Original Article

The Tip and Torque adjustable bracket as a new concept in design: *An in vitro study*

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ABSTRACT

Objectives: To test a new concept in bracket design—the tip and torque adjustable bracket (TTAB)—to identify its integral ability to change both tip and torque.

Materials and Methods: The newly designed TTAB underwent independent testing using the orthodontic measurement and simulation system. The TTAB incorporated Roth tip and torque prescription values, with the unique quality of the bracket to enhance or reduce the innate prescribed values of tip (by either +10° or –10°) and torque (by either +7.5° or –7.5°). The TTAB was tested using both the incorporated standard Roth prescription on the rate of canine retraction (sliding mechanics), using 0.018-inch stainless-steel (SS) arch wire, and with alteration of tip values (–10° and +10°). Similarly, frictional measurements and torque evaluations using 0.019 × 0.025-inch SS arch wire were undertaken with the standard prescription and altered torque (+7.5° and –7.5°). In addition, a number of control investigations were performed. Differences were analyzed using analysis of variance.

Results: The rate of observed tooth movement for the TTAB with its prescribed baseline values was comparable to that of the control brackets. Importantly, the alteration of TTAB tip to –10° and +10° significantly ($P < .001$) increased and reduced, respectively, the rates of canine retraction. In the alteration of torque, at +7.5° and –7.5°, the bracket delivered a moment of +9.3 (2.8) Nmm and –11.9 (3.8) Nmm, respectively, to the lateral incisor ($P < .001$).

Conclusions: This in vitro study demonstrates a new concept in preadjusted edgewise bracket design, offering adjustable tip and torque, with the potential for expanded clinical scope. (*Angle Orthod.* 2022;92:380–387.)

KEY WORDS: Adjustable; Bracket; Design

INTRODUCTION

The specialty of orthodontics has witnessed a natural evolution in bracket design, from the standard edgewise bracket to the more contemporary preadjusted edgewise bracket. The introduction by Andrews[1] of a customized bracket, which took specific account of the tooth's desirable tip and torque, served to both simplify and facilitate tooth movement and, in particular, sliding mechanics. Controversy continues over the specific bracket prescription variables of tip and, more notably, torque.[2] Thus, the advent of a bracket system that permits clinicians to adapt to the specific needs of each malocclusion would offer greater scope. The precise impact of these prescription variations on the final tooth position is indeed complex and multifactorial, influenced by mechanical properties, such as bracket and arch wire dimension and material, and also by clinical variables, such as the mode of arch wire ligation, thickness of the adhesive layer, and bracket placement relative to the morphology of the tooth surface.[3,4]

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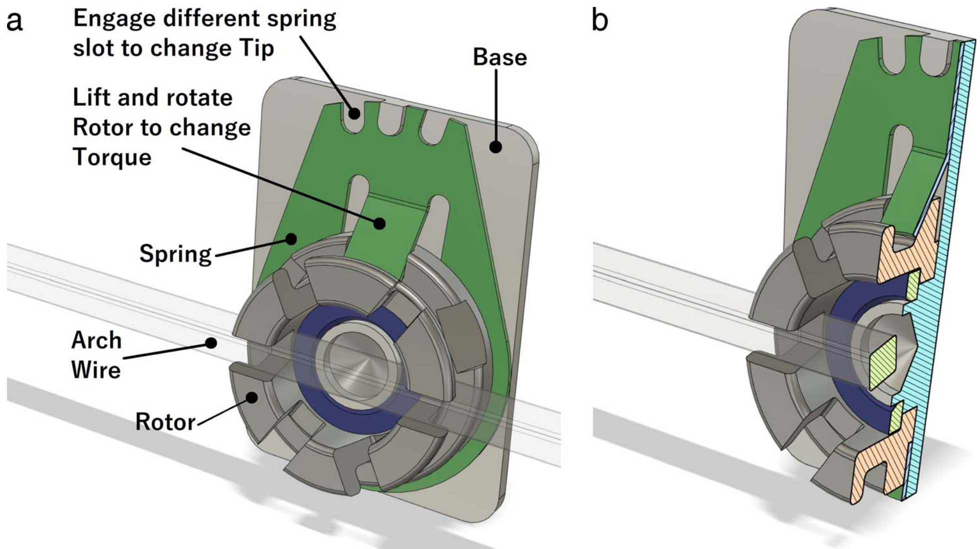

Figure 1. The tip and torque adjustable bracket (TTAB). (a) Labeled components; (b) sectional view.

