Original Article

Evaluation of the load system produced by a single intrusion bend in a maxillary lateral incisor bracket with different alloys

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ABSTRACT

Objectives: To evaluate if a 0.5-mm vertical bend applied on an incisor bracket produces movements in other planes and if different wires influence these effects.

Materials and Methods: An acrylic model of a treated patient with brackets passively bonded was attached to an Orthodontic Force Tester, and a load cell was attached to the left lateral incisor. Thirty 0.019 $\times$ 0.025-inch archwires were divided into three groups according to their alloy: SS (stainless steel), B-Ti (beta-titanium), and MF (beta-titanium wire coated with nickel-titanium). Step-bends of 0.5 mm high were placed on the lateral incisor bracket using a universal plier, and the forces and moments in three dimensions were statistically analyzed by analysis of variance and Tukey post hoc test.

Results: SS produced a larger force (3.4 N) than the B-Ti (1.41 N) and the MF (0.53 N; $P < .001$). Lingual forces were produced by the SS (0.82 N) and B-Ti (0.31 N) groups, while in the MF group, the force was insignificant. SS produced a mesial force of 0.24 N, while the B-Ti force was insignificant and MF produced 0.09 N. Groups produced different crown-distal tipping moments (SS $=$ 31.48 N-mm, B-Ti $=$ 11.7 N-mm, and MF $=$ 4.55 N-mm) and different crown-buccal tipping moments. SS produced larger moments (3.63 N-mm) than B-Ti (1.02 N-mm) and MF (0.36 N-mm) wires. A mesial-out rotational moment was observed in all groups (SS $=$ 7.17 N-mm, B-Ti $=$ 3.46 N-mm, and MF $=$ 0.86 N-mm).

Conclusions: A 0.5-mm intrusion bend produced lingual and mesial side effects. In addition to the distal and buccal crown-tipping moments, there was a mesial-out moment. Compared with SS, B-Ti and MF wires produced lower forces. These more flexible wires showed side effects with lesser intensity. (*Angle Orthod.* 2018;88:611–616.)

KEY WORDS: Bends; Intrusion; Mechanics

INTRODUCTION

Finishing is one of the most challenging phases of orthodontic treatment because it requires wire-bending experience and controlled movement of teeth. Typically, orthodontists place small bends or twists in thicker wires, which have decreased clearance between the wire-slot interfaces, to achieve reasonable control of tooth movement. However, the recent use of finishing wires of smaller dimension produces larger clearance in relation to the bracket slot than those originally proposed. In addition, it is difficult to make perfect bends in a three-dimensional (3D) plane without influencing the archwire shape in the other two planes. This can lead to undesirable movements during this phase, especially on heavy wires, such as stainless steel (SS), which is the most common finishing wire used today.[1]

Beta-titanium alloy wires have increased in popularity, and their use for finishing has increased. Small

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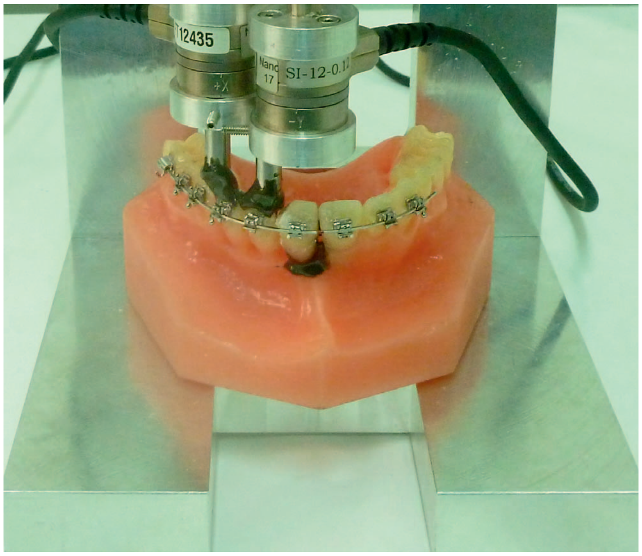

