SPECIAL ARTICLE

Changes over time in canine retraction: An implant study

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Introduction: The objective of this study was to analyze rates of canine movement over the first 2 months of continuous retraction, when rate changes are expected. **Methods:** Ten patients with bone markers placed in the maxilla and the mandible had their canines retracted over a 2-month period. Retraction was accomplished with beta-titanium alloy T-loop springs. Standardized 45° oblique cephalograms where taken initially and every 28 days thereafter. The radiographs were scanned and digitized twice (the average was used for the analyses). The radiographs were superimposed by using the bone markers and oriented on the functional occlusal plane. Paired *t* tests were used to compare side and jaw effects. **Results:** There were no significant differences between sides. The maxillary cusp was retracted 3.2 mm, with less movement during the first (1.1 mm) than during the second 4 weeks (2.1 mm). The maxillary apices did not move horizontally. There were no significant vertical movements in the cusps and apices of the maxillary canines. The mandibular cusp was retracted 3.8 mm—1.1 mm during the first and 2.7 mm during the second 4 weeks. The mandibular apices were protracted 1.1 mm. The cusps and apices were intruded 0.6 and 0.7 mm, respectively. The only difference between jaws was the greater protraction of the mandibular apices during the second 4 weeks and in overall movement. **Conclusions:** The rate of canine cusp retraction was greater during the second than the first 4 weeks. The mandibular canines were retracted by uncontrolled tipping whereas the maxillary canines were retracted by controlled tipping. (Am J Orthod Dentofacial Orthop 2009;136:87-93)

Knowing the rate of tooth movement gives the orthodontist important physiologic and clinical information. Physiologically, rates of movement are indirect indicators of bone turnover and remodeling. Clinically, differences in rates of tooth movement determine whether and when to use intermaxillary mechanics during space closure. Understanding how teeth move is the basis for making treatment more efficient.

Animal studies show 4 phases of tooth movement after force application.[1,2] The tooth first shows an immediate slight movement, followed by a lag phase associated with hyalinization, a third phase with accelerated rates, and a fourth phase of constant movement. Of the human studies describing canine movements[3-21] (Tables I and II), most provide insufficient information to evaluate the lag phase, 2 studies[3,16] support a clear lag phase, and 4 do not.[5,6,11,14] For example, Iwasaki et al[11] could not detect the lag phase when low forces and high moments were applied to the canine, suggesting an even stress distribution to the root surface. The 4 studies that did not identify a lag phase based their rates of tooth movement on intraoral or model measurements; because of the lack of stable references, both measurements might be expected to be less reliable than radiographic assessments, which have been shown to be adequate in 45° radiographs.[22] With respect to frictionless mechanics, the only evidence of a lag phase is based on graphs of space closure showing decreased rates between the first and second weeks of canine retraction.[16]

In addition to uncertainty about the lag phase, the clinical literature reports highly variable rates of canine retraction. Rates range from approximately 0.2 mm per month[3] to over 2.5 mm per month.[18] Since the rates of tooth movement are also highly variable among subjects, the small sample sizes could explain some differences across studies.[7,23-25] It has also been established that continuous forces produce faster tooth movement than intermittent forces,[9,26] and that, generally, higher forces produce higher rates of tooth movement up to a point.[27] Moreover, friction mechanics produce lower rates of tooth movement then frictionless mechanics because the net force transmitted to the tooth to be moved

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Table I. Human clinical studies on canine retraction with mechanics involving some kind of friction (1 month = 4 weeks)

Author	*Clear evidence of lag phase*	*Movement per month (mm)*	*Patients (n)*	*Arch*	*Measurement*
Storey and Smith[3]	Yes	.21	5	Md	Models
Hixon et al[4]	N/A	.85	8	Md	Oblique (25°) radiographs
Andreasen and Zwanziger[5]	No	.96	14	Both	Clinical
Huffman and Way[6]	No	1.37 and 1.20	25	Mx	Clinical
Yamasaki et al[7]	N/A	1.3 (SD 0.16)	8	Both	Clinical
Ziegler and Ingervall[8]	N/A	1.33 (SD 0.58)	21	Mx	Clinical
Daskalogiannakis and McLachlan[9]	N/A	1.22	6	Mx	Model
Lotzof et al[10]	N/A	2.34	12	Mx	Model
Iwasaki et al[11]	No	1.27 and 0.87	7	Mx	Model
Hayashi et al[12]	N/A	1.81 (SD 0.19)	4	Mx	Model
Herman et al[13]		1.34 (first 2 months)	14	Mx	Model
Limpanichkul et al[14]	No	0.37	12	Mx	Model
Bokas and Woods[15]	N/A	1.75	12	Mx	Model

N/A, Information not available; *Md,* mandible; *Mx,* maxilla.

