Original Article

The impact of orthodontic traction on outcomes in impacted canine management: a quantitative analysis

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ABSTRACT

Objective: To evaluate the effects of orthodontic traction of impacted maxillary canines on treatment duration, alveolar bone levels, white spot lesions (WSLs), root resorption, and the need for auxiliary appliances.

Materials and Methods: In this retrospective study, 116 patients were divided into two groups: 58 with unilaterally impacted maxillary canines and 58 controls without impaction. All patients received nonextraction treatment using labial fixed appliances. Pretreatment and posttreatment panoramic radiographs, intraoral photographs, and intraoral scans were analyzed. The collected data were used to compare the groups across five clinical parameters. Statistical analyses included the Mann-Whitney *U*-test, Wilcoxon signed-rank test, χ^2 test, and Cochran's Q test, with significance set at $P < .05$.

Results: The impaction group had significantly longer treatment duration (mean = 2.64 ± 0.99 years) than controls (mean = 1.85 ± 0.60 years). Alveolar bone loss was significantly greater in teeth adjacent to the impacted canine and between the impacted and nonimpacted sides within the impaction group ($P < .05$). WSL incidence was higher in the impaction group, especially in posterior teeth ($P = .0034$). Root resorption patterns differed by region: maxillary incisors were more affected in the impaction group, whereas mandibular posterior teeth showed more resorption in controls. The use of auxiliary appliances was significantly greater in the impaction group.

Conclusions: Impacted canine treatment is associated with increased treatment time, greater alveolar bone loss, higher risk of WSLs, and distinct root resorption patterns. These findings highlight the importance of individualized treatment planning, careful biomechanical control, and preventive strategies in managing impacted canines. (*Angle Orthod*. 2025;00:000–000.)

KEY WORDS: Impacted canine; Orthodontic traction; Alveolar bone loss; White spot lesions; Root resorption

INTRODUCTION

Impacted teeth are defined as teeth that fail to erupt 1 year beyond their expected eruption time. Maxillary canines are the most frequently impacted teeth after third molars.[1] The etiology of impacted canines includes abnormal eruption paths, mechanical obstructions, systemic diseases, hereditary factors, and congenital syndromes. Ectopic canines may lead to root resorption in adjacent teeth.[2] Untreated impacted canines may lead to various complications.[3]

The management of impacted canines requires a multidisciplinary approach. Treatment options encompass extraction, preventive therapies, autotransplantation, surgical exposure followed by orthodontic traction, and nonintervention.[1,3] Treatment planning should consider patient age, cooperation, oral hygiene, skeletal variations, and canine position.[4–7]

External apical root resorption is one of the most common iatrogenic effects of orthodontic treatment.[8] Various patient-related and mechanical factors contribute to this risk. Additionally, white spot lesions (WSLs), resulting from enamel demineralization due to plaque retention, are a frequent side effect of fixed

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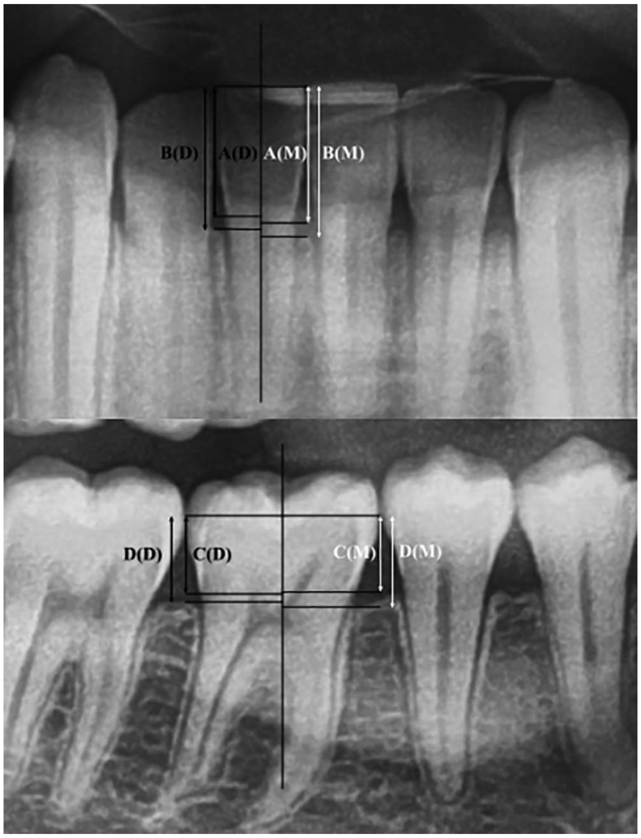

Figure 1. Representative images from panoramic radiographs demonstrating the reference points used to evaluate treatment-related alveolar bone changes. For anterior teeth (incisors and canines): (A) (M/D) Distance from the incisal edge to the cemento-enamel junction (CEJ) on the mesial/distal side. (B) (M/D) Distance from the incisal edge to the alveolar crest on the mesial/distal side. For posterior teeth (premolars and molars): (C) (M/D) Distance from the marginal ridge to the CEJ on the mesial/distal side. (D) (M/D) Distance from the marginal ridge to the alveolar crest on the mesial/distal side. The A/B ratio was calculated for anterior teeth, and the C/D ratio for posterior teeth, both before and after treatment.

appliances.[9,10] Periodontal changes, including gingivitis, gingival hyperplasia, and recession, are also commonly associated with orthodontic therapy.[11] Treatment duration is a significant factor influencing complication risk.[12]

Radiographic imaging is essential for diagnosis and treatment planning. A dental panoramic tomogram (DPT) and cone-beam computed tomography (CBCT) are commonly used modalities. While DPT provides an overall assessment, CBCT offers more precise evaluation of root resorption and alveolar bone status.[13,14]

Orthodontic traction of impacted maxillary canines is a common clinical procedure but carries increased risks, such as root resorption, prolonged treatment time, and greater appliance complexity. In the present study, we aimed at quantitatively assessing the effects of orthodontic traction of impacted canines on treatment outcomes. These findings are expected to support more informed and individualized clinical treatment planning.

