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Original Article

Diagnostic Concordance of Panoramic Radiographs and Cone-Beam Computed Tomography and their Influence on Treatment Decision-Making for Impacted Canines

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Main Points

- Parameters derived from panoramic radiographs were significantly associated with the cone-beam computed tomography (CBCT)-derived KPG index, indicating diagnostic concordance between two-dimensional (2D) and three-dimensional (3D) imaging modalities for evaluating the severity of maxillary canine impaction.
- Higher severity values in both 2D and 3D imaging parameters were strongly associated with the clinical decision to surgically extract impacted maxillary canines rather than attempt orthodontic eruption.
- An α angle of ≥46.1° and a d distance of ≥12.3 mm were identified as 2D screening thresholds associated with the decision for surgical extraction of impacted maxillary canines.
- Given the comparable diagnostic performance of 2D and 3D parameters, panoramic radiographs may serve as effective first-line screening tools, with CBCT reserved for precise surgical planning in complex cases that exceed the identified 2D thresholds, thereby optimizing the balance between diagnostic benefit and patient safety.

ABSTRACT

Objective: To evaluate the diagnostic concordance between panoramic radiographs and cone-beam computed tomography (CBCT) and to determine their comparative diagnostic performance in relation to the treatment decision of impacted maxillary canines.

Methods: Radiographic records of 51 impacted maxillary canines in 44 patients (37 unilateral and 7 bilateral cases) were analyzed. Panoramic radiographic evaluations included sector classification, the α angle, and the d distance. The KPG index was used in CBCT assessments to determine impaction severity.

Results: All imaging parameters showed high intra- and interrater reliability (intraclass correlation coefficients ≥0.927; κ≥0.658; p<0.001). Significant associations were found between the panoramic radiographic parameters (sector, α angle, and d distance) and the CBCT-based KPG index, and between sector classification and buccopalatal position (p<0.05). Regarding treatment decisions, higher parameter values were significantly associated with the choice of surgical extraction (p<0.05). Receiver operating characteristic analysis demonstrated acceptable to excellent discriminatory ability for panoramic radiograph-based and CBCT-based parameters [area under the curve (AUC): 0.715 to 0.843], with no differences among the AUC values (p>0.05). A d distance ≥12.3 mm and an α angle ≥46.1° were identified as thresholds associated with the decision for surgical extraction.

Conclusion: Panoramic radiographic parameters demonstrated diagnostic concordance with CBCT, and their performance was comparable to CBCT-based assessment for treatment decisions. The identified 2D thresholds may serve as an effective first-line screening tool for identifying complex cases likely to require surgical extraction, signaling a level of severity at which the superior anatomical detail of CBCT is warranted for precise surgical planning.

Keywords: Cuspid, impacted tooth, panoramic radiography, cone-beam computed tomography

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INTRODUCTION

Maxillary canines play a vital role in establishing functional occlusion, supporting midfacial esthetics, and maintaining the continuity of the dental arch.[1] However, maxillary canines commonly experience disturbances during their eruption because they originate deep within the maxilla, lateral to the piriform fossa. They follow the longest and most complex path to reach their final position in the dental arch, increasing the risk of ectopic eruption and impaction.[2,3] The prevalence of impacted maxillary canines has been reported to range from 1% to 3% in the general population.[3,4] If left untreated, impacted canines may lead to various complications, including displacement or resorption of adjacent teeth, alveolar bone loss, cyst formation, infection, and gingival recession.[3] Therefore, early and accurate diagnosis is essential for effective intervention and optimal treatment outcomes.[5]

The management of impacted canines requires an interdisciplinary approach, with multiple factors influencing the final orthodontic and periodontal outcomes.[6] Pretreatment radiographic features observed on panoramic radiographs, such as the inclination of the impacted canine (α angle), vertical distance between the cusp tip of the impacted canine and the occlusal plane (d distance), and position of the cusp tip relative to adjacent teeth (sector classification),[7] have been studied as predictors of both the duration and outcomes of orthodontic and interceptive treatment for impacted canines.[8,9] However, the introduction of cone-beam computed tomography (CBCT) has greatly improved the diagnostic accuracy of impacted maxillary canines by providing three-dimensional (3D) visualization, that enables a more comprehensive assessment of impaction severity, buccopalatal position, depth, surrounding bone coverage, and root resorption of adjacent teeth.[1,10-12] The KPG index, a grid-based scoring system that assesses cusp and root tip positions along the x, y, and z axes, quantifies the difficulty of impaction, thereby supporting clinicians in formulating effective treatment strategies.[13]

Although CBCT has been shown to enhance diagnostic confidence[14] and influence treatment decisions regarding impacted canines,[15] other studies have reported no significant differences between two-dimensional (2D) and 3D modalities.[4,14] This conflicting evidence complicates the benefit-to-risk assessment during treatment planning, since concerns regarding higher radiation exposure due to the use of CBCT persist.[1]

