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Influence of maxillary canine impaction characteristics and factors associated with orthodontic treatment on the duration of active orthodontic traction

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Introduction: Orthodontic traction of a maxillary impacted canine (MIC) increases the orthodontic treatment time. Therefore, the objective of this study was to evaluate the influence of MIC characteristics and factors associated with orthodontic treatment on the duration of active orthodontic traction. **Methods:** This follow-up and retrospective study included 45 MICs orthodontically tractioned into the occlusal plane with the use of a standardized protocol. MIC characteristics, including type, sector, side, location, height, and complexity of impaction, as well as α and β angles and canine root length and area were measured. Likewise, factors associated with orthodontic treatment, including sex, age, malocclusion, premolar extractions, previous incisor root resorption, ANB, APDI, and SNA angles, and PNS-ANS distance were also evaluated. The statistical analysis included multiple linear regressions to estimate the influence of all variables on the duration of traction ($\alpha = 0.05$). **Results:** Sex had significant influence ($P = 0.027$) on the time of traction; in female patients, the time was 2.05 months more than in male patients. Bilateral impaction treatment increased the time by 2.74 months compared with unilateral cases ($P = 0.001$). Traction of bicortically centered impacted canines increased the duration of traction by 2.85 months ($P = 0.001$). Finally, the traction time increased in 2.35 months ($P = 0.046$) when the impaction sectors were 4 or 5 (close to the midline). **Conclusions:** The duration of active orthodontic traction of MIC is mainly influenced by sex, bilateral type, bicortically centered location, or when MIC is located in sector 4 or 5 close to midline, increasing the traction time by some months. (Am J Orthod Dentofacial Orthop 2019;156:391-400)

One of the most frequent questions that the orthodontist addresses when treating a patient with a maxillary impacted canine (MIC) is how long the traction will last. This information is necessary for the treatment plan because of its direct influence on the total time of orthodontic treatment.[1,2] However, MIC cases present different characteristics of impaction in the maxilla,[3] including the impaction type (unilateral or bilateral), location (palatally, buccally, or bicortically centered),[4–7] sector of impaction (1 to 5),[8,9] height (distance to occlusal plane), and angulation (α and β angles)[8]; these variables can make one treatment more complex than another and consequently change the time of traction.

The duration of active orthodontic traction of MIC reported in the scientific literature is variable. Most publications indicate that on average it can take 8 months,[10,11] although some cases have been reported that reached the occlusal plane in only 3 months after the beginning of traction,[12] and others took approximately 1 year of traction.[13] The canine impaction characteristics seem to directly influence the traction time, showing more prolonged traction time

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Table I. Definition of impacted canine characteristics and factors associated with orthodontic treatment

Term	*Definition*
Impacted canine characteristic	
Type	Unilateral or bilateral
Sector[8,9]	Erikson and Kurol classification: sector 1, 2, 3, 4, or 5
Side	Right or left
Location[4-7]	Palatally, buccally, or bicortically located (at the level of the occlusion line or precisely centered in the alveolar bone in the middle of the 2 cortical bones)
Height[9]	Distance "d": perpendicular distance from the cusp tip of the impacted canine to the occlusal plane formed by a tangent to the incisal edge of the maxillary central incisor and the occlusal surface of the maxillary first molar
Complexity	Low-complexity group: patients with impacted maxillary canines in sectors 1, 2, or 3 (α angle $\leq 40°$ in sector 3); high-complexity group: patients with impacted maxillary canines in sectors 3, 4, or 5 (α angle $>40°$ in sector 3)
α angle[3]	Angle formed between the interincisor midline and the long axis of the impacted canine
β angle[3]	Angle formed between the long axis of the canine and the long axis of lateral incisor
Root length	Measured in mm on the longitudinal axis from a perpendicular projection to the mesial cementoenamel junction in the coronal section up to the vertex of the radicular apex of each impacted canine (root length before dilaceration plus root length after dilaceration up to the vertex were measured; Fig 1)
Canine root area	Measured in the coronal section in mm^2 from the mesial cementoenamel junction, continuing along the contour of the entire root to the distal cementoenamel junction (Fig 1)
Factors associated with orthodontic treatment	
Sex	Male or female
Age	Years
Malocclusion	Angle Class I, II/1, II/2, or III
Premolar extractions	Present or absent
Previous incisor root resorption	Present or absent root resorption of central or lateral upper incisor near to impacted canine (only affected side) through CBCT exploration in volume rendering and 3D sections
ANB angle[16]	Angle formed by subspinale, nasion, and submental points
APDI angle[17]	Anteroposterior dysplasia indicator: the arithmetic sum of 3 angles: Frankfort horizontal plane to facial plane and A-B plane to facial plane and to Frankfort plane
SNA angles[16]	Angle formed by sella, nasion, and subspinale points
PNS-ANS distance	Distance between posterior nasal spine to anterior nasal spine (palatal plane)

