angle between the long axis of the canine and the XZ plane before surgical exposure
Angle3_2 (°)	Angle between the long axis of the canine and the long axis of the lateral incisor before surgical exposure of the canine. Long axis of the lateral incisor is the line between the lateral incisor apex and the midpoint of the incisor edge of the lateral incisor.
Bone density (HU)	Alveolar bone density measured on the central area of cancellous bone above around the impacted maxillary canine in axial section. Region of interest is set to 1 mm × 1 mm.
Interdental distance (mm)	Distance from the distal CEJ of the lateral incisor to the mesial CEJ of the first premolar before surgical exposure of the canine
Pre-tx root length (mm)	Distance from the canine apex to the canine CEJ before surgical exposure
Post-tx root length (mm)	Distance from the canine apex to the canine CEJ after surgical exposure
Ratio of root length	Ratio of pre-tx root length to post-tx root length
Post-Distance3_YZ (mm)	Distance from the canine cusp tip to the YZ plane after forced eruption
Post-Distance3_XY (mm)	Distance from the canine cusp tip to the XY plane after forced eruption
Post-Distance3_XZ (mm)	Distance from the canine cusp tip to the XZ plane after forced eruption
Distance3_mov (mm)	Distance between the canine cusp tip before surgical exposure and after forced eruption (moving distance of the canine cusp tip through the duration of forced eruption)
Duration (mo)	Duration from the date of surgical exposure to the date that the tooth was fully ligated in the main arch with a nickel-titanium wire (duration of forced eruption)

CEJ, cemento–enamel junction; HU, Hounsfield unit; NP, nasopalatine.

*YZ plane: The plane passing through the point anterior nasal spine and the line NP canal, referred to as the midsagittal plane. The NP canal is the line between the superior foramina of the NP canal and the incisive foramen; †XY plane: The plane passing through the point superior foramina of the NP canal and normal to the inferior border line of the nasal floor, referred to as the coronal plane; ‡XZ plane: The plane passing through the point superior foramina of the NP canal and normal to the XY and YZ planes, referred to as the axial plane.

The main outcome variable was duration, meaning the duration of forced eruption, defined as the period from the date of the surgical exposure to the date that the tooth was fully ligated in the main arch with a nickel-titanium wire.

Other variables mentioned in this study are described in Table 1.

Statistical analysis

Examiner reliability was evaluated with the 2-way mixed-effects intraclass correlations for replicated measurements. All the variables mentioned in this study were

measured twice on 5 randomly selected canines, with at least 14 days between the measurement interval.

For statistical analysis, Statistical Analysis Software was used (version 9.4; SAS, Cary, NC). Measurement data were expressed as the mean ± standard deviation. Count data were expressed as the frequency and percentage. Simple linear regression was used to analyze the relationship between various factors and duration. Stepwise regression was used to analyze the relationship between significant factors and duration. We considered $P < 0.05$ to indicate statistical significance.

Table II. Descriptive statistics: Means and standard deviations of each variable

Variables (scale)	Sample size (n)	Mean \pm SD
Age (y)	29	12.5 \pm 2.9
Radio2D (mm)	29	2.6 \pm 2.3
Radio2D_m (mm)	18	4.2 \pm 1.3
Radio3D (mm ³)	29	268.5 \pm 249.2
Radio3D_m (mm ³)	18	432.7 \pm 164.6
Distance3_YZ (mm)	29	8.4 \pm 5.1
Distance3_XY (mm)	29	8.5 \pm 3.6
Distance3_XZ (mm)	29	13.0 \pm 4.0
Distance2_YZ (mm)	29	14.9 \pm 1.8
Distance2_XY (mm)	29	11.5 \pm 3.0
Distance2_XZ (mm)	29	23.6 \pm 2.8
Distance4_YZ (mm)	29	21.2 \pm 2.0
Distance4_XY (mm)	29	2.3 \pm 1.7
Distance4_XZ (mm)	29	22.4 \pm 4.5
Angle3_YZ ($^{\circ}$)	29	20.4 \pm 16.4
Angle3_XY ($^{\circ}$)	29	26.6 \pm 12.0
Angle3_XZ ($^{\circ}$)	29	51.2 \pm 16.6
Angle3_2 ($^{\circ}$)	29	37.4 \pm 16.2
Bone density (HU)	29	413.2 \pm 107.1
Interdental distance (mm)	29	9.7 \pm 2.3
Pre-tx root length (mm)	29	14.5 \pm 1.3
Post-tx root length (mm)	29	15.6 \pm 1.5
Ratio of root length	29	0.9 \pm 0.1
Post-Distance3_YZ (mm)	29	16.2 \pm 4.7
Post-Distance3_XY (mm)	29	8.5 \pm 4.0
Post-Distance3_XZ (mm)	29	20.3 \pm 5.2
Distance3_mov (mm)	29	11.8 \pm 5.2

HU, Hounsfield unit; SD, standard deviation.