Previous research on impacted maxillary canines has primarily focused on how imaging modality affects localization accuracy, diagnostic confidence, pre-surgical planning, and duration of treatment.[1,16-19] Although a recent study derived panoramic radiograph-based cut-off values for predicting orthodontic treatment success or failure after active traction had been attempted,[20] to the best of our knowledge, no previous study has evaluated panoramic radiograph parameters and the CBCT-derived KPG index within the same quantitative diagnostic-accuracy framework in relation to the treatment decision of orthodontic eruption versus surgical extraction. Consequently, evidence-based 2D screening thresholds specifically designed to predict the need for surgical extraction remain unavailable, leaving a critical gap in the ability to objectively justify CBCT use under the As Low As Reasonably Achievable (ALARA) principle. Furthermore, most previous studies have relied solely on orthodontic examiners,[16,21] potentially overlooking the interdisciplinary nature of these cases where oral surgeons play a key diagnostic role. Therefore, the aim of this study was to evaluate the diagnostic concordance between panoramic radiographs and the CBCT-derived parameters, assess inter-rater reliability between an orthodontist and an oral surgeon, and determine the comparative diagnostic performance of parameters derived from panoramic radiographs and CBCT for treatment decision-making, thereby providing quantitative evidence to guide the selective use of CBCT.

METHODS

This retrospective study was approved by the İzmir Tınaztepe University Non-Interventional Clinical Trials Ethics Committee (approval number: MUKCE2025/05, date: 20.02.2025) and was conducted in accordance with the ethical standards of the Declaration of Helsinki. Written informed consent was obtained from patients who agreed to the use of their radiographs in this study. Sample size calculation (version 3.1.9.4, G*Power; Kiel University, Kiel, Germany) was performed using a significance level of 5% and a statistical power of 80% to detect a Pearson correlation coefficient of r=0.4.[16] Based on this calculation, a minimum of 46 impacted maxillary canines was required. Radiographic records (panoramic radiographs and CBCT) of 44 patients with maxillary canine impactions (37 unilateral and 7 bilateral) were selected from the hospital archive, starting with the most recent and continuing backward until the required sample size was achieved.

All radiographic images were obtained from the Oral and Maxillofacial Radiology Department of İzmir Tınaztepe University. Panoramic radiographs were acquired using the MyRay Hyperion X5 system (Cefla, Imola, Italy) with exposure parameters of 76 kV, 7 mA, and an exposure time of 14.2 seconds. Cone-beam computed tomography images were obtained using the MyRay Hyperion X9 Pro 3D system (Cefla, Imola, Italy) at 90 kV, 8 mA, and an exposure time of 26.4 seconds. Inclusion was restricted to radiographs characterized by the clear delineation of key anatomical landmarks, including the cusp tip and apex of the impacted canine and the roots of adjacent teeth and by the absence of artifacts or positioning errors. Radiographs exhibiting anatomical superimposition or technical flaws that compromised landmark identification were excluded. Furthermore, patients presenting with cleft lip or palate, craniofacial syndromes, metabolic bone diseases, dental anomalies (e.g., agenesis, peg-shaped laterals, supernumerary teeth), or prior or ongoing orthodontic treatment were excluded.

The severity of maxillary canine impaction on panoramic radiographs was assessed using three parameters: the mesiodistal position of the cusp tip relative to adjacent teeth (sector classification), the angle between the long axis of the impacted canine and the midline constructed from the anterior nasal spine to the intermaxillary suture (α-angle), and the vertical distance from the cusp tip to the occlusal plane (d-distance) (Figure 1).[7] Higher sector classifications, α angles, and d distances were associated with greater severity of impaction. Additionally, the complexity of the impacted canines was categorized as low or high based on the criteria described by Arriola-Guillén et al.[22] Canines located in sectors 1, 2, or 3 with an α angle ≤40° were considered low-complexity, whereas those in sector 3 with an α angle >40°, or in sectors 4 or 5, were considered high-complexity.

The KPG index was used to determine the severity of maxillary canine impaction on CBCT scans.[13] This method involves a grid-based scoring system applied to three axes (x, y, and z) to evaluate the severity of impaction. In each plane, the positions of the cusp tip and root tip of the impacted canine were assigned scores ranging from 0 to 5, and the total KPG score was calculated by summing the cusp and root tip scores across all three planes (Figure 2). Based on the final score, the level of treatment difficulty was categorized as easy (0-9), moderate (10-14), difficult (15-19), or extremely difficult (≥20). While the classification by Arriola-Guillén et al.[22] utilizes the term "complexity" and the KPG index[13] utilizes "treatment difficulty", both systems were interpreted in this study as identifying the severity of impaction and the associated orthodontic challenge. The buccopalatal position of the impacted canine within the dental arch (buccal, mid-alveolus, or palatal) was determined using the occlusal reference line along the z-axis of the KPG index.