in more complex cases.[14,15] The determination of the traction complexity of an MIC is influenced mainly on various characteristics of impaction, as well as by factors associated with orthodontic treatment and intrinsic factors of each patient. However, few studies have been reported in the scientific literature, and they concluded that MIC traction time is mainly influenced by canine impaction characteristics, including the α angle, the impaction distance to the occlusal plane, and the impaction sector.[11,15] Another study indicated that the mesiodistal position of the canine could be the most useful predictor to know the duration of orthodontic traction.[14] Likewise, Nieri et al,[10] using a bayesian method (a graphic method to evaluate a possible causal relationship among variables) to identify the factors that directly influence the duration of the traction, concluded that the bilateral type, as well as the α angle and the distance of impaction, are those that increase the traction time.

These studies showed that specific characteristics of MIC are factors that directly modify the active traction time. However, because there are few reports and some of them used the same sample but changed the prediction method,[10,11,15] other studies including different samples should be performed to confirm the influence of these specific variables on the duration of orthodontic traction of MICs. Furthermore, other factors also could be directly related to the time of active traction, such as the root length and area of the canines, evaluated mainly with the use of cone-beam computed tomography (CBCT), which were not normally included by previous studies in the conventional prediction methods.

For these reasons, the purpose of the present study was to evaluate the influence of maxillary canine impaction characteristics and factors associated with orthodontic treatment on active orthodontic traction duration, including new variables obtained with the use of CBCT.

MATERIAL AND METHODS

This follow-up and retrospective study was approved by the Ethics and Research Committee of the

Universidad Científica del Sur, Lima, Perú (00021). The sample involved 30 patients (11 male, 19 female; overall mean age 18.16 ± 7.32) attending a private clinic in Bogotá, Colombia, from 2010 to 2018 and treated by a single experienced orthodontist (G.A.R.-M.). The subjects included 45 MICs orthodontically tractioned to the occlusal plane with the use of a standardized protocol. The minimum sample size was determined by a formula to estimate 1 mean (time of traction; http://www.lee.dante.br) at 95% confidence level with a standard deviation of 1.61 months and a maximum error of the estimate of 0.5 months (data obtained from a previous pilot study). The required number was 40 MICs, and 45 were included.

The inclusion criteria comprised individuals of both sexes with at least 1 MIC with complete records, including clinical histories, extra- and intraoral photographs, panoramic and lateral head films, and CBCT before treatment. Individuals with brackets, maxillary surgeries before the study, or agenesis of a maxillary tooth were excluded.

CBCT scans of all patients were taken with the use of PaX-Uni 3D (Vatech Co, Hwaseong, Korea) set at 4.7 mA, 89 KVp, voxel size 0.125, and exposure time 15 seconds. Each field of view mode was 8 cm × 8 cm^2. The DICOM files were imported into Dolphin-3D software (version 11.7; Dolphin Imaging, Chatsworth, Calif).

Characteristics of MICs were measured with the use of multiplanar and 3D reconstructions. The definitions of all measured variables are presented in Table 1. Type of impaction, impaction sector,[8,9] side, location,[4-7] height,[9] complexity of MIC traction, α and β angles,[3] canine root length, and canine root area were measured (Fig 1). Likewise, factors associated with orthodontic treatment, such as sex, age, malocclusion, premolar extractions, previous incisor root resorption, ANB,[16] APDI,[17] and SNA angles, and PNS-ANS distance also were evaluated.