Table II. Human clinical studies on canine retraction with frictionless mechanics (1 month = 4 weeks)

Author	*Clear evidence of lag phase*	*Movement per month (mm)*	*Patients (n)*	*Arch*	*Measurement*
Boester and Johnston[16]	Yes	.98 mm	10	Mx/Md	Oblique (22.5°) radiographs
Ziegler and Ingervall[8]	N/A	1.79 (SD 0.39)	21	Mx	Clinical
Dincer and Iscan[17]	N/A	.85 (SD .41) .59 (SD .35) Mx; 1.03 (SD .85) .39 (SD .15) Md	12 Mx/8 Md	Mx/Md	Lateral radiographs
Tanne et al[18]	N/A	2.43	10	Mx	N/A
Lee[19]	N/A	2.24	7	Mx	Clinical
Daskalogianakis and McLachlan[9]	N/A	0.63	6	Mx	Model
Darendeliler et al[20]	N/A	1.43 (SD 0.58)	15	Mx	Lateral radiographs
Hasler et al[21]	N/A	0.91	22	Mx	Model
Hayashi et al[12]	N/A	1.95 (SD 0.34)	4	Mx	Model

N/A, Information not available; *Md,* mandible; *Mx,* maxilla.

might be smaller because of friction. The rate of movement can also be influenced by the type of tooth movement. Bodily movement, for example, has lower rates than tipping[28,29]; retraction of teeth into recent extraction sites is faster than retraction into healed sites.[21] In the literature pertaining to frictionless retraction, only 1 study used oblique radiographs necessary to reliably evaluate apical movements of each side.[16]

The objective of this study was to analyze rates of canine movement over the first 2 months of continuous retraction, when rate changes are expected because of the lag phase.[1-3,16] To more accurately superimpose the maxilla and the mandible, tantalum bone markers were used, and 45° oblique cephalograms made it possible to better distinguish the right and left canines. The aims were to determine whether the rates of movement were the same over time, whether there were differences between sides, and whether maxillary and mandibular canines have similar movement patterns.

MATERIAL AND METHODS

This prospective study included 10 patients (6 adolescent girls, 4 adolescent boys) aged 17.4 ± 2.6 years of age at the start of treatment, selected according to the following criteria: Class I molar relationship, treatment requiring 4 premolar extractions, maxillary and mandibular dental protrusion, and good hygiene and healthy dentition.

Four tantalum bone markers were placed in the maxilla (2 apical to the first molars and 1 on each side of the

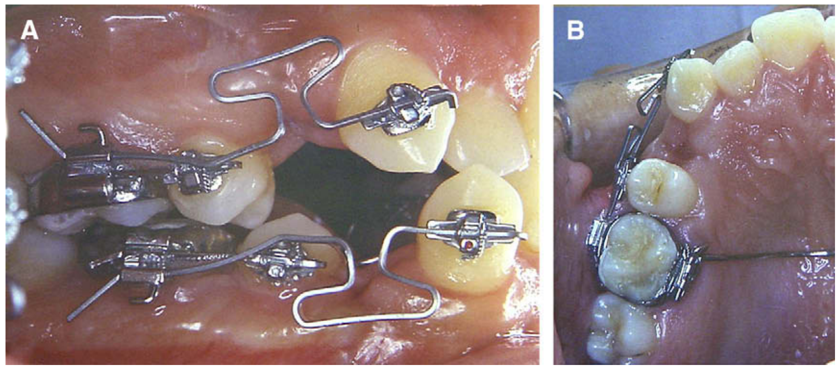

Fig 1. A, Lateral view of the segmented system used for the canine retraction; **B,** occlusal view.

Table III. Changes in maxillary and mandibular canine cusp tips and apices during the first (T1-T2) and second (T2-T3) 4 weeks of retraction and over the entire 8-week period (total change), with statistical comparisons over time (horizontally) and between jaws (vertically)

	Cusp tip							*Apex*						
	T1-T2		*T2-T3*		*Prob Sig*	*Total change*		*T1-T2*		*T2-T3*		*Prob Sig*	*Total change*	
	Mean	*SD*	*Mean*	*SD*		*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*		*Mean*	*SD*
Horizontal														
Maxillary	1.06†	.55	2.14†	1.24	.028*	3.20†	1.41	.08	.45	–.13	.63	.487	–.05	.53
Mandibular	1.05†	.88	2.73†	1.43	.002*	3.78†	2.01	–.16	.34	–.92†	.37	.001*	–1.08†	.47
Prob	.967		.261			.292		.289		.005*			<.001*	
Vertical														
Maxillary	–.21	.95	.33	.54	.499	.12	1.37	–.38	.79	–.15	1.2	.699	–.53	.96
Mandibular	–.22	.62	–.38	1.2	.752	–.59†	.94	–.46†	.57	–.20	.96	.562	–.66†	.83
Prob	.981		.405			.286		.830		.941			.785	