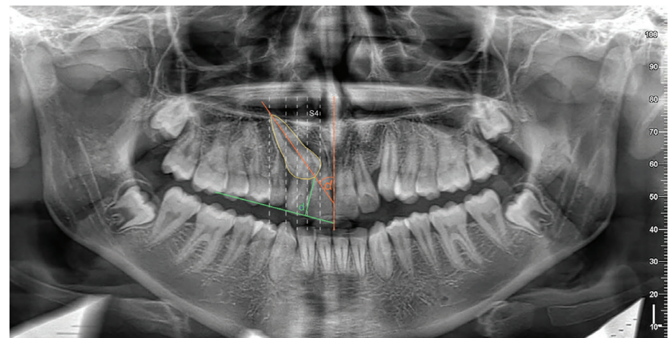

Figure 1. Parameters used during evaluation with panoramic radiographs. White lines: sector classification (S4) of the cusp tip of the impacted maxillary canine; orange lines: α angle between the long axis of the impacted canine and the midline; green lines: d distance from the cusp tip to the occlusal plane.

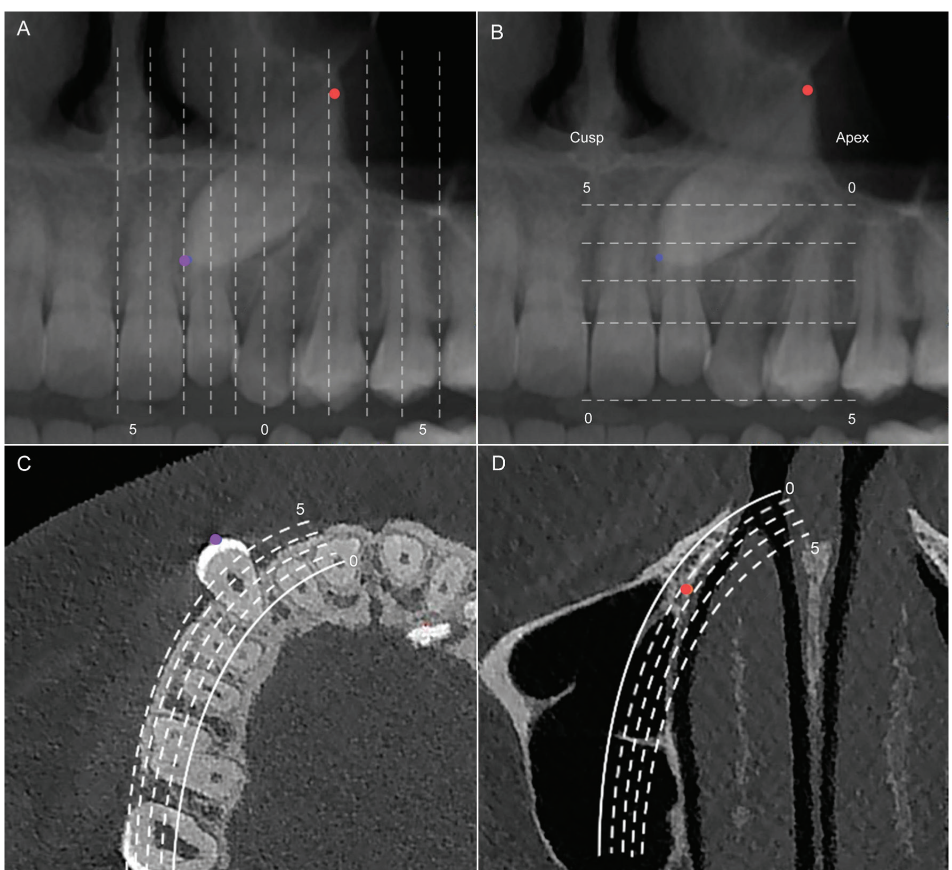

Figure 2. KPG index. The purple dot represents the cusp tip, and the orange dot represents the apex of the impacted maxillary canine. A) Mesiodistal dimension (x-axis); B) Vertical dimension (y-axis); C) Deviation of the cusp tip from the occlusal arch (z-axis); and D) Deviation of the apex from the occlusal arch (z-axis).

In addition to the radiographic evaluation, patient records were retrospectively reviewed to classify cases into two groups based on the final treatment decision: orthodontic eruption or surgical extraction of the impacted canines. Receiver operating characteristic (ROC) curve analysis was subsequently performed to evaluate the discriminatory ability of parameters derived from panoramic radiographs and CBCT in differentiating between these treatment groups. The area under the curve (AUC) was calculated to assess overall discriminatory ability, and optimal cut-off points were determined by identifying the point on the ROC curve that maximized the sum of sensitivity and specificity.[23] Area under the curve values were interpreted as follows: ≤0.5 indicated no discrimination; 0.5-0.7, poor discrimination; 0.7-0.8, acceptable discrimination; 0.8-0.9, excellent discrimination; and >0.9, outstanding discrimination.[24]

All measurements on panoramic radiographs and relevant CBCT slices were performed using ImageJ software (version 1.54, Java 1.8.0_345, 64-bit; U.S. National Institutes of Health, Bethesda, MD, USA). Prior to the study, an orthodontist (G.A.S.) and an oral surgeon (M.B.E.) calibrated their measurement techniques using 10 randomly selected records. Both examiners then independently evaluated the full dataset under blinded conditions to determine interrater reliability. Intrarater reliability was assessed by the orthodontist, who repeated the measurements one month later. Only the orthodontist's initial measurements were used for subsequent statistical analyses.