For training and calibration phase, 4 trained orthodontists (L.E.A.-G., G.A.R.-M., Y.A.R.-C., A.A.-D.C.) evaluated the characteristics of MICs in each tomographic scan. Interobserver concordance was assessed by means of kappa test, which showed perfect agreement (1.0). For continuous variables, 1 investigator (L.E.A.-G.) performed all measurements twice with a month's interval. The intraobserver concordance was evaluated by means of the intraclass correlation coefficient. Values higher than 0.8 (95% CI 0.75-0.95) were obtained. Finally, random errors were calculated with the use of the Dahlberg formula.[18] Dahlberg coefficients were smaller than 1 mm or 1 mm^2 for all quantitative variables.

A controlled canine traction technique was used by 1 expert orthodontist (G.A.R.-M) seeking to control the

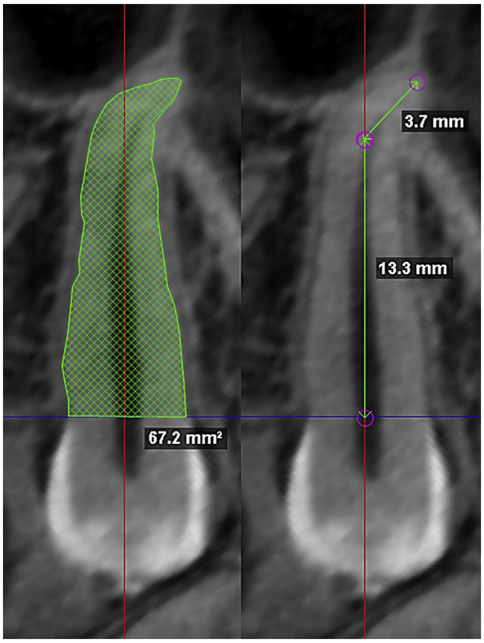

Fig 1. Measurements of the root area and length (before root dilaceration plus length after root dilaceration up to the vertex) of the impacted maxillary canine by means of tomographic coronal slices.

influence of the clinician's experience and the technique used. This technique included a closed surgical approach to traction the impacted canines. A single rigid temporary anchorage device on first permanent molars was soldered on bands of 1.2 mm (0.047″) stainless steel wire (Dentaurum & Co, Ispringen, Germany) with multiple palatal-occlusal-vestibular soldered hooks in 0.028″ wire to pull the MIC (Fig 2). Then, nickel-titanium closed helicoid coil springs 0.010″ × 0.036″ of 8 mm and 13 mm length and with 100 g or 150 g force (Dentos, Daegu, Korea) were used to perform traction. Activations of 4-5 mm were performed every 4-8 weeks until the occlusal plane was reached (Figs 3 and 4). In bilateral canine impaction cases the traction was started at the same time. Finally, the MIC traction time was counted from the moment the traction started, immediately after the canine exposure surgery until it reached the occlusal plane.

Statistical analysis

All statistical analyses were performed with the use of SPSS software for Windows (version 19.0; IBM, Armonk, NY). Shapiro-Wilk test determined the data distribution. Multiple linear regressions estimated the influence of all variables on the duration of traction. First, a multiple

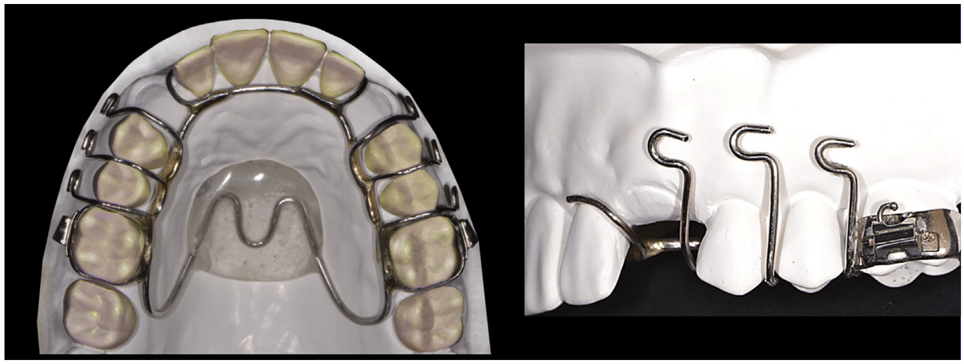

Fig 2. Illustration of the anchorage device used for the traction of maxillary impacted canines.