Prob, Probability; *Sig,* significance.
*Significant differences (P <0.05); †significant movement (P <0.05).

midpalatal suture, apical to the central incisors) and 3 in the mandible (2 apical to the first molars and 1 in the symphysis, apical and between the central incisors) according to the methods of Björk[30] and Björk and Skieller.[31] All patients gave informed consent, as required by the human subjects committee of Faculdade de Odontologia de Araraquara-Universidade Estadual Paulista (UNESP), which also approved the study's execution protocol.

The patients had their first molars banded and brackets (slot, .022 in) bonded to their second premolars. After leveling and alignment of the segments, the molars and the premolars were held as a segment by a .019 × .025-in stainless steel (SS) wire, tied with SS ligatures. Passive tranpalatal arches and lingual arches of 0.9-mm (.036 in) SS wires were used to consolidate the left and right segments. Brackets were bonded to the canines, and standardized 45° oblique cephalograms where taken 14 days after the first premolars were extracted (Fig 1).

A .017 × .025-in beta-titanium alloy T-loop spring (TTLS), preactivated for group A anchorage, with dimensions of 6 × 10 mm,[32] was placed in each patient's quadrant by using the following protocol: (1) the TTLS was made of a straight beta-titanium alloy wire (.017 × .025 in) and adjusted to be passive to the canine bracket and molar auxiliary tube on each side, (2) a 45° preactivation bend (second order) was placed directly below the posterior ear of the loop,[33] (3) antirotational bends (first order) where applied to the TTLS,[32] and (4) the TTLS was positioned with the anterior extremity of the loop directly above the canine bracket, secured with SS ties (.25 mm) and reactivated 4 mm (based on the separation of the lower vertical extremities of the loop).

The patients were evaluated every 28 days, exactly, for a total of 8 weeks. All patients where aware of the importance of the study, and none missed any appointments. They were also informed about the potential radiation hazards of multiple exposures, and consent was

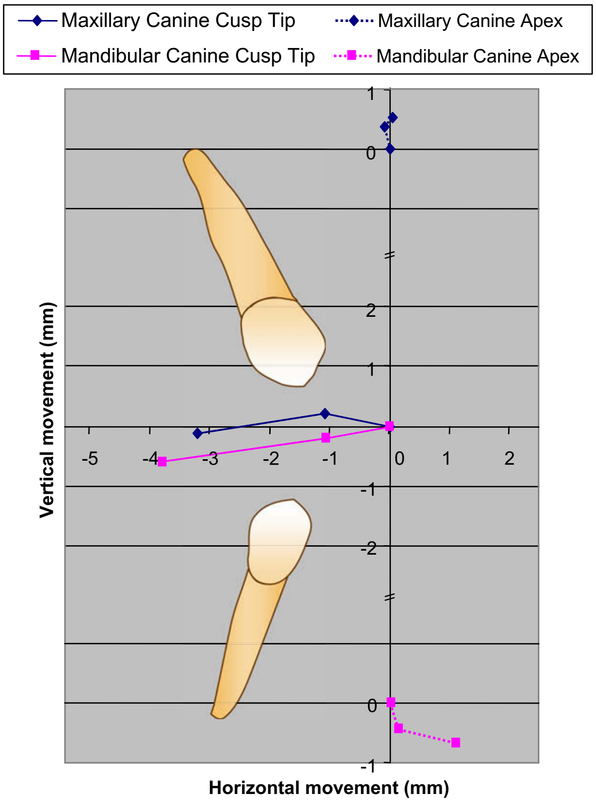

Fig 2. Movements of maxillary and mandibular canines cusp tips and apices during the 2 months of retraction. Markers on the lines distinguish movements during the first and second months of treatment. Negative values indicate extrusion and retraction of the maxillary canines, and intrusion and retraction of the mandibular canines.

obtained from each subject. During each appointment, the springs were removed, standardized 45° oblique cephalograms were taken of both sides, and the springs were reactivated to 4 mm.

