Original Article

Vertical Forces in Labial and Lingual Orthodontics Applied on Maxillary Incisors—A Theoretical Approach

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Abstract: Theoretical and experimental biomechanical analyses explain most labial orthodontics (LaO); however, lingual orthodontic (LiO) biomechanical principles are rarely introduced. The objective of this study was to apply basic biomechanical considerations in understanding the influence of maxillary incisor inclination and to compare the effect of labial vs lingual intrusive/extrusive forces on tooth movement. Basic anatomic and geometric hypotheses were assumed, ie, tooth length (crown and root), location of the center of resistance, and crown thickness. Incisor inclination as related to a perpendicular line to the occlusal plane (OP) varied between −35° (retroclination) and 45° (proclination). A 0° inclination was defined as a tooth position with its long axis perpendicular to the OP. The buccolingual moment for characterizing root movement was calculated for an applied force perpendicular to the OP. The results showed that when using LaO, an extrusion force resulted in labial root movement from a retroclination of 20° up to a proclination of 45°. In LiO, labial root movement occurred only when the tooth was proclined more than 20°. In all other tooth inclinations, lingual root movement occurred. The opposite tooth movement occurred when an intrusive force was applied. Application of a vertical force has different clinical effects on tooth movement with labial and lingual appliances. Application of a lingual force is more complicated, and its effect on tooth movement depends on bracket position and initial tooth inclination. (*Angle Orthod* 2004;74:195–201.)

Key Words: Lingual orthodontics; Intrusion; Extrusion

INTRODUCTION

Understanding and applying basic biomechanical principles in treatment improves the efficacy of the appliance system and simplifies the treatment. This may improve the force delivery and achieve more predictable tooth movement with minimal side effects in any orthodontic technique.

Theoretical and experimental biomechanical analyses explain most labial orthodontics (LaO); however, the biomechanical principles of lingual orthodontics (LiO) are rarely introduced. Therefore, some guidelines are needed when applying these principles to the lingual technique.

The lingual technique is considered more difficult than the labial one because of the anatomic variations and the difficulty in direct access to the lingual surface. The immediate problem that confronted LiO at its earliest stages was the inaccuracy of bracket positioning. It is well known that the key factor for successful orthodontic treatment is precise bracket positioning, especially when more treatment is built into the brackets.[1] Therefore, many efforts have been made to improve the accuracy of lingual bracket positioning.

Several direct and indirect bonding procedures have been developed for the lingual technique, to apply the Straight Wire concept to treatment and avoid the difficulties of wire bending. The only direct bonding procedure developed for LiO is the Lingual Bracket Jig,[2] which also enables indirect bonding. The indirect bonding procedures include the TARG system (Torque Angulation Reference Guide),[3] the Slot Machine,[4] the CLASS system (Customized Lingual Appliance Setup Service),[5] the CRCS system (Convertible Resin Core System),[6] the bending arch technique,[7,8] and the TOP system (Transfer Optimized Positioning).[9,10] However, each has its own accuracy limitations, and the accuracy of bracket positioning is still compromised.[11]

Another complication in bracket positioning is rebonding after bracket loss[9] or when a bracket cannot be initially bonded in an ideal position because of the malocclusion.

