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Three-Dimensional Position of Impacted Maxillary Canines on Cone-Beam Computed Tomography and Its Association With the Duration of Orthodontic Alignment: A Retrospective Cohort Study

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Abstract

Introduction and aim: The three-dimensional position of an impacted maxillary canine may influence the complexity and duration of orthodontic alignment. Cone-beam computed tomography (CBCT) enables quantitative assessment of canine position in multiple spatial dimensions, potentially improving treatment planning and predicting alignment time. This study aimed to assess the association between the three-dimensional position of impacted maxillary canines, quantified along the transverse (X), sagittal (Y), and vertical (Z) axes using CBCT, and the time required for orthodontic alignment following surgical exposure and traction. The objectives were to compare canine position and alignment time according to the anatomical location of impaction (palatal, buccal, or mid-alveolar) and to determine whether the three-dimensional positional coordinates remained independently associated with alignment time after adjustment for relevant clinical and demographic factors.

Materials and methods: This retrospective observational cohort study included 108 patients with unilateral impacted maxillary canines treated with fixed orthodontic appliances, surgical exposure, and orthodontic traction. Pretreatment CBCT images were reoriented using standardized anatomical reference planes, and the three-dimensional position of each impacted canine was quantified along the transverse (X), sagittal (Y), and vertical (Z) axes. Alignment time was defined as the interval from the initiation of orthodontic traction to the complete alignment of the canine within the dental arch. Associations between the three-dimensional position and alignment time were assessed using Pearson's correlation and multivariable linear regression.

Results: The mean patient age was 23.24±4.78 years, and the mean alignment time was 10.17±1.48 months. The transverse, sagittal, and vertical coordinates were positively correlated with alignment time (all $p<0.001$). Alignment time differed significantly according to impaction location, with mid-alveolar canines requiring the shortest alignment time (9.09±1.70 months; $p=0.002$). In the multivariable analysis, X ($B=0.319$, $p<0.001$), Y ($B=0.509$, $p<0.001$), and Z ($B=0.327$, $p<0.001$) remained independently associated with longer alignment time. Age ($B=0.048$, $p=0.038$), canine angulation ($B=0.047$, $p=0.002$), and arch-length discrepancy ($B=0.292$, $p<0.001$) were also significant predictors. The regression model explained 63.0% of the variance in alignment time (adjusted $R^2=0.608$; $p<0.001$).

Conclusion: Greater three-dimensional displacement of impacted maxillary canines was associated with prolonged orthodontic alignment, with the sagittal position showing the strongest association. Quantitative CBCT-based assessment may provide clinically useful information for treatment planning and individualized counseling regarding the expected duration of alignment.

Categories: Dentistry
Keywords: cone-beam computed tomography, cuspid, impacted, orthodontic treatment, retrospective studies, tooth

Introduction

Maxillary canine impaction is a common developmental anomaly that can complicate orthodontic treatment and prolong the duration of active therapy [1]. Maxillary canines play an important role in dental esthetics, functional occlusion, and arch stability; therefore, the preservation and orthodontic alignment of an impacted canine are generally preferred when a favorable treatment prognosis can be achieved [2]. Surgical exposure followed by orthodontic traction is an established approach for bringing impacted canines into the dental arch [3]. However, the duration required to achieve successful alignment varies considerably between

patients.

Several clinical and radiographic factors may influence the difficulty and duration of orthodontic traction, including the location of impaction, morphology of adjacent lateral incisors, canine angulation, root development, available arch space, relationship with adjacent teeth, and degree of displacement from the normal eruption pathway [4,5]. Traditionally, the position of an impacted canine is evaluated using two-dimensional radiographs and categorical classifications. Although these approaches provide clinically useful information, they may not adequately represent the complex three-dimensional position of impacted teeth. Cone-beam computed tomography (CBCT) enables multiplanar visualization and quantitative assessment of impacted canines relative to reproducible anatomical reference planes. Therefore, a three-dimensional coordinate system can provide continuous measurements of the transverse, sagittal, and vertical displacements of the canine cusp, potentially offering a more precise representation of impaction severity [6,7].

Materials And Methods

Study design, setting, and ethical considerations

This single-center retrospective observational cohort study was conducted in the Department of Orthodontics, Kothiwal Dental College and Research Centre, Moradabad, India, in February 2024 using retrospectively retrieved clinical and radiographic records from the preceding years (January 2021 to January 2024). The study included patients who had undergone orthodontic treatment for unilateral impacted maxillary canines at the institution. The study protocol was approved by the Institutional Ethical Review Board of the college (#KDCRC/IERB/2/2024/SS48, dated February 6, 2024). As the study involved the retrospective analysis of existing clinical records and CBCT images obtained during routine patient care, no additional diagnostic or therapeutic procedures were performed for the purpose of this study. All records were anonymized before analysis, and a unique study identification number was assigned to each observation.