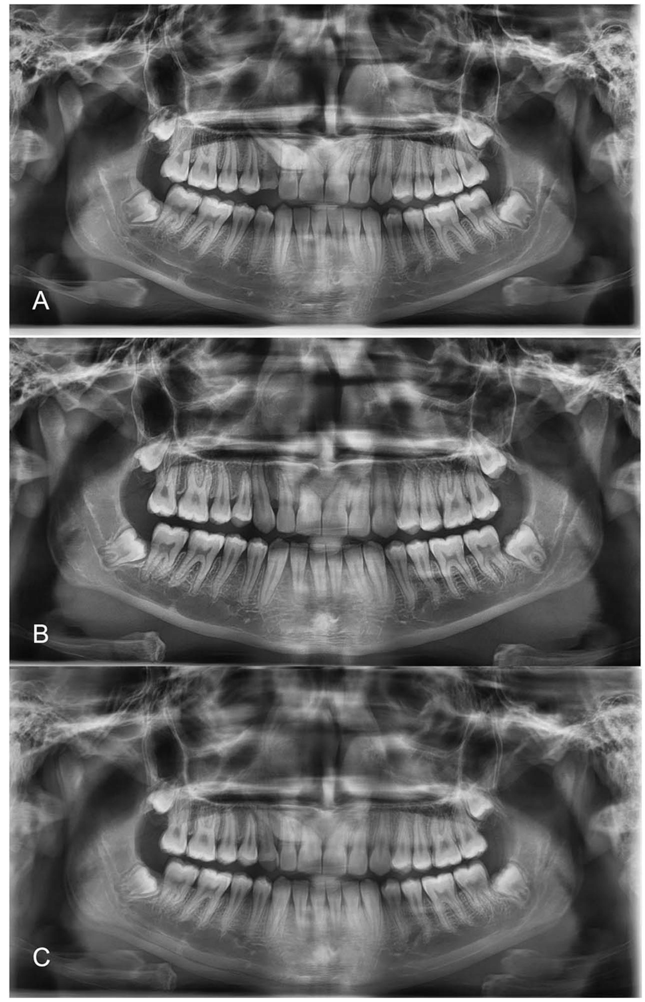

Figure 2. (A) Pretreatment panoramic radiograph. (B) Posttreatment panoramic radiograph. (C) Superimposition of pretreatment and post-treatment panoramic radiographs.

MATERIALS AND METHODS

Ethical approval was obtained from the Clinical Research Ethics Committee of Uşak University Faculty of Medicine (Ref No: 549-549-11). Archival records from the Faculty of Dentistry at Uşak University were reviewed. The impaction group consisted of patients with unilaterally impacted maxillary canines (mean age = 14.5 years), while the control group included matched patients without impaction (mean age = 15.25 years). Initial and final intraoral photographs, panoramic radiographs, and three-dimensional (3D) intraoral scans were analyzed.

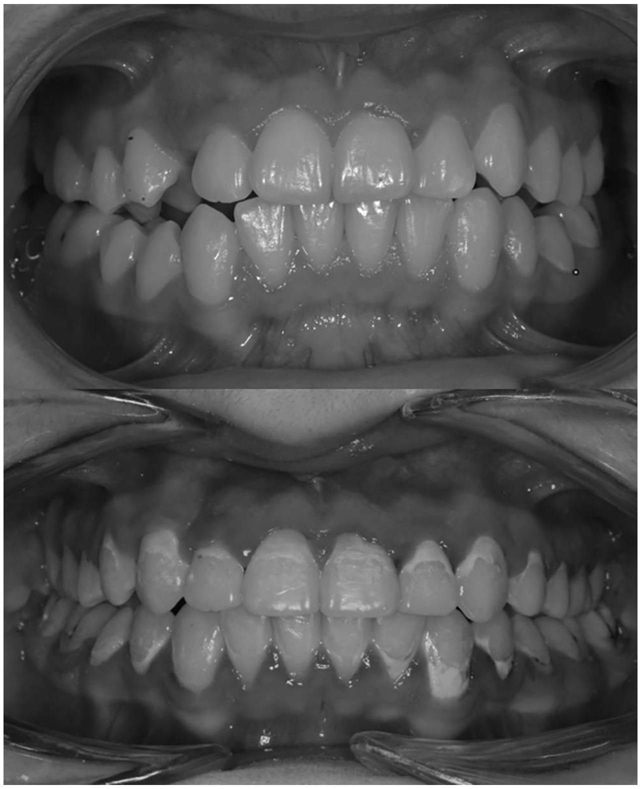

Figure 3. The initial and final intraoral photographs of the patients to be examined were visually evaluated.

Inclusion criteria for the impaction group were as follows:

1. presence of an impacted canine before treatment,
2. no missing or extracted permanent teeth,
3. treatment with fixed orthodontic appliances only,
4. nonextraction orthodontic treatment (excluding deciduous canines), and
5. no periodontal disease or active dental caries at baseline.

The control group included patients without impacted canines but otherwise matched in age, treatment type, and complexity. Baseline treatment difficulty was assessed using the Index of Complexity, Outcome and Need (ICON), confirming no significant difference between groups ($P = .631$).

A total of 58 patients with buccally impacted canines were included. All impacted teeth were treated using the closed eruption technique. Impaction was attributed to ectopic eruption paths or retained primary canines.

Table 1. Group-Specific Data on Treatment Duration[a]

Group	Mean ± SD
Impaction	2.64 ± 0.99
Control	1.85 ± 0.60

[a] Treatment duration data are presented in years.