Figure 1. An acrylic model from an orthodontically treated patient bonded to the OFT. A guide wire allowed passive positioning of the brackets and tubes. The left lateral incisor and canine were individually attached to each load cell and were subsequently separated from the model.

bends or twists in the finishing phase with beta-titanium produces lower forces compared with SS (approximately 40% less) and may undergo twice the deflection without permanent deformation.[2] Other resilient wires, such as the nickel-titanium tubing of beta-titanium[3] (Flexy-Multi, Orthometric, Marília, Brazil, produced by Beijing Smart Technology, Beijing, China), designed to be used for finishing may prove to be equally useful for the that specific stage.

Despite the large number of studies comparing orthodontic wires of various alloys, most of them used a three-point bending test in the methods, with free extremities. This type of investigation may be excellent for comparing the different properties of the wire, but it might fail to show the real levels of forces actually applied to the teeth by a continuous wire. Even in the classic article of Burstone and Koenig,[4] which analyzed the load system of a step-bend, only a two-tooth segment without mesial and distal supports was evaluated. A more ideal method to compare the loads produced by wires in brackets would be to measure the forces and moments produced by a full orthodontic appliance on a system that could simulate a real clinical situation. The Orthodontic Force Tester (OFT)[5] is a 3D measurement system suited for this purpose, and it has already been used in several investigations to measure and compare orthodontic loads.[6–15] It has never been used to measure the load systems of finishing bends.

Knowledge concerning the intensity of forces applied in orthodontics is important, especially for intrusive movements because of the predisposition for root resorption in this type of movement when excessive forces are used.[16,17] Some authors have already established that 10–25 gf (or 0.9–0.24 N) is probably sufficient to intrude a lower incisor without any deleterious effects.[18–20] Precisely applying such relatively low force levels has already been shown to be possible with an intrusion arch.[19,21]

Even though some studies have used a full arch simulation to study load systems in orthodontics,[22–24] the literature fails to show how much force is applied to a specific tooth when an intrusion bend is placed on a finishing wire. Therefore, the aim of this study was to measure whether a standardized intrusive vertical bend in a maxillary lateral incisor produces any side effects in other planes of space. In addition, the study investigated whether the use of different finishing wires affected these possible side effects.

MATERIALS AND METHODS

Roth prescription 0.022-inch-slot self-ligating brackets and molar tubes (Morelli, Sorocaba, Brazil) were bonded passively with epoxy glue (JB Weld Co, Sulfur Springs, Tex), using a 0.019×0.025-inch SS archwire as a guide, to an orthodontically treated patient's model poured in acrylic resin. The model was secured with epoxy glue (JB Weld Co) to an OFT table (Figure 1). Load cells (Multi-Axis Force/Nano 17 Torque, Industrial Automation, Apex, Ind) with force measurement ranges of 0–20 N and 0–100 N/mm were bonded to the maxillary left lateral incisor and canine. Those teeth were separated from the model that remained attached to the OFT base so that the forces and moments produced could be measured without affecting the load system. Only the data collected from the lateral incisor bracket were used. The origin of the coordinates was transferred to the center of the lateral bracket by the OFT custom software (Purdue University, West Lafayette, Ind; Figure 2) with the *x*-axis perpendicular to the bracket in the buccolingual direction (Figure 3). This custom modification of the ATI transducer software (ATI Industrial Automation Inc, Apex, NC) registered the moment-force ratios produced when a force was applied to the bracket away from the load cell origin (center of the load cell). The insertion of those offset values into the software calibration window (Figure 2) allowed the calculation of the measurements three-dimensionally back to the origin at the center of the lateral incisor bracket, with the *x*-axis and *z*-axis perpendicular to it. The 0.019×0.025-inch SS archwire applied as a guide was used to calibrate and zero the load cell to isolate the response of the step-bend in the system.