Eligibility criteria

All retrieved clinical and radiographic records were screened against the predefined eligibility criteria before inclusion in the final study sample. Particular attention was given to the completeness of pretreatment CBCT images and orthodontic treatment records to ensure reliable assessment of canine position and alignment duration. Only observations meeting all eligibility requirements were retained for the final analysis. Patients' eligibility criteria are summarized in Table *1*.

Inclusion criteria	Exclusion criteria
Unilateral impacted permanent maxillary canine confirmed by pretreatment CBCT.	Bilateral canine impaction.
Canine located in the palatal, buccal, or mid-alveolar region of the maxilla.	Craniofacial syndromes, cleft lip and/or palate.
Impacted maxillary canines classified as easy (KPG score: 0-7) or moderately difficult (KPG score: 8-14) according to the KPG 3D classification system.	Systemic conditions affecting bone metabolism or orthodontic tooth movement.
Age older than 12 years at the initiation of orthodontic treatment.	Pathological lesions associated with impacted canines (such as cysts, odontomas, supernumerary teeth).
At least two-thirds of root development or completed root formation.	Canines with ankylosis or severe resorption of adjacent incisors that altered the treatment plan.
Diagnostic-quality pretreatment CBCT scan of the maxillary dentition.	Extraction of the impacted canine, autotransplantation, or other nonstandard treatment approaches.
Comprehensive fixed orthodontic treatment involving surgical exposure, orthodontic traction, and complete documentation of dates (appliance placement, surgical exposure, traction initiation, canine alignment).	Previous orthodontic treatment or discontinuation for nonclinical reasons.

TABLE 1: Inclusion and exclusion criteria.

KPG classification [6,8,9].

CBCT: cone-beam computed tomography; KPG: Kau-Pan-Gallerano

Sample size determination

The sample size was determined using G*Power version 3.1 (Düsseldorf, Germany: Heinrich Heine University Düsseldorf) for a multiple linear regression model with six predictors [10]. Assuming a medium effect size (Cohen's f^2=0.15), a significance level of 0.05, and 80% statistical power, the minimum required sample size was 98 canine observations. To account for potential exclusions due to incomplete records, the sample size was increased by approximately 10%, yielding a target of 108 observations. A total of 108 eligible impacted maxillary canines were included in the final analysis.

CBCT acquisition and image reconstruction

A total of 162 patient records were initially screened for eligibility during the study period (January 2021 to January 2024). Following assessment against the predefined inclusion and exclusion criteria, 54 records were excluded, while 108 eligible impacted maxillary canine observations were selected for the final analysis. All patients underwent CBCT imaging as part of their routine orthodontic diagnostic assessment before the initiation of treatment. The CBCT examinations were acquired using a Carestream CS 9600 three-dimensional imaging system (Atlanta, GA: Carestream Dental LLC). The scans were obtained using a standardized orthodontic imaging protocol with a voxel size of 0.20 mm, a field of view of 10×10 cm, a tube voltage of 90 kV, a tube current of 8 mA, and an exposure time of approximately 15 s. The patient was positioned according to the manufacturer's positioning protocol, with the head stabilized to minimize movement during image acquisition. Only scans with adequate image quality and complete visualization of the impacted canine and surrounding maxillary structures were included for analysis.

Digital Imaging and Communications in Medicine (DICOM) datasets were reconstructed and evaluated using Carestream 3D Imaging Software (Atlanta, GA: Carestream Dental LLC). Before measurement, each CBCT volume was reoriented in the multiplanar reconstruction environment to establish reproducible anatomical reference planes. The axial plane was oriented parallel to the palatal plane defined by the anterior and posterior nasal spines. The midsagittal plane was aligned through the cranial midline and anterior nasal spine, and the coronal plane was positioned perpendicular to the sagittal and axial reference planes. Standardized three-dimensional orientation was performed before each measurement to minimize variability arising from differences in patient head positioning during acquisition.

Three-dimensional localization of impacted maxillary canines

The three-dimensional position of each impacted canine was assessed using a Cartesian coordinate system

established with reference to standardized anatomical planes. The cusp tip of the impacted canine served as the principal measurement landmark. The X-coordinate represented the transverse (buccopalatal) position and was defined as the perpendicular distance from the canine cusp tip to the midsagittal plane. The Y-coordinate represented the sagittal (anteroposterior) position and was defined as the distance from the canine cusp tip to a predefined coronal reference plane. The Z-coordinate represented the vertical (superoinferior) position and was defined as the distance from the canine cusp tip to a predefined occlusal reference plane. All measurements were recorded as absolute distances in millimeters, without assigning positive or negative directional values (Figure *1*). Similar three-dimensional CBCT-based approaches have been used to characterize the spatial position and severity of impacted maxillary canines [8,9].

