Changes in alveolar bone morphology after traction of buccally vs palatally unilateral maxillary impacted canines: A cone-beam computed tomography study

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Introduction: The objective of this study was to evaluate the 3-dimensional changes in alveolar bone morphology after traction of buccally vs palatally unilateral maxillary impacted canines (MIC). **Methods:** Following a split-mouth model, 27 cone-beam computed tomography images of unilaterally MIC (14 palatally and 13 buccally) and 27 contralateral unimpacted controls were obtained before and after traction using nickel-titanium closed-coil springs and a rigid anchorage appliance. Alveolar bone height and width were measured in the axial, coronal, and sagittal slides by 3 calibrated orthodontists, taking into account the impaction characteristics. A *t* test was used to compare the 2 groups, and a paired *t* test was applied for intragroup comparisons (both sides). A multiple linear regression model was used to evaluate the influence of the predictor variables on alveolar bone dimensional changes. **Results:** The alveolar height showed a significantly greater decrease in palatally MIC (2.09 to 2.79 mm) than buccally MIC (0.28 to 0.57 mm) ($P < 0.05$) for all surfaces. However, the alveolar width increased similarly in both groups up to 1.36 mm. In general, the affected side had a more significant height loss and greater increases in alveolar width than the nonaffected side. Regression analysis indicated that buccally MIC and age decreased alveolar changes, whereas female sex increased alveolar changes ($P < 0.05$). **Conclusions:** MIC traction with nickel-titanium closed-coil springs and heavy anchorage induces significant 3-dimensional changes in alveolar bone characterized by alveolar bone height decreases and cervical alveolar bone width increases. The height decrease is greater in palatally than in buccally MIC. (Am J Orthod Dentofacial Orthop 2021;159:258-70)

Orthodontic-surgical traction of maxillary impacted canines (MIC) is a complex treatment and may have consequences on the alveolar bone and roots of the involved teeth. The evaluation of alveolar bone changes after traction of impacted teeth helps to explain the therapeutic limits of the orthodontic dental movement considering the concepts of movement "with the bone," "within the bone," and "through the bone."[1,2]

The extrusive traction forces have an action/reaction effect that acts on the enamel-cement complex of dental roots and leads to important changes in the alveolar bone, including bone loss, dehiscence or cortical fenestrations, and gingival recession. These changes can be observed in both the impacted canine and adjacent teeth.[3,4] The buccolingual, vertical, and anteroposterior position, associated with the severity of the MIC, may increase the treatment time, its complexity, and the periodontal sequelae of the traction.[5]

Changes in the movement pathway may be different in palatal vs buccal traction of MIC. Periodontal damage has been shown to be more severe in palatally displaced

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canines and is usually associated with more aggressive surgical procedures, exposing the root at the cementoenamel junction level. In contrast, Parkin et al[6] demonstrated that the traction of palatally displaced canines generates an irrelevant clinically periodontal affection, whereas buccal traction has been reported to represent a periodontal challenge that reduces the level of the attached gingiva and the width of the alveolar and cortical bone.[7]

Most studies concerning bone changes have been performed using 2-dimensional (2D) intraoral x-ray periapical and panoramic images. These images have limitations, particularly in the anterior region, because of midsagittal over-projection.[8,9] Cone-beam computed tomography (CBCT) technology overcomes these limitations, allowing the accurate quantitative and qualitative evaluation of changes in bone height, alveolar width, and cortical thickness in complex situations.[10,11] However, no studies have compared the effects of both types of MIC traction on alveolar bone 3-dimensionally with CBCT.

Different alternatives have been described for MIC traction, including the use of metallic chains and ligatures, elastomeric chains, bent loops, and modified hooks.[12-15] To protect soft tissues and adjacent teeth, the use of rigid customized palatal anchorage and traction with nickel-titanium closed-coil springs (Ni-TiCCS) has been proposed as a treatment alternative. Thus, MIC traction can be controlled in the orthogonal x-, y-, and z-axes.[16-18]

Some studies have evaluated the alveolar bone changes associated with the traction of unilateral MIC using 3-dimensional (3D) images, without contrasting the location from which the MIC was tractioned.[8,9,11,19-23] In addition, a comparison of alveolar bone changes after traction of buccally vs palatally unilateral MIC is required, which would be useful to provide important information to clinicians for treatment planning and prognosis. Therefore, the purpose of the present study was to compare the dimensional changes in alveolar bone after traction of buccally vs palatally unilateral MIC and to compare the changes between impacted and nonimpacted contralateral canines on CBCT images.

MATERIAL AND METHODS

This retrospective, longitudinal, split-mouth model study was approved by the Ethics in Research Committee of the Universidad Científica del Sur, Lima, Perú (Approval no. 00008). CBCT images of 27 patients (15 women and 12 men aged between 13 and 39 years) with unilateral MIC were obtained before (T0) and after (T1) canine traction. Two groups were defined regarding the type of impaction, with 14 MIC located as palatal and 13 as buccal. In addition, the nonaffected side was evaluated as a control. The CBCT scans were selected from a population of patients with a MIC diagnosis and treated by the same orthodontist (G.A.R.M).

The sample size was calculated considering 80% study power with a significance level of 0.05 (95% confidence level) to obtain a significant difference between groups of 2 mm (buccally MIC = 2.5 mm vs palatally MIC = 0.5 mm) on alveolar buccal height using a standard deviation of 2 mm (buccally MIC) vs 1.5 mm (palatally MIC), which was obtained in a previous pilot study and whose data were included in the final study. A minimum sample size of 13 was determined with the use of OpenEpi software (http://openepi.com/SampleSize/SSMean.htm).