RESULTS

Among the study population of 27 patients, 29 treated labially displaced canines were assessed: 14 right maxillary canines (48%) and 15 left maxillary canines (52%). Six canines (21%) belonged to male patients and 23 canines (79%) belonged to female patients. Eighteen canines (62%) had dental follicles, and the sample size of Radio2D_m and Radio3D_m was 18. All canines moved into the arch over a period of 13.0 \pm 8.3 months (range, 5–33 months). The means and standard deviations for each continuous variable are described in Table II. The intraclass correlation coefficients between repeated measurements were high, ranging from 0.93 to 0.99, except for the bone density ($r = 0.83$).

The influence of each factor on the duration of traction was estimated using regression analysis. Simple regression analysis (Table III) indicated that the only significant factor with duration of traction as the dependent factor was Angle3_YZ ($P = 0.0010$). The other variables were not significantly associated with the duration of traction.

Stepwise regression analysis, with the duration of traction as one of the 3 dependent variables included

in our formula, indicated a statistically significance with Angle3_YZ ($P = 0.0040$), being the correlation coefficient of the regression shown in Table IV, equal to 0.664. Sex ($P = 0.0715$) and age ($P = 0.1403$) were not associated with the duration of traction.

In the Pearson correlation analysis, Angle3_YZ was positively related to the duration of traction ($r = 0.580$; $P = 0.001$). A graphic model of the regression is shown in Figure 2. In the simple linear regression model, 34% ($R^2 = 0.336$) of the variation in traction duration could be explained by variation in Angle3_YZ.

DISCUSSION

Patients with impacted maxillary canines typically endure long treatment time, and prediction of orthodontic treatment duration would be beneficial to patients and clinicians. Previous studies^{17,18} on the duration of orthodontic treatment have found that some of the most critical factors related to treatment time include the number of treatment phases, pretreatment skeletal pattern, and number of negative chart entries regarding oral hygiene, missed appointments, and replaced brackets and bands. Stewart et al⁵ showed that the effect of impacted canines was significantly greater than the error associated with such variables in a case-control study. Therefore, these potential confounders were not considered in the present study.

Previous studies^{2,4-14,19} have focused on pretreatment variables on panoramic radiographs to predict the duration of treatment of impacted maxillary canines, and the location of impacted canines on panoramic views appears to affect treatment duration. Previous results have confirmed the role of the location of the impaction on treatment duration; however, which of these independent factors are more reliable for predicting treatment duration consistently has not been confirmed.

Studies have been affected by limitations regarding the reliability of panoramic radiographs. As reported by Fleming et al,¹³ the reliability of panoramic radiographs in the anterior maxilla is limited: impacted canine angle and distance compared with the midline are generally overestimated; furthermore, in patients with small interincisor angles or with a major intermaxillary discrepancy, apical or coronal parts of anterior teeth can appear out of focus or even invisible. Overestimation of the angulation of misplaced canines and the distance of the tooth from the midline is typical of panoramic views,²⁰ with distortions in the horizontal plane tending to be nonlinear.²¹

Because of the limitations of the aforementioned radiographic modality, several studies started to use

Table III. Simple regression analysis showing the influence of various factors on traction duration