Fig 3. Single rigid temporary anchorage device soldered of 1.2 mm stainless steel wire with multiple palatal-occlusal-vestibular soldered hooks in 0.028″ wire to pull maxillary impacted canines.

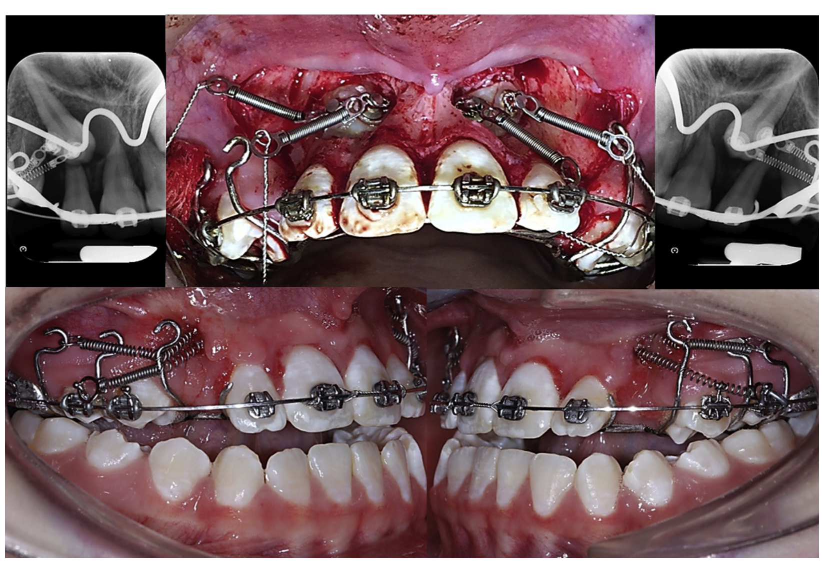

Fig 4. Nickel-titanium closed helicoid coil springs of 8 mm and 13 mm lengths were used to perform traction.

linear regression model using the overfit method was evaluated,[19] and this allowed selecting the variables that possibly influenced the MIC traction time (P ˂0.25). Likewise, for a better analysis of the categoric variables that had more than 2 values, we transformed them into dummy variables. Subsequently, a second multiple linear regression model was reevaluated to identify the variables that could influence the outcome

Table II. Descriptive statistics of qualitative variables

Variable	*Value*	*n*	*%*
Sex	Male	11	36.7
	Female	19	63.3
	Total	30	100.0
Malocclusion	Class I	20	66.7
	Class II/2	5	16.7
	Class III	5	16.7
	Total	30	100.0
Premolar extractions	Absent	21	70.0
	Present	9	30.0
	Total	30	100.0
Incisor root resorption near to MIC	Absent	27	60.0
	Present	18	40.0
	Total	45	100.0
Type of impaction	Unilateral	15	33.3
	Bilateral	30	66.7
	Total	45	100.0
Impaction side	Right	25	55.6
	Left	20	44.4
	Total	45	100.0
Impacted canine traction complexity	Noncomplex	20	44.4
	Complex	25	55.6
	Total	45	100.0
Impacted canine location	Palatally	20	44.4
	Buccally	18	40.0
	Bicortically	7	15.6
	Total	45	100.0
Canine impaction sector	Sector 0, 1, 2, or 3	39	86.7
	Sector 4 or 5	6	13.3
	Total	45	100.0

variable. The significance level was set at $P <0.05$ for all of the tests.

RESULTS

The average duration of active orthodontic traction of the 45 MICs was an 8.40 ± 3.26 months (range 4-16 months). Tables II and III present descriptive statistics of all qualitative and quantitative variables evaluated as independent variables (predictors) in the MIC traction time (outcome variable).

A multiple linear regression model was used to evaluate the influence of the predictive variables on the duration of MIC traction (Table IV). Seven variables had a value of $P <0.25$ according to the overfit method.[19] Those 7 variables only were included in a new regression. In that regression, the only variable that presented $P >0.25$ was dummy 1 (impacted canine location; $P = 0.802$). For this reason, this was excluded and a new regression including only 6 variables was performed.