The inclusion criteria consisted of patients of both sexes, older than the age of 12 years, with unilateral MIC, either buccal or palatal, treated with the same orthosurgical traction technique. The exclusion criteria were subjects with syndromes or craniofacial deformities, endoperiodontal lesions, previous orthodontic treatment, history of maxillary surgery or dentoalveolar trauma in the maxillary anterior teeth.

Some demographic data, MIC characteristics (eg, alpha angle, sector and height of impaction), and basic 2D diagnostic data were obtained from the clinical and radiographic registers.[23] CBCT images were obtained at (T0) and (T1), defining T1 as the moment when the MIC reached the occlusal plane and traction was ended.

The measurements obtained from the CBCT images were performed by 3 trained and calibrated orthodontists (G.A.R.M, L.E.A.G, and Y.A.R.C). The intra- and interobserver agreement in location and sector of MIC was evaluated with a kappa coefficient achieving values >0.9. To evaluate the intraobserver reliability regarding the height and width change measurements, the same examiner (G.A.R.M) re-evaluated the 30% of the sample, randomly selected, after a 30-day interval. The data were analyzed with the intraclass correlation coefficient, which also provided values >0.9. In addition, the random error, estimated by the Dahlberg formula, was <1 mm.[24]

The location of each unilateral MIC was defined as buccal or palatal following clinical criteria and CBCT axial section evaluations.[25-27] The clinical criteria were (1) prominence of the MIC over the mucoperiosteum; (2) in the axial view, canine appearance over the buccal or palatal cortical region; (3) MIC crown positioned over the buccal or palatal region of the lateral incisor root; and (4) surgical access according to the surgeon.

CBCT scans of all patients were obtained with PaX-Uni 3D equipment (Vatech, Hwaseong, South Korea) set at 89 kVp; 4.7 mA; 0.125-mm voxel size; scan time, 15 seconds (mean), and field of view of 8 × 8 cm^2. Digital Imaging and Communications in Medicine images were analyzed with 3D software (version 11.8; Dolphin Imaging and Management Solutions, Chatsworth, Calif) using multiplanar and 3D reconstructions. The panoramic images derived from CBCT were used to determine the impaction sector according to Ericson and Kurol.[28] Five sectors were considered. Sector 1 was the cusp tip of the MIC located between the mesial aspect of the first premolar to the distal aspect of the lateral incisor. Sector 2 was the cusp tip of the MIC located between the distal aspect of the lateral incisor and the long axis of the lateral incisor. Sector 3 was the cusp tip of the MIC located between the long axis of the lateral incisor and the mesial aspect of the lateral incisor. Sector 4 was the cusp tip of the MIC located between the mesial aspect of the lateral incisor and the long axis of the central incisor. Sector 5 was the cusp tip of the MIC located between the long axis of the central incisor and the interincisor midline. The impaction alpha angle was defined as the angle between the long axis of the MIC and the interincisal midline, and the canine height was measured as the perpendicular distance from the cusp tip of the MIC to the incisal plane (Fig 1).[29-31]

Sagittal, coronal, and axial sections were evaluated using the same software (Dolphin Imaging 11.8). Using the multiplanar reformation, we identified the vertical axis located in the middle of the canine alveolar space, delimited between the lateral incisor and the first premolar. This axis was also centered on the deciduous pulp conduct axis, when present at T0, or on the pulp conduct of the permanent canine at T1 (at the level of the cervical bone crest, as a reference). This procedure allowed rotations in the 3 planes before the measurements (*red line*, Figs 2 and 3). Palatal and buccal and mesial and distal heights were measured from the alveolar crest to the nasal floor on the sagittal and coronal views, respectively. In the sagittal view, the buccopalatal widths were measured at 3 levels (cervical, middle, and apical) every 6 mm from the alveolar crest. In the axial view, the buccopalatal cervical widths were measured mesially (proximal to the lateral incisor) and distally (proximal to the premolar) to the canine at the level of the alveolar ridge. All measurements were performed for the MIC and the control canine at T0 and T1.

All patients were treated by an expert and trained orthodontist following the same treatment protocol (G.A.R.M). The biomechanical sequence of orthodontic treatment followed a rigorous protocol in all subjects. Fixed orthodontic appliances with 0.022 × 0.028-in (Synergy; Rocky Mountain Orthodontics, Denver, Colo) and copper nickel-titanium (Ormco, Glendora, Calif) 0.016 × 0.022-in archwires were used. The deciduous canine in the impaction side was always present during the beginning of the mechanics. Thus, once the anterior and posterior segments were aligned and leveled, the space preparation for the MIC was performed with 0.012 × 0.045-in open coil springs (Rocky Mountain Orthodontics). One month before surgery, the rigid anchorage device (1.1-mm or 1.2-mm stainless steel, Dentaurum, Ispringen, Germany) associated with a palatal acrylic button, and with occlusal-palatal-buccal stepped extensions distal to the lateral incisor and on the proximal sides of premolars and molars (performed with a 0.028-in wire), was cemented. The buccal extensions protect the tissues and avoid immersions of the Ni-TiCCS in the soft mucoperiosteal tissue. Ni-TiCCS 0.010 × 0.036-in and of 8 and 13 mm (Dentos, Daegu, Korea) were used to provide 100-150 g of force when they were activated for transalveolar traction of the MIC (Fig 4).

A 0.017 × 0.025-in stainless steel archwire, passively placed and distally cinched to the most distal molar, was used before traction for maxillary arch consolidation. A closed surgical technique was performed in all patients with an individualized osteotomy that never exceeded the MIC cementoenamel junction.[3,5,6,29] Before the Ni-TiCCS fixation, an absolute transsurgical isolation was performed. The activation was performed immediately after the spring fixation and individualization of the anchorage (Fig 5), and it was maintained during traction (6-7 mm every 6 weeks). Four to 6 months after the initiation of traction, the anchorage and traction springs were removed, and the MIC was leveled. Then, the finalization phase was initiated.