Thirty 0.019×0.025-inch rectangular archwires were divided into three groups according to their alloy. The

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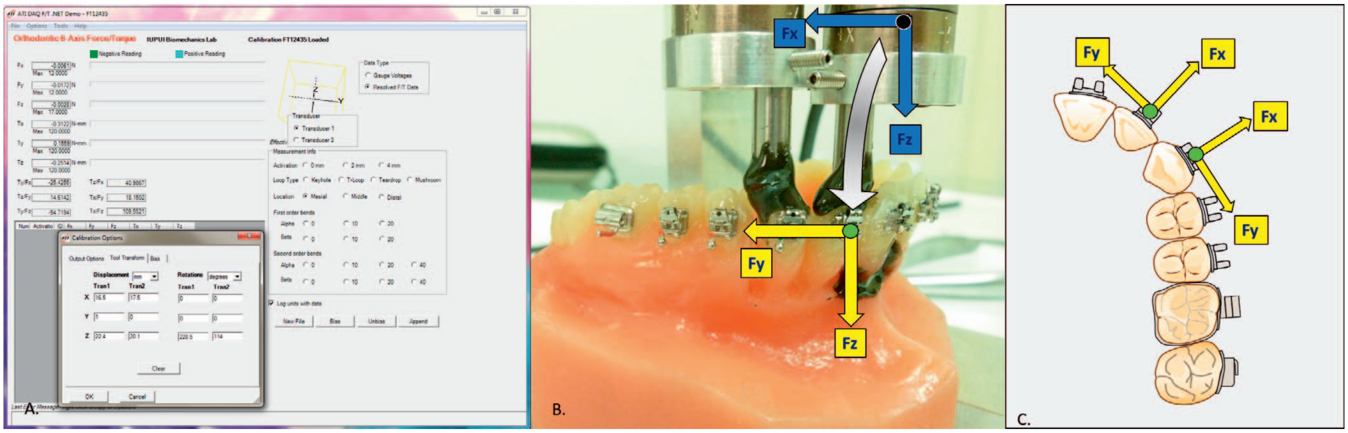

Figure 2. The custom software had a calibration window (A) that allowed the transferring of the origin of measurements from the center of the load cell (black dot) to the center of the lateral incisor bracket (green dot). The original axes (blue arrows) (B) were rotated and transferred to the lateral bracket (yellow arrows) (B and C).

SS group was composed of SS wires (Orthometric, produced by G&H Wire Company, Franklin, Ind), the B-Ti group was composed of beta-titanium wires (Beta Flex, Orthometric, produced by Beijing Smart Technology), and the MF group was composed of beta-titanium wires coated with nickel-titanium.

Archwire passivity was checked using the software screen before each 0.5-mm step was placed using an intraoral bending plier (Ormco, Glendora, Calif). The location of the bends was standardized by placing two felt-tip pen markings on a passive template wire at the middle of the distance between the lateral and canine brackets and between the lateral and central incisor brackets. An acrylic template was produced by the guide wire and was used to verify all bends (Figure 4). Archwires not matching the template were discarded.

The archwires were inserted into the brackets and tubes. After carefully checking the central location of the bends, the software collected the force and moments produced (Figure 5). Tests were conducted at a temperature of 37°C ± 1°C. Data were saved and analyzed using SPSS software version 16.0 (Chicago, Ill). Analysis of variance was used to detect differences in the forces and moments measured among the groups. Tukey post hoc test was applied to identify differences among groups.

