ORIGINAL ARTICLE

Group A T-loop for differential moment mechanics: An implant study

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Introduction: When anchorage control is critical and compliance is less than ideal, efficient treatment depends on differential tooth movements. The purpose of this study was to evaluate the distal tipping of partially retracted canines and the mesial movement of the molars. **Methods:** Eleven patients had their maxillary and mandibular canines partially retracted with TMA (Ormco Corp, Orange, Calif) T-loop springs with 45° gable bends distal to the loops preactivated for group A (maximum anchorage). Metallic bone markers served as references. The canines were retracted until enough space was available for alignment of the incisors without proclination. Oblique (45°) radiographs were taken immediately before the initial activation and after partial retraction. The radiographs were scanned, superimposed on the bone markers, and measured digitally. **Results:** The mandibular canine crowns were retracted (4.1 ±1.9 mm) and intruded (0.7 ± 0.3 mm) by uncontrolled tipping. In contrast, the maxillary canine crowns were retracted (3.2 ± 1.4 mm) by controlled tipping. The maxillary and mandibular molars crowns were protracted by similar amounts (1.0 ± 0.6 and 1.2 ±1.2 mm, respectively) by controlled tipping, without significant extrusion. The molars were protracted approximately 0.3 mm for every 1 mm of canine retraction. **Conclusions:** The T-loop spring used in this investigation produced controlled tipping of the maxillary canines, but it did not produce controlled tipping of the mandibular canines or translation of the molar as expected. (Am J Orthod Dentofacial Orthop 2009;135:182-9)

Full-step Class II extraction patients, patients with bimaxillary protrusion and lip incompetence, and asymmetric extraction patients often require maximum anchorage in the posterior segment. When anchorage control is critical and compliance is less than ideal, efficient treatment depends on differential movement of teeth. This can be accomplished by translating the posterior segment, effectively minimizing tooth movement by distributing the force over a larger root surface area, and by controlled tipping of the anterior segment, maximizing crown movements while maintaining the position of the apex.[1,2] The actual tooth movement depends on the point of force application (ie, the bracket), the line of force application (LFA), the tooth's center of resistance (CRes), the moment produced when the force is not applied to the CRes, and the moment-to-force (MF) ratio (Fig 1, *A*). Practically, if the force applied to a tooth is perpendicular to its long axis, the MF ratio needed to produce translation is determined by the distance between the bracket and the CRes. In the literature, it is usually assumed that the LFA is perpendicular to the tooth's long axis, suggesting that MF ratios of approximately 10/1 mm and 7/1 mm are required for translation and controlled tipping, respectively.[3-8]

Because of confounding factors that could alter the perpendicular distance of the CRes to the LFA, theoretical MF ratios might not be expected to translate into clinical reality. For example, teeth are usually not located perpendicular to the occlusal plane; this effectively reduces the vertical distances between the CRes and the LFA and alters the MF ratio required for translation (Fig 1, *B*). For the same reason, longer teeth require more moment for translation than smaller teeth.[9-11] The MF ratio could also be affected by the height of the alveolar crest, root shape, and the distance from the LFA to the CRes, which could change because of root resorption or periodontal disease.[9,10,12] Various tooth movements—eg, tipping, extrusion, and intrusion—could also change the force system.[13]

In 1990, Marcotte[4] introduced a .017 × .025-in TMA (Ormco Corp, Orange, Calif) T (10 × 6 mm) loop spring (TTLS) preactivated with a 45° gable bend distal to the loop. It theoretically generates MF ratios of 7/1 mm on the anterior extremity and 10/1 mm in the

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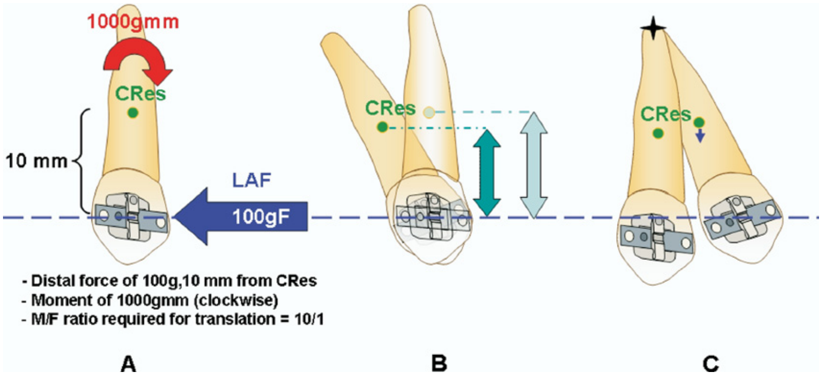