Table 2. Comparison of Alveolar Bone Level Changes Between the Groups[a]

Measurement Site	Impaction Group (Mean ± SD)	Control Group (Mean ± SD)	*P* Value
11M	0.022 ± 0.051	0.021 ± 0.046	.905
11D	0.023 ± 0.052	0.021 ± 0.046	.839
12M	0.052 ± 0.073	0.030 ± 0.060	.018
12D	0.106 ± 0.123	0.030 ± 0.060	<.001
13M	0.141 ± 0.120	0.010 ± 0.059	<.001
13D	0.140 ± 0.106	0.010 ± 0.059	<.001
14M	0.108 ± 0.149	0.041 ± 0.118	.022
14D	0.058 ± 0.123	0.041 ± 0.118	.529
15M	0.080 ± 0.139	0.049 ± 0.156	.169
15D	0.080 ± 0.139	0.049 ± 0.156	.169
16M	0.046 ± 0.111	0.038 ± 0.117	.929
16D	0.046 ± 0.111	0.038 ± 0.117	.929
17M	0.063 ± 0.167	0.068 ± 0.155	.742
17D	0.063 ± 0.167	0.068 ± 0.155	.742
21M	0.037 ± 0.079	0.019 ± 0.055	.136
21D	0.041 ± 0.082	0.019 ± 0.055	.089
22M	0.063 ± 0.093	0.034 ± 0.058	.110
22D	0.117 ± 0.164	0.034 ± 0.058	.002
23M	0.143 ± 0.116	0.033 ± 0.051	<.001
23D	0.139 ± 0.109	0.033 ± 0.051	<.001
24M	0.115 ± 0.174	0.015 ± 0.127	.006
24D	0.073 ± 0.130	0.015 ± 0.127	.079
25M	0.104 ± 0.164	0.057 ± 0.142	.128
25D	0.100 ± 0.161	0.057 ± 0.142	.159
26M	0.076 ± 0.136	0.045 ± 0.100	.265
26D	0.076 ± 0.136	0.045 ± 0.100	.265
27M	0.119 ± 0.133	0.072 ± 0.144	.093
27D	0.119 ± 0.133	0.072 ± 0.144	.093
31M	0.035 ± 0.053	0.032 ± 0.052	.756
31D	0.035 ± 0.053	0.032 ± 0.052	.756
32M	0.022 ± 0.057	0.026 ± 0.062	.715
32D	0.022 ± 0.057	0.026 ± 0.062	.715
33M	0.038 ± 0.062	0.029 ± 0.055	.286
33D	0.038 ± 0.062	0.029 ± 0.055	.286
34M	0.073 ± 0.123	0.026 ± 0.091	.045*
34D	0.073 ± 0.123	0.026 ± 0.091	.045*
35M	0.076 ± 0.124	0.038 ± 0.101	.076
35D	0.076 ± 0.124	0.038 ± 0.101	.076
36M	0.043 ± 0.124	0.031 ± 0.123	.820
36D	0.043 ± 0.124	0.031 ± 0.123	.820
37M	0.056 ± 0.126	0.069 ± 0.122	.369
37D	0.056 ± 0.126	0.069 ± 0.122	.369
41M	0.039 ± 0.050	0.028 ± 0.065	.166
41D	0.039 ± 0.050	0.028 ± 0.065	.166
42M	0.032 ± 0.077	0.024 ± 0.067	.219
42D	0.032 ± 0.077	0.024 ± 0.067	.219
43M	0.017 ± 0.065	0.025 ± 0.060	.749
43D	0.017 ± 0.065	0.025 ± 0.060	.749
44M	0.052 ± 0.137	0.022 ± 0.138	.044*
44D	0.056 ± 0.140	0.022 ± 0.138	.030*
45M	0.067 ± 0.129	0.045 ± 0.093	.240
45D	0.066 ± 0.130	0.045 ± 0.093	.276
46M	0.073 ± 0.113	0.041 ± 0.108	.077
46D	0.073 ± 0.113	0.041 ± 0.108	.077
47M	0.084 ± 0.143	0.063 ± 0.083	.951
47D	0.084 ± 0.143	0.063 ± 0.083	.951

[a] M indicates mesial; D, distal. Numbers refer to FDI tooth numbering system.

* Statistically significant differences ($P < .05$).

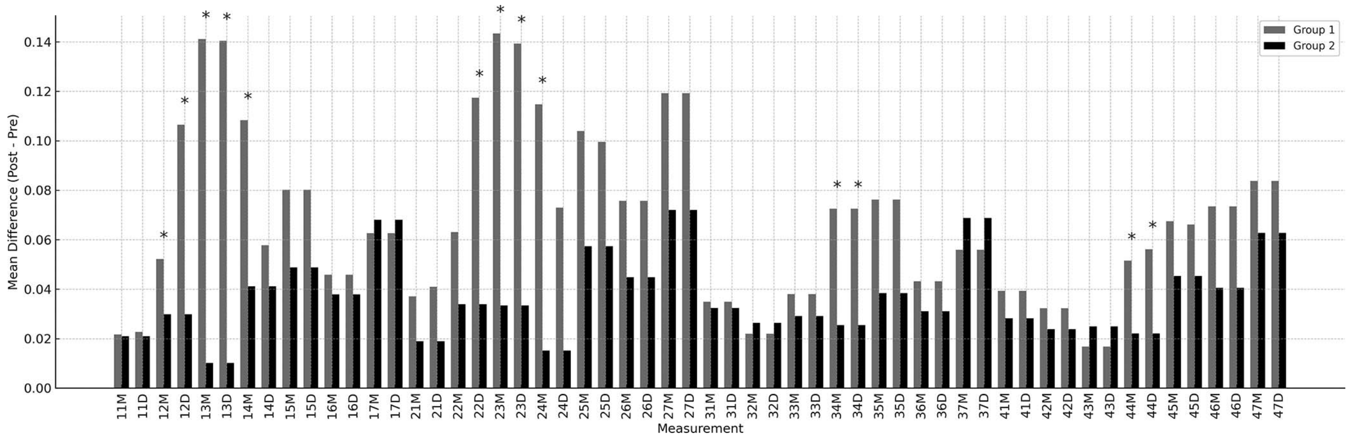

Figure 4. Comparison of mean differences (posttreatment − pretreatment) in alveolar bone level measurements (Group 1 = impaction group; Group 2 = control group). * indicates statistically significant difference between the groups ($P < .05$).