RESULTS

All groups produced different intrusive forces ($P < .001$) on the lateral incisor bracket (Table 1). SS wires produced 3.4 N, while B-Ti produced 1.41 N and MF produced 0.53 N. The buccolingual forces were also different ($P < .001$). SS wires produced a 0.82-N lingual force, while B-Ti wires produced 0.3 N and the MF produced a statistically insignificant force. Mesiodistally, SS wires produced a larger mesial force (0.24 N; $P < .001$). B-Ti wires produced a statistically

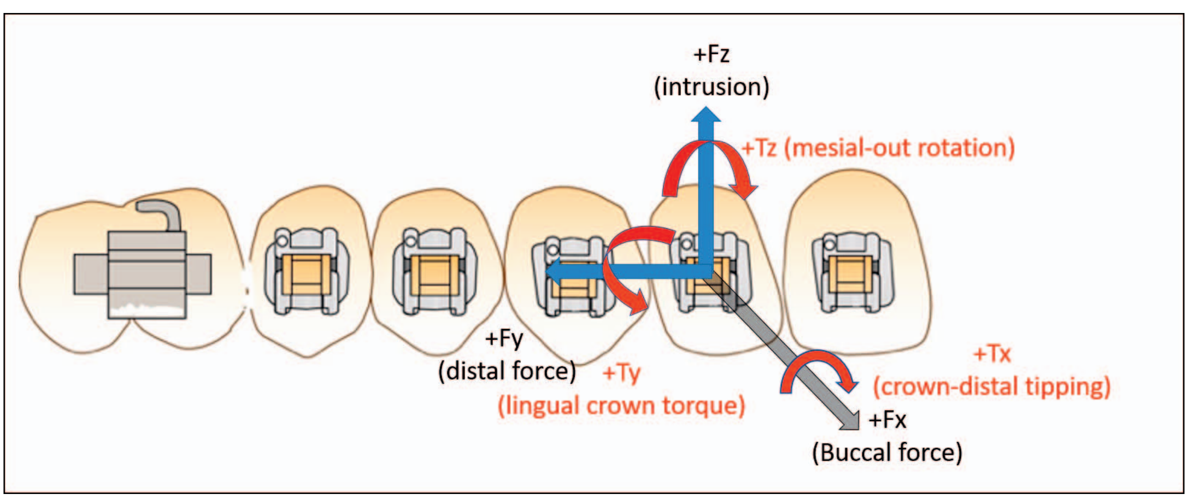

Figure 3. Origin of the measurements, axes of force (blue arrows), and moments (red arrows), depicting the direction of positive measurements.

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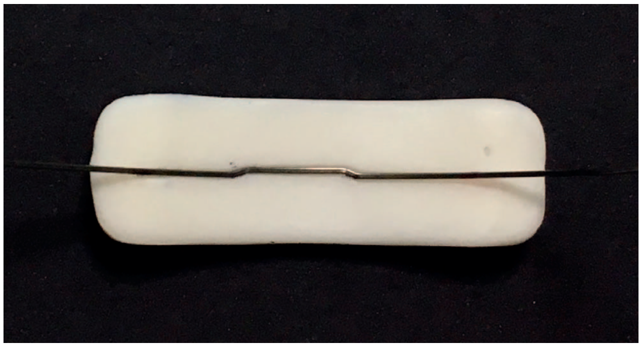

Figure 4. Template used for bend calibration.

insignificant force, while MF produced a 0.09-N distal force.

All groups produced different crown-distal tipping moments at the bracket ($P < .001$; Table 1). While the SS wires produced larger moments (31.48 N-mm), B-Ti wires produced 11.7 N-mm and the MF group produced 4.55 N-mm. Differences were also found in the intensity of the buccal-lingual tipping moments among groups ($P < .001$). SS wires produced larger moments (3.63 N-mm) than both of the other groups (B-Ti = 1.02 N-mm and MF = 0.36 N-mm), but there was no difference found between the B-Ti and MF groups. All three groups produced mesial-buccal rotational moments of different intensity ($P < .001$). Moments were larger in the SS group (7.17 N-mm) than in the other two groups, which produced 3.46 N-mm and 0.86 N-mm moments for B-Ti and MF wires, respectively.