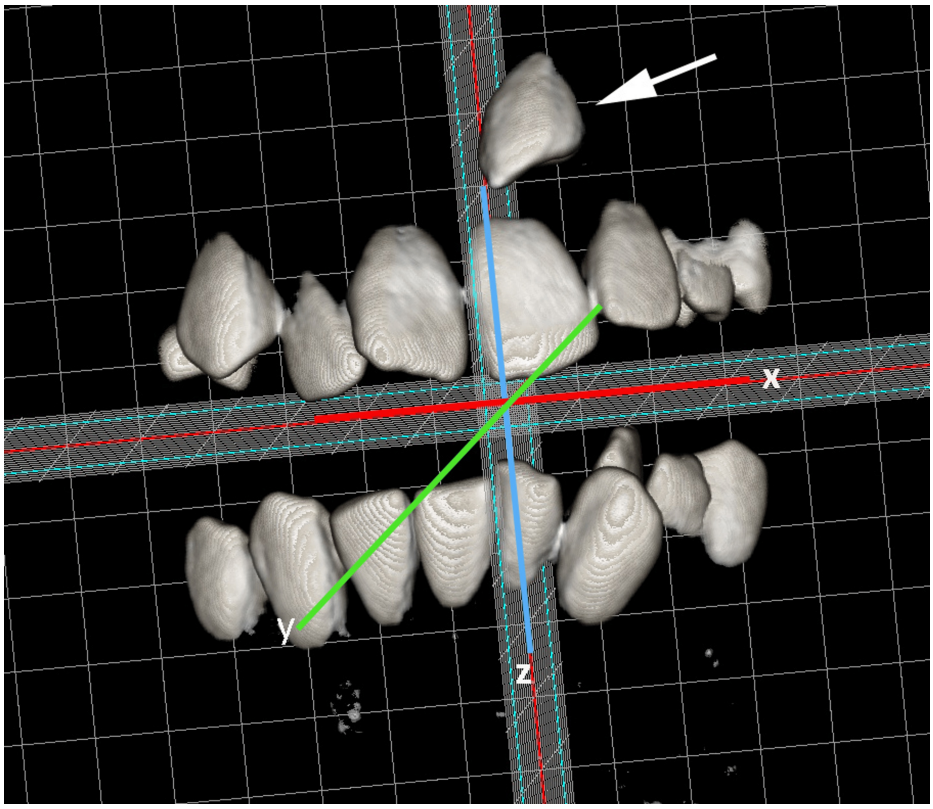


FIGURE 1: Three-dimensional CBCT reconstruction illustrating the coordinate system used for localization of the impacted maxillary canine (white arrow).

The transverse (X), sagittal (Y), and vertical (Z) axes were used to quantify the three-dimensional position of the canine cusp tip relative to the predefined anatomical reference planes.

In addition to the X-, Y-, and Z-coordinates, canine angulation was measured as the angle formed by the long axis of the impacted canine and the predefined sagittal reference plane. The presence or absence of the primary canine, arch-length discrepancy, side of impaction, and anatomical location of the impacted canine were also recorded. The use of three-dimensional CBCT measurements permits localization of impacted canines in the transverse, sagittal, and vertical dimensions, which cannot be fully represented using conventional two-dimensional radiographic measurements [4-7].

Classification of impaction

The impacted canines were categorized according to their buccal or palatal anatomical position as palatal, buccal, or mid-alveolar. The classification was based on the position of the canine crown within the maxillary alveolar process on multiplanar CBCT assessment. CBCT-based assessment is particularly suitable for determining the buccal and palatal positions of impacted maxillary canines [11]. The three location categories were subsequently used to compare the three-dimensional coordinates and orthodontic alignment time.

Orthodontic treatment protocol

All patients underwent comprehensive fixed orthodontic treatment according to the institutional orthodontic protocol. Adequate space for the impacted canine was created before surgical exposure, as

required. Following surgical exposure, an orthodontic attachment was bonded to the exposed canine, and orthodontic traction was initiated. Traction was generally applied using elastic thread with an approximate force of 20-25 g, with activation at approximately three-week intervals. Following initial disimpaction, the canine was progressively aligned using 0.014-inch nickel-titanium (NiTi) archwire, followed by 0.016-inch NiTi and stainless-steel archwires. Treatment was performed by experienced orthodontists (MM, FR) following the departmental treatment protocol. The primary canine was recorded as present or absent at the initiation of treatment. Arch-length discrepancy was recorded in millimeters from the orthodontic diagnostic records. Traction mechanics were categorized according to the technique documented in the treatment records and were subsequently compared descriptively with respect to alignment time.

Definition of orthodontic alignment time

Orthodontic alignment time was calculated in months from the initiation of orthodontic traction to the complete incorporation of the impacted canine into the dental arch. The starting point was defined as the date on which the orthodontic attachment was bonded to the surgically exposed canine and traction was initiated. The endpoint was defined as the date on which the canine was clinically aligned within the dental arch and could be engaged with the working archwire.

Examiner calibration and measurement reliability

Two examiners (MAW, GS) independently performed the CBCT measurements after calibration using 20 CBCT scans that were not included in the final study. The calibration procedure standardized the CBCT orientation, identification of the canine cusp tip, establishment of the reference planes, and measurement of the X-, Y-, and Z-coordinates. The examiners were blinded to the orthodontic alignment times during the radiographic assessment.