In biomechanical terms, fixed appliances are able to apply both forces and corresponding moments to the tooth, which are collectively referred to as the "force system."[5] Thus, successful orthodontic treatment relies on the ability to apply an appropriate force system to the tooth in question while minimizing the unwanted biomechanical effects on the adjacent teeth and their clinical side effects, such as pain and resorption. Clinical examples of this are seen during all stages of fixed appliance treatment, from arch leveling and alignment to space redistribution and finishing. During these movements, both forces and moments are created in all three planes of space, and the relative force system acting on the tooth can be represented by the corresponding three-dimensional force and moment vectors (x, y, and z).[6]

The Orthodontic Measurement and Simulation System (OMSS) developed at the University of Bonn has demonstrated both reliability and validity in measuring forces and moments generated in all three planes of space during tooth movement.[3,4,6,7] The system therefore overcomes many of the limitations posed by in vitro testing and pure mathematical measures.[8] Of greatest significance to clinical practice, the OMSS permits both absolute and simulated tooth movements through the application of two force-moment sensors.

The present in vitro study tested a new concept in bracket design: the tip and torque adjustable bracket (TTAB), to identify its integral ability to change both tip and torque values, and the study tested the following hypotheses:

1. The TTAB performs similar to control brackets in tooth translation.
2. The introduction of positive and negative tip within the TTAB has a direct effect on the rate of tooth movement.
3. The frictional characteristics of the TTAB are comparable to those of a control bracket and are influenced by the method of ligation.
4. The introduction of enhanced or reduced torque within the TTAB has an equivalent effect on root position.

MATERIALS AND METHODS

The TTAB Design

The TTAB was designed and manufactured (international patent publication WO2020/161494 A1) with a 0.022 × 0.028-inch slot dimension and using the principles of preadjusted edgewise design. The bracket incorporated a standard Roth tip and torque prescription value, with the unique quality to enhance or reduce the innate prescribed values of tip by either +10° or –10° and of torque by either +7.5° or –7.5° (Figure 1).

The tip value is changed by lifting the Green spring and engaging the central Gray notch on the bracket base (Figure 1), which represents the TTAB neutral value (ie, the incorporated Roth tip). To enhance the tip by +10°, the Green spring is lifted and rotated to the right, such that the far left groove is engaged. To reduce the tip by –10°, the Green spring is lifted and rotated to the left. To adjust the torque value, the central rotor spring is lifted and rotated. In the present setting (Figure 1), the arch wire is seen to engage the central TTAB slot. To enhance (+7.5°) or decrease (–7.5°) the torque prescription, the rotor spring is rotated clockwise or anti-clockwise, respectively, to engage the respective arch wire slots.

The OMSS

The OMSS utilizes two force-moment sensors that are mounted on independent motor-driven positioning tables with full three-dimensional movement in a temperature-controlled chamber. The OMSS may be regarded as a form of 'electronic typodont' in which the wax has been replaced by force sensors, a mathematical model of tooth movement, and the motorized positioning tables. The OMSS allows the investigator to analyze and compare different orthodontic treatment devices, bracket systems, or arch wire types under standardized conditions. In addition, the OMSS registers the full applied force systems (force and moment) acting on the tooth to be moved and the corresponding three-dimensional movement (x-, y-, and z-) vectors in all components (translation and rotation) through a central computer (Figure 2).[6,7]

Simulated Tooth Movement Testing

The OMSS facilitated simulation measurements in relation to sliding mechanics and friction, while activation measurements were used for torque.