The radiographs were scanned with a ruler for calibration at 450 dpi. Viewbox software (dHAL orthodontic software, Athens, Greece) was used to digitize the radiographs and make the measurements. Six landmarks were digitized in each quadrant, including the canine apex, the canine cusp tip, the second premolar cusp tip, the mesial cusp tip of the first molar, and both mesial and distal bone markers used for superimposition by the software. The digitization was performed twice by the same investigator (R.P.M.), and measurements were averaged to reduce error. T2 (4 week) and T3 (8 week) radiographs were superimposed on the initial (T1) radiograph by using the best fit of the bone markers. Each quadrant was evaluated separately. The radiograph that most clearly showed the apex and the tip of canine (not necessarily the same radiographs) was used to standardize each subject's tooth size.

The T1 functional occlusal plane, defined by the cusp tip of the second premolar and the mesial cusp tip of the first molar, was used as the reference plane for the measurements. After superimposing on the bone markers, the T1 functional occlusal plane was transferred by the software to the T2 and T3 images and used for orientation. The vertical and horizontal displacements of the cusps and apices of the canines were measured and recorded by subtracting the values at T2 and T3 from those at T1.

The measurements were transferred to SSPS software (version 12.0, SPSS, Chicago, Ill) for statistical analyses. The skewness and kurtosis statistics indicated approximately normal distributions. Paired *t* tests were used to compare side and jaw effects. Paired *t* tests of replicates showed that systematic errors were 0.006 to 0.075 mm; random method errors were 0.036 to 0.178 mm.[34]

RESULTS

The movements of the right and left canines were averaged because there were no significant ($P > 0.05$) differences between sides.

The maxillary canine cusp tip was moved distally 3.2 mm over the 8-week retraction period (Table III). The changes during the first 4 weeks (1.1 mm) were significantly ($P = 0.03$) less than changes during the second 4 weeks (2.1 mm). There was no significant vertical movement of the cusp tip. The maxillary apices were maintained in place, both vertically and horizontally, during the 2 months of retraction.

The mandibular canine cusp tip was retracted 3.8 mm, again with significantly ($P = 0.002$) less movement during the first (1.1 mm) than second (2.7 mm) intervals. The cusp tip was intruded significantly (0.6 mm) over the 8-week period. The mandibular apices were protracted 1.1 mm anteriorly and intruded 0.7 mm. During the first month of retraction, the apices of the mandibular canines maintained their positions horizontally and were intruded 0.5 mm; during the second month, they were protracted 0.9 mm and maintained their positions vertically.

With the exception of the apices during the second 4-week period, the mandibular and maxillary canines had similar amounts of movement. The anterior movements of the mandibular apices were significantly ($P = 0.005$) greater than the anterior movements of the maxillary canines (0.9 vs 0.1 mm) during the second 4 weeks and were largely responsible for the greater overall anterior movements (1.1 vs 0.05 mm).