Fig 1. A, System of forces acting on a tooth when a single force is applied away from the CRes (evaluated in 2 dimensions); **B,** effects of tipping and changes in angulation of the LFA on the distance of the LFA to the CRes; **C,** effect of true controlled tipping on the vertical position of the CRes.

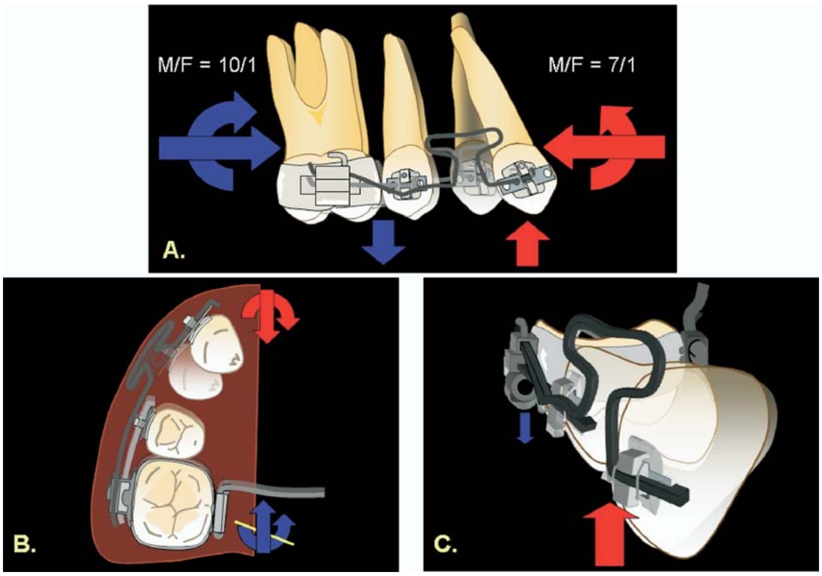

Fig 2. Theoretical system of force of a group A TTLS: **A,** lateral view; **B,** occlusal view; **C,** anteroposterior view.

posterior extremity of the TTLS.[3,4] To achieve equilibrium, an intrusive force at the canines and an extrusive force at the molars are generated (Fig 2). This TTLS holds promise in group A (maximum anchorage) anchorage patients who require controlled tipping of the canines and translation of the posterior segment because it generates asymmetrical moments.[3,4] It is important to determine whether unwanted tooth movement occurs with the TTLS because its effects have not been systematically evaluated in a clinical situation.

The purpose of this prospective clinical investigation was to evaluate the movements produced during partial retraction of the maxillary and mandibular canines with a group A TTLS.[4] Uniquely, in this study, we used 45° oblique radiographs and metallic bone markers to ensure accurate and precise measures of tooth movement. Our aims were to determine whether controlled tipping occurs in the anterior segment and translation occurs in the posterior segment.

MATERIAL AND METHODS

This prospective sample included 11 patients (7 female, 4 male) approximately 18.5 ± 3.7 years of age at the start of treatment, selected according to the following criteria: Class I molar relationships, 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 (1 apical to the first molars and 1 on each side of the midpalatal suture, apical to the central incisors), and 3 were placed in the mandible (1 apical to the first molars and 1 in the symphysis, apical and between the central incisors) according to the methods of Björk[14] and Björk and Skieller.[15] All patients provided informed consent, as approved by the human subjects committee of the Araraquara School of Dentistry, Universidade Estadual Paulista, Araraquara, Brazil, where the study was performed.

The segmented arch technique includes consolidation of teeth into segments to allow for easier planning and more predictable systems of forces.[3] The posterior segment (Fig 2), also called beta, has the posterior teeth on each side united by a large and stiff wire. The right and left sides are connected by a stiff transpalatal arch (TPA), transforming the several posterior teeth into a large multirooted tooth with 1 CRes. The anterior segments, also called alpha, included the right and left maxillary canines.