Variables (scale)	Duration of traction			
	Coefficient estimate	Standard error	t value	Pr > t
Age (y)	0.9379	0.5303	1.77	0.0882
Radio2D (mm)	-0.3061	0.6969	-0.44	0.6641
Radio2D_m (mm)	2.2222	1.1099	2.00	0.0625
Radio3D (mm ³)	-0.0063	0.0063	-1.00	0.3283
Radio3D_m (mm ³)	0.0007	0.0098	0.07	0.9453
Distance3_YZ (mm)	-0.3721	0.3083	-1.21	0.2379
Distance3_XY (mm)	-0.2852	0.4406	-0.65	0.5230
Distance3_XZ (mm)	-0.5597	0.3816	-1.47	0.1540
Distance2_YZ (mm)	-0.5102	0.8704	-0.59	0.5626
Distance2_XY (mm)	0.4991	0.5288	0.94	0.3537
Distance2_XZ (mm)	-0.0700	0.5633	-0.12	0.9020
Distance4_YZ (mm)	0.6850	0.7911	0.87	0.3942
Distance4_XY (mm)	1.0917	1.0348	1.05	0.3015
Distance4_XZ (mm)	0.5454	0.3372	1.62	0.1175
Angle3_YZ (°)	0.2940	0.0795	3.70	0.0010*
Angle3_XY (°)	-0.1211	0.1317	-0.92	0.3661
Angle3_XZ (°)	-0.1812	0.0901	-2.00	0.0545
Angle3_2 (°)	0.1723	0.0931	1.85	0.0750
Bone density (HU)	-0.0015	0.0150	-0.10	0.9230
Interdental distance (mm)	-0.7829	0.6846	-1.14	0.2628
Pre-tx root length (mm)	1.4550	1.2021	1.21	0.2366
Post-tx root length (mm)	-0.0753	1.0697	-0.07	0.9444
Ratio of root length	47.6397	24.3999	1.95	0.0613
Post-Distance3_YZ (mm)	-0.1904	0.3416	-0.56	0.5819
Post-Distance3_XY (mm)	-0.1542	0.4007	-0.38	0.7034
Post-Distance3_XZ (mm)	-0.1265	0.3090	-0.41	0.6854
Distance3_mov (mm)	0.2597	0.3063	0.85	0.4040

HU, Hounsfield unit.

*P value < 0.01.

CBCT for imaging. CBCT images are inherently more accurate than traditional x-rays because the beam projection is orthogonal, meaning that the x-ray beams are approximately parallel to one another, and the object is near the sensor. This explains why little projection effect and no magnification are observed.²² Kau et al¹⁶ introduced a new measuring scale for cases of impacted canines, based on 3 different CBCT views, to grade the difficulty of impaction and the potential efficacy of treatment. They believed that the sum of scores for the cusp tip and root tip in 3 views determined the

anticipated difficulty of treatment. This grading may be useful in treatment planning, but its clinical usefulness and reliability have not yet been evaluated. Because this grading is the sum of scores, it is difficult to evaluate the effect of each factor.

This study assessed the influence of each factor of impacted maxillary canines regarding the duration of forced eruption using CBCT and 3D reconstruction. Another distinguishing feature may be the choice of variables; previous studies^{2,4-14,19} on the treatment duration of impacted maxillary canines have focused on canine location, angle, distance, and sector of impaction. However, this is the first study to include the presence of dental follicles, size of dental follicles, bone density, and root length to determine whether they play a role in determining treatment duration. Regression analysis was used to evaluate which of the variables were significantly related to the treatment duration of impacted canines.

Age appeared to affect treatment duration in previous studies.^{4-7,13} Zuccati et al⁴ suggested that treatment duration for impacted canines might be remarkably

Table IV. Stepwise regression analysis of the traction duration showing correlation with Angle3_YZ

Variables (scale)	Coefficient estimate	Standard error	t value	Pr > t
(Intercept)	-5.7970	6.7749	-0.856	0.4003
Angle3_YZ (°)	0.2525	0.0797	3.166	0.0040*
Sex	5.8918	3.1303	1.882	0.0715
Age (y)	0.7178	0.4713	1.523	0.1403

*P value < 0.05.

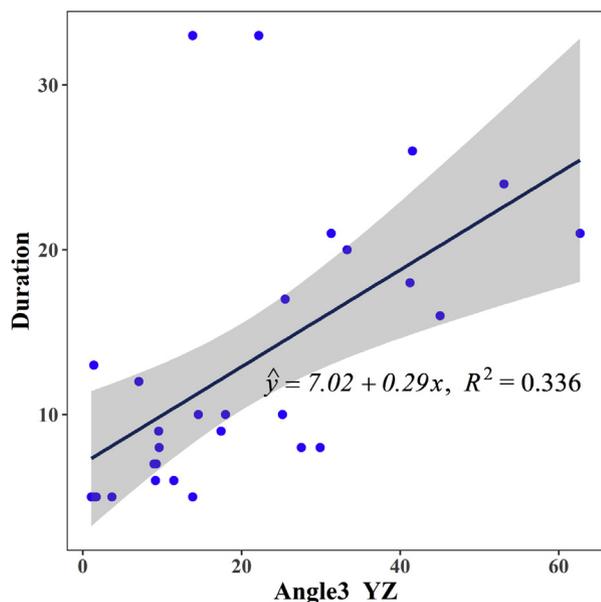


Fig 2. Correlation of Angle3_YZ with duration of traction. The gray bands around the line represent the standard error of the regression line.