All measurements were undertaken by a single examiner (ELE), following a period of training and calibration, and under the direct supervision of the OMSS principal investigator (CB), in an independent research center (Bonn, Germany). The in vitro testing was limited to the five lateral incisor (tooth 12) TTABs (for torque alterations) and five canine (tooth 13) TTABs (for sliding mechanics) in the study. The baseline Roth tip and torque values for tooth 12 were 5° and 12°, and for tooth 13 they were 13° and –2°, respectively. The TTABs under test were attached to aligned and leveled acrylic resin replica of Frasaco model teeth (Henry Schein Dental, Kent, UK). The brackets were aligned to ensure passive engagement of a 0.019 × 0.025-inch stainless-steel (SS) arch wire in their slots, with Victory Series™ (3M Unitek, Seefeld, Germany) pradjusted (Roth prescription) brackets bonded to tooth 12 and tooth 15, in order to provide the arch wire support. The following simulation measurement cycles were repeated 200 times.

1. Translation (sliding mechanics). In order to test the sliding mechanics, the TTAB was used in its pre-set Roth prescription (referred to as 'neutral'). The upper right first premolar (tooth 14) and canine (tooth 13) were removed from the acrylic model and replaced by the force-moment sensor attached to tooth 13 TTAB. This set-up was designed to simulate patients with significant anchorage requirements (eg, severe incisor crowding, increased overjet) to permit the canine to be retracted initially. Sliding was performed on a 0.018-inch SS arch wire, applying a nickel-titanium super-elastic closing coil attached directly to the TTAB tooth 13 bracket and second sensor arm (Figure 2) with SS ligatures. The spring was preactivated to ensure that it was on the unloading plateau during the simulated tooth movement and generated an almost constant force of 0.5–0.7 N. The test was repeated twice for each of the TTABs (tooth 13). In order to help standardize the ligation force of the steel ligatures and arch wire engagement as far as was practically permissible, they were ligated as tightly as possible and then released by 180°. A single trained operator (ELE) performed all of the ligation to ensure consistency in the technique.