For intraexaminer reliability, 20% of the study observations were remeasured by each examiner after a two-week interval. Interexaminer reliability was assessed by comparing the measurements obtained independently by the two examiners. Reliability was evaluated using the intraclass correlation coefficient (ICC), with a two-way mixed-effects model for absolute agreement. The mean of the two examiners' measurements was used for the final statistical analysis. Alignment-time data were extracted independently from the clinical records without access to the CBCT measurements. Intraexaminer and interexaminer agreement for the X-, Y-, and Z-coordinates was high (ICC >0.89).

Statistical analysis

Statistical analysis was performed on the coded data by a blinded statistician (SB) using IBM SPSS version 25 (Armonk, NY: IBM Corp.) statistics for Windows. Continuous variables were expressed as mean±standard deviation (SD), and categorical variables were presented as frequencies and percentages. The association between the X-, Y-, and Z-coordinates and alignment time was evaluated using Pearson's correlation coefficient. Differences in mean alignment time between the two groups were evaluated using an independent-samples t-test. Accordingly, alignment time was compared according to sex, side of impaction, presence or absence of the primary canine, and traction mechanics. The effect size for two-group comparisons was expressed as Cohen's d.

Differences in three-dimensional canine coordinates, canine angulation, arch-length discrepancy, and alignment time among the palatal, buccal, and mid-alveolar impaction groups were evaluated using one-way analysis of variance (ANOVA), with eta squared (η^2) reported as the effect size, followed by a post hoc Tukey test. A multivariable linear regression analysis was performed with alignment time (in months) as the dependent variable. The independent variables entered into the final model were X-coordinate, Y-coordinate, Z-coordinate, age at treatment initiation, canine angulation, and arch-length discrepancy. Regression coefficients (β), robust standard errors, t-values, p-values, 95% confidence intervals (CIs), and standardized β coefficients were reported. The coefficient of determination (R^2) and adjusted R^2 were used to describe the explanatory performance of the regression model. Multicollinearity was assessed using the variance inflation factor (VIF). Statistical significance was set at a two-sided $p<0.05$.

Results

A total of 108 impacted maxillary canines were included in this analysis. The mean age at treatment initiation was 23.24±4.78 years, and the mean alignment time was 10.17±1.48 months. Females accounted for 56.5% (61) and males for 43.5% (47) of the observations. Palatal impaction was the most frequent, occurring in 65 (60.2%) cases, followed by buccal impaction in 25 (23.1%) and mid-alveolar impaction in 18 (16.7%) cases. The complete demographic and clinical characteristics are shown in Table *2*. Significant differences were observed in the X-, Y-, and Z-coordinates of palatal, buccal, and mid-alveolar impactions. Alignment time also differed significantly according to impaction location, with mid-alveolar canines requiring the shortest alignment time (9.09±1.70 months; p=0.002) (Table *3*).

Variables		Overall (n=108)
Age at treatment initiation, years	Mean±SD	23.24±4.78
	Median (IQR)	23.5 (20.2-26.5)
Sex, n (%)	Female	61 (56.5)
	Male	47 (43.5)
Side of impaction, n (%)	Left	58 (53.7)
	Right	50 (46.3)
Impaction location, n (%)	Palatal	65 (60.2)
	Buccal	25 (23.1)
	Mid-alveolar	18 (16.7)
Primary canine present, n (%)	No	70 (64.8)
	Yes	38 (35.2)
KPG class, n (%)	0-7	65 (60.2)
	8-14	43 (39.8)
X-coordinate, mm	Mean±SD	6.25±1.44
Y-coordinate, mm	Mean±SD	17.32±1.42
Z-coordinate, mm	Mean±SD	17.23±1.52
Canine angulation, in degrees	Mean±SD	25.64±6.52
Arch-length discrepancy, mm	Mean±SD	4.38±1.43
Alignment time, months	Mean±SD	10.17±1.48

TABLE 2: Demographic, clinical, radiographic, and treatment characteristics of the study sample.

Continuous variables are presented as mean±standard deviation (SD) and, where indicated, median (interquartile range {IQR}); categorical variables are presented as n (%) with percentages calculated from the total sample (n=108). X-, Y-, and Z-coordinates represent the transverse, sagittal, and vertical positions of the canine cusp tip on CBCT, respectively, expressed in millimeters. Canine angulation is expressed in degrees and arch-length discrepancy in millimeters.

CBCT: cone-beam computed tomography; KPG: Kau-Pan-Gallerano

Parameters	Palatal (n=65)	Buccal (n=25)	Mid-alveolar (n=18)	ANOVA F	p-Value	Effect size η²
X-coordinate, mm	5.10±1.35	8.81±1.08	6.79±1.33	76.64	<0.001*	0.594
Y-coordinate, mm	17.14±1.39	16.92±1.37	18.52±1.45	8.22	<0.001*	0.135
Z-coordinate, mm	16.86±1.47	16.61±1.62	19.44±1.52	23.22	<0.001*	0.307
Canine angulation, in degrees	26.32±6.41	24.84±6.80	24.47±6.50	0.88	0.418	0.017
Arch-length discrepancy, mm	4.45±1.42	4.34±1.47	4.18±1.48	0.25	0.781	0.005
Alignment time, months	10.43±1.33	10.29±1.38	9.09±1.70	6.39	0.002*	0.108

TABLE 3: Comparison of three-dimensional canine position, canine angulation, arch-length discrepancy, and alignment time according to the location of impacted maxillary canines.