Table III. Descriptive statistics of quantitative variables

Variable	*n*	*Mean*	*SD*
Age (y)	30	18.16	7.32
α angle (°)	45	45.24	17.98
β angle (°)	45	43.75	20.90
Impacted canine height (mm)	45	11.37	4.08
ANB angle (°)	45	3.75	2.39
APDI angle (°)	45	81.72	6.15
SNA angle (°)	45	84.89	5.06
PNS-ANS distance (mm)	45	47.94	4.56
Canine root length (mm)	45	15.62	2.16
Canine root area (mm^2)	45	63.53	10.11

Table V presents the multiple linear regression model to evaluate the traction time including only the 6 selected variables according to the overfit method.[19] We observed that sex had significant influence ($P = 0.027$) on the traction time: in female patients the traction time was 2.049 months more than in male patients. In bilateral cases, the traction time increased 2.74 months compared with unilateral ($P = 0.001$). For each degree that the β angle increased, the traction time increased by 0.055 months ($P = 0.009$). Bicortically impacted canine traction increased the traction time by 2.85 months ($P = 0.001$). Finally, the traction time of the impacted canines increased by 2.35 months ($P = 0.046$) when they were impacted in sectors 4 or 5 (close to midline) compared with sectors 1, 2, or 3. For this final model the coefficient of determination was 53.8%. In this way, the final prediction equation could be summarized as: Duration of active traction of MIC = −6.967 + 2.049 (sex: 0 = male; 1 = female) + 2.740 (type of impaction: 0 = unilateral; 1 = bilateral) + 0.055 (β angle) + 0.175 (PNS-ANS distance) + 2.857 (impacted canine location: 0 = palatally or buccally; 1 = bicortically) + 2.355 (canine impaction sector: 0 = sectors 1, 2, and 3; 1 = sectors 4 and 5).

DISCUSSION

An approximate prediction of orthodontic traction time of an MIC is useful for orthodontists because they could plan their treatment more accurately regarding the time involved in this traction and the patients could know in how much time they could have a harmonious smile. This duration of traction could be influenced by the characteristics of canine impaction and by factors associated with orthodontic treatment. Therefore, the purpose of the present study was to evaluate the influence of MIC characteristics and factors associated to

Table IV. Multiple linear regression model to evaluate the duration of maxillary impacted canine traction in months

				95% CL	
Independent variable	*Value*	*β*	P	*Lower*	*Upper*
Constant		−9.444	0.455	−35.164	16.276
Sex	Male	–	–	–	–
	Female	3.266	0.012*†	0.791	5.742
Age	Years	−0.081	0.428	−0.290	0.127
Premolar extractions	Absent	–	–	–	–
	Present	−0.966	0.588	−4.604	2.673
Incisor root resorption	Absent	–	–	–	–
	Present	−1.574	0.387	−5.265	2.118
Type of impaction	Unilateral	–	–	–	–
	Bilateral	1.816	0.150†	−0.709	4.340
Impaction side	Right	–	–	–	–
	Left	−0.627	0.477	−2.422	1.168
Impacted canine complexity	Noncomplex	–	–	–	–
	Complex	−0.597	0.722	−4.029	2.835
α angle	°	0.032	0.650	−0.113	0.178
β angle	°	0.052	0.235†	−0.037	0.141
Impacted canine height	mm	−0.250	0.323	−0.763	0.263
ANB angle	°	0.263	0.601	−0.764	1.291
APDI angle	°	−0.072	0.651	−0.396	0.252
SNA angle	°	0.133	0.357	−0.160	0.427
PNS-ANS distance	mm	0.256	0.071†	−0.024	0.537
Canine root length	mm	−0.374	0.298	−1.101	0.353
Canine root area	mm^2	0.007	0.925	−0.147	0.161
Dummy 1 (impacted canine location)	Palatally and bicortically	–	–	–	–
	Buccally	2.156	0.236†	−1.506	5.818
Dummy 2 (impacted canine location)	Palatally and buccally	–	–	–	–
	Bicortically	4.679	0.007*†	1.390	7.968
Dummy 1 (malocclusion)	Class I and Class III	–	–	–	–
	Class II	1.605	0.261	-1.274	4.484
Dummy 2 (malocclusion)	Class I and Class II	–	–	–	–
	Class III	2.670	0.277	−0.626	5.966
Canine impaction sector	Sectors 1, 2, and 3	–	–	–	–
	Sectors 4 and 5	3.211	0.068†	−0.264	6.686

R^2 = 0.699; regression *P* = 0.016.
*Statistically significant (*P* <0.05); †Selected variables (*P* <0.25).