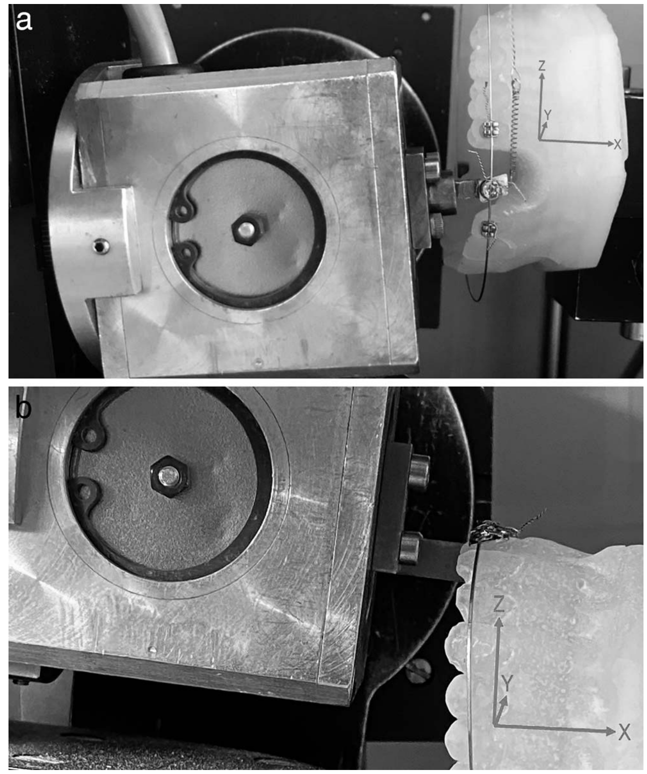

Figure 2. Detailed views of the orthodontic measurement and simulation system (OMSS). OMSS coordinate conventions are indicated in both figures. The retraction path coincides with the (positive) Z-axis (a); the torque axis coincides with the Y-axis (b). (a) The upper right first premolar (tooth 14) and canine (tooth 13) were removed from the acrylic model, and tooth 13 was replaced by the force-moment sensor attached to tooth 13 TTAB. Sliding was performed on a 0.018-inch SS arch wire, applying a nickel-titanium super-elastic closing coil attached directly to the tooth 13 TTAB and second sensor arm. (b) Arrangement for torque measurements: Two Victory Series™ brackets were fixed to the adjacent teeth (11 and 13) of the acrylic model, while the test bracket (tooth 12) was connected to the OMSS sensor via a lever arm.

Control investigations were performed to compare the rate of tooth movement using the discovery® (Dentaurum, Germany) standard edgewise and Victory

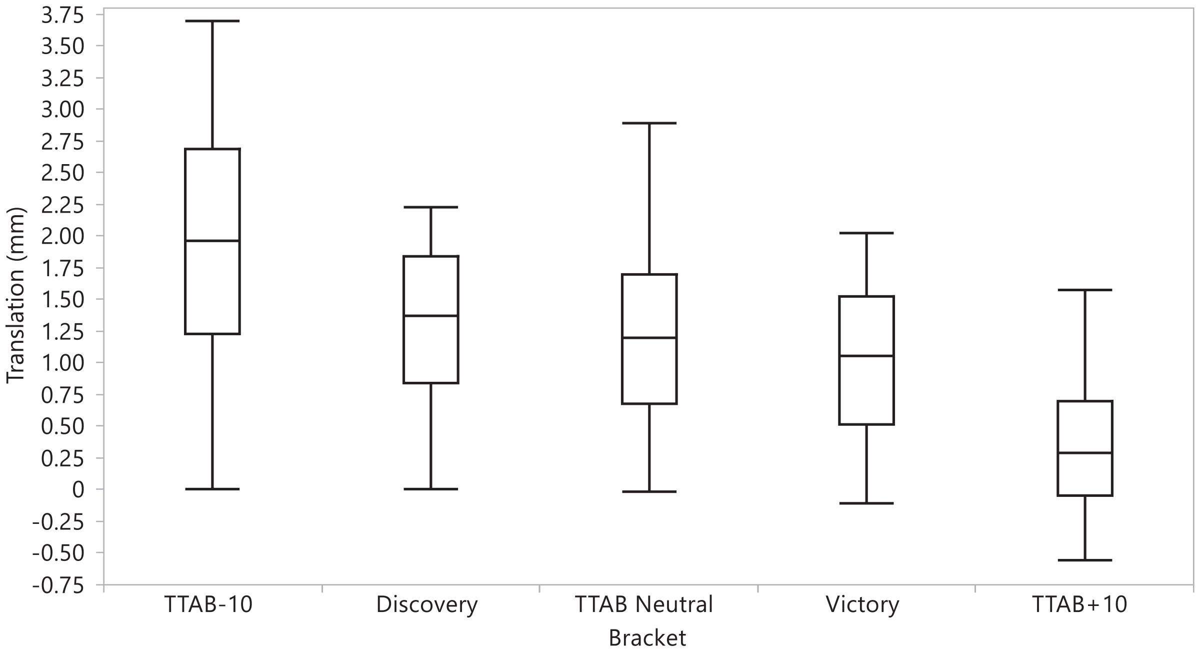

Figure 3. Measured translation (mm) for all test brackets. TTAB −10, fully adjustable bracket with −10° tip. TTAB +10, fully adjustable bracket with +10° tip.

Series™ (3M Unitek) preadjusted (Roth prescription) canine brackets. Both brackets had the same 0.022 × 0.028-inch slot and bracket width dimensions.