*P<0.05 was considered statistically significant.

Values are presented as mean±SD. Groups were compared using one-way analysis of variance (ANOVA), η²=eta squared (effect size: ~0.01 small, ~0.06 medium, and ~0.14 large).

Post hoc Tukey-Kramer Honestly Significant Difference (HSD) tests, controlling for unequal sample sizes and multiple comparisons, revealed significant between-group differences for three variables. For the X-coordinate, all pairwise comparisons were significantly different (p<0.001), with the buccal group demonstrating the highest values. Regarding the Y- and Z-coordinates, the mid-alveolar group differed significantly from both the palatal and buccal groups (p<0.001), whereas the palatal and buccal groups did not differ from each other. For alignment time, the mid-alveolar group completed treatment significantly faster than the palatal (p<0.001) and buccal (p=0.002) groups. No significant intergroup differences were observed for canine angulation or arch-length discrepancy (p>0.05) (Table *4*).

Parameters	Comparison	Mean difference (95% CI)	q statistics	p-Value
X-coordinate	Palatal vs. buccal	-3.71 (-4.40 to -3.02)	-18.738	<0.001*
	Palatal vs. mid-alveolar	-1.69 (-2.45 to -0.93)	-7.736	<0.001*
	Buccal vs. mid-alveolar	2.02 (1.13 to 2.91)	7.891	<0.001*
Y-coordinate	Palatal vs. buccal	0.22 (-0.46 to 0.90)	1.089	0.443
	Palatal vs. mid-alveolar	-1.38 (-2.13 to -0.63)	-6.208	<0.001*
	Buccal vs. mid-alveolar	-1.60 (-2.48 to -0.72)	-6.137	<0.001*
Z-coordinate	Palatal vs. buccal	0.25 (-0.47 to 0.97)	1.146	0.421
	Palatal vs. mid-alveolar	-2.58 (-3.37 to -1.79)	-10.733	<0.001*
	Buccal vs. mid-alveolar	-2.83 (-3.76 to -1.90)	-10.055	<0.001*
Canine angulation	Palatal vs. buccal	1.48 (-1.47 to 4.43)	1.739	0.221
	Palatal vs. mid-alveolar	1.85 (-1.39 to 5.09)	1.980	0.165
	Buccal vs. mid-alveolar	0.37 (-3.24 to 3.98)	0.339	0.81
Arch-length discrepancy	Palatal vs. buccal	0.11 (-0.53 to 0.75)	0.594	0.673
	Palatal vs. mid-alveolar	0.27 (-0.43 to 0.97)	1.329	0.349
	Buccal vs. mid-alveolar	0.16 (-0.66 to 0.98)	0.679	0.634
Alignment time	Palatal vs. buccal	0.14 (-0.56 to 0.84)	0.679	0.632
	Palatal vs. mid-alveolar	1.34 (0.56 to 2.12)	5.926	<0.001*
	Buccal vs. mid-alveolar	1.20 (0.28 to 2.12)	4.554	0.002*

TABLE 4: Post hoc pairwise comparison.

*P<0.05 was considered statistically significant.

Values represent the mean difference between groups (group 1 minus group 2). The q statistics were derived using the Tukey-Kramer HSD test, which accounts for unequal sample sizes.

HSD: Honestly Significant Difference

All three-dimensional coordinates demonstrated significant positive correlations with alignment time (p<0.001). The strongest correlation was observed for the Y-coordinate (r=0.500), followed by the X-coordinate (r=0.404) and Z-coordinate (r=0.318) (Table *5*). Alignment time was not significantly associated with sex, side of impaction, presence of primary canines, or traction mechanics (all p>0.05) (Table *6*).

Predictors	Pearson's r	p-Value	Effect interpretation
X-coordinate	0.404	<0.001*	Moderate positive
Y-coordinate	0.500	<0.001*	Moderate positive
Z-coordinate	0.318	<0.001*	Small-to-moderate positive

TABLE 5: Correlations between three-dimensional canine position and orthodontic alignment time.

*P<0.05 was considered statistically significant.

Pearson's correlation coefficient (r) was used to assess the relationship between each coordinate (mm) and alignment time (months). Interpretation of r: <0.30 small, 0.30-0.50 moderate, and >0.50 strong (approximate).

Variables	Group	n	Alignment time, mean±SD	Test statistic	p-Value	Effect size
Sex	Female	61	10.20±1.56	t=0.254	0.800	Cohen's d=0.05
	Male	47	10.13±1.38			
Side	Left	58	10.03±1.47	t = -1.084	0.281	Cohen's d=0.21
	Right	50	10.34±1.49			
Primary canine	Absent	70	10.19±1.46	t=0.164	0.871	Cohen's d=0.03
	Present	38	10.14±1.54			
Traction mechanics	Standard	67	10.27±1.32	t=0.855	0.396	Cohen's d=0.18
	Alternative	41	10.01±1.71			

TABLE 6: Comparison of orthodontic alignment time according to demographic, anatomical, and treatment-related characteristics.