The following clinical parameters were evaluated:

1. treatment duration,
2. alveolar bone levels (pretreatment and posttreatment),
3. root resorption severity at the end of treatment,
4. number of teeth exhibiting WSLs, and
5. number of auxiliary appliances used in addition to routine fixed appliances.

The following methods were used for evaluation.

Treatment Duration

Recorded from patient files, and group means with standard deviations were calculated.

Alveolar Bone Level

For each tooth, the ratio of two different measurements was calculated on panoramic radiographs taken at the start and end of treatment (Figure 1). To improve the accuracy of the measurements, the panoramic radiographs were superimposed using PowerPoint to assess alignment and ensure compatibility prior to measurement (Figure 2). All measurements were conducted using OsiriX Lite software version 14.1.1 (Pixmeo SARL, Bernex, Switzerland). Differences between the final and initial values were calculated and compared between groups.

Root Resorption

Pretreatment and posttreatment panoramic radiographs (OPGs) were evaluated to assess the presence and severity of root resorption using a standardized index.[14] Teeth were scored from 0 to 4, with 0 indicating no resorption and higher scores representing increasing severity. Evaluations were performed independently by both examiners.

WSLs

Initial and final intraoral photographs and 3D intraoral scans were visually examined (Figure 3). Newly developed WSLs were scored as 1; teeth without lesions were scored as 0. Evaluations were conducted on a tooth-by-tooth basis for each patient.

Additional Orthodontic Appliances

The number of auxiliary appliances used in addition to routine fixed orthodontic materials was recorded for each patient, and group means were calculated.

These appliances included:

- transpalatal arches and similar anchorage devices,
- orthodontic miniscrews,
- expanded archwires,
- gold chains,
- distalization appliances, and
- Kilroy springs and other prefabricated eruption springs.

Statistical Analysis

In this study, we planned to investigate the differences and relationships between independent variables in the main hypotheses of the research. Sample size was determined using G*Power software (version 3.1.9.7; Heinrich Heine University, Düsseldorf, Germany) with a power of 0.80, $\alpha = 0.05$, and an effect size of 0.3697 derived from a previous study.[15] This yielded a minimum of 58 patients per group. Initially, 128 patient records were reviewed, but 12 were excluded due to incomplete data. Post hoc power analyses confirmed that the study remained adequately powered ($\geq$80%) for key parameters.

Statistical analyses were performed using IBM SPSS Statistics for Windows, Version 23.0 (IBM Corp., Armonk, NY, USA) and R software, Version 4.4.1 (R Foundation for Statistical Computing, Vienna, Austria). The Shapiro-Wilk and Kolmogorov-Smirnov tests assessed the normality of continuous variables. Normally distributed

Table 3. Comparison of Alveolar Bone Level Changes Between the Impacted and Nonimpacted Sides in the Impaction Group

Measurement Site	Impacted Side (Mean ± SD)	Nonimpacted Side (Mean ± SD)	*P* Value
Central Incisor (M)	0.032 ± 0.078	0.027 ± 0.054	.508
Central Incisor (D)	0.036 ± 0.082	0.027 ± 0.054	.780
Lateral Incisor (M)	0.072 ± 0.092	0.043 ± 0.072	.018*
Lateral Incisor (D)	0.148 ± 0.168	0.076 ± 0.106	.012*
Canine (M)	0.168 ± 0.120	0.116 ± 0.109	.007*
Canine (D)	0.160 ± 0.101	0.119 ± 0.110	.016*
1st Premolar (M)	0.137 ± 0.182	0.086 ± 0.134	.153
1st Premolar (D)	0.065 ± 0.134	0.066 ± 0.119	.897
2nd Premolar (M)	0.115 ± 0.165	0.066 ± 0.131	.122
2nd Premolar (D)	0.111 ± 0.163	0.066 ± 0.131	.151
1st Molar (M)	0.055 ± 0.107	0.062 ± 0.145	.877
1st Molar (D)	0.055 ± 0.107	0.062 ± 0.145	.877
2nd Molar (M)	0.087 ± 0.177	0.087 ± 0.145	.737
2nd Molar (D)	0.087 ± 0.177	0.087 ± 0.145	.737

* Statistically significant differences ($P < .05$).

variables were analyzed with the independent samples *t*-test, while the Mann-Whitney *U*-test was applied to nonnormally distributed data. Paired comparisons (impacted vs nonimpacted side) were assessed using the Wilcoxon signed-rank test.

Categorical variables were compared using the χ^2 test, Yates' correction, or Fisher's exact test as appropriate. Cochran's Q test with Bonferroni correction was used to evaluate within-groups differences in WSL distribution. Root resorption severity was analyzed using the Mann-Whitney *U*-test and χ^2 test by tooth group.

Quantitative data are reported as mean ± SD or median (min–max), and categorical data as frequency (percentage). Statistical significance was set at $P < .05$.

RESULTS

Treatment Duration

The mean treatment duration was 2.64 ± 0.99 years in the impaction group and 1.85 ± 0.60 years in the controls, indicating a significantly longer treatment time in the impacted canine group (Table 1).

Alveolar Bone Level Changes

Measurements were labeled based on tooth number and site (M, mesial; D, distal). Method error was evaluated for selected posterior teeth (16M, 26M, 36M, and 46M) using Dahlberg's formula and Pearson correlation. All teeth showed low measurement error (≤0.095), indicating high reliability. Although Pearson correlation coefficients ranged from moderate to low (r = 0.281–0.537), all were statistically significant ($P < .01$), suggesting consistent measurement despite biological variability over time.

Statistically significant changes in alveolar bone level between the initial and final records were observed at 12M, 12D, 13M, 13D, 14M, 22D, 23M, 23D, 24M, 34M, 34D, 44M, and 44D (Table 2, Figure 4). The impaction group generally showed greater changes in bone level, whereas higher values in controls were observed at sites such as 17M, 17D, 37M, 37D, 43M, and 43D.