The partial retraction is accomplished by the group A preactivated TTSL. It develops an MF ratio of 10/1 mm on the beta extremity, to produce translation, and an MF ratio of 7/1 mm on the alpha extremity, to produce controlled tipping (assuming that the CRes of each segment is located 10 mm perpendicular to the LFA). That difference of MF ratios generates vertical forces to achieve equilibrium (Fig 2, *A* and *C*). These forces, extrusive on the beta segment, are expected to be neutralized by the occlusal forces and are intrusive in the alpha segment, helping to maintain crown level. The canine rotation expected from moments associated with retraction (LFA is buccal to the CRes) are to be neutralized by the antirotation bends incorporated in the TTLS (Fig 2, *B*). The reciprocal moments do not occur in the beta segment because the force is bilateral, and the moments are canceled (the TPA connects the right and left segments). Small changes in the buccolingual inclinations of the canines can occur because the intrusive force (Fig 2, *C*) is applied buccally to the CRes; the reciprocal moments in the beta segment are cancelled by the TPA.

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 premolars were held as a segment by a .019 × .025-in stainless steel wire, tied with stainless steel ligatures. Passive TPAs and lingual arches of 0.9 mm (.036 in) stainless steel wires were used to consolidate the left and right segments. Brackets were bonded to the canines, and standardized 45° radiographs where taken 14 days after the first premolars were extracted.

One .017 × .025-in TTLS of group A anchorage, with dimensions of 6 × 10 mm,[4] was placed in each patient's quadrant by using the following protocol.

1. The TTLS was made of straight beta-titanium alloy wires (.017 × .025 in) and adjusted to be passive to the canine bracket and the molar auxiliary tube on each side.
2. A 45° preactivation bend was placed directly below the posterior limit of the loop.[16]
3. Antirotational bends where applied to the TTLS.[4]
4. The TTLS was positioned with the anterior extremity of the loop directly above the canine bracket. It was secured with stainless steel ties (.25 mm) and activated 4 mm (based on the separation of the lower vertical extremities of the loop).

The patients were evaluated every 28 days. During each appointment, the springs where removed, standardized 45° radiographs were taken of both sides, pictures were taken, and the springs were reactivated 4 mm. This schedule continued until enough space was created for leveling and alignment of the teeth without incisor proclination. One patient required only 1 appointment, 8 required 2 appointments, and 2 required 3 appointments.

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. The final radiograph was superimposed on the initial 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 the canine and the molar (not necessarily the same radiographs) was used to standardize each subject's tooth size.

Eight landmarks were digitized in each quadrant, including the canine apex, the canine cusp tip, the canine's CRes (a third of the total distance from the alveolar crest to the apex),[5,12,17] the center of the canine bracket, the second premolar cusp tip (average of the lingual and buccal cusps), the first molar mesial cusp tip, the first molar CRes (furcation of the molar),[18,19] and the auxiliary tubes of the first molars (located vertically in the middle of the tube and horizontally at the entrance of the tube).

The initial 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 initial functional occlusal plane was transferred by the software to the final image. The interbracket distance, the vertical and horizontal distances

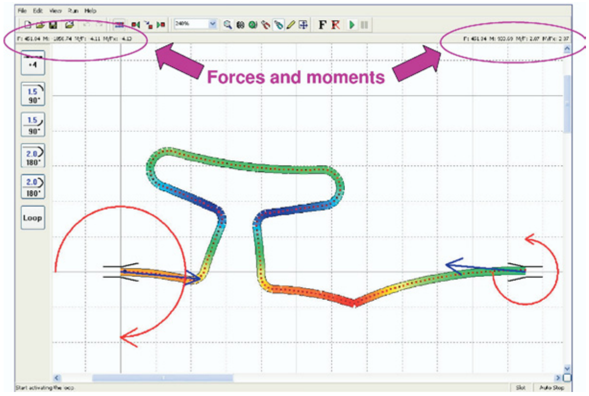

Fig 3. Approximate system of forces of the TTLS used in this study, estimated by the loop software. The left bracket is the canine bracket, and the right bracket is the molar tube. Gross forces and moments need to be corrected by a factor of .88. Each square equals 4 mm^2.

between the brackets and the CRes of the canines, the vertical distance from the auxiliary tubes to the CRes of the molars, the inclination of the canines, and the vertical and horizontal displacements of the cusps and apices of the molars and canines were measured. The centers of rotation (CRot) were estimated based on the intersection of the perpendicular bisectors of the lines joining the initial and final apices and cusps.