1a. Alteration of tip. The sliding mechanics were repeated with the tip altered to −10° and +10° to assess the impact on the rate of canine (tooth 13) retraction. Each measurement was repeated twice for each of the TTABs.

2. Frictional measurements. The above set-up was repeated on a 0.019 × 0.025-inch SS arch wire, applying a nickel-titanium super-elastic closing coil attached directly to the TTAB on tooth 13 and second sensor, and was repeated twice for each of the five TTABs. Control investigations were performed to compare frictional values using the discovery® and Victory Series™ canine brackets. In addition, the impact on frictional values was assessed comparing SS and elastomeric ligatures.

3. Alteration of torque. In order to test the inherent property of the TTAB to adjust the torque value within the bracket, the upper right lateral incisor (tooth 12) was removed from the acrylic model, and the TTAB on tooth 12 was bonded directly to the force-moment sensor. In this configuration, an adjustment within the OMSS system was performed, with the 0.019 × 0.025-inch SS arch wire in place and all force-moments set to zero. Following this, 15° of buccal through to 15° of palatal root torque were applied to the right lateral incisor bracket in incremental steps of 0.5° along the central axis of the slot. The bracket was re-set to its initial position after each activation and the subsequent moments recorded in the sagittal plane. Each measurement was repeated once after religation. The measurement range for the torque moments using the OMSS was ±450 Nmm, with a torque threshold of 0.5 Nmm.

Data Analysis

For assessing the differences in sliding mechanics and alteration of tip and torque, analysis of variance (ANOVA) was utilized. In the case of frictional measurement, a two-way ANOVA was used, both with Tukey post hoc tests in order to maintain an overall $\alpha = .05$ for multiple comparisons. All analyses were carried out using JMP®, Version 14 Pro (SAS Institute Inc, Cary, NC).

RESULTS

Translation (Sliding Mechanics) and Alteration of Tip

The results first served to confirm that, with the TTAB, the mean (±standard deviation) rate of distal

Table 1. The Mean and Standard Deviation (SD) for the Rate of Tooth Translation (mm), Applying a Constant Force, Using the Discovery®, TTAB-N (Incorporated Standard Roth Prescription), and Victory™ Brackets.

Level	Mean	SD	N[a]
Discovery	1.30	0.60	400
TTAB-N	1.20	0.67	2000
Victory	1.01	0.60	1200

[a] N = number of observations.

Table 2. .Analysis of Variance for Translation (mm) for the Three Different Brackets (Discovery®, TTAB Neutral, and Victory™)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Bracket	2	2451.46	1225.73	2.395.15	<.0001
Error	5997	3068.99	0.51		
C. Total	5999	5520.45			

Table 4. Analysis of Variance for Translation (mm) for the Three TTAB Brackets (–10° Tip, Neutral, and +10° Tip)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Bracket	2	39.6569	19.8284	48.5807	<.0001
Error	3597	1468.1318	0.4082		
C. Total	3599	1507.7886			

tooth movement was 1.2 (±0.7) mm, with a mean force application of 0.66 N. This compared favorably with both the discovery® (1.3 [±0.6] mm) and Victory Series™ (1.0 [±0.6] mm) brackets, reaching statistical significance ($P < .001$) (Figure 3; Tables 1 and 2).

The introduction of an alteration of the tip within the TTAB to –10° significantly increased the rate of canine (tooth 13) retraction to 1.9 (±0.9) mm. In contrast, alteration of the tip to +10° significantly reduced the rate of canine retraction to 0.4 (±0.5) mm, reaching statistical significance ($P < .001$) (Figure 3; Tables 3 and 4).

Frictional Measurements

In order to compare all categories simultaneously while allowing for only 5% type I error, a two-way ANOVA was conducted with a Tukey post hoc test (Tables 5 and 6).