Within the impaction group, the Wilcoxon signed-rank test revealed that alveolar bone loss was significantly greater in specific regions on the impacted side than the nonimpacted side (Table 3, Figure 5).

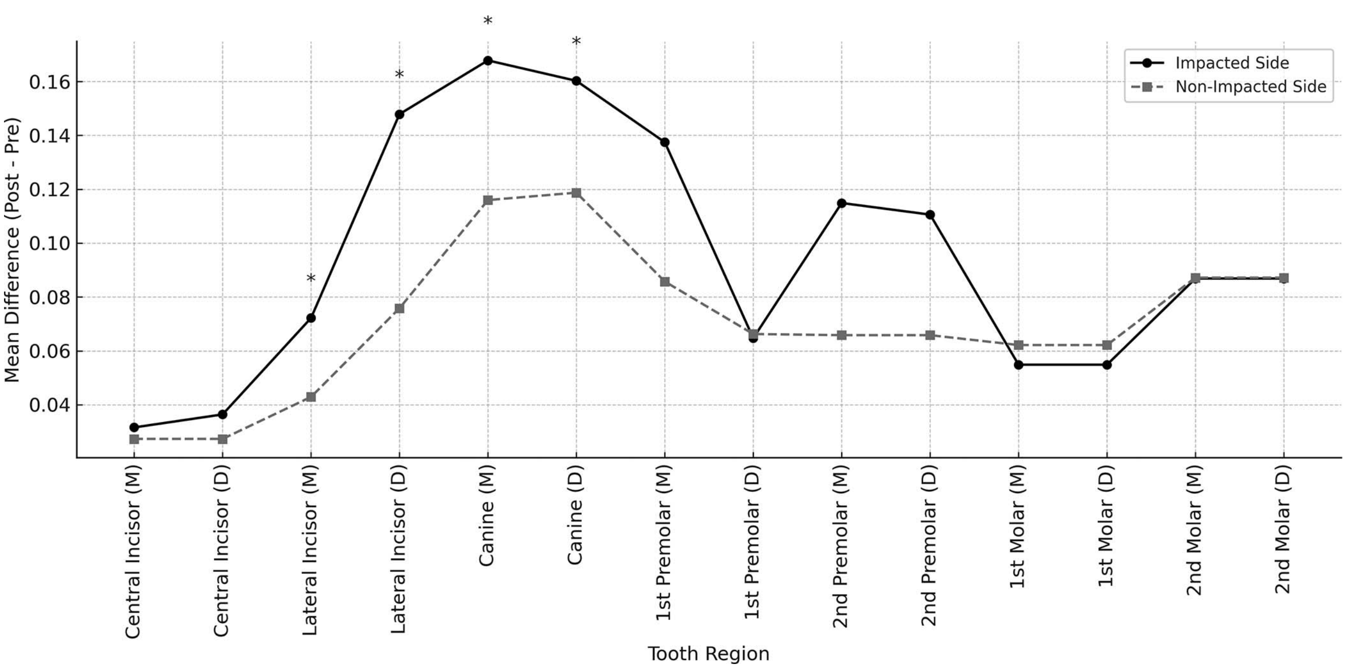

Figure 5. Comparison of alveolar bone level changes between the impacted and nonimpacted sides in patients with impacted maxillary canines (Group 1 = impaction group; Group 2 = control group). * indicates statistically significant difference between the groups ($P < .05$).

Table 4. Comparison of the Number of Newly Formed WSLs at the Beginning and End of Treatment of Teeth According to Groups[a]

Tooth Number	Impaction Group	Control Group	Total	Test Statistic	*P* Value
11					
WSL(−)	46 (79.3)	49 (84.5)	95 (81.9)	0.233	.630[b]
WSL(+)	12 (20.7) ABC[c]	9 (15.5) ABC	21 (18.1) BCDE		
12					
WSL(−)	43 (74.1)	43 (74.1)	86 (74.1)	0.000	1.000[b]
WSL(+)	15 (25.9) C	15 (25.9) BC	30 (25.9) E		
13					
WSL(−)	44 (75.9)	49 (84.5)	93 (80.2)	0.868	.352[b]
WSL(+)	14 (24.1) BC	9 (15.5) ABC	23 (19.8) CDE		
14					
WSL(−)	46 (79.3)	50 (86.2)	96 (82.8)	0.544	.461[b]
WSL(+)	12 (20.7) ABC	8 (13.8) ABC	20 (17.2) ABCDE		
15					
WSL(−)	47 (81)	50 (86.2)	97 (83.6)	0.252	.616[b]
WSL(+)	11 (19) ABC	8 (13.8) ABC	19 (16.4) ABCDE		
16					
WSL(−)	48 (82.8)	51 (87.9)	99 (85.3)	0.276	.600[b]
WSL(+)	10 (17.2) ABC	7 (12.1) ABC	17 (14.7) ABCDE		
17					
WSL(−)	48 (82.8)	55 (94.8)	103 (88.8)	3.119	.077[b]
WSL(+)	10 (17.2) ABC	3 (5.2) A	13 (11.2) ABC		
21					
WSL(−)	46 (79.3)	49 (84.5)	95 (81.9)	0.233	.630[b]
WSL(+)	12 (20.7) ABC	9 (15.5) ABC	21 (18.1) BCDE		
22					
WSL(−)	47 (81)	42 (72.4)	89 (76.7)	0.772	.379[b]
WSL(+)	11 (19) ABC	16 (27.6) C	27 (23.3) DE		
23					
WSL(−)	47 (81)	46 (79.3)	93 (80.2)	0.000	1.000[b]
WSL(+)	11 (19) ABC	12 (20.7) ABC	23 (19.8) CDE		
24					
WSL(−)	48 (82.8)	50 (86.2)	98 (84.5)	0.066	.798[b]
WSL(+)	10 (17.2) ABC	8 (13.8) ABC	18 (15.5) ABCDE		
25					
WSL(−)	49 (84.5)	50 (86.2)	99 (85.3)	0.000	1.000[b]
WSL(+)	9 (15.5) ABC	8 (13.8) ABC	17 (14.7) ABCDE		
26					
WSL(−)	46 (79.3)	49 (84.5)	95 (81.9)	0.233	.630[b]
WSL(+)	12 (20.7) ABC	9 (15.5) ABC	21 (18.1) BCDE		
27					
WSL(−)	49 (84.5)	55 (94.8)	104 (89.7)	2.324	.127[b]
WSL(+)	9 (15.5) ABC	3 (5.2) A	12 (10.3) ABC		
31					
WSL(−)	54 (93.1)	55 (94.8)	109 (94)	–	1.000[d]
WSL(+)	4 (6.9) A	3 (5.2) A	7 (6) A		
32					
WSL(−)	53 (91.4)	54 (93.1)	107 (92.2)	–	1.000[d]
WSL(+)	5 (8.6) AB	4 (6.9) A	9 (7.8) AB		
33					
WSL(−)	47 (81)	52 (89.7)	99 (85.3)	1.103	.294[b]
WSL(+)	11 (19) ABC	6 (10.3) ABC	17 (14.7) ABCDE		
34					
WSL(−)	48 (82.8)	51 (87.9)	99 (85.3)	0.276	.600[b]
WSL(+)	10 (17.2) ABC	7 (12.1) ABC	17 (14.7) ABCDE		
35					
WSL(−)	49 (84.5)	50 (86.2)	99 (85.3)	0.000	1.000[b]
WSL(+)	9 (15.5) ABC	8 (13.8) ABC	17 (14.7) ABCDE		
36					
WSL(−)	46 (79.3)	43 (74.1)	89 (76.7)	0.193	.660[b]
WSL(+)	12 (20.7) ABC	15 (25.9) BC	27 (23.3) DE		