The measurements were transferred to SSPS software (version 12.0, SPSS, Chicago, Ill) for the statistical analyses. The skewness and kurtosis statistics indicated approximately normal distributions. Paired *t* tests were used to compare side and jaw effects. Replicate analyses showed that systematic errors were 0.006 to 0.075 mm; random method errors were 0.036 to 0.178 mm.[20]

Loop software (version 1.7, dHAL Orthodontic Software) was used to estimate the TTLS force system. The forces estimated by the software were corrected as described by Halazonetis[21] to 396 gF horizontally and 35.4 gF vertically (Fig 3). The forces were distal and extrusive on the anterior bracket, producing a MF ratio of 4.1/1 mm; they were anterior and intrusive on the posterior bracket, producing a MF ratio of 2.1/1 mm.

RESULTS

Because there were no significant (P >0.05) differences between the right and left sides, they were averaged to simplify the presentation of the results.

The interbracket distances, the horizontal and vertical distances to the CRes, and the inclinations of the canines showed no significant (P <0.05) differences between the maxilla and the mandible (Table I). The average interbracket distance was 23.2 mm; the canine bracket was located 2.1 mm anterior and 8.8 mm occlusal to the CRes. The auxiliary tube was located approximately 6.0 mm occlusal to the CRes of the molars (Table I and Fig 4).

The maxillary and mandibular canine crowns were significantly retracted (3.2 and 4.1 mm, respectively) and intruded slightly (0.1 and 0.7mm, respectively). The maxillary and mandibular canine apices were intruded 0.7 and 0.6 mm, respectively (Fig 5). The mandibular canine apices were moved mesially approximately 1.2 mm; this was significantly (P <0.05) more than the 0.1-mm mesial movement of the maxillary canines (Table II).

The maxillary and mandibular molar crowns were significantly protracted (1 and 1.2 mm, respectively) with no significant vertical movements. With the exception of a slight intrusion of the apex of the maxillary molars (0.2 mm), the apices of the maxillary and mandibular molars were not moved significantly.

Vertically, the average CRots for the maxillary canines and the molars were at the level of the apices (Fig 5), indicating controlled tipping. For the mandibular canines, the CRot was between the apex and the CRes, indicating uncontrolled tipping. Controlled tipping was assumed when the CRot was approximately at the level of the apex; uncontrolled tipping was assumed when the CRot was between the apex and the estimated CRes. Horizontally, the average CRot was anterior to the CRes for both the maxillary and mandibular canines, indicating intrusion, and around the apex for both molars, indicating vertical control.

DISCUSSION

The mandibular canines were intruded and retracted with uncontrolled tipping by using the TTLS. The crowns were displaced distally approximately 4.1 mm and intruded 0.7 mm, and the apices were moved anteriorly and intruded approximately 1.2 and 0.6 mm, respectively. The CRot was located between the apex and the CRes. The TTLS did not produce controlled tipping as expected for the mandibular canines. According to the relationship between the MF ratio and tooth movements, only a small change of the MF ratio would have been needed to produce controlled tipping.[3,22] Uncontrolled tipping was due to insufficient moment on the canines. This was caused by the design of the loop, which should have been larger; the position of the loop, which should have been placed more anteriorly; and the location of the tip-back bend, which was too far to the anterior. Although more moment was needed on the canine, efforts must be made to ensure

Table I. Initial values of the position of teeth and brackets in the group studied

	Maxillary		*Mandibular*		*Group differences*
	Mean	*SD*	*Mean*	*SD*	P *value*
Interbracket distance (mm)	22.98	1.97	23.32	2.07	0.730
Horizontal distance do Canine Cres (mm)	2.11	1.37	2.07	1.93	0.389
Vertical distance to the Canine CRes (mm)	8.87	1.80	8.84	1.73	0.560
Vertical distance to the Molar CRes (mm)	5.94	0.94	6.08	0.97	0.973
Inclination of the Canine (degrees)	101.04	12.76	102.91	6.49	0.196