With the TTAB, applying the same force magnitude, the mean (±SD) rate of canine (tooth 13) retraction with elastomeric ligatures was 0.2 (±0.2) mm, while with the SS ligatures, it was 1.0 (±0.6) mm and statistically significant. With the Discovery® bracket, the mean (±SD) rate of canine retraction with elastomeric ligatures was 0.4 (±0.2) mm, while with the SS ligatures, it was 1.0 (±0.5) mm and statistically significant. With the Victory Series™ bracket, the mean (±SD) rate of canine retraction with elastomeric and SS ligatures was 0.2 (±0.2) and 0.8 (±0.5) mm, respectively, and statistically significant. Figure 4 provides a visual illustration of the measurements and their distribution using Box plots.

Alteration of Torque

The alteration in torque expression by the TTAB was measured using a 0.019 × 0.025-inch SS arch wire. At +7.5°, the bracket delivered a moment of +9.3 (±2.8) Nmm, while at –7.5°, the bracket delivered a moment of –11.9 (±3.8) Nmm to the lateral incisor. These differences were highly statistically significant ($P < .001$) (Figure 5; Tables 7 and 8).

Table 3. The Mean and Standard Deviation (SD) for the Rate of Tooth Translation (mm), Applying the Three Tip Values in Canine (Tooth 13) Tip and Torque Adjustable Bracket (TTAB)

Tip Value	Mean	SD	N[a]
TTAB-10	1.92	0.93	2000
TTAB-N	1.20	0.67	2000
TTAB +10	0.36	0.47	2000

[a] N = number of observations.

DISCUSSION

When considering the preadjusted edgewise bracket design, the inherent torque and tip prescription values may not be entirely applicable in malocclusions that exhibit specific traits (eg, palatally positioned lateral incisors requiring buccal root torque). Proponents[3,9,10] have argued the relative benefits of their specific design and prescription in achieving an optimal result, while their comparative clinical utility remains to be established. Thus, the rationale behind the design of a TTAB was to overcome the inherent limitations of a "one-prescription-fits-all" approach. The TTAB offers similar advantages to flipping the bracket (for reversing the torque value in the above example) or to the use of contralateral brackets (for reversing the tip value, for example, with mandibular canines in Class III malocclusions). Presently, clinicians wishing to achieve a greater degree of tip with conventional brackets can achieve this through bracket positioning at the commencement of treatment. The advantage of the TTAB is the ability it offers to retain the bracket in the optimal position on the tooth and to alter the spring to achieve the desired change. In this context, the TTAB could be viewed as offering Begg-style mechanics, allowing quick space closure by using tip at the commencement of treatment, and changing the tip later in treatment to upright the roots. Thus, the bracket offers all the

Table 5. Frictional Comparisons of Canine (Tooth 13) Tooth Translation by Bracket and Ligature, Showing the Mean and Standard Deviation (SD) for the Rate of Tooth Movement (mm), Using the Discovery®, Tip and Torque Adjustable Bracket in Neutral (Incorporated Standard Roth Prescription; TTAB-N), and Victory™ Brackets

Bracket	Ligatures	Mean	SD	N[a]
Discovery	Steel	0.99	0.48	400
TTAB-N	Steel	0.97	0.59	2000
Victory	Steel	0.79	0.53	1200
Discovery	Elastic	0.40	0.21	400
TTAB-N	Elastic	0.23	0.18	2000
Victory	Elastic	0.21	0.15	1200

[a] N = number of observations.