Table 4. Continued

Tooth Number	Impaction Group	Control Group	Total	Test Statistic	*P* Value
37					
WSL(−)	49 (84.5)	53 (91.4)	102 (87.9)	0.731	.254[b]
WSL(+)	9 (15.5) ABC	5 (8.6) AB	14 (12.1) ABCD		
41					
WSL(−)	54 (93.1)	55 (94.8)	109 (94)	–	1.000[d]
WSL(+)	4 (6.9) A	3 (5.2) A	7 (6) A		
42					
WSL(−)	53 (91.4)	54 (93.1)	107 (92.2)	–	1.000[d]
WSL(+)	5 (8.6) AB	4 (6.9) A	9 (7.8) AB		
43					
WSL(−)	45 (77.6)	52 (89.7)	97 (83.6)	2.266	.132[b]
WSL(+)	13 (22.4) ABC	6 (10.3) ABC	19 (16.4) ABCDE		
44					
WSL(−)	46 (79.3)	51 (87.9)	97 (83.6)	1.007	.316[b]
WSL(+)	12 (20.7) ABC	7 (12.1) ABC	19 (16.4) ABCDE		
45					
WSL(−)	48 (82.8)	50 (86.2)	98 (84.5)	0.066	.798[b]
WSL(+)	10 (17.2) ABC	8 (13.8) ABC	18 (15.5) ABCDE		
46					
WSL(−)	47 (81)	50 (86.2)	97 (83.6)	0.252	.616[b]
WSL(+)	11 (19) ABC	8 (13.8) ABC	19 (16.4) ABCDE		
47					
WSL(−)	49 (84.5)	53 (91.4)	102 (87.9)	0.731	.393[b]
WSL(+)	9 (15.5) ABC	5 (8.6) AB	14 (12.1) ABCD		
Test statistic	68.079	93.822	134.182		
P	$<$.001[e]	$<$.001[e]	$<$.001[e]		

[a] WSL(+) indicates white spot lesion present; WSL(−), white spot lesion absent. Data are No. (%).
[b] Yates correction.
[c] No difference between tooth numbers with the same letter within each group and regardless of group.
[d] Fisher's exact test.
[e] Cochran's Q test.

White Spot Lesions

Statistical data are presented in Table 4. In both groups, as well as when the groups were combined, the distribution of WSLs among different teeth showed statistically significant differences ($P < .001$, Table 4). Multiple comparisons are indicated by lettering within the table.

When each tooth was compared individually between groups, no statistically significant differences in the occurrence of WSLs were observed ($P > .05$). However, when evaluated collectively using Cochran's Q test, a significant difference between the groups was found ($P < .001$).

Subgroup analysis based on tooth regions (Table 5) revealed a statistically significant difference among posterior teeth ($P = .0034$), while differences in canines approached statistical significance ($P = .0934$).

The incidence of WSLs was lowest in the mandibular incisors (teeth 31, 32, 41, and 42), with rates around 6–8%. Higher WSL rates, ranging from 20–25%, were observed in teeth such as 12, 22, and 36.

Table 5. Subgroup Analysis Based on Tooth Regions

Region	χ^2	Degrees of Freedom	*P* Value
Incisors	0.13	1	.72128
Canines	2.81	1	.09339
Posteriors	8.58	1	.00340*

* Statistically significant differences ($P < .05$).

Root Resorption

The Mann-Whitney *U*-test results comparing root resorption scores between groups are presented in Table 6. Statistically significant differences were found in teeth 31, 34, 36, 45, 46, and 47 ($P < .05$).

The overall distribution of root resorption severity by group is shown in Table 7. Intergroup differences were statistically significant according to the χ^2 test ($P < .001$, Table 8).

When categorized by tooth type (Table 9), significant differences were observed among incisors, canines, and molars ($P < .05$), whereas no significant difference was found among premolars.

The distribution of root resorption levels across different tooth groups is also illustrated in Figure 6.