Statistical Analysis

Descriptive statistics (mean, standard deviation, median, minimum, and maximum) were used to summarize all study variables. Intra- and interrater reliabilities were assessed using intraclass correlation coefficients (ICC) for continuous variables and weighted kappa or Cohen's kappa for categorical variables.

Because 7 of the 44 patients contributed bilateral impacted canines, generalized estimating equations (GEE) analyses were used to account for the clustering of canines within patients. Generalized estimating equations was applied to compare α-angle and d-distance across KPG index categories and to identify associations between radiographic parameters (complexity group, α angle, d distance, KPG score) and treatment decision. Pairwise comparisons between KPG index categories were performed with Bonferroni adjustment for multiple comparisons. For the associations between complexity group and KPG index category and between buccopalatal position and sector classification, Fisher's exact tests with Monte Carlo simulation were used because GEE modelling for these outcomes was not feasible due to quasi-complete separation in the former (all easy cases were low-complexity and all extremely difficult cases were high-complexity) and sparse cell counts in the latter. Receiver operating characteristic curve analysis was performed to evaluate the discriminatory ability of each parameter to differentiate canines managed with orthodontic eruption from those managed with surgical extraction. Pairwise comparisons of AUC values were performed using the DeLong test.

All statistical tests were two-sided, and statistical significance was set at $p<0.05$. All analyses were performed using SPSS software (version 26.0; IBM Corp., Armonk, NY, USA), with the exception of the AUC confidence intervals and pairwise DeLong comparisons, which were calculated in R (version 4.6.0; R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Descriptive statistics for the panoramic radiographic and CBCT-derived parameters evaluated in this study, are presented in Table 1. Continuous parameters demonstrated almost perfect inter- and intrarater reliability (ICC ≥0.927), while categorical parameters exhibited substantial to almost perfect agreement (κ≥0.658) ($p<0.001$) (Table 2).

Table 1. Descriptive statistics of qualitative and quantitative variables

Qualitative variables	
Gender	
Female, n (%)	30 (68.2)
Male, n (%)	14 (31.8)
Sector	
S1, n (%)	2 (3.9)
S2, n (%)	9 (17.6)
S3, n (%)	8 (15.7)
S4, n (%)	18 (35.3)
S5, n (%)	14 (27.5)
Complexity group	
Low-complexity, n (%)	17 (33.3)
High-complexity, n (%)	34 (66.7)
Buccopalatal position	
Buccal, n (%)	13 (25.5)
Mid-alveolus, n (%)	10 (19.6)
Palatal, n (%)	28 (54.9)
Treatment decision	
Orthodontic eruption, n (%)	35 (68.6)
Surgical extraction, n (%)	16 (31.4)
Quantitative variables	
Age (years)	
Mean ± SD	20.13±10.17
Median	16.66
Min-max	10.51-59.62
α angle (°)	
Mean ± SD	39.15±18.11
Median	38.29
Min-max	2.85-83.61

Table 1. Continued	
Qualitative variables	
d distance (mm)	
Mean ± SD	12.48±4.66
Median	11.95
Min-max	1.20-24.54
KPG score	
Mean ± SD	14.12±2.65
Median	14.00
Min-max	7-20

SD, standard deviation; Min-max, minimum-maximum.

The distributions of complexity group, α angle, and d distance across the four KPG index categories are presented in Table 3. A significant association was observed between the KPG index and the panoramic radiographic complexity group (p=0.026). All canines in the easy category were classified as low-complexity, whereas all canines in the extremely difficult category were classified as high-complexity. Generalized estimating equations analyses revealed significant differences in both the α angle and the d distance across the KPG index categories (p<0.001). The mean α angle increased progressively from 11.92±12.20° in the easy category to 67.41±10.59° in the extremely difficult category (p<0.001). Similarly, the mean d distance increased from 10.12±7.05 mm to 22.71±2.58 mm across the same range (p<0.001).