A new CBCT was taken (T1) to evaluate the 3D changes in the root and alveolar bone and to visualize the consequences of the traction on MIC and the nonimpacted teeth after the end of MIC traction. This decision was adopted according to the as low as reasonably achievable principle, international guidelines and is supported by evidence-based science.[32,33]

Statistical analysis

The statistical analyses were performed using SPSS Statistics for Windows (version 19.0; IBM Corp, Armonk, NY). Descriptive statistics of height and width changes in millimeters were calculated for both groups, palatally and buccally MIC. Data normality was assessed with the Shapiro-Wilk test. The Independent *t* test or Mann-Whitney U test was used (depending on the

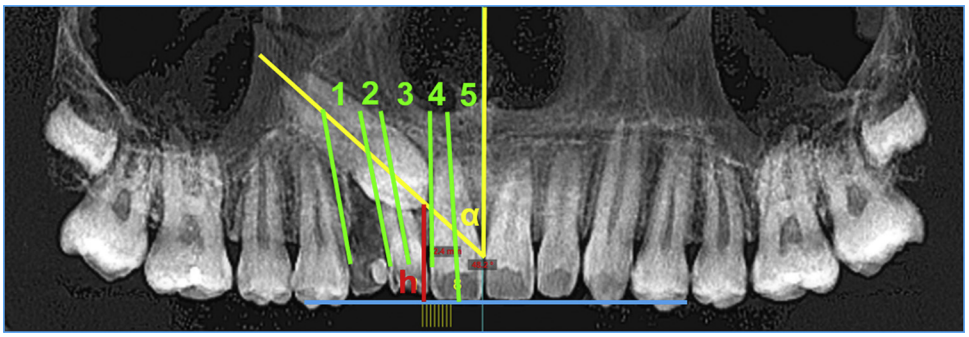


Fig 1. Sectors 1-5, alpha angle (α), and height of the cusp to the incisal plane (h), according to Ericson and Kurol.[28]

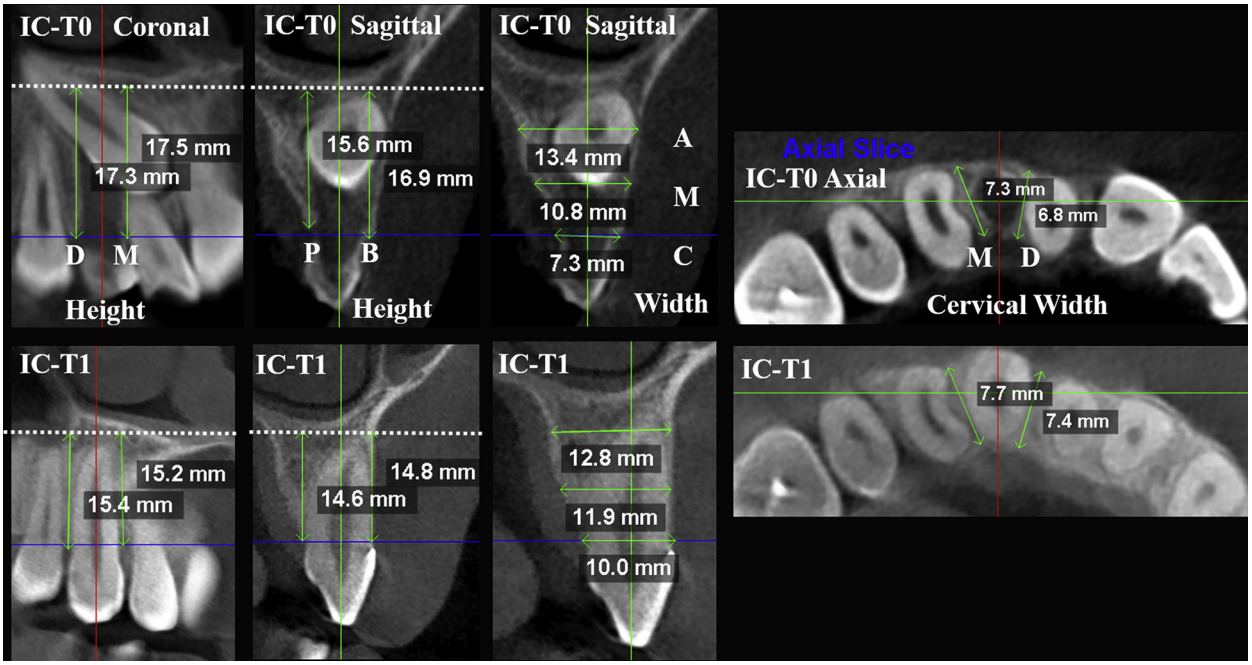


Fig 2. MIC before (T0) and after (T1) traction. Heights from the alveolar crest to the nasal floor (*dotted white line*). Mesial (M) and distal (D) height measurements in the coronal section. Palatal (P) and buccal (B) heights, and cervical (C), middle (M), and apical (A) width measurements every 6 mm from the alveolar crest in the sagittal section. Mesial (M) and distal (D) cervical width measurements at the level of the alveolar ridge in the axial section.

data normality) to compare height and width changes between groups (buccally vs palatally unilateral MIC groups), and the paired *t* test or Wilcoxon signed rank test was used (depending on the data normality) to compare the affected vs the nonaffected sides in each MIC group. Finally, multiple linear regression analyses were applied only to the outcome variables that fulfilled the assumptions of normality and homoscedasticity to evaluate the influence of each variable on height and width changes. An initial regression analysis with all predictor variables followed by a second regression analysis with only predictor variables showing *P* values smaller than 0.25 was performed (overfit method).[34] Statistical significance was set at 0.05 for all statistical tests.