Table 6. Comparison of Scores of Teeth With Root Resorption Between Groups

Tooth Number	Impaction Group (Mean ± SD)	Control Group (Mean ± SD)	U[a]	P Value
11	1 ± 1.026	0.724 ± 0.914	1439	.143
12	0.983 ± 1.132	0.81 ± 1.017	1545.5	.408
13	0.431 ± 0819	0.241 ± 0.572	1542	.274
14	0.224 ± 0.563	0.19 ± 0.545	1628	.619
15	0.138 ± 0.476	0.241 ± 0.709	1595.5	.383
16	0.19 ± 0.687	0.052 ± 0.223	1592	.284
17	0.034 ± 0.184	0.086 ± 0.339	1623	.396
21	1.069 ± 1.09	0.793 ± 1.005	1444	.154
22	0.948 ± 1.099	0.69 ± 0.922	1475	.206
23	0.397 ± 0.771	0.259 ± 0.609	1558.5	.334
24	0.224 ± 0.563	0.276 ± 0.72	1673.5	.941
25	0.19 ± 0.576	0.259 ± 0.715	1647	.74
26	0.103 ± 0.552	0.052 ± 0.223	1680.5	.983
27	0.034 ± 0.263	0.086 ± 0.339	1596.5	.18
31	0.155 ± 0.489	0.414 ± 0.795	1442.5	.044*
32	0.224 ± 0.563	0.397 ± 0.748	1524.5	.211
33	0.172 ± 0.596	0.172 ± 0.464	1607	.449
34	0.034 ± 0.263	0.155 ± 0.451	1510.5	.031*
35	0.121 ± 0.564	0.19 ± 0.512	1543.5	.132
36	0.017 ± 0.131	0.172 ± 0.464	1478	.015*
37	0.034 ± 0.263	0.103 ± 0.36	1568	.101
41	0.172 ± 0.5	0.414 ± 0.795	1467	.077
42	0.241 ± 0.601	0.397 ± 0.748	1531.5	.232
43	0.172 ± 0.534	0.172 ± 0.464	1634	.639
44	0.069 ± 0.368	0.138 ± 0.395	1543	.098
45	0.017 ± 0.131	0.19 ± 0.476	1449	.008*
46	0.017 ± 0.131	0.138 ± 0.395	1507.5	.028*
47	0 ± 0	0.069 ± 0.256	1566	.043*

[a] U indicates Mann-Whitney U-test.
* Statistically significant differences ($P < .05$).

Additional Orthodontic Appliances

The number of auxiliary orthodontic appliances used during treatment was recorded for each patient, and group means were calculated. The mean number of appliances was 1.87 in the impaction group and 0.86 in controls.

DISCUSSION

In this study, we evaluated orthodontic treatment outcomes in patients with and without impacted maxillary canines based on five clinical parameters: treatment duration, alveolar bone level changes, the incidence of WSLs, root resorption severity, and the use of auxiliary appliances.

Table 7. Overall Distribution of Root Resorption Severity by Group

	Impaction Group, No. (%)	Control Group, No. (%)
0: No resorption	1380 (84.98%)	1332 (82.02%)
1: Irregular root contour	94 (5.79%)	143 (8.81%)
2: Less than 2 mm resorption	116 (7.14%)	135 (8.31%)
3: Less than one-third root resorption	32 (1.97%)	12 (0.74%)
4: More than one-third root resorption	2 (0.12%)	2 (0.12%)

Table 8. Distribution of Root Resorption Severity Between Groups

Statistic	Value
χ^2	21.51
Degrees of freedom	4
P value[a]	.00025

[a] $P < .001$.

Treatment duration is known to vary depending on several factors, including case complexity, appliance type, and patient compliance. In this study, the impaction group exhibited a significantly longer mean treatment time (2.64 ± 0.99 years) than controls (1.85 ± 0.60 years), which agreed with previous findings, demonstrating prolonged treatment in cases involving canine traction.[15–17] This likely reflects the additional clinical challenges posed by surgical exposure and guided eruption.

Alveolar bone level changes were assessed using a normalized ratio based on reference landmarks. Although different reference points were used for anterior (incisal edge) and posterior (marginal ridge) teeth, the calculated ratio was normalized to the cementoenamel junction, which enabled comparable assessment of alveolar bone levels across various tooth regions. This approach allowed for consistent evaluation of bone level changes despite anatomical variability. In the literature, it is generally suggested that orthodontic forces alone do not cause attachment loss,[18] but authors of studies have reported conflicting findings in cases with impacted canines.[19,20] To isolate the influence of impaction, patient characteristics such as age, sex, and periodontal health were matched across groups.

Significant alveolar bone loss was observed in teeth adjacent to the impacted canine, supporting the hypothesis that mechanical stress, prolonged force application, and surgical procedures contributed to localized bone remodeling. The Wilcoxon test further confirmed that the impacted side exhibited significantly more bone loss than the nonimpacted side.

The incidence of WSLs was significantly higher in the impaction group, in line with studies in which prolonged treatment time and complex biomechanics

Table 9. Root Resorption Categorized by Tooth Regions

Teeth	χ^2	Degrees of Freedom	P Value
Incisors	12.16	4	.01623*
Canines	8.58	3	.03545*
Premolars	9.20	4	.05632
Molars	14.00	4	.00730*

* Statistically significant differences ($P < .05$).