*P<0.05 was considered statistically significant.

Alignment time is expressed in months as mean±standard deviation (SD); groups were compared using an independent-samples t-test; Cohen's d=standardized mean difference (0.2 small, 0.5 medium, 0.8 large).

In the multivariable regression analysis, the X-, Y-, and Z-coordinates remained significantly associated with alignment time after adjusting for age, canine angulation, and arch-length discrepancy. The Y-coordinate showed the strongest independent association, with each 1-mm increase associated with an approximately 0.51-month increase in alignment time. The model explained 63.0% of the variance in alignment time (adjusted R^2=0.608; p<0.001) (Table 7).

Predictors	B (unstandardized regression coefficient)	Robust SE	t-value	p-Value	95% CI	β (standardized regression coefficient)
X-coordinate, per mm	0.319	0.062	5.18	<0.001*	0.197-0.442	0.382
Y-coordinate, per mm	0.509	0.057	8.94	<0.001*	0.396-0.622	0.481
Z-coordinate, per mm	0.327	0.055	5.94	<0.001*	0.218-0.436	0.335
Age, per year	0.048	0.023	2.10	0.038*	0.003-0.094	0.155
Canine angulation, in degrees	0.047	0.015	3.11	0.002*	0.017-0.077	0.208
Arch-length discrepancy, per mm	0.292	0.059	4.98	<0.001*	0.176-0.408	0.283

TABLE 7: Multivariable linear regression analysis of factors associated with orthodontic alignment time.

*P<0.05 was considered statistically significant.

Model statistics: R^2=0.630; adjusted R^2=0.608; F(6, 101)=28.66; p<0.001; Cohen's f^2=1.70; maximum VIF=1.07; Durbin-Watson=2.06. The dependent variable was orthodontic alignment time (in months). The multivariable model included transverse coordinate (X), sagittal coordinate (Y), vertical coordinate (Z), age, canine angulation, and arch-length discrepancy. Robust standard errors were used in the regression model.

VIF: variance inflation factor; SE: standard error

Intraexaminer and interexaminer reliability of the three-dimensional CBCT measurements was assessed using intraclass correlation coefficients based on a two-way mixed-effects model for absolute agreement. The results indicate excellent agreement across all three coordinates, with intraexaminer intraclass correlation coefficients (ICCs) ranging from 0.93 to 0.95 and interexaminer ICCs ranging from 0.90 to 0.92 (Table *8*).

Coordinate	Intraexaminer ICC (95% CI)	Interexaminer ICC (95% CI)
X-coordinate (transverse), mm	0.94 (0.87-0.97)	0.91 (0.82-0.96)
Y-coordinate (sagittal), mm	0.93 (0.85-0.97)	0.90 (0.80-0.95)
Z-coordinate (vertical), mm	0.95 (0.89-0.98)	0.92 (0.84-0.96)

TABLE 8: Intraexaminer and interexaminer reliability of three-dimensional CBCT measurements.

ICC: intraclass correlation coefficient; CBCT: cone-beam computed tomography

Discussion

The present study demonstrated that the three-dimensional position of impacted maxillary canines on pretreatment CBCT images was significantly associated with the time required for orthodontic alignment following surgical exposure and traction. All three spatial coordinates were positively correlated with alignment time, with the sagittal Y-coordinate demonstrating the strongest association. This finding suggests that the initial spatial displacement of the impacted canine, rather than its categorical location, is an important determinant of the mechanical difficulty and duration of orthodontic alignment. Previous studies have shown that pretreatment radiographic characteristics, including canine position, distance from the occlusal plane, and sector location, are associated with the duration of orthodontic traction [12-14]. Baccetti et al. reported significant associations between the pretreatment alpha-angle, d-distance, and sector and traction duration [12], whereas Fleming et al. found that the horizontal position of the canine crown was associated with treatment duration [13].

The stronger association observed for the Y-coordinate in the present study may be related to the greater orthodontic displacement required when the canine is positioned farther from its intended position within the dental arch. A displaced canine must follow a longer and potentially more complex eruption path, requiring controlled movement around adjacent roots and through the alveolar process. This interpretation is supported by Yang et al., who found that the distance between the impacted canine and occlusal plane showed the strongest correlation with traction duration [15]. More recently, a three-dimensional CBCT study demonstrated that cusp-tip displacement, including horizontal and labiopalatal displacement, was significantly associated with traction duration and explained a substantial proportion of its variability [16]. These findings support the biological and mechanical rationale for using continuous three-dimensional measurements rather than relying solely on conventional categorical classifications.