DISCUSSION

The 0.5-mm intrusive bend produced forces and moments of different magnitudes in all of the wires tested. The intrusive forces were greater in SS than in B-Ti and smaller in MF. These results were not unexpected as B-Ti has a relative stiffness of less than half (0.42) of SS.[3,25] Comparing the intrusive forces found in B-Ti with SS (Table 1), the same ratio was found. Even though there is little published data regarding the MF wire, it was expected that it would be more flexible than B-Ti because of its thinner core and

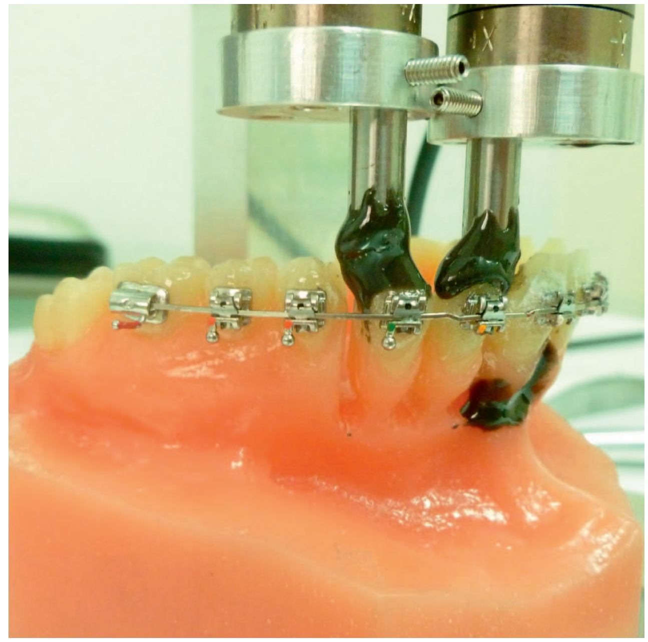

Figure 5. Measurement system that registered forces and moments produced at the maxillary lateral incisor bracket from a 0.5-mm bend.

its more flexible coating (nickel-titanium). There has been only one report[4] describing MF wire as having a different behavior and greater flexibility as compared with B-Ti wire. Although the literature comparing wires is extensive, most of the reports were restricted to either tensile or three-point bending tests.[26] These can be used to compare stiffness of wires accurately but would be unable to provide the actual forces applied to the teeth. Past investigations tried to simulate an arch shape[27] or used finite element models.[28] For specific situations, these reports depicted configurations that simulated clinical presentations.[29] A downside to such methods is that the force values found are valid only for the specific situation shown (ie, for an extruded lateral incisor). In this region of the archwire, as compared with the straight part of the same archwire, more side effects might be found because a vertical bend will naturally create forces and moments in multiple dimensions.

SS produced an intrusive force of 3.4 N in this study, which may be considered high by most orthodontists to

Table 1. Mean Values, Standard Deviations, and Significant Differences for the Lateral Incisor[a]

	Fz (N)	Fx (N)	Fy (N)	Mx (N-mm)	My (N-mm)	Mz (N-mm)
Group	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
SS	3.40 (0.39)$_a$	−0.82 (0.26)$_a$	−0.24 (0.21)$_a$	31.48 (3.73)$_a$	−3.63 (0.99)$_a$	7.17 (2.91)$_a$
B-Ti	1.41 (0.20)$_b$	−0.31 (.16)$_b$	−0.02 (0.16)*$_b$	11.7 (1.75)$_b$	−1.02 (0.38)$_b$	3.46 (1.34)$_b$
MF	0.53 (0.17)$_c$	−0.04 (0.27)*$_c$	0.09 (0.11)$_b$	4.55 (1.70)$_c$	−0.36 (0.53)$_b$	0.86 (2.63)$_b$
P (significance)	<.001	<.001	<.001	<.001	<.001	<.001

[a] To convert Newtons into grams-force, multiply by 102. The same subscript letters indicate that there was no significant difference within the same variable ($P > .05$)

* Indicates nonsignificant values.