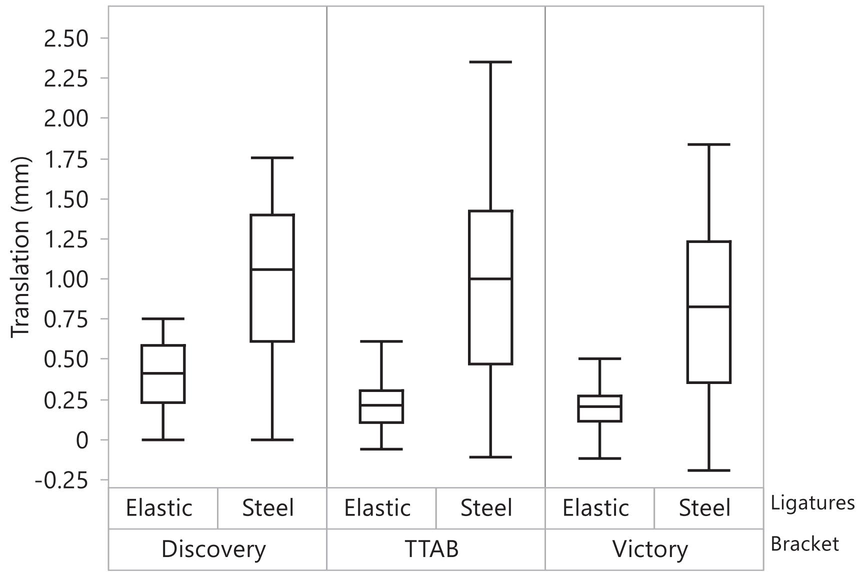

Figure 4. Measured translation (mm) for the different combinations of three brackets and ligatures. TTAB, tip and torque adjustable bracket; elastic, elastomeric ligature; steel, stainless-steel ligature.

familiarities of a preadjusted edgewise bracket, with a baseline Roth prescription, but the added clinical freedom to increase or reduce tip and torque without the need to introduce arch wire adjustments or to change the bracket choice/position (patient discomfort). There is an added potential of enhanced treatment efficiency and cost savings (reduced bracket inventory and arch wire changes).

To overcome some of the inherent limitations reported with in vitro testing,[8,11] the present study identified a unique research center with specific research and design expertise in utilizing an OMSS. Evaluation of the TTAB was undertaken by independent investigators to minimize the risk of bias. The OMSS was used to test a number of hypotheses and permitted comparison of the TTAB directly with standard (0°) and preadjusted (Roth prescription) edgewise brackets as valuable controls. The research team plans to evaluate the clinical utility and performance of the TTAB in a clinical trial using both patient- and clinician-centered outcome measures.

Table 6. Tukey Multiple Post Hoc Comparisons for Measured Translation (in mm) for the Different Combinations of Brackets and Ligatures

Bracket	Ligature[a]	Least Square Mean
Discovery	Steel A	0.99
TTAB-N	Steel A	0.97
Victory	Steel B	0.79
Discovery	Elastic C	0.40
TTAB-N	Elastic D	0.23
Victory	Elastic D	0.21

[a] Note: Levels not connected by same letter are significantly different. Overall $\alpha = .05$.

The TTAB permitted sliding mechanics at a very similar rate of tooth movement to that afforded by the control brackets. More importantly, the ability to alter the inherent tip by 10° and to alter its impact on canine retraction was evident, with a difference of 1 mm. This could carry a significant clinical benefit, as an average of 1 mm of space closure per month has been reported in a number of clinical trials.[12,13] The capacity to alter the mesio-distal root tip could prove to be very useful in not only minimizing the unwanted tipping effect observed with round SS arch wires during space distribution but also, equally, in permitting root uprighting without the addition of arch wire adjustment or bracket repositioning. A comparison was also undertaken of the rate of tooth movement using a 0.019 $\times$ 0.025-inch SS arch wire with the TTAB and control brackets. In this instance, as expected, the rate of tooth movement was slower, compared with that associated with the 0.018-inch SS arch wire. However, the method of ligation applied demonstrated a very significant effect on the rate of observed tooth movement, with elastomeric ligatures resulting in slower canine retraction. The literature is controversial with regard to the reported effects of ligation method on the rate of tooth

Table 7. The Mean and Standard Deviation (SD) in Torque Expression, Measured by the Moment (Nmm) of Force on the Lateral Incisor Tip and Torque Adjustable Bracket (TTAB) at +7.5°, Neutral, and −7.5°

Torque Value	Mean	SD	N[a]
Torque +7.5°	9.27	2.80	10
Torque N, °	−1.06	3.12	20
Torque −7.5°	−11.95	3.75	10

[a] N = number of observations.