RESULTS

The age and sex distribution of the sample and MIC characteristics by groups are summarized in Table I. In

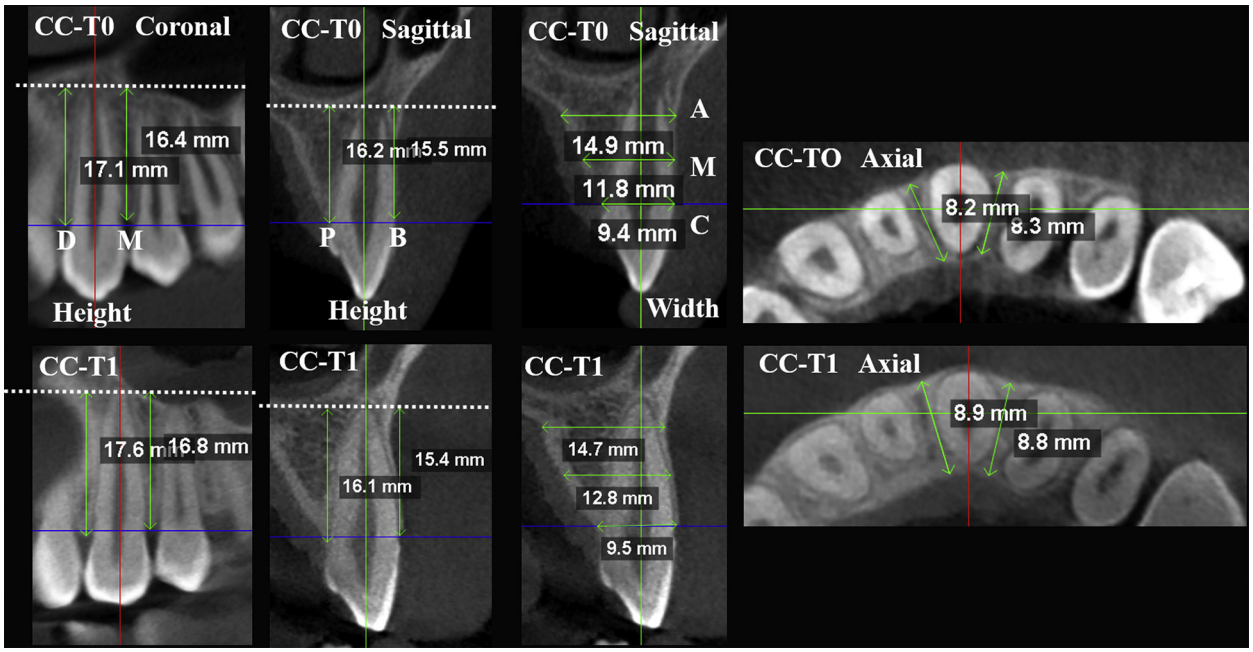


Fig 3. Control canine from the nonaffected side before (T0) and after (T1) traction. Heights from the alveolar crest to the nasal floor (*dotted white line*). Mesial (M) and distal (D) height measurements in the coronal section. Palatal (P) and buccal (B) heights, and cervical (C), middle (M), and apical (A) width measurements every 6 mm from the alveolar crest, in the sagittal section. Mesial (M) and distal (D) cervical width measurements at the level of the alveolar ridge in the axial section.

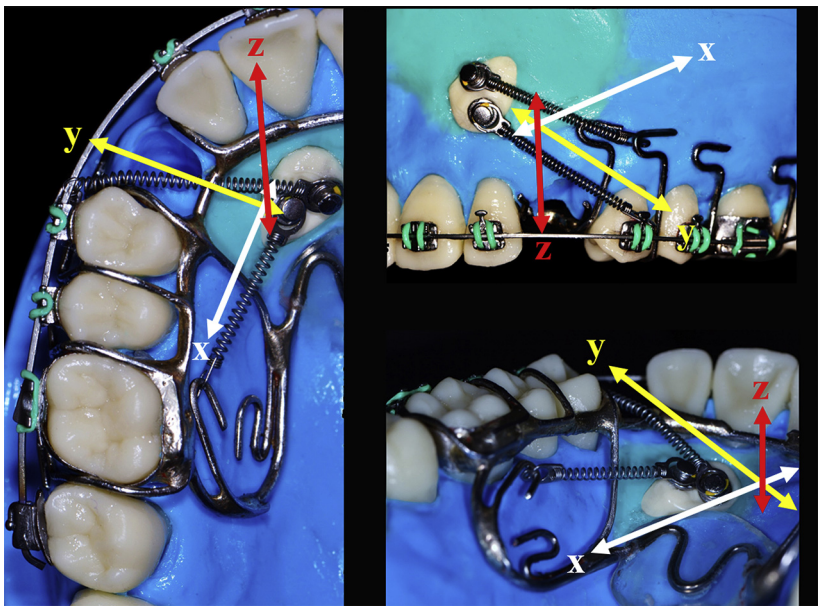


Fig 4. Control of buccal and palatal traction of unilateral MIC in the x-, y-, and z-axes. Traction with Ni-TiCCS and a rigid palatal anchorage appliance with buccal extensions and palatal hooks. Distal traction on the x-axis (*white arrow*), buccal traction on the y-axis (*yellow arrow*), and extrusive traction on the z-axis (*red arrow*).