Table V. Final multiple linear regression model to evaluate the duration of maxillary impacted canine traction in months

				95% CL	
Independent variable	*Value*	*β*	P	*Lower*	*Upper*
Constant		−6.967	0.182	−17.340	3.406
Sex	Male	–	–	–	–
	Female	2.049	0.027*	0.240	3.858
Type of impaction	Unilateral	–	–	–	–
	Bilateral	2.740	0.001*	1.158	4.321
β angle	°	0.055	0.009*	0.014	0.096
PNS-ANS distance	mm	0.175	0.071	−0.016	0.366
Dummy 2 (impacted canine location)	Palatally and buccally	–	–	–	–
	Bicortically	2.857	0.001*	1.196	4.517
Canine impaction sector	Sectors 1, 2, and 3	–	–	–	–
	Sectors 4 and 5	2.355	0.046*	0.047	4.663

R^2 = 0.538; *P* <0.001.
*Statistically significant (*P* <0.05).

orthodontic treatment on the duration of active orthodontic traction.

Some publications have been reported describing the presence of specific features of MIC that directly influence the duration of active traction, finding that α angle, d distance, and impaction sector are valid indicators for the duration of orthodontic traction.[11,15] Similarly, a paper using a bayesian network analysis (an intermediate graphic approach between statistics and artificial intelligence) concluded that bilateral impaction, pretreatment α angle, more severe tooth displacement, and greater distance ("d") of the impacted canine from the occlusal plane were associated with more prolonged treatment.[10] Finally, Fleming et al[14] pointed out that an accurate prediction of duration for orthodontic alignment of a palatally located MIC is difficult, although the mesiodistal position of the canine may be a useful predictor of treatment duration. All of these articles identify some common characteristics of the MIC position that could directly influence the active time of traction. However, there are still few studies,[10,14] and some use different prediction methods with the same sample,[11,15] so it seems necessary to evaluate what occurs in different samples to confirm their results or increase valuable information. The importance of the present study is that it included some variables that were not usually considered in previous prediction methods, including the root length and area of the MIC. Although they did not significantly influence the duration of active traction ($P > 0.05$), they could have increased the tensile strength and consequently the treatment time. However, in the present study neither of these variables produced this effect.

The duration of active orthodontic traction of MIC reported by most publications is an average of 8 months.[10,11] Similarly, our study found a similar traction time of 8.40 ± 3.26 months. Furthermore, previous studies on traction time of impacted canines generally did not take into account the patient's cephalometric characteristics, and some variables could modify the traction time.[10,11,14] These variables include maxillary position and length (SNA, PNS-ANS values) or the skeletal relationship (ANB or APDI angles). It could be thought that greater maxillary length or maxillary protrusion make the eruption of impacted canines more possible because of more available space for it.[20] However, that possibility was not observed in this study. In contrast to previous studies that found that greater canine impaction height or greater α angle increase the traction time, our study did not find that relationship.[10,11,15] It could be considered that the traction time may be shorter for an impacted canine in a very high position but in the premolar and lateral incisor sector compared with a canine impacted at a medium or low height but close to the midline. Regarding the α angle, we consider that the traction vector of an impacted canine frequently will be distal. Therefore, the resolution of an impacted canine will be adequately solved, independently from its horizontal position.