Table 2. Intrarater and interrater reliability of parameters derived from panoramic radiographs and CBCT

	Reliability coefficient	95% CI Lower; upper	p-value
Panoramic radiograph parameters			
Sector			
Intrarater	0.985‡	0.955; 1.000	<0.001*
Interrater	0.940‡	0.881; 0.998	<0.001*
α angle			
Intrarater	0.995†	0.991; 0.997	<0.001*
Interrater	0.995†	0.991; 0.997	<0.001*
d distance			
Intrarater	0.927†	0.874; 0.958	<0.001*
Interrater	0.931†	0.881; 0.960	<0.001*
CBCT			
x-axis: cusp			
Intrarater	0.987‡	0.963; 1.000	<0.001*
Interrater	0.949‡	0.900; 0.999	<0.001*
x-axis: apex			
Intrarater	0.981‡	0.945; 1.000	<0.001*
Interrater	0.705‡	0.580; 0.830	<0.001*
y-axis: cusp			
Intrarater	1.000‡	1.000; 1.000	<0.001*
Interrater	0.935‡	0.863; 1.000	<0.001*
y-axis: apex			
Intrarater	1.000‡	1.000; 1.000	<0.001*
Interrater	0.658‡	0.634; 1.000	<0.001*
z-axis: cusp			
Intrarater	0.941‡	0.884; 0.999	<0.001*
Interrater	0.886‡	0.812; 0.961	<0.001*
z-axis: apex			
Intrarater	0.975‡	0.940; 1.000	<0.001*
Interrater	0.863‡	0.779; 0.947	<0.001*
KPG score			
Intrarater	0.911‡	0.834; 0.987	<0.001*
Interrater	0.773‡	0.693; 0.852	<0.001*

Table 2. Continued			
	Reliability coefficient	95% CI Lower; upper	p-value
Buccopalatal position			
Intrarater	1.000	1.000; 1.000	<0.001*
Interrater	1.000	1.000; 1.000	<0.001*

*Significant at p<0.001.
‡Weighted Kappa: used for ordinal parameters (sector; x, y and z axes; KPG score); †ICC: used for continuous parameters (d distance and α angle); Cohen's Kappa: used for nominal parameters (buccopalatal position).
CI, confidence interval; CBCT, cone-beam computed tomography; ICC, intraclass correlation coefficient.

Table 3. Comparison of complexity group, α angle, and d distance according to the KPG index

Panoramic radiograph parameters	KPG index				p-value
	Easy (n=3)	Moderate (n=26)	Difficult (n=20)	Extremely difficult (n=2)	
Complexity group, n (%)†					0.026*
Low-complexity	3 (100.0)	10 (38.5)	4 (20.0)	0 (0.0)	
High-complexity	0 (0.0)	16 (61.5)	16 (80.0)	2 (100.0)	
α angle (°)‡					<0.001***
Mean ± SD	11.92±12.20	35.30±14.32	45.42±17.58	67.41±10.59	
Median	7.12	34.96	41.73	67.41	
Min-max	6.79-25.79	9.83-57.51	18.91-83.61	59.92-74.91	
d distance (mm)‡					<0.001***
Mean ± SD	10.12±7.05	11.09±4.02	13.63±3.80	22.71±2.58	
Median	8.46	10.26	13.32	22.71	
Min-max	4.04-17.86	6.78-19.44	7.04-24.42	20.88-24.54	

*Significant at p<0.05.***Significant at p<0.001.
†Fisher's exact test ($FET_{complexity}$=7.590); ‡Generalized estimating equations analysis. p-values represent the overall test of differences across the four KPG index categories.
SD, standard deviation; Min-max, minimum-maximum.

Pairwise comparisons of the α angle and the d distance among KPG index categories are presented in Table 4. For the α angle, significant differences were observed in all comparisons involving the easy or extremely difficult categories. The easy category showed significantly lower α angle values than the moderate (mean difference =-23.76°, p=0.026), difficult (-33.79°, p<0.001), and extremely difficult (-55.45°, p<0.001) categories, while the extremely difficult category showed significantly higher values than the Moderate (31.69°, p<0.001) and difficult (21.66°, p=0.005) categories. The moderate and difficult categories did not differ significantly (mean difference =-10.03°, p>0.05). For the d distance, the extremely difficult category showed significantly greater values than all other KPG categories (p≤0.004), and the difficult category showed significantly greater values than the moderate category (mean difference =-3.08 mm, p=0.047). The easy category was not statistically distinguishable from the moderate or difficult categories (p>0.05), which likely reflects the limited sample size of the easy category (n=3).

A significant association was also found between sector classification and buccopalatal position (p<0.001). Buccal impactions were predominantly located in sectors 2 and 3; palatal impactions were predominantly located in sectors 4 and 5; mid-alveolus impactions were more widely distributed across the sectors.

Of the 51 canines, 35 (68.6%) were managed by orthodontic eruption and 16 (31.4%) underwent surgical extraction. All four radiographic parameters were found to be significantly associated with the treatment decision (p<0.05) (Table 5). High-complexity canines had greater odds of surgical extraction compared to low-complexity canines (OR=6.68; 95% CI, 1.10-40.55; p=0.039), although the wide confidence interval likely reflects the small number of extraction events in the low-complexity category (n=2 of 17) and should therefore be interpreted with caution. Higher α angles, greater d distances, and higher KPG scores were also significantly associated with increased odds of surgical extraction. Each 1° increase in the α angle was associated with a 9% increase in the odds of extraction [odds ratio (OR)=1.09, 95% CI 1.04-1.14, p=0.001], each 1-mm increase in the d distance was associated with a 43% increase (OR=1.43, 95% CI 1.18-1.73, p<0.001), and each 1-point increase in the KPG score was associated with a 71% increase (OR=1.71, 95% CI 1.21-2.41, p=0.002).