Significant differences were also observed in the X-, Y-, and Z-coordinates according to whether the canine was palatal, buccal, or mid-alveolar. The alignment time was shortest for mid-alveolar canines, suggesting that a relatively favorable position within the alveolar process may provide a shorter path to the dental arch. Conversely, palatal and buccal displacement may require greater transverse or vertical correction and consequently longer traction. Recent evidence similarly indicates that palatally positioned canines generally require longer treatment than buccally positioned canines, while canines located more mesially or farther from their intended eruption position tend to require greater treatment time [15,17]. However, the present findings also indicate that anatomical classification alone may not adequately capture treatment complexity because considerable variation can exist within each impaction category.

The absence of significant differences in alignment time according to sex, side of impaction, primary canine status, or traction mechanics indicates that these factors contributed less to treatment duration than the actual three-dimensional position of the impacted canine in this cohort. This is broadly consistent with the study by Baccetti et al., who reported that age, sex, and site of impaction did not significantly influence active traction duration, whereas pre-treatment radiographic characteristics were important determinants [12]. Similarly, Zuccati et al. found no significant correlation between age and the number of visits required to complete canine forced eruption [18]. Nevertheless, another study reported significant effects of sex, bilateral impaction, or specific treatment characteristics, emphasizing that treatment duration is multifactorial and may vary according to population, treatment protocol, and outcome definition [19].

In the multivariate analysis, all three coordinates remained independently associated with alignment time after adjustment for age, canine angulation, and arch-length discrepancy. The Y-coordinate had the largest standardized effect, while canine angulation and arch-length discrepancy were also significantly associated with longer alignment. These findings are clinically plausible because an unfavorable canine inclination may require additional correction before alignment, whereas inadequate arch space can necessitate preparatory orthodontic movement. Importantly, the model explained 63.0% of the variability in alignment time, indicating that three-dimensional canine position combined with selected clinical characteristics provides substantial information regarding treatment duration, although other biological and treatment-related factors remain influential.

An interesting finding was the apparent difference between the overall associations of three-dimensional coordinates with alignment time and the mean values observed across the anatomical impaction groups. Although all three coordinates demonstrated positive correlations with alignment time in the overall study population, mid-alveolar canines exhibited the highest mean sagittal and vertical coordinate values but required the shortest alignment time. Conversely, palatal canines demonstrated the lowest mean transverse coordinate value but required the longest alignment time. These observations suggest that the relationship between the measured spatial coordinates and orthodontic alignment time may be influenced by the anatomical location of the impacted canine. The absolute distances measured from the anatomical reference planes do not necessarily represent the actual orthodontic movement required to bring the canine into the dental arch. In particular, mid-alveolar canines may have a relatively favorable anatomical relationship with the alveolar process, potentially allowing more direct orthodontic movement despite greater measured sagittal and vertical distances. In contrast, palatally positioned canines may require more complex traction mechanics because of their anatomical relationship with the surrounding structures and adjacent teeth. Therefore, the overall positive correlations should be interpreted in the context of impaction location, and coordinate measurements should not be considered independent indicators of treatment complexity without considering the anatomical position of the canine.

Clinically, these findings suggest that pretreatment CBCT assessment can provide useful supplementary information for individualized treatment planning and patient counseling. Rather than simply describing an impacted canine as palatal, buccal, or mid-alveolar, clinicians may benefit from considering its quantitative transverse, sagittal, and vertical displacements. This may facilitate more realistic expectations regarding the duration of orthodontic traction and help identify cases that require more complex mechanics. However, the use of CBCT should be justified by the diagnostic requirements of the individual patient and should not be obtained solely for treatment-time estimation.

This study has several limitations. First, its retrospective, single-center design may limit the generalizability of the findings and introduce selection bias. Although impaction location was compared across groups, it was not included in the multivariable regression model; similarly, the Kau-Pan-Gallerano (KPG)

classification was used to restrict eligibility to easy and moderately difficult cases but was not incorporated as an adjustment variable. Therefore, residual confounding related to anatomical location and impaction severity cannot be excluded. Second, the surgical exposure technique (open or closed eruption) was not recorded in a standardized manner and could not be evaluated as a potential predictor, despite its possible influence on traction duration. Third, although the radiographic examiners and statistician were blinded to the relevant clinical outcome data during their assessments, the treating operators were not blinded to the canine position, which may have influenced treatment decisions and mechanics. In addition, severe adjacent incisor root resorption was excluded when it altered the treatment plan, but the degree of root resorption was not quantitatively assessed or included in the regression model. Finally, the analysis did not account for possible clustering of bilateral impacted canines within the same patient. These limitations should be considered when interpreting the observed associations, and prospective multicenter studies with standardized documentation of surgical technique, case difficulty, and treatment protocols are warranted.

Conclusions

The three-dimensional position of impacted maxillary canines on pretreatment CBCT images was significantly associated with the duration required for orthodontic alignment. Greater measured distances along the transverse, sagittal, and vertical axes were associated with prolonged alignment, with the sagittal coordinate showing the strongest association. These findings suggest that quantitative three-dimensional assessment may provide supplementary information for treatment planning and patient counseling when CBCT is clinically indicated. However, CBCT should not be obtained solely for predicting alignment duration. Prospective studies are warranted to validate these associations and establish clinically applicable individualized estimation models.