longer in patients older than 25 years. Zhang et al⁶ reported that adults showed significant increases in treatment duration for impacted canines. However, in a study conducted by Stewart et al,⁵ the age–duration relationship was inverse: the younger the patient, the longer the orthodontic treatment. In this study, regression analysis showed that age was not significantly associated with the duration of traction, which is supported by Becker and Chaushu⁷ and Fleming et al.¹³ This variance in the age–duration relationship might be explained by younger patients having residual eruptive potential but tending to have severely positioned tooth requiring treatment.^{5,23}

The lower limit of canine impaction is usually set over 12 years. However, in this study, the patients were aged 9–22 years in the study population. Frequently, an impacted maxillary canine could not be noticed by the patient or diagnosed by the dentist until the age of 12–14 years because the rest of dentition often displayed only a mild malocclusion or crowding problem.⁵ However, the diagnosis of maxillary canine impaction can be made after 8 years old, especially if the angulation of the canine with the midline is considered.^{24,25} The most desirable approach for managing impacted maxillary canines would be early detection and timely interception of potential impaction.^{26,27} An age range of 9–22 years might not be wide enough to show the age correlation with treatment time. However, the success rate of forced eruption was very low in the

adults,⁷ and it was rare for the adult patients to desire forced eruption of impacted canines in our clinic. This is a limitation of this study, so further studies with adults might be needed.

Previous studies^{28–31} have described the features of the dental follicles of erupting maxillary canines. However, they did not focus on the relationship between follicle size and treatment duration. Tooth eruption is a long-lasting multifactorial process composed of several overlapping phases, which seem to involve the size of the dental follicle.³¹ Because 58% of dental follicles of the maxillary canines have an irregular shape with asymmetrical extensions,²⁹ all dimensions of dental follicles must be measured. In this regression analysis, the presence of a dental follicle, follicle size in panoramic images, and follicle volume were not significantly associated with the treatment duration. This might have been because, in the surgical exposure of impacted maxillary canines, the dental follicular tissue is removed from the surface of the enamel; therefore, the pretreatment follicle presence, size, and volume does not play a critical role in influencing the forced eruption duration.

Previous studies^{4,19} have addressed the vertical distance of impacted canines in panoramic images as major contributors to determine the treatment duration. Zuccati et al⁴ and Ericson and Kuroi¹⁹ reported a direct correlation of duration with the distance between the canine cusp tip and the occlusal plane; the greater the vertical distance, the longer the duration. However, Fleming et al,¹³ Dubovska et al,¹⁴ and McSherry³² reported that the horizontal mesiodistal location of the canine is a factor that significantly affects the treatment duration. This was also supported by Zuccati et al⁴ who demonstrated a relationship between the need for more treatment visits and a more mesial position of the canine. This study evaluated not only canine distance from 3 planes but also lateral incisor and first premolar distance. The results showed no correlation between any distance component and treatment duration. Unlike previous^{4,13,14,19,32} studies, the canine distances from the reference planes were found to be noninfluential, possibly because factors were intercorrelated, or the sample size was small to validate the effect. The pretreatment distances of the lateral incisor and first premolar from the reference planes did not significantly affect treatment duration. This result might be because the treatment duration is determined by the canine location rather than eruption, leveling, and alignment for the lateral incisor or premolar.

The pretreatment angulation of canines with respect to the midline in panoramic radiographs significantly influenced the duration of treatment in previous

studies.^{2,10,12,14} In the present study, only Angle3_YZ showed a statistically significant correlation with the duration of treatment in the regression analysis. Furthermore, in the Pearson correlation analysis, Angle3_YZ showed a strong positive relationship with the treatment duration. Angle3_XY and Angle3_XZ did not indicate a statistically significance in the analysis. These results may be explained by the direction of forced eruption. Impacted canines with a higher Angle3_YZ have a closer crown and farther apex relative to the midsagittal plane. Active traction cannot be directed to a place in the dental arch because it may result in resorption of the roots of the incisors located in the direction of the traction.¹⁴ Therefore, they require therapeutic uprighting with orthodontic traction on the opposite side of the lateral incisor root. When located closer to the occlusal plane, root torsion must be added to obtain the correct position, resulting in extension of the treatment duration. In addition, the rate of orthodontic tooth movement largely depends on how fast the alveolar bone resorbs in the direction of tooth movement.^{29,33} Because the uprighting of the impacted canine may increase the surface area of the resorbed alveolar bone, the uprighting of the aligned canine may result in prolonged treatment duration.