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intrude an upper lateral incisor, since 0.1 to 0.24 N (10–25 gf) is estimated to be enough to intrude one incisor.[18–20,28] Because a correlation might exist between root resorption and high intrusive forces,[16,17] intrusion may require more careful attention by orthodontists. Moreover, excessive forces applied to the brackets might lead to debonding, thereby increasing the chair time required. Therefore, the use of wires with greater flexibility than SS, such as B-Ti or MF, which produced 1.41 and 0.53 N, respectively, may be more appropriate for intrusion.

Unexpected buccolingual forces were observed as a side effect to the vertical bends, even with the standardized bends used. This was probably due to a change in the shape of the orthodontic arch as the active bend was inserted into the brackets, such as what happens to orthodontic loops in their neutral position.[30] This deflection associated with the amount of wire added between the brackets by the bend probably produced this side effect. In addition, a normal force not perfectly vertical from the archwire acting on the bracket could produce buccolingual forces if the slots were not entirely parallel to the transverse plane. Because the forces produced between the wires were different (because of their moduli of elasticity), the undesirable buccal forces were smaller in B-Ti and insignificant in MF. This points to a smaller chance of side effects with the more flexible wires because the unwanted forces may be suboptimal or even subthreshold. Thus, an intrusive bend placed in SS may cause space opening, which could be prevented by tying the teeth together with steel ties and/or by using lighter wires. Similar results have not been previously reported in the literature because isolated intrusive bends in continuous arches have not been previously evaluated while the load systems of intrusion arches were investigated.[28,29,31] Mesial forces were also detected but were either statistically or clinically insignificant (–0.02 N and 0.09 N, in B-Ti and MF wires, respectively). The wire shape during activation may also have been responsible for this effect. Although the mesiodistal forces were small (–0.24 N) in SS, they would still require tying the teeth together to avoid space opening.

High tipping moments, consistent with the stiffness of the wires, were produced at the bracket. In addition, the standardization of the bends did not guarantee centering between the brackets, producing a crown-distal tipping tendency. The archwire being curved in this specific region prevented a perfect centering of the bend with conventional orthodontic instruments, which is probably also impossible to accomplish chairside. As a bend is placed closer to the bracket, the tipping tendency will be larger on it because of the greater stiffness of the wire in that region. However, that effect may go unnoticed clinically, because the intruded tooth may return to its initial axial position, provided there is small second-order clearance between the wire and the bracket and provided the wire is stiff enough, allowing a “shape-driven orthodontic”[32] effect because there are mesial and distal supporting points (provided by the adjacent brackets). In situations in which there are no mesial or distal supports of a tooth being moved, such as an on a second molar being intruded, the estimation of movement based on a shape-driven approach will not be predictable, since the deflection of the wire and the different bracket angulations modify the force system.[4]

Moments tending to tip the lateral incisor crown buccally, proportional to the stiffness of the wires, also occurred on the lateral incisor bracket. The deflection that the wire assumes due to its flexibility when being inserted into the slots probably generated a twist in the wire, causing this effect. The use of thicker wires, aiming to decrease play in the third order, was not enough to prevent a buccolingual tipping tendency. This could have been minimized if there had been a buccal tipping restriction, provided by a bracket with less torque prescription or by a compensatory twist in the wire. However, this effect was minimized in the more flexible wires, suggesting their use as a way to avoid the side effects described. In addition to the side effects, the deflection of the wires also produced rotational moments in the lateral incisor bracket in the mesial-buccal direction. Again, this effect probably occurred because the brackets were closer to one of the bends and possibly would be temporary, as long as the first-order play was small.

CONCLUSIONS

- A 0.5-mm intrusion bend applied to the upper lateral incisor bracket in all archwires produced lingual and mesial forces as side effects. In addition, crown-distal and crown-buccal tipping moments were detected, as well as mesial-buccal rotation.
- B-Ti and MF wires produced, in that order, smaller intrusive forces and often insignificant side effects, when compared with SS wires.

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