Additional Information

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All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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References

1. Manne R, Gandikota C, Juvvadi SR, Rama HR, Anche S: Impacted canines: etiology, diagnosis, and orthodontic management. J Pharm Bioallied Sci. 2012, 4:234-8. 10.4103/0975-7406.100216

2. Bishara SE: Impacted maxillary canines: a review . Am J Orthod Dentofacial Orthop. 1992, 101:159-71. 10.1016/0889-5406(92)70008-X
3. Bedoya MM, Park JH: A review of the diagnosis and management of impacted maxillary canines . J Am Dent Assoc. 2009, 140:1485-93. 10.14219/jada.archive.2009.0099
4. Majumder S, Siddiqui S, Wani MA, Sattar S, Rozy F, Kundal S, Gupta S: Exploring the link between adjacent lateral incisor morphology and unilateral maxillary canine impaction: a cone-beam computed tomography study. Cureus. 2025, 17:10.7759/cureus.76806
5. Güllü YÖ, Özlü FÇ: Prediction of the success of orthodontic treatment of impacted maxillary canines using panoramic radiography parameters: a retrospective cross-sectional study. BMC Oral Health. 2024, 24:10.1186/s12903-024-05343-x
6. Bajjad AA, Ahemad MS, Gupta S, Mehjabeen F, Guin S, Mehra S, Rajesh R: Assessment of clinical validity of KPG index for 3D classification of impacted maxillary canines by cone beam computed tomography in patients. Orthod Craniofac Res. 2024, 27:48-55. 10.1111/ocr.12788
7. Lee JN, Kim HJ, Park HS: The influence of three-dimensional cone beam computed tomography (CBCT) data on decision-making for maxillary impacted canines. Appl Sci (Basel). 2025, 15:10.3390/app152413061
8. Dalessandri D, Migliorati M, Rubiano R, Visconti L, Contardo L, Di Lenarda R, Martin C: Reliability of a novel CBCT-based 3D classification system for maxillary canine impactions in orthodontics: the KPG index. ScientificWorldJournal. 2013, 2013:10.1155/2013/921234
9. Martín DE, English JD, Kau CH, et al.: The KPG index - a novel 3D classification system for maxillary canine impactions. Tex Dent J. 2012, 129:265-74.
10. Faul F, Erdfelder E, Buchner A, Lang AG: Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. Behav Res Methods. 2009, 41:1149-60. 10.3758/BRM.41.4.1149
11. Grisar K, Piccart F, Al-Rimawi AS, Basso I, Politis C, Jacobs R: Three-dimensional position of impacted maxillary canines: prevalence, associated pathology and introduction to a new classification system. Clin Exp Dent Res. 2019, 5:19-25. 10.1002/cre2.151
12. Baccetti T, Crescini A, Nieri M, Rotundo R, Prato GP: Orthodontic treatment of impacted maxillary canines: an appraisal of prognostic factors. Prog Orthod. 2007, 8:6-15.
13. Fleming PS, Scott P, Heidari N, Dibiase AT: Influence of radiographic position of ectopic canines on the duration of orthodontic treatment. Angle Orthod. 2009, 79:442-6. 10.2319/042708-238.1
14. de-la-Rosa-Gay C, Valmaseda-Castellón E, Figueiredo R, Hernández-Mangas A, Camps-Font O: Prediction of traction time for the alignment of impacted maxillary canines. BMC Oral Health. 2025, 26:10.1186/s12903-025-07181-x
15. Yang JS, Cha JY, Lee JY, Choi SH: Radiographical characteristics and traction duration of impacted maxillary canine requiring surgical exposure and orthodontic traction: a cross-sectional study. Sci Rep. 2022, 12:10.1038/s41598-022-23232-7
16. Park YS, Choi EH, Jamal H Alwaznah F, et al.: Is apex position a determining factor in the orthodontic traction duration of unilateral impacted maxillary canines? A cone-beam computed tomography-based 3-dimensional study. Am J Orthod Dentofacial Orthop. 2026, 169:168-76. 10.1016/j.ajodo.2025.09.015
17. Vasović D, Pajević T, Vučić L, Glišić B, Juloski J: Factors influencing treatment duration of impacted maxillary canines. Angle Orthod. 2025, 95:266-73. 10.2319/080824-643.1
18. Zuccati G, Ghobadlu J, Nieri M, Clauser C: Factors associated with the duration of forced eruption of impacted maxillary canines: a retrospective study. Am J Orthod Dentofacial Orthop. 2006, 130:349-56. 10.1016/j.ajodo.2004.12.028
19. Arriola-Guillén LE, Castillo AA, Ruíz-Mora GA, Rodríguez-Cárdenas YA, Silveira HL: Influence of maxillary canine impaction characteristics and factors associated with orthodontic treatment on the duration of active orthodontic traction. Am J Orthod Dentofacial Orthop. 2019, 156:391-400. 10.1016/j.ajodo.2018.10.018