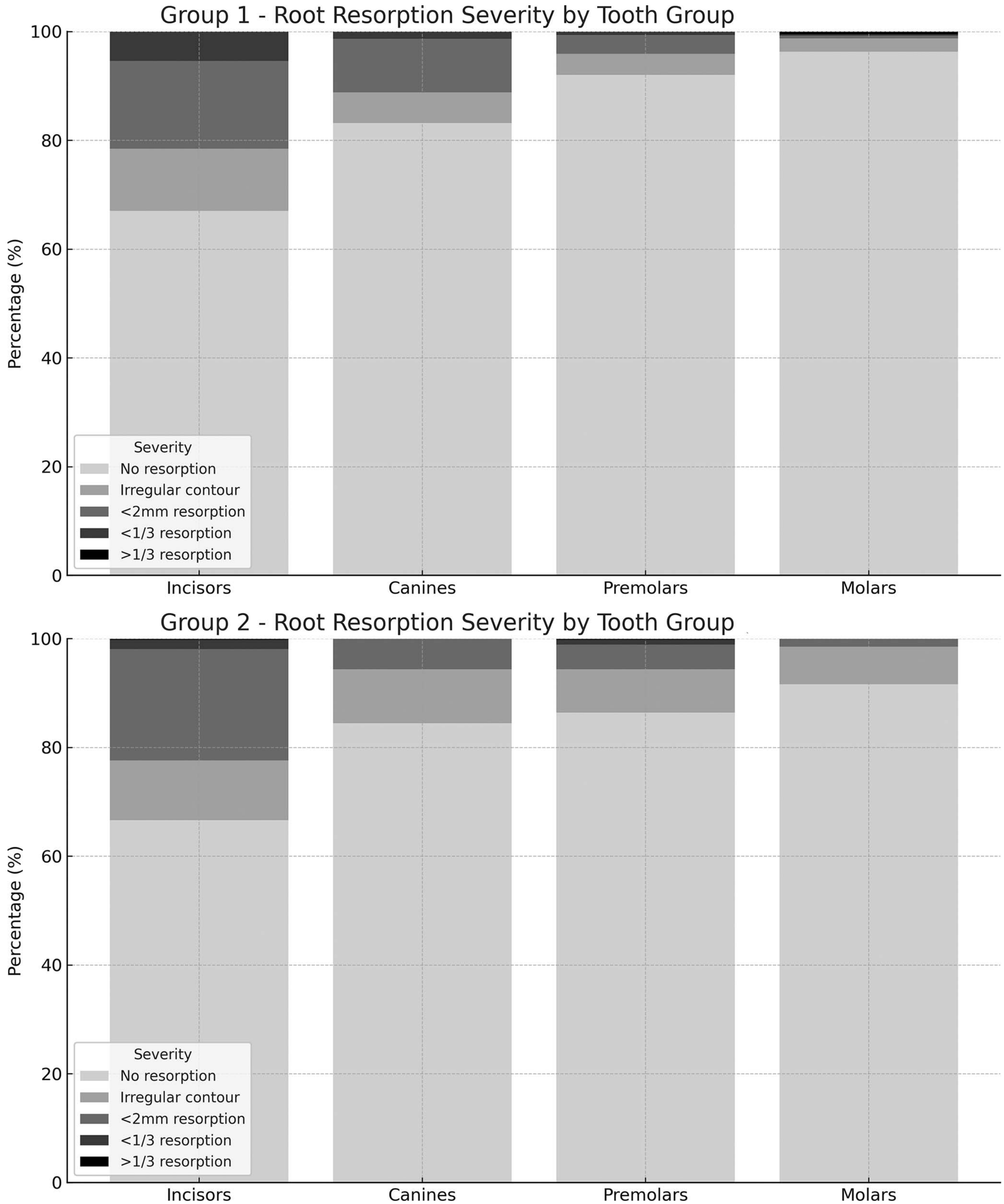

Figure 6. Comparison of root resorption scores between the impacted (Group 1) and control (Group 2) groups for each individual tooth.

were identified as risk factors.[9] The greater need for auxiliary appliances as well as transient difficulties in maintaining oral hygiene following surgical exposure may explain the increased occurrence of WSLs in this group. Although individual intergroup comparisons by tooth were not statistically significant, collective evaluation revealed a significant difference in overall WSL distribution, particularly in posterior teeth.

Root resorption analysis revealed a region-specific pattern. Greater resorption was observed in mandibular teeth (31, 34, 36, 45, 46, and 47), with more resorption in the control group. Among these, tooth 45 demonstrated the greatest significance ($P = .008$). Conversely, the maxillary anterior region showed the highest root resorption scores in the impaction group. These findings suggest that root resorption may be influenced more by biomechanics and anatomical constraints than by the presence of impaction alone. This was consistent with previous studies in which authors have indicated that impacted canines themselves do not directly increase the risk of incisor root resorption.[21,22]

The need for auxiliary appliances was noticeably greater in the impaction group (1.85) than the control group (0.86). Differences in the need for auxiliary appliances and treatment duration suggested greater treatment difficulty in patients with impacted canines, potentially increasing treatment costs and the financial burden on the orthodontist.

A limitation of the present study was the use of two-dimensional panoramic radiographs for the assessment of alveolar bone levels and root resorption, as these images are prone to distortion. To minimize the impact of such distortion on longitudinal data, radiographs taken at the beginning and end of treatment were superimposed, and only those demonstrating good alignment were included in the analysis. In addition, the use of panoramic radiographs enabled the inclusion of a larger sample size and ensured consistency in data collection. In contrast, assessment of WSLs was performed using 3D intraoral scans and clinical photographs, which provided more accurate and detailed information.

In summary, impacted maxillary canines present significant clinical challenges. The associated increase in treatment time, enamel demineralization, alveolar bone changes, and root resorption highlights the need for early diagnosis, careful planning, and vigilant monitoring. Use of 3D imaging, individualized biomechanical protocols, and economic impact assessments should be considered essential components of future orthodontic strategies.

CONCLUSIONS

- The eruption of impacted maxillary canines significantly prolongs treatment duration and increases the need for auxiliary orthodontic appliances, thereby raising treatment complexity and overall cost.
- A notable effect was also observed on the alveolar bone level, particularly in teeth adjacent to the impacted canine, highlighting the biological impact of traction mechanics and prolonged force application.
- Patients with impacted canines also demonstrated a higher incidence of enamel demineralization (WSLs), underlining the importance of oral hygiene maintenance throughout the traction process.
- Root resorption severity did not differ markedly from that observed in nonimpacted cases, indicating that impaction alone may not constitute a primary risk factor.
- These findings highlight the need for early diagnosis, careful biomechanical control, and preventive strategies to ensure favorable outcomes and realistic treatment expectations in patients requiring orthodontic traction of impacted canines.

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