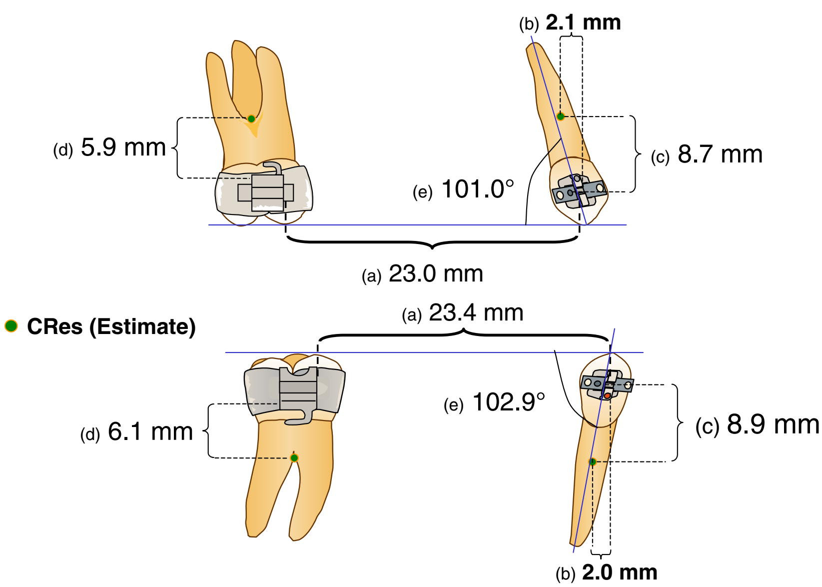

Fig 4. Measurements (average) in this study: *a,* interbracket distance; *b,* horizontal distance from the bracket to the canine CRes; *c,* vertical distance from the bracket to the canine CRes; *d,* vertical distance from the auxiliary tube of the molar to the CRes (of the molar); *e,* inclination of the canines.

that the posterior moment is always greater than the anterior moment. This difference rotates the occlusal plane by intruding the canine and extruding the molar to achieve equilibrium. This also helps to control canine retraction, because such rotation, with an intrusive force anterior to the canine's CRes, make it possible to produce controlled tipping with a lower moment on the canines.[23] During deactivation of the spring, the whole system of forces can change by the movement of the teeth, requiring a self-corrective loop with proper compensation,[13] or the spring must be readjusted every month.

There was greater control of the maxillary than mandibular canines during retraction. They showed controlled tipping on average. Vertically, the CRot was located closer to the apex of the maxillary than the mandibular canines, and the apex did not move anteriorly as much as did the apex of the mandibular canine. This indicates that the maxillary canines intruded; thus, the vertical level of their crowns was maintained (Fig 1, *B* and *C*), and they were tipped with a MF ratio sufficient for controlled tipping. The crowns of the maxillary canines were not retracted as much as the mandibular canines, and there was no intrusion of the crown. Differences between the jaws in canine movement might have been due to the larger distance between the LFA and the CRes in the mandible. If the mandible offers more resistance to movement than the maxilla, it shifts the mandibular CRes apically; this could also explain the differences observed.

The maxillary and mandibular molar crowns were protracted approximately 1.1 mm by controlled tipping, without significant intrusion or extrusion. Anchorage control was greater than previously reported by some[24-26] and less than reported by others.[1,2] The primary objective of the TTLS in the posterior region was to produce translation of the molar, which occurred in only a few patients. The MF ratios were too low;