Table 4. Pairwise comparisons of α angle and d distance across KPG index categories

Pairwise comparison	α angle (°)			d distance (mm)		
	Mean difference	95% CI lower; upper	p-value	Mean difference	95% CI lower; upper	p-value
Easy vs. moderate	-23.76	-45.69; -1.83	0.026*	-1.37	-11.07; 8.32	1.000
Easy vs. difficult	-33.79	-55.41; -12.16	<0.001*	-4.45	-14.07; 5.16	1.000
Easy vs. extremely difficult	-55.45	-81.15; -29.75	<0.001*	-12.94	-22.94; −2.93	0.004*
Moderate vs. difficult	-10.03	-22.99; 2.94	0.248	-3.08	-6.14; −0.02	0.047*
Moderate vs. extremely difficult	-31.69	-47.34; -16.04	<0.001*	-11.57	-15.46; −7.67	<0.001*
Difficult vs. extremely difficult	-21.66	-38.89; -4.43	0.005*	-8.48	-12.65; −4.31	<0.001*

*Significant at Bonferroni-adjusted p<0.05. Generalized estimating equations analysis.
CI, confidence interval.

Table 5. Generalized estimating equations analysis of complexity group, α angle, d distance and KPG score in relation to treatment decision

	Orthodontic eruption	Surgical extraction	OR	95% CI lower; upper	p-value
Complexity group, n (%)†			6.68	1.10; 40.55	0.039*
Low-complexity	15 (88.2)	2 (11.8)			
High-complexity	20 (58.8)	14 (41.2)			
α angle (°)‡			1.09	1.04; 1.14	0.001***
Mean ± SD	32.96±15.94	52.70±15.26			
d distance (mm)‡			1.43	1.18; 1.73	<0.001***
Mean ± SD	10.78±3.85	16.21±4.15			
KPG score‡			1.71	1.21; 2.41	0.002**
Mean ± SD	13.29±2.51	16.00±2.12			

*Significant at p<0.05; **Significant at p<0.01; ***Significant at p≤0.001.
†For complexity group, low-complexity is the reference category.
‡For continuous predictors, the OR represents the change in odds of extraction per one-unit increase (per 1°, 1 mm, and 1 point, respectively).
OR, odds ratio; CI, confidence interval.

The ROC curve analysis demonstrated acceptable-to-excellent discrimination by all four parameters between canines managed with orthodontic eruption and those managed with surgical extraction (Table 6, Figure 3). The d distance had the highest AUC (0.843; 95% CI: 0.721-0.939), followed by the α angle (0.813; 95% CI: 0.677-0.921), the KPG score (0.796; 95% CI: 0.661-0.910), and the sector classification (0.715; 95% CI: 0.559-0.847). Pairwise comparisons revealed no significant differences among the AUC values (p>0.05), indicating comparable discriminatory performance across the evaluated parameters. The optimal cut-off values were ≥4.5 for sector (sensitivity 50.0%, specificity 82.9%), ≥46.1° for α angle (sensitivity 68.8%, specificity 82.9%), ≥12.3 mm for d distance (sensitivity 87.5%, specificity 74.3%), and ≥15.5 for the KPG score (sensitivity 62.5%, specificity 85.7%).

DISCUSSION

To the best of our knowledge, this is the first study to directly compare panoramic radiograph parameters with the CBCT-based KPG index within a single diagnostic-accuracy framework regarding the clinical decision between orthodontic eruption and surgical extraction of impacted maxillary canines. The main finding was that panoramic radiographic parameters showed diagnostic concordance with the KPG index and provided comparable discriminatory ability in guiding this treatment decision. Consistent with previous studies,[7,13] our results suggest that radiographic indicators of impaction severity derived from both panoramic radiographs and CBCT may effectively inform treatment planning.

The management of impacted maxillary canines presents a complex diagnostic and therapeutic challenge for orthodontists. Although panoramic radiographs are the standard for initial radiographic examination, they are inherently limited by image distortion, magnification errors, structural superimposition, and lack of 3D information.[21] In contrast, CBCT offers superior anatomical detail and accuracy, significantly enhancing the localization of impacted canines and the evaluation of adjacent structures, thereby improving diagnostic reliability and treatment planning.[15] However, routine use of CBCT remains debated because its higher radiation dose and increased exposure raise concerns about long-term cancer risk, particularly in radiosensitive groups such as children and female patients.[25] Therefore, while CBCT provides significant clinical advantages, its application should be justified through evidence-based practice, and adherence to the ALARA principle is essential to ensure an optimal balance between diagnostic benefit and patient safety.[1,25]

Several previous studies have compared the diagnostic accuracy of panoramic radiography and CBCT to minimize radiation exposure. These studies suggest that CBCT consistently offers superior diagnostic accuracy for the localization of impacted maxillary canines[10,11,14,19] and highlight the limitations of 2D imaging, particularly in assessing the vertical position of the crown. Salari et al.[18] and Botticelli et al.[12] reported that conventional radiographs often overestimate the vertical position of the cusp tip, whereas CBCT provides a more accurate assessment. In the present study, although the d distance and KPG index represent fundamentally different measurement systems, the d distance increased progressively across the KPG index categories. This finding suggests that despite methodological differences, vertical measurements derived from 2D imaging may provide clinically meaningful insights into the severity of impaction.