The multiple linear regression model applied in this study revealed that specific variables increase the time of active traction. We used this model to establish a prediction equation achieving a coefficient of determination of 53.8% that could be clinically relevant.[18] The description of this equation included independent variables that showed significant influence, including sex, type of impaction, β angle, PNS-ANS distance, impacted canine location, and canine impaction sector. Clinically, this mathematic model means that the orthodontist should consider these predictor variables, that in female patients the MIC traction time is 2 months longer than in male patients, and that the duration of active traction in bilateral cases is 2.74 months longer than unilateral cases. In addition, for each degree that the β angle increases, the traction time increases by 0.05 months, and the time of traction of a bicortically impacted canine or one in sectors 4 or 5 (ie, close to the midline) increases by 2.85 months or 2.35 months, respectively.

The fact that bilateral impaction, β angle, bicortical location, and canine impaction sector 4 or 5 influenced in the increase of traction time could be expected, because these cases involve approaches with greater complexity and more elaborate biomechanical planning. Cases with different severities of MIC were included in the present study to have greater variability of this condition; therefore, any relationship between a predictor variable and the time of traction could be detected.[21-23] Regarding sex, the fact that traction time increased in female patients, could be explained as an inherent characteristic of the sample. Further studies should be performed to evaluate the influence of sex in treatment time of MICs.

We found coincidences with previously published articles in the identification of predictor variables that increase the MIC traction time. However, the use of a multivariate analysis that included variables that were not evaluated previously, the use of dummy variables to improve the comparisons of variables with more than 2 categories, and finally the grouping of the impaction sector into 2 groups according to a clinical criterion make the final predictive model proposed useful to orthodontists when planning their treatments. Thus, they would calculate an approximate time of traction of an MIC with an accuracy higher than 50%.

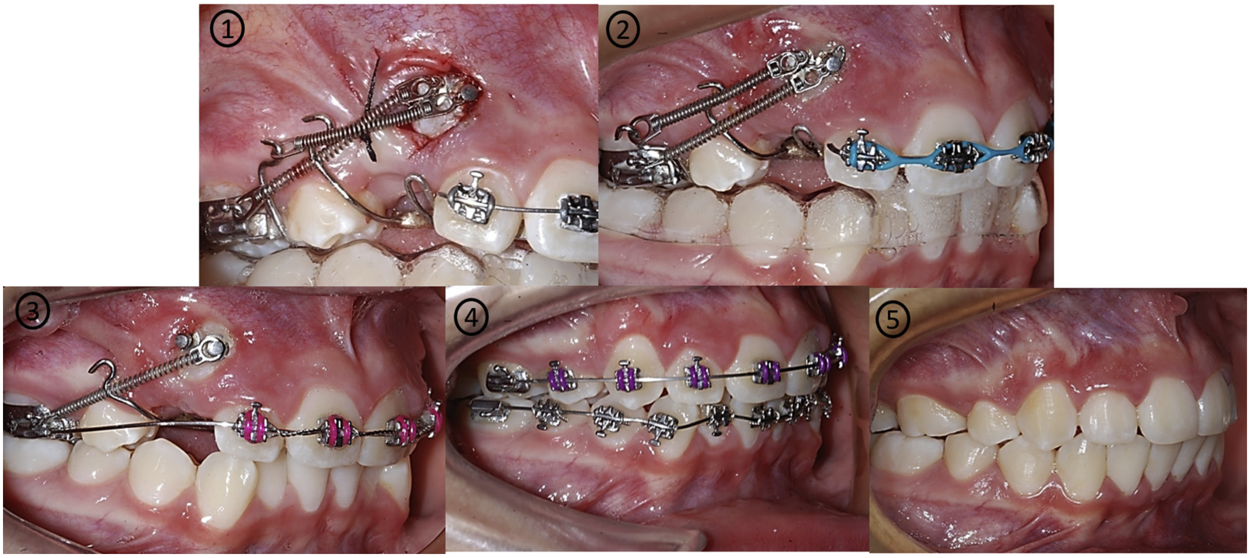

Fig 5. Sequence of maxillary impacted canine traction in an example case, including the final result.