The mechanics of impacted canines associated with lateral incisors may suggest a relationship between Angle3_2 and treatment duration. Fleming et al¹³ reported that a horizontal position of the canine crown relative to the adjacent teeth showed a statistically significant correlation with the duration of treatment. A weak inverse correlation was found with the angle between the canine and lateral incisor axes on panoramic radiographs and the number of visits.⁴ The canine-to-lateral incisor angle has been found to have a direct influence on canine impaction when CBCT is used.³⁴ However, in this study, Angle3_2 showed no significant relationship with treatment duration.

Zucatti et al⁴ speculated that bone density can act as a prognostic factor of forced eruption; the rate of tooth movement seems to depend on the density of the bone.³⁵ Animal experiments inducing decreased bone density and altered bone metabolism after nutritional hyperparathyroidism³⁶ and acute and chronic corticosteroid treatment³⁷ have shown rapid tooth movement. The rate of tooth movement in dense compact bone is slower than in weak sponge bone.³⁸ Similarly to Hao et al,³⁹ who scanned 128 patients' jaw bones using CBCT and assessed the bone density using Simplant software, the present study measured the bone density above impacted canines. The intraexaminer reliability was lower for the bone density ($r = 0.83$), probably because of variability in reproducing and replicating

selected bone tissue. However, in this study, bone density did not appear to significantly affect treatment duration.

Smith and Buschang⁴⁰ described the proportional root lengths (root length \div total tooth length) of mandibular canines, and the ratio of the root length is used as a metric for predicting eruption timing. CBCT was found to be precise in measurements of root length, with a high level of reproducibility.⁴¹ The method chosen in this study to obtain the root length has been previously described by Kim et al⁴² and Silva et al⁴³ and involved using the cemento–enamel junction as a reference. However, treatment duration was found to be independent of the ratio of root length. This result might be explained by the process of forced eruption relying on orthodontic traction force rather than spontaneous eruption.

Stewart et al⁵ found that the greater the distance that canines must move to correctly erupt, the longer the treatment will take. However, Distance3_mov does not show a positive relationship with treatment duration, possibly because of the nonlinear biomechanics of traction of the impacted canines. First, the canine must be uprighted and distanced from the roots of the lateral incisors, thus preventing resorption.¹⁴ Once the canine has been distanced and uprighted, the traction may be directed toward the arch. In this study, Distance3_mov was the linear distance of the cusp tip during forced eruption. Therefore, this factor may not indicate the distance that the canine actually moves, thus having no correlation with treatment duration.

Measurements other than Angle3_YZ did not appear to affect the treatment duration significantly. Only Angle3_YZ seemed to predict the duration of forced eruption, accounting for 34% of the observed variations. From the regression analysis, the following regression model can be made:

$$\text{Duration of traction (month)} = 7.02 + 0.29 \times \text{Angle3_YZ } (^{\circ}), R^2 = 0.336.$$

From the formula, if given the value of Angle3_YZ, the duration of traction can be predicted. In clinical situations, the estimated time for forced eruption increases by approximately 3 months if Angle3_YZ increases by 10° calculated from the formula. Based on these results, predicting the duration of treatment may be meaningful for both patients and clinicians. In addition, Angle3_YZ may indicate the inclination of the impacted maxillary canines to the midline in panoramic radiographs, and the results may allow clinicians to approximate a prediction at a glance. Consequently, radiographic examination of severe medial inclination of the impacted canines may signal to the clinician the likelihood of prolonged treatment duration. Thus, the patient may choose a treatment option other than forced eruption.

This study has some limitations. The study was retrospective in nature, and the inclusion criteria limited the sample size. Some factors were found to be related to treatment duration by some authors but noninfluential by others, possibly because the factors were intercorrelated. Therefore, additional studies are needed to confirm or reject the results of this study and should include increased sample sizes and a randomized controlled design to validate the prediction model. Moreover, subsequent studies are needed to confirm the correlation of the factors mentioned in this regression analysis and to provide a definitive comparison.

CONCLUSIONS

Many pretreatment factors have been mentioned as predictors to estimate forced eruption duration for impacted maxillary canines. In this retrospective study, the following conclusions were drawn:

- 1) Angle3_YZ was the only factor significantly associated with the duration of orthodontic traction. This predictor accounted for 34% of the observed variations.
- 2) More inclined canines with respect to the midsagittal plane required longer treatment duration: an additional 0.3 months may be required if the inclination is increased by 1°.

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