The ROC curve analysis was used to evaluate the discriminatory ability of each radiographic parameter in the surgical extraction decision, given its recognition as the method of choice for quantifying the accuracy and discriminative performance of medical diagnostic tests.[26,27] All four evaluated parameters demonstrated good discriminatory ability, with panoramic radiographic and CBCT-based measurements providing comparable diagnostic information for the treatment decision. Among panoramic radiographic variables, an α angle exceeding 46.1° and a d distance of 12.3 mm or greater were identified as radiographic indicators associated with the clinical decision to extract impacted maxillary canines. The angulation threshold is consistent with the findings of Güllü and Çakmak Özlü,[20] who identified a cut-off value of 44.3° for treatment failure, suggesting that angulations above this threshold may significantly hinder eruption. In contrast, the lower threshold of 34.8° reported by Alqerban et al.[27] likely reflects the focus on early prediction of impaction rather than the surgical extraction decision evaluated in the present study. Regarding vertical position, our identified cut-off of 12.3 mm was notably lower than the 22.3 mm threshold reported by Güllü and Çakmak Özlü,[20] likely reflecting differences in clinical endpoints, as in their study the threshold was defined for the failure of active treatment, whereas the present study established a threshold for the initial decision to extract. For the KPG index, the ROC

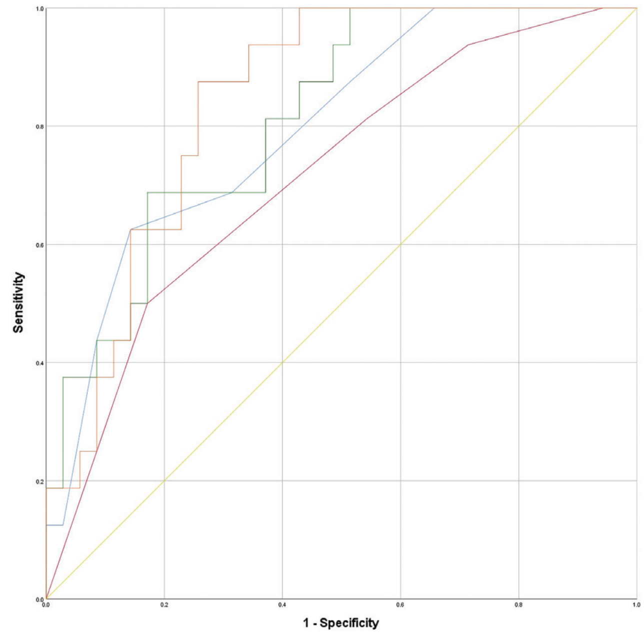

Figure 3. ROC curve of treatment decision. Blue line: KPG score; red line: sector; green line: α angle; orange line: d distance; yellow line: reference.
ROC, receiver operating characteristic.

analysis identified a score of 16 or higher as the threshold associated with the decision to perform surgical extraction, which closely aligns with the transition from "moderate" (10-14) to "difficult" (15-19) complexity in the original classification. Taken together, the comparable diagnostic performance of panoramic radiographs and CBCT-based parameters, combined with the substantially lower radiation exposure associated with panoramic radiographs, suggests that 2D parameters available on initial panoramic radiographs may serve as a useful first-line screening tool to identify complex cases that require the superior anatomical detail of CBCT for precise surgical planning.

Consistent with previous research,[17,21] ta significant association was also observed between sector classification on panoramic radiographs and the buccopalatal position of impacted maxillary canines as determined by CBCT. Buccally impactions were predominantly observed in sectors 2 and 3, whereas palatal impactions were most frequently located in sectors 4 and 5.

Table 6. AUC of parameters derived from panoramic radiographs and CBCT

Variable	AUC 95% CI (lower; upper)	Cut-off value	Prediction criteria	Sensitivity (%)	Specificity (%)
Sector	0.715 0.559; 0.847	4.5	Sector 5 indicates extraction	50.0	82.9
α angle (°)	0.813 0.677; 0.921	46.1	≥46.1° indicates extraction	68.8	82.9
d distance (mm)	0.843 0.721; 0.939	12.3	≥12.3 mm indicates extraction	87.5	74.3
KPG Score	0.796 0.661; 0.910	15.5	≥16 indicates extraction	62.5	85.7

Pairwise comparisons of AUCs were performed using the DeLong test. No statistically significant differences were found between AUC values (all p>0.05).
CBCT, cone-beam computed tomography; AUC, area under the curve; CI, confidence interval.