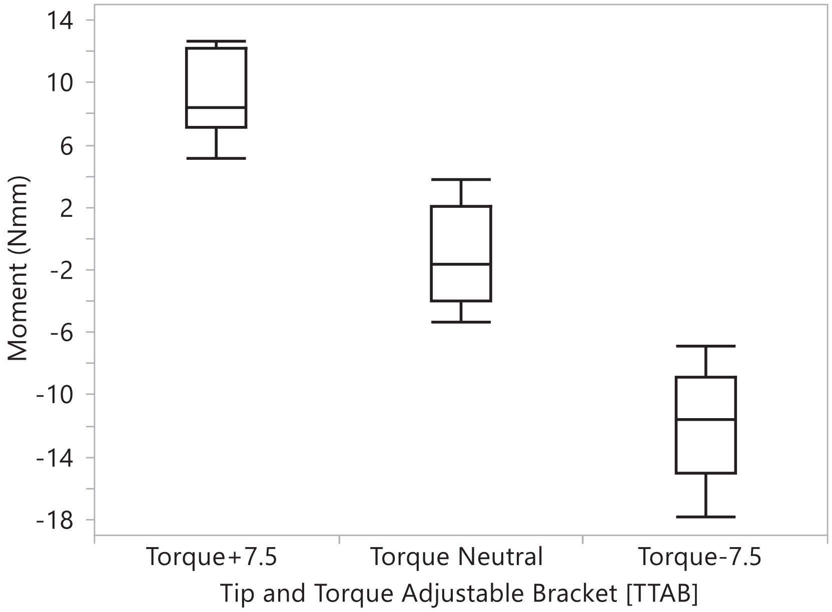

Figure 5. Measured moment (Nmm) for the three tip and torque adjustable bracket (TTAB) torque values (+7.5°, Neutral and –7.5°).

movement. While in vitro tests have provided conflicting results,[14–16] clinical trials primarily designed to compare space closure between self-ligating and conventional elastomeric ligation have failed to detect any such difference.[12,13] The observed difference could be due to the influence of the remodeling capacity of the periodontal ligament.[17] In vitro studies are limited to recording only the initial force system,[14–16] whereas with in vivo studies, any binding between the brackets, wires, and ligation method is likely to change with time and intraoral environmental factors.[12,13]

The TTAB uniquely permits alteration of torque by 7.5° in either direction. The OMSS provided a validated and reliable measure of the force-moments generated within the bracket.[4] Despite the fact that there is no agreed scientific consensus of the optimal torque moment, there is general agreement in the literature that 5 Nmm is near the optimal torque for an incisor.[18–20] However, it has also been shown that the amount of torque delivered to the tooth may be suboptimal to the given bracket prescription because of the variability of bracket and arch wire dimensions.[4,21] Thus, the capacity of the bracket to offer additional or, indeed, reduced torque to the tooth can be of significant clinical benefit. The TTAB was observed to deliver a change in moments at its various torque settings.

Table 8. ANOVA for Moment (Nmm) in Respect to the Three Torque Levels (+7.5°, Neutral, and –7.5°) for the Three Tip and Torque Adjustable Brackets (TTABs)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Bracket	2	2252.84	1126.42	108.85	<.0001
Error	37	382.88	10.35		
C. Total	39	2635.72			

CONCLUSIONS

- A new concept in preadjusted edgewise bracket design with adjustable tip and torque was tested, and all hypotheses were accepted.
- In terms of tooth translation, the TTAB compared favorably with controls. Alteration of tip directly affected the rate of tooth movement, and alteration of torque had an equivalent effect on root position. The frictional characteristics of the TTAB were comparable to those of control brackets and were influenced by the method of ligation applied.

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