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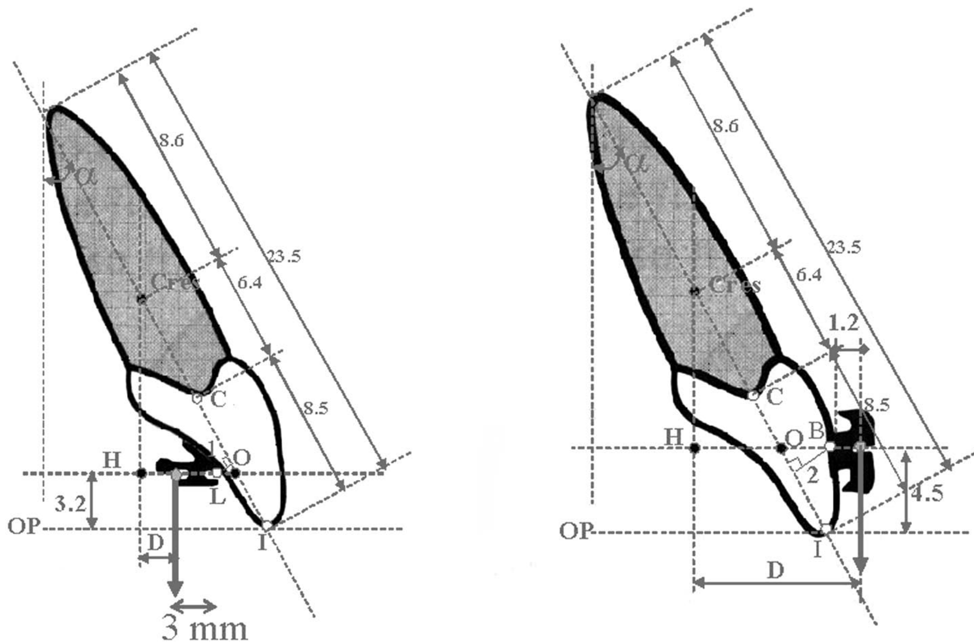

FIGURE 1. Mathematical model of an incisor with a lingual and a labial bracket.

Rebonding procedures are less accurate than the initial bonding, and direct bonding in LiO is always less accurate than indirect bonding. Many times, an additional laboratory setup of the brackets is needed.

It is obvious that bending wires is an unavoidable part of LiO treatment, despite application of the Straight Wire concept and regardless of the method used for positioning the bracket. A simple force applied by wire bending in one direction could cause a different movement of the tooth on which it acts, depending on the location of the line of force relative to the center of resistance (C_{res}) of the tooth.[12] The point of force application (PF) is different in lingual and labial orthodontics. Therefore, the question of the line of force relative to the center of resistance is different and could produce different tooth movements.

This article presents a mathematical model that was developed to apply basic biomechanical considerations in understanding the influence of maxillary incisor inclination and comparing the effect of labial vs lingual intrusive and extrusive forces on tooth movement of an incisor.

MATERIALS AND METHODS

A mathematical model of an incisor was developed based on basic anatomic and geometric assumptions (Figure 1). Tooth length (crown and root) was considered to be 23.5 mm,[13] with a crown length (CL) from the incisal edge to the cingulum of 8.5 mm and a root length of 15 mm.

The location of the C_{res} was calculated as 6.4 mm measured from the cingulum. This is based on the approximation that the C_{res} distance is two-thirds of the palatal alveolar bone height, measured from the root apex.[14] The distance between the bracket slot and the tooth surface was considered to be 1.2 mm for labial and 3 mm for lingual, and the vertical distance between the bracket slot and the occlusal plane (OP) was considered to be 4.5 and 3.2 mm for labial and lingual surfaces, respectively. Incisor inclination α was defined as the angle between the incisor long axis and the perpendicular line to OP that passes through the tooth apex. For this study, α varied between $-30°$ (retroclination) and 45° (proclination), whereas 0° was defined as tooth positioning with its long axis perpendicular to the OP. The force, labial or lingual, acted on each bracket slot in a direction perpendicular to the OP. Its equivalent force system at the C_{res} can be calculated as a single force and a moment.[15] Although the influence of the force when transmitted to C_{res} creates extrusive or intrusive movement, the buccolingual moment developed characterizes tooth root movement tendency.

Several points were defined on the model to calculate the buccolingual moment, ie, points along the long tooth axis and points along a line parallel to the OP that passes through the labial or lingual bracket slot. On the long tooth axis, I = incisal edge, O = a point where the above two lines intersect, and C = a point where the long axis intersects the cemento-enamel junction and the C_{res} point. On the line parallel to the OP, B or L = intersection of the line with the buccal or lingual tooth surface, respectively, and H = the point at which the parallel line intersects a perpendicular line to the OP that passes through C_{res}.

In both cases, the distances $CC_{res} = 6.4$ mm and $IC_{res} = 8.5 + 6.4 = 14.9$ mm were assumed. Basic trigonometric equations were applied to calculate the horizontal distance D between the applied force and C_{res} (Figures 1 and 2).