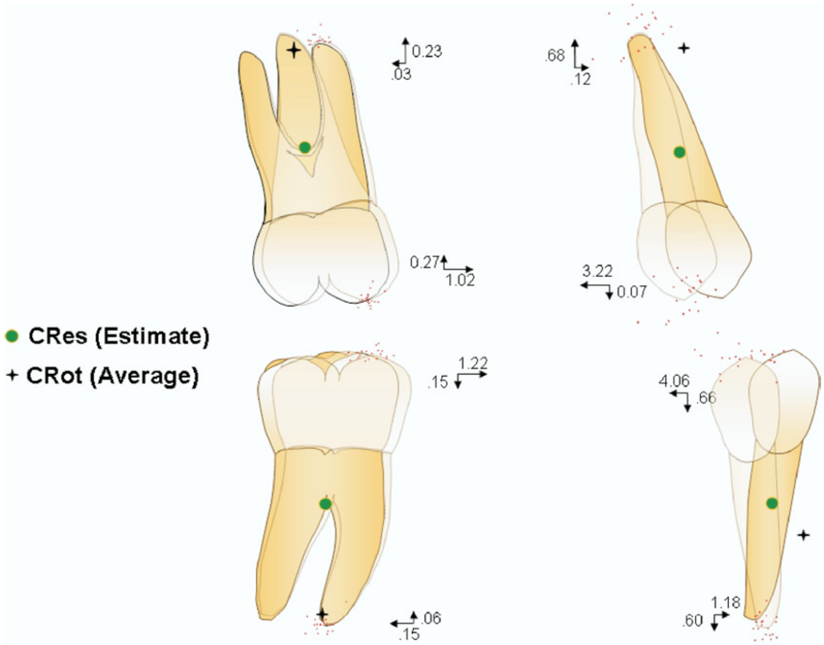

Fig 5. Average displacements of the apices and cusps tips of the canines and molars and the relationships of CRots and CRes. Individual variability is depicted by *red dots*.

Table II. Horizontal and vertical treatment changes of the canines and molars (negative values indicate anterior and apical movements measured relative to the occlusal plane)

	Maxillary		*Mandibular*		*Group differences*
	Mean	*SD*	*Mean*	*SD*	P *value*
Canine					
Cusp Horizontal	3.22*	1.41	4.06*	1.89	0.090
Cusp Vertical	0.07	0.38	−0.66*	0.27	0.214
Apex Horizontal	−0.13	0.13	−1.18*	0.58	<0.001†
Apex Vertical	−0.68*	0.28	−0.60*	0.79	0.838
Molar					
Cusp Horizontal	1.02*	0.58	1.22*	1.21	0.415
Cusp Vertical	−0.27	0.48	−0.15	0.39	0.538
Apex Horizontal	−0.03	0.69	−0.15	0.77	0.850
Apex Vertical	−0.23*	0.46	0.06	0.61	0.087

*Significant movement ($P < 0.05$); †Significant changes ($P < 0.05$).

higher ratios would have been necessary to produce pure translation. The low MF ratio posteriorly was probably caused by the location of the tip-back bend, which should have been positioned in relation to the molar tube rather than to the spring. When the bend was closer to the molar tube than to the canine bracket, more moment was produced on the molar tube, and the canine was intruded (Fig 6, *A*). When it was closer to the canine, more moment was produced on the canine bracket, and the molars were extruded (Fig 6, *B*). Both situations can be seen in Figure 5, even though the canines were generally intruded. Because both the maxillary and mandibular canines were intruded, molar extrusion was expected, but occlusal forces probably played a role in maintaining the molars' vertical positions. This implies that the moment was smaller at the