This distribution pattern suggests that sector classification on panoramic radiographs may offer predictive value for estimating the buccopalatal orientation of impacted canines. However, previous studies have also reported only slight to fair agreement between 2D and 3D imaging in determining the buccopalatal position, with 2D modalities often suggesting a more palatal location; this may lead to inaccurate diagnoses, particularly in cases of mid-alveolar impactions.[12]

High reliability for parameters derived from both panoramic radiographs and CBCT was observed in this study and is consistent with previous research reporting intrarater agreement for key diagnostic features, such as sector location, buccopalatal position, and root resorption, across both imaging modalities.[17,21] Haney et al.[15] reported comparable intrarater agreement but observed slightly better consistency with 2D radiographs, although this difference was not significant. In contrast, Dalessandri et al.[16] found higher intrarater reliability using the KPG index compared to 2D methods, suggesting greater reproducibility with CBCT-based evaluations. Regarding interrater reliability, the present study is consistent with the findings of Ngo et al.[21] and Jung et al.,[17] who reported high agreement for various diagnostic features of impacted canines on both panoramic radiographs and CBCT images. In contrast, Alqerban et al.[5] and Dalessandri et al.[16] reported a higher interrater agreement with CBCT than with conventional 2D imaging. Notably, unlike studies that relied solely on orthodontists,[16,21] the inclusion of different specialists in the present study supports the findings of Wriedt et al.,[4] who found no diagnostic differences between dental specialties.

From a clinical perspective, the findings of this study support a more selective imaging strategy for impacted maxillary canines. While the superior anatomical detail of CBCT is undeniable, its routine use must be carefully balanced against the ALARA principle. This radiation burden is particularly critical in complex cases in which multiple 3D imaging sessions may be required during treatment. To guide selective CBCT referral, the present results establish specific panoramic thresholds to help identify high-complexity cases in which CBCT is most likely to provide critical added value for surgical planning. Finally, including both an orthodontist and an oral surgeon as examiners reflects the interdisciplinary nature of managing these cases and addresses a methodological limitation of previous comparative studies that relied solely on orthodontic raters.

Study Limitations

Several limitations of this study should be considered when interpreting the results. First, this was a single-center retrospective study with a relatively limited sample size, which may affect the generalizability of the results. The limited number of surgical extraction events (n=16) also precluded a multivariable assessment of whether combining radiographic parameters would improve discriminatory performance beyond that of individual parameters. Second, although the present study evaluated the association between radiographic parameters and the implemented treatment modality (surgical extraction versus orthodontic eruption), it did not assess long-term clinical success measures, such as total treatment duration and the incidence of eruption failure necessitating secondary extraction. Another important limitation is that the treatment decision, which is multifactorial and may also be influenced by clinician experience and patient preferences rather than anatomical difficulty alone, was used as an indicator of impaction complexity in this study. Beyond this clinical issue, a methodological limitation is the use of the actual treatment decision as the outcome variable in ROC analysis. Because the clinicians who made the treatment decisions had access to the same radiographic information evaluated in this study, some degree of circularity is unavoidable. Therefore, the discriminatory performance of the radiographic parameters may have been overestimated, and the identified cut-off values should be interpreted as thresholds associated with observed treatment decisions rather than as independently validated predictors of treatment success, eruption failure, or absolute need for extraction. Finally, important clinical variables, including occlusal characteristics, arch length discrepancy, and available space for the impacted canine were not evaluated and therefore could not be incorporated into the analyses, although they may also have influenced treatment decisions.

CONCLUSION

Within the limitations of this retrospective study, parameters derived from panoramic radiographs were significantly associated with the CBCT-derived KPG index and demonstrated diagnostic performance comparable to that of CBCT-based assessment for treatment decisions regarding impacted maxillary canines. Panoramic radiography may serve as an effective, low-radiation, first-line screening tool: specific indicators, such as the d distance or the α angle, can justify the use of CBCT for precise anatomical assessment. This stepwise imaging strategy supports the ALARA principle, ensuring that 3D imaging is reserved for cases where it provides critical added value for surgical planning. Prospective studies with larger sample sizes are needed to validate these thresholds and establish evidence-based imaging guidelines.

Ethics

Ethics Committee Approval: This study was approved by the İzmir Tınaztepe University Non-Interventional Clinical Trials Ethics Committee (approval number: MUKCE2025/05, date: 20.02.2025).

Informed Consent: Written informed consent was obtained from patients who agreed to the use of their radiographs in this study.

Footnotes

Author Contributions: Surgical and Medical Practices - G.A.S.; Concept - M.B.E., M.G.K.; Design - G.A.S.; Data Collection and/or Processing - G.A.S., M.B.E.; Analysis and/or Interpretation - G.A.S.; Literature Search - M.B.E., M.G.K.; Writing - M.B.E., M.G.K.

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