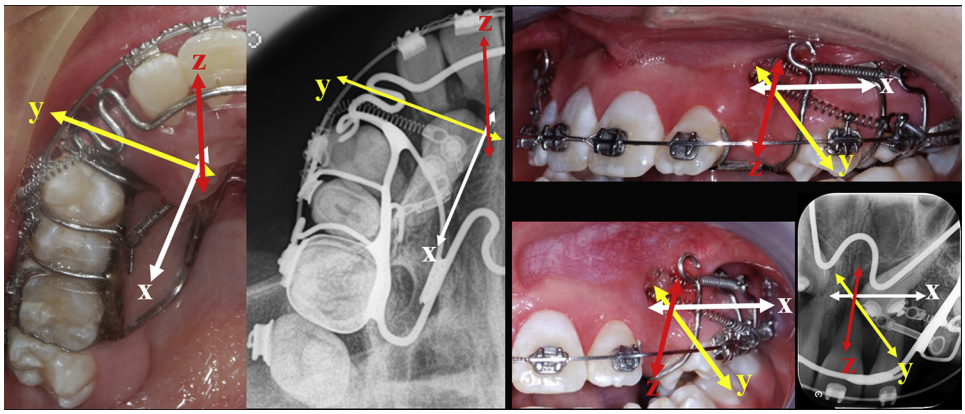


Fig 5. Clinical and radiographic images of palatobuccal movement in the y-axis (*yellow arrow*), mesiodistal movement in the x-axis (*white arrow*), and extrusive movement in the z-axis (*red arrow*) of palatally and buccally MIC with Ni-TiCCS activated over the rigid anchorage.

Table I. Sample demographic and MIC characteristics

Demographics	*n*	*Mean*	*SD*	P
Sex		Age		
Male	12	19.08	5.48	0.510
Female	15	20.93	8.22	
Impaction type		Alpha angle		
Palatally	14	51.57	22.67	0.332
Buccally	13	43.77	17.74	
Impaction type		Impaction height		
Palatally	14	14.43	4.38	0.010*
Buccally	13	10.69	2.18	
Impaction type		Traction time		
Palatally	14	5.71	1.06	0.579
Buccally	13	5.46	1.26	

*Statistically significant at $P < 0.05$ (t test).

Table II. Association between type and sector of maxillary canine impaction

	Impaction sector					
Type of impaction	*1*	*3*	*4*	*5*	*Total*	P
Palatally	2	5	5	2	14	0.625
Buccally	4	5	2	2	13	
Total	6	10	7	4	27	

Note. Significance tested with Fisher exact test.

addition, the traction time in months (palatal, 5.71 ± 1.06; buccal, 5.46 ± 1.26) was similar between groups ($P = 0.579$). The palatally MIC group showed significantly higher impaction than the buccally MIC group. The MIC was mainly located in sectors 3, 4, and 5 in both groups (78% of the sample; Table II).

The alveolar height changes (T0 − T1) showed statistically significant differences between the groups (buccally vs palatally unilateral MIC groups) for all measurements. The palatally MIC height changes ranged from 2.09 to 2.79 mm, whereas the buccally MIC height changes ranged from 0.28 to 0.57 mm. Otherwise, the alveolar width changes were not statistically significantly different between groups (Table III).

After palatally MIC traction, the buccal, mesial, and distal alveolar heights showed statistically significantly greater decreases (2.52 to 2.79 mm), and the cervical and mesial widths showed significant increases (0.74 to 1.36 mm) on the affected side, as compared with the nonaffected side (Table IV).

After buccally MIC traction, the palatal, buccal, mesial, and distal alveolar heights showed statistically significantly greater decreases (0.28 to 0.57 mm), and the cervical width showed a significant increase (1.26 mm) on the affected side, as compared with the nonaffected side (Table V).

The multivariate analysis (Table VI) indicated that the buccally impacted canine condition decreased the alveolar height. Similarly, age and sex had a significant influence on some alveolar heights. For each year, reductions of 0.18 and 0.17 mm occurred in palatal and buccal heights, respectively. Women presented greater palatal, buccal, and distal height loss (1.83, 1.76, and 2.25 mm, respectively) than men. Finally, the alpha angle of canine impaction was the only variable that had a significant influence on the cervical width (Table VII).

DISCUSSION

The traction of MIC is associated with morphologic changes in the involved tooth, in the adjacent teeth, and the surrounding dentoalveolar structure. This study

Table III. Comparison of alveolar changes in mm (T0 − T1) between buccally vs palatally MIC

							95% CI	
Measure	*Impacted canine position*	*n*	*Mean*	*SD*	P	*Mean difference*	*Lower limit*	*Upper limit*
Palatal height changes	Palatally	14	2.09	2.64	0.034*,†	1.81	0.04	3.59
	Buccally	13	0.28	1.70				
Buccal height changes	Palatally	14	2.52	2.34	0.011*,†	1.95	0.33	3.58
	Buccally	13	0.57	1.68				
Mesial height changes	Palatally	14	2.76	2.95	0.019*,‡	2.37	0.42	4.31
	Buccally	13	0.39	1.75				
Distal height changes	Palatally	14	2.79	2.22	0.006*,‡	2.32	0.73	3.92
	Buccally	13	0.47	1.76				
Cervical width changes	Palatally	14	−1.36	1.14	0.836‡	−0.1	−1.04	0.85
	Buccally	13	−1.26	1.24				
Middle width changes	Palatally	14	−0.07	2.23	0.274†	−0.86	−2.51	0.78
	Buccally	13	0.79	1.89				
Apical width changes	Palatally	14	−0.14	2.45	0.262‡	−0.99	−2.75	0.78
	Buccally	13	0.85	1.95				
Mesial width changes	Palatally	14	−0.74	1.02	0.328‡	−0.39	−1.17	0.41
	Buccally	13	−0.35	0.96				
Distal width changes	Palatally	14	−0.76	0.99	0.063‡	−0.64	−1.32	0.04
	Buccally	13	−0.12	0.69				

Note. Negative value = increase; positive value = decrease.
*Statistically significant at $P < 0.05$; †Significance tested with Mann-Whitney U test; ‡Significance tested with Independent *t* test.