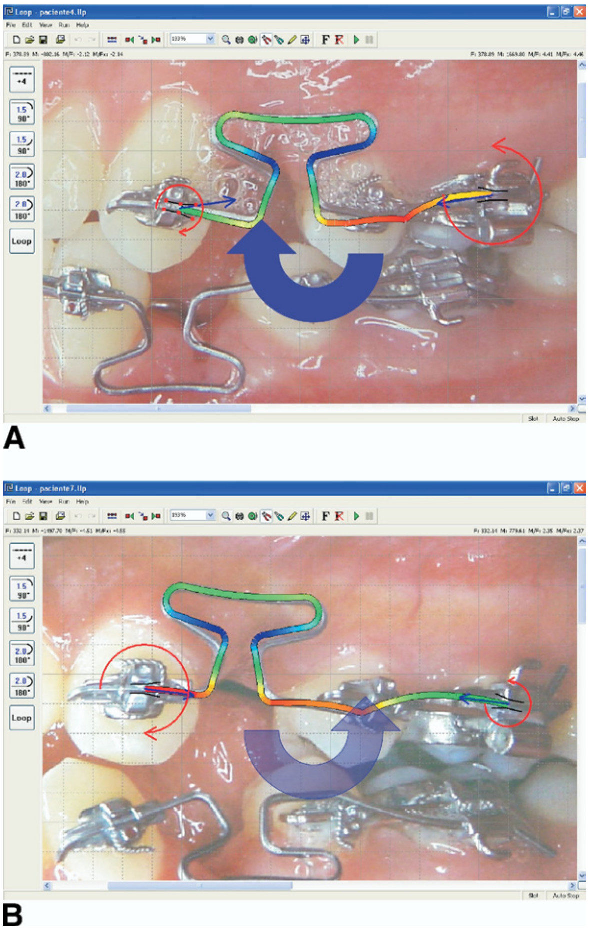

Fig 6. A, Approximated force system in a subject with desirable force directions (estimated with loop software). *Blue arrow* (added by the authors) shows the moment produced by the vertical forces on the canines and the posterior segments to achieve equilibrium. B, Approximated force system in a subject with undesirable force directions (estimated with loop software). *Blue arrow* (added by the authors) shows the moment produced by the vertical forces on the canines and the posterior segments to achieve equilibrium.

canines than at the molars, because, otherwise, the canines would have been extruded and the molars intruded. Because of anatomic differences and a lack of standardization of the loop's tip-back bend, the estimates of the loop software could not be applied, on average, to the patients studied.

As previously mentioned, the planned tooth movements of our sample, especially for the mandibular teeth, required a higher MF ratio. This can be accomplished by increasing the moment, by decreasing the force, or by changing the MF ratio required to produce the desired movements. The easiest way to increase the moment is by altering the dimensions of the spring,[13,27,28] by bringing the TTLS closer to the bracket,[29] or by increasing the angulation between wire and bracket.[3] On the anterior segment, the moment could have been increased by preactivating the TTLS anteriorly, as shown by Burstone.[3] In the posterior segment, the moment could have been increased by bringing the distal gable closer to the molar (about 4 mm from the tube). Alternatively, headgear could have been added to produce distal crown tipping of the posterior segment. The denominator of the MF ratio can be decreased by diminishing the activation of the spring or by increasing the amount of wire used in the spring. Finally, it is possible to change the moment required for a desired movement by changing the LFA, while maintaining the MF ratio of the spring. This can be done by ensuring that the LFA passes closer to the CRes, by either bonding the brackets more cervically or having higher intrusive forces anterior to the CRes.

Based on the results of this study, the MF ratios typically recommended are excessive and should be different for the posterior and anterior segments (or the canines).[3-6,8] With the exception of the 8/1 mm MF ratio suggested for translation of the incisors[7,12] and values ranging from 4.1 mm to 6.7 mm (location of the CRes) apical to the brackets in anterior segments,[30] most laboratory and experimental estimates of MF ratios to produce translation vary from 10 mm to 14 mm[5,31-33]; these are too high based on our findings. The differences are due to the LFA, which is usually evaluated perpendicular to the teeth and overestimates the resistance offered by the bone. When teeth are initially tipped, the distance between the LFA and the CRes becomes smaller than when they are upright (Fig 1, *B*). The smaller the distance, the less moment required to produce the same movement. Although the same spring was used in both jaws (presumably the MF ratio was the same) and the estimated distances from the LFA and the CRes were also the same, the mandibular canines showed less control than the maxillary canines. This suggests that more moment is required for the mandibular canines than the maxillary canines for the same kind of movement. Lower MF ratios are required in molars than in canines to produce the same amount of movement because the LFA is closer to the CRes. Since the molar auxiliary tube is positioned farther apically than the canine bracket, it further decreases the MF ratio required for tooth movement.

CONCLUSIONS

Based on a sample of 11 patients whose canines were partially retracted with the TTLS for approximately 2.1 months, we concluded the following.

1. The mandibular canines were intruded and retracted by uncontrolled tipping. The crowns were retracted 4.1 mm and intruded 0.7 mm, and the apices were protracted 1.2 mm and intruded 0.6 mm.
2. The maxillary canines were also intruded and retracted by controlled tipping. The crowns were retracted 3.2 mm, and the apex was intruded 0.7 mm.
3. The maxillary and mandibular molars crowns were protracted similar amounts (1.0 and 1.2 mm, respectively) by controlled tipping, without significant extrusion. Their apices maintained their positions vertically and horizontally.
4. The molars crowns were protracted approximately 0.3 mm for every 1 mm of canine crown retraction.

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