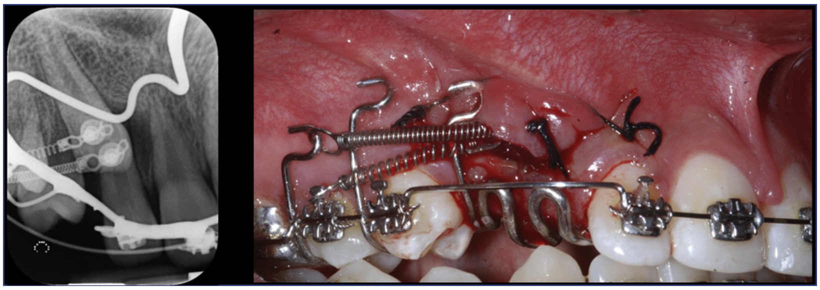

Fig 6. Maxillary impacted canine traction in a noncomplex case.

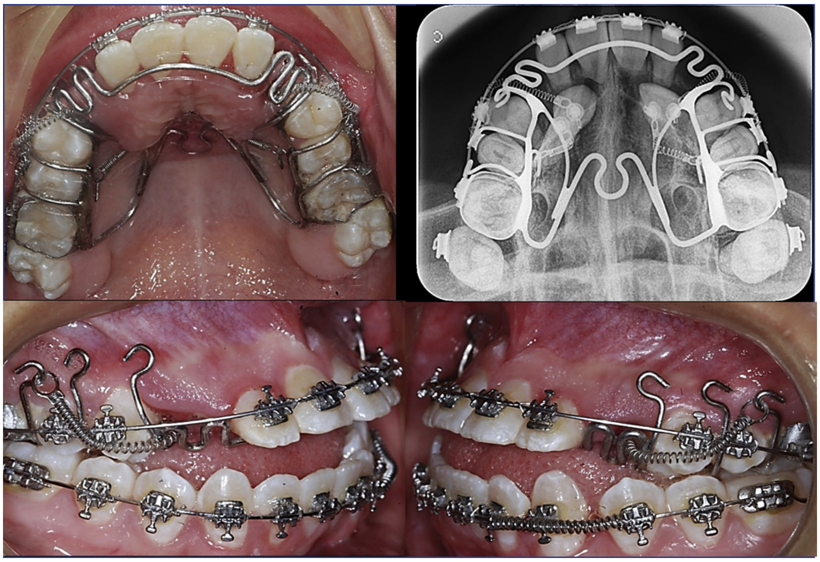

Fig 7. Maxillary impacted canine traction in a complex case.

In the present study, we controlled the influence of the traction technique or the orthodontist experience, because the cases were treated by only 1 orthodontist with more than 20 years of experience (G.A.R.-M.), and the traction technique included a standardized traction protocol that allowed an efficient traction of impacted canines (Figs 5-7). Furthermore, the orthodontist did not know that the data would be evaluated for this investigation purpose. In addition, the anchorage method used in this study allowed the efficient traction of the impacted canines controlling for the secondary effects of traction, such as the intrusion of neighbor teeth. For this, heavy wires were worked on the palate joining all the structures involved in supporting the traction forces as a single block. In addition, buccal hooks mainly served to prevent the insertion of the springs in the gum and ensure a continuous traction force (Fig 2). It could be expected that, independently from the appliance, traction mechanics that permits the control of the traction vectors and side-effects would produce similar results. Nevertheless, this should be confirmed in future studies.

An exact predictive model is difficult to define, because there are variables that cannot be controlled, such as biologic variability, bone response to orthodontic movement, bone density, and others, that together should increase the accuracy of a predictive method. Control and inclusion of these variables should be performed in future studies. We found that specific characteristics of canine impaction are those that most influence the duration of active traction of an MIC and that the factors related to orthodontic treatment did not significantly modify the treatment time. However, this proposed predictive model should be evaluated in future studies (cohort studies or randomized controlled trials) to prove its efficacy. Likewise, the ability to extrapolate the results requires studies with large sample sizes; although studies with similar samples were previously published,[2,14] this was the first study including the use of CBTC to measure root area and length, variables that could have been related to the increase of the time of traction, and more studies with larger samples are necessary.

CONCLUSIONS

The duration of orthodontic traction of maxillary impacted canines of this study subjects is mainly influenced by the sex of the patient, the condition of bilateral impaction, canines impacted bicortically, and sectors close to the midline, and these factors may increase the traction time by a few months. Nevertheless, further independent studies with greater sample sizes are needed to confirm our results.

SUPPLEMENTARY DATA

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ajodo.2018.10.018.

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