Table IV. Alveolar changes (T0 − T1) after canine traction between palatally impacted canine side and the nonimpacted side

					95% CI		
Measurement	*n*	*Mean*	*SD*	*Mean difference*	*Lower limit*	*Upper limit*	P
Palatal height changes							
Affected side	14	2.09	2.64	1.71	−0.45	3.88	0.111†
Nonaffected side	14	0.38	2.72				
Buccal height changes							
Affected side	14	2.52	2.34	2.71	0.61	4.81	0.015*,†
Nonaffected side	14	−0.19	3.02				
Mesial height changes							
Affected side	14	2.76	2.95	3.15	0.87	5.43	0.011*,†
Nonaffected side	14	−0.39	2.82				
Distal height changes							
Affected side	14	2.79	2.22	2.54	0.9	4.19	0.013*,‡
Nonaffected side	14	0.25	1.89				
Cervical width changes							
Affected side	14	−1.36	1.14	−1.71	−2.44	−0.97	<0.001*,†
Nonaffected side	14	0.35	1.20				
Middle width changes							
Affected side	14	−0.07	2.23	−0.18	−1.3	0.94	0.735†
Nonaffected side	14	0.11	1.07				
Apical width changes							
Affected side	14	−0.14	2.45	−0.73	−2.3	0.85	0.336†
Nonaffected side	14	0.59	1.41				
Mesial width changes							
Affected side	14	−0.74	1.02	−0.78	−1.5	−0.05	0.037*,‡
Nonaffected side	14	0.04	0.96				
Distal width changes							
Affected side	14	−0.76	0.99	−1.31	−2.12	−0.51	0.105*,†
Nonaffected side	14	0.55	1.04				

Note. Negative value = increase; positive value = decrease.
*Statistically significant at $P < 0.05$; †Significance tested with paired *t* test; ‡Significance tested with Wilcoxon signed rank test.

Table V. Alveolar changes (T0 − T1) after canine traction between buccally impacted canine side and nonimpacted side

					95% CI		
Measurement	*n*	*Mean*	*SD*	*Mean difference*	*Lower limit*	*Upper limit*	P
Palatal height changes							
Affected side	13	0.28	1.70	2.16	0.46	3.87	0.013*,‡
Nonaffected side	13	−1.88	2.96				
Buccal height changes							
Affected side	13	0.57	1.68	2.60	0.87	4.33	0.007*,‡
Nonaffected side	13	−2.03	2.93				
Mesial height changes							
Affected side	13	0.39	1.75	2.28	1.12	3.45	0.003*,‡
Nonaffected side	13	−1.89	1.83				
Distal height changes							
Affected side	13	0.47	1.76	1.95	0.47	3.42	0.014*,†
Nonaffected side	13	−1.48	1.97				
Cervical width changes							
Affected side	13	−1.26	1.24	−1.31	−2.07	−0.56	0.003*,†
Nonaffected side	13	0.05	0.67				
Middle width changes							
Affected side	13	0.79	1.89	0.94	−0.24	2.13	0.100‡
Nonaffected side	13	−0.15	0.88				
Apical width changes							
Affected side	13	0.85	1.95	0.59	−0.94	2.11	0.420†
Nonaffected side	13	0.26	1.25				
Mesial width changes							
Affected side	13	−0.35	0.96	−0.01	−0.51	0.48	0.947†
Nonaffected side	13	−0.34	1.11				
Distal width changes							
Affected side	13	−0.12	0.69	0.42	−0.20	1.03	0.166†
Nonaffected side	13	−0.54	0.87				

Note. Negative value = increase; positive value = decrease.
*Statistically significant at $P < 0.05$; †Significance tested with paired *t* test; ‡Significance tested with Wilcoxon signed rank test.

was performed to evaluate the dimensional changes in the alveolar bone of the tractioned canine and its corresponding control, considering the position of the impacted tooth (either palatal or buccal). It is important to consider that the 3D location of MIC in the alveolar bone plays an important role in the orthodontic movement mechanics and consequently on the surrounding bone remodeling. This 3D location can vary widely even with the same type of impaction (ie, buccal or palatal); in this way, 2 patients of MIC will rarely be similar. In addition, it is important to emphasize that in our study, groups were somewhat similar regarding MIC characteristics (except for the impaction height), traction time, and impaction sector. In this way, the alveolar bone dimension changes could not be strongly affected by these variables, making group comparisons more reliable. Although an effort to make groups comparable was made, some variables showed large standard deviations (ie, alpha angle). This finding could somewhat compromise the groups' similarity even in the absence of statistically significant difference. Then, caution should always be taken in the external validity of the results.

In addition, this study did not aim to perform measurements of the buccal of the periodontal status nor clinical evaluation of the vestibular keratinized margin of attached gum. Remodeling changes in height and width of the alveolar bone were only analyzed. Moreover, the methodology for alveolar height and width evaluations used in this study, as parameters of dimensional changes, were based on previously reported morphometric measurements.[21,22]

Although CBCT offers geometric advantages over conventional intraoral radiographs as documented by many authors,[7-11] no studies have evaluated dimensional changes in the alveolar bone or bone loss in unilateral impacted maxillary canine teeth undergoing orthodontic-surgical traction. Few studies have provided CBCT control comparing 2 times (T0 and T1) corresponding to initial and after traction movement. According to evidence-based guidelines and the

Table VI. Multiple linear regressions for alveolar height measurements

Model	B	P	95% CI for B		r^2
			Lower limit	Upper limit	
Palatal height changes					
Constant	6.77	0.001*	3.16	10.37	0.568
Age	−0.18	0.002*	−0.28	−0.08	
Sex					
Male	–	–	–	–	
Female	1.83	0.013*	0.42	3.25	
Canine position					
Palatal	–	–	–	–	
Buccal	−1.65	0.046*	−3.27	−0.04	
Height	−0.18	0.085	−0.38	0.03	
Buccal height changes					
Constant	6.45	<0.001*	3.23	9.67	0.611
Age	−0.17	0.001*	−0.27	−0.08	
Sex					
Male	–	–	–	–	
Female	1.76	0.009*	0.49	3.02	
Canine position					
Palatal	–	–	–	–	
Buccal	−1.61	0.030*	−3.06	−0.17	
Height	−0.12	0.172	−0.3	0.06	
Distal height changes					
Constant	3.79	0.042*	0.15	7.44	0.527
Age	−0.07	0.196	−0.17	0.04	
Sex					
Male	–	–	–	–	
Female	2.25	0.003*	0.82	3.68	
Canine position					
Palatal	–	–	–	–	
Buccal	−2.05	0.016*	−3.68	−0.41	
Height	−0.08	0.403	−0.29	0.12	

*Statistically significant at $P < 0.05$.

as low as reasonably achievable principle, the use of 3D images can be justified before and after a specific treatment for diagnosis and follow-up in some circumstances (eg, impacted teeth). This procedure allows axial and coronal evaluations, which are impossible to perform with 2D radiographs. Each CBCT is necessary to evaluate the severity of malposition, root resorption, and possible bone loss effects consequent to the traction.[30-33]

The orthodontic treatment followed the same protocol for all patients, and all the patients were managed by the same orthodontist; in this way, the orthodontic protocol associating Ni-TiCCS with a reinforced customized anchorage was standardized for all patients. This association allowed biomechanical control of the magnitude, direction, and x-, y-, and z-axes sense of force using superelasticity, memory, and light continued force concepts with a wide range of activation, as previously reported for orthodontic mechanics (Figs 4 and 5).[14-18] Manhartsberger and Seidenbusch,[16] as well as Schubert,[17] have documented the control, simplicity, efficiency, and cost benefits of Ni-TiCCS for retraction mechanics. These advantages were complemented with the use of a custom rigid palatal anchorage, with buccal extensions, which was adapted for the short period of traction (approximately 6 months) to protect adjacent teeth and soft tissues against the effects of action/reaction forces, avoiding immersion of the springs in the mucoperiosteum. These mechanics also approximated the canine center of resistance to the force of traction. It can be argued that, currently, mini-implants could be used for these purposes. However, the system presented in this study has a reduced fabrication cost and avoids the use of mini-implants. Thus, it could be considered as an alternative for institutional public health or when the use of mini-implants is refused by patients or are difficult to obtain (Figs 4 and 5).[31]

Many studies have focused on the periodontal clinical effects of MIC traction using conventional periapical and panoramic x-ray films. Some studies[3-6] have compared periodontal conditions between treated MIC

Table VII. Multiple linear regressions for alveolar width measurements

Model	B	P	95% CI for B		r^2
			Lower limit	Upper limit	
Cervical width changes—affected side					
Constant	−0.79	0.389	−2.66	1.08	0.298
Canine position					
Palatal	–	–	–	–	
Buccal	0.18	0.709	−0.79	1.14	
Alpha angle	−0.04	0.007*	−0.07	−0.01	
Height	0.11	0.195	−0.06	0.27	
Apical width changes—affected side					
Constant	−2.76	0.153	−6.62	1.11	0.184
Canine position					
Palatal	–	–	–	–	
Buccal	1.88	0.064	−0.12	3.88	
Alpha angle	−0.04	0.180	−0.10	0.02	
Height	0.32	0.065	−0.02	0.66	
Mesial width changes—affected side					
Constant	−0.53	0.557	−2.36	1.31	0.060
Canine position					
Palatal	–	–	–	–	
Buccal	0.27	0.565	−0.68	1.22	
Alpha angle	0.01	0.426	−0.02	0.04	
Height	−0.05	0.505	−0.22	0.11	
Distal width changes—affected side					
Constant	0.20	0.784	−1.31	1.72	0.228
Canine position					
Palatal	–	–	–	–	
Buccal	0.32	0.402	−0.46	1.11	
Alpha angle	0.01	0.284	−0.01	0.04	
Height	−0.11	0.102	−0.24	0.02	

*Statistically significant at $P < 0.05$.

and contralateral controls, with no significant clinical nor significant differences. Quirynen et al,[22] in a split-mouth clinical study, recommended traction as a method with small periodontal impact. However, Szarmach et al[35] found an association between the mechanic factors and oral hygiene with periodontal deterioration. Silva et al[19] used CBCT after traction only to evaluate the effects of traction on roots and bone of the canine and adjacent teeth over the long term. They observed minimal damage to these structures. Because some studies have observed important bone loss and lingual cortical width reduction after orthodontic treatment, specifically in the anterior mandibular region,[20,21,36,37] it is possible that MIC traction mechanics may reflect a similar behavior. However, these effects are not usually studied regarding MIC traction.

According to Lund[11] and Garlock,[37] conventional orthodontic treatments with and without extraction produces tridimensional alveolar changes on CBCT per se. The results of the present study indicate that the traction treatment produced significant changes in width and alveolar height in both groups (Tables IV and V). The forces of traction with Ni-TiCCS remodel the alveolar shape and size in the MIC region,[14-18] which can be expected because of the intrusive effect on the adjacent lateral incisor and first premolar, with reciprocal action/reaction forces. In addition, this phenomenon could be considered as a response of remodeling and bone resistance to extrusive traction, specifically for the complex palatal and transalveolar path of traction (from palatal to buccal) in palatally MIC (Table III). Therefore, Caprioglio,[3] Hansson,[4] and Parkin[6] explain how palatally impacted canines still present some challenges. The significant greater alveolar height reduction observed in the traction of palatally MIC compared with buccally MIC probably occurred as a side effect of the complex crown-root movement on the x-, y-, and z-axes until the achievement of an adequate buccal and occlusal position (Figs 5 and 6).[14]

Another factor that has not been clearly described by other authors and that may be involved in the reduction of alveolar height is the absence of follicle and periodontal ligament on the enamel of the MIC crown, which does not produce osteogenesis or remodeling when the tooth moves through the bicortical bone toward the occlusal plane. In addition, the greater impaction of palatal canines could be influenced by the greater alveolar height reduction in this group (Table III). However, additional studies are needed to examine these possibilities. The alveolar height of the buccal MIC was less affected, which could be related to the low resistance to traction for the evident thinness of its cortical and mucoperiosteum (Fig 6).

Coinciding with Quirynen,[22] the statistically significant increase in alveolar width at the cervical and mesial levels of the MIC (Tables IV and V) was probably related to the increase in mesial and distal alveolar cervical width of the MIC associated with the increase in width at the bone crest level because of differences in mesiodistal and buccopalatal dimensions between the deciduous canine before traction and permanent MIC after traction (Fig 7).

Crescini,[5,29] using different biomechanics and methodology, found that the final periodontal status does not depend on age, gender, or pretreatment radiographic features. In our study, the regression analysis estimated the influence of co-variables (sex, age, position, sector, angle, and distance) and indicated that

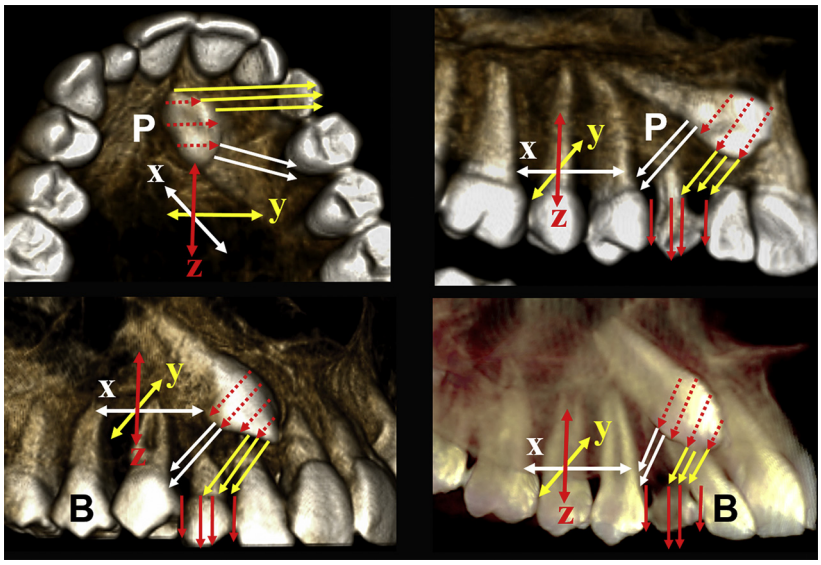


Fig 6. Complex palatal and transalveolar path in the x-, y-, and z-axes of a palatally MIC (P) toward the buccal and occlusal position, with a reciprocal action/reaction effect, remodeling, and bone resistance to extrusive traction, which can cause greater palatal bone height reduction. The height of the buccally MIC (B) can be less affected because of the thinness of its cortical and mucoperiosteum and the low resistance to traction. Palatobuccal movement in the y-axis (*yellow arrow*), mesiodistal movement in the x-axis (*white arrow*), and extrusive movement in the z-axis (*red arrow*).

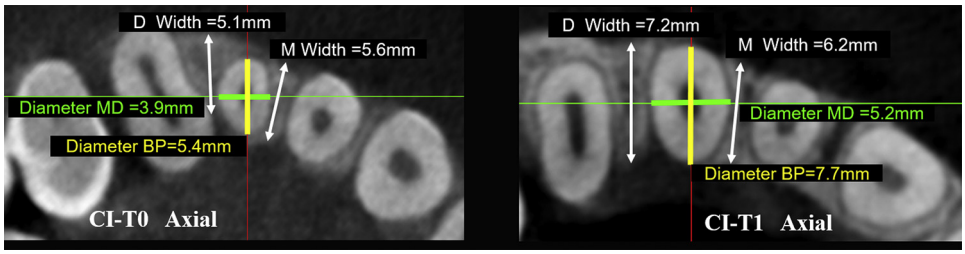


Fig 7. Increase in mesial (M) and distal (D) cervical alveolar width in MIC associated with the increase in width at the bone crest level because of differences in mesiodistal and buccopalatal diameters between deciduous canine before traction (T0) and permanent MIC after traction (T1).

the sex variable had a significant influence on the dimensional alveolar height changes (Table VI). The change in palatal, buccal, and distal height (1.83 mm, 1.76 mm, and 2.25 mm, respectively) was greater in women than in men. Age had a slight influence on the palatal and buccal width reduction (calculated amount of reduction per year, 0.18 mm and 0.17 mm, respectively). Finally, the regression analysis corroborated that palatally MIC traction had a greater impact on the alveolar height change compared with buccally MIC traction.

In contrast to conventional orthodontic mechanics, unilateral MIC traction requires a 3D diagnosis, an individualized anchoring device, oral surgery, 3D biomechanical control, efficient force, and transalveolar extrusive traction. This traction causes alveolar bone changes (remodeling) with evident reductions in the alveolar bone height and increases in cervical alveolar width. Further studies evaluating the effects of the orthodontic traction of MIC on the buccal and palatal cortical thickness and in the periodontal status are necessary to better clarify the concepts of traction "with the bone," "inside the bone," and "through the bone."[1]

CONCLUSIONS

1. Palatally MIC traction showed a greater alveolar bone height decrease than buccally impacted canine traction.

2. Sex and age influence these alveolar dimensional changes.
3. Alveolar width increased similarly in both palatal and buccal impaction traction patients.

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