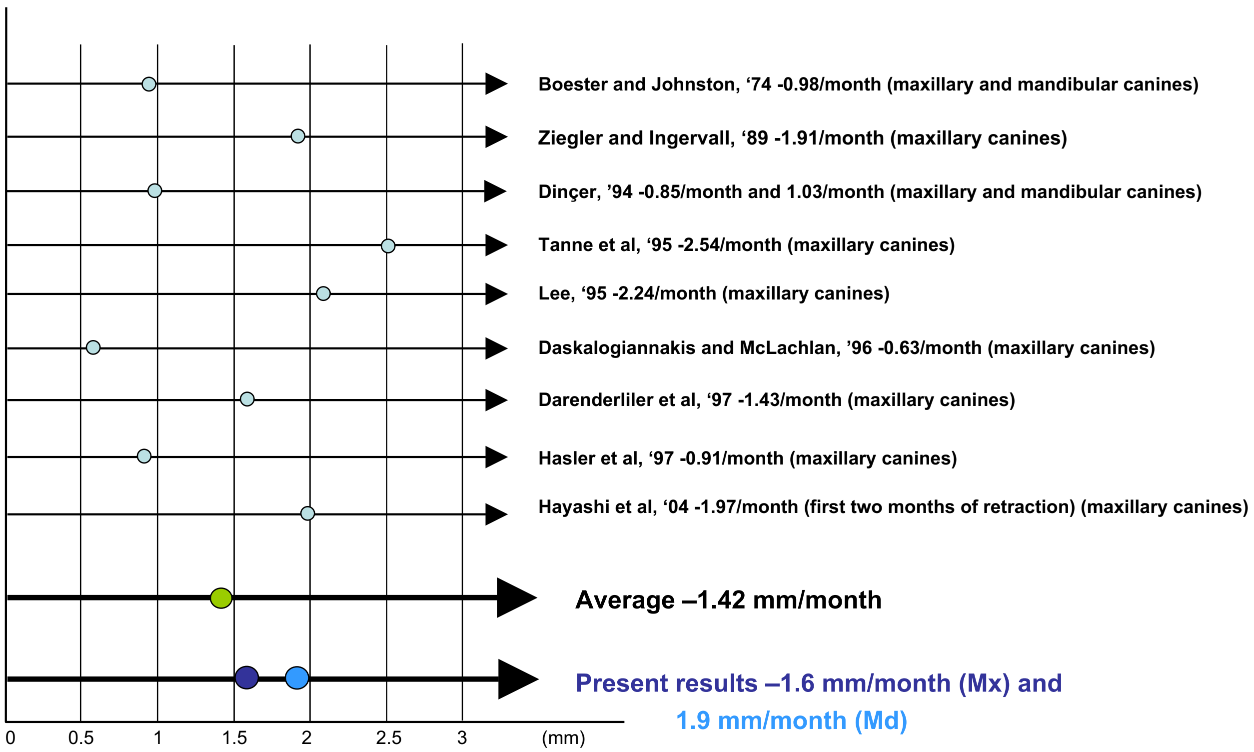

Fig 3. Clinical studies in humans reporting rates of canine movement for frictionless mechanics. Mean values and the average of the 9 studies are shown. The *blue line* depicts our results for the maxillary and mandibular canines (month, 4 weeks or 28 days).

DISCUSSION

The rates of canine cusp tip movements were greater during the second than the first 4 weeks of retraction (Fig 2). This provides indirect evidence of a lag phase during the first month of movement. Of the 9 articles pertaining to human canine retraction with frictionless mechanics (Table II), only 1 reported a clear lag phase during the first month of movement.[16] The remaining studied did not provide sufficient information (eg, only initial and final records were taken, large force variations, and so on) to identify a lag phase.[8,9,12,17-21] Our results support the results of animal studies showing an initial lag phase.[1,2] Our findings also indicate that the lag phase of space closure reported by Boester and Johnson[16] was, at least in part, associated with arrest of canine retraction. Clinically, this is important because canines should be expected to move slower during the first month of retraction than during the subsequent months.

Rates of maxillary and mandibular canine cusp retraction are approximately midway between the rates previously reported for frictionless mechanics. Monthly movements were approximately 0.2 to 0.5 mm, or 12% to 33% greater (Fig 3) in this study than the computed monthly average of canine retraction (limited to the first 2 months when possible) from previous studies.[9,16,17,20,21] Although various biologic and biomechanical factors could explain the high variability in rates of canine retraction across studies, the use of models and clinical assessments to determine tooth movements must be considered as potentially problematic.

Differences between maxillary (1.6 mm/4 weeks) and mandibular (1.9 mm/4 weeks) canine cusp tips were small and insignificant. Theoretically, greater movement of the mandibular canine crown might have been expected because it underwent uncontrolled tipping (ie, the crown moved distally 1.9 mm, and the apex moved mesially 1 mm) compared with the controlled tipping in the maxilla. Uncontrolled tipping might be expected to produce a greater movement, assuming it generates more stress than controlled tipping, because the rates of crown movements have been shown to be inversely proportional to the amounts of stress generated by the root moving through bone.[35] Iwasaki et al[36] recently demonstrated this relationship clinically. Differences between controlled and uncontrolled tipping are clinically relevant because rates of tooth movement can be slowed or increased, relatively, by moving teeth in different ways (ie, uncontrolled tipping, controlled tipping, and translation).[28,29] Importantly, post-hoc tests showed that our study had insufficient power to rule out a difference between jaws in the amounts of canine cusp retraction.

The results suggests that the TTLS preactivation or design should be different for maxillary and mandibular canine retractions. The 4 mm of activation of the TTLS delivered 396 gf horizontally and 35.4 gf vertically, with a moment-to-force (MF) ratio of 4.1/1.[37] Although the ideal force for tooth movement has not yet been determined, higher forces generally produce greater rates of tooth movement, up to a point.[27,32] Also, the MF ratio produced by the TTLS, although not high enough according to the literature, produced controlled tipping in the maxillary canines and uncontrolled tipping in the mandibular canines.[32,35,38,39] That suggests that a higher MF ratio is needed to retract the mandibular canines by controlled tipping. It is also possible that lower MF ratios than those reported in the literature could be used for maxillary canine retraction.

CONCLUSIONS

1. Rates of canine cusp tip retraction were greater during the second than the first 4 weeks of retraction.
2. The only significant difference in tooth movements between jaws pertained to the canine apices, which moved anteriorly 1 mm in the mandible and did not move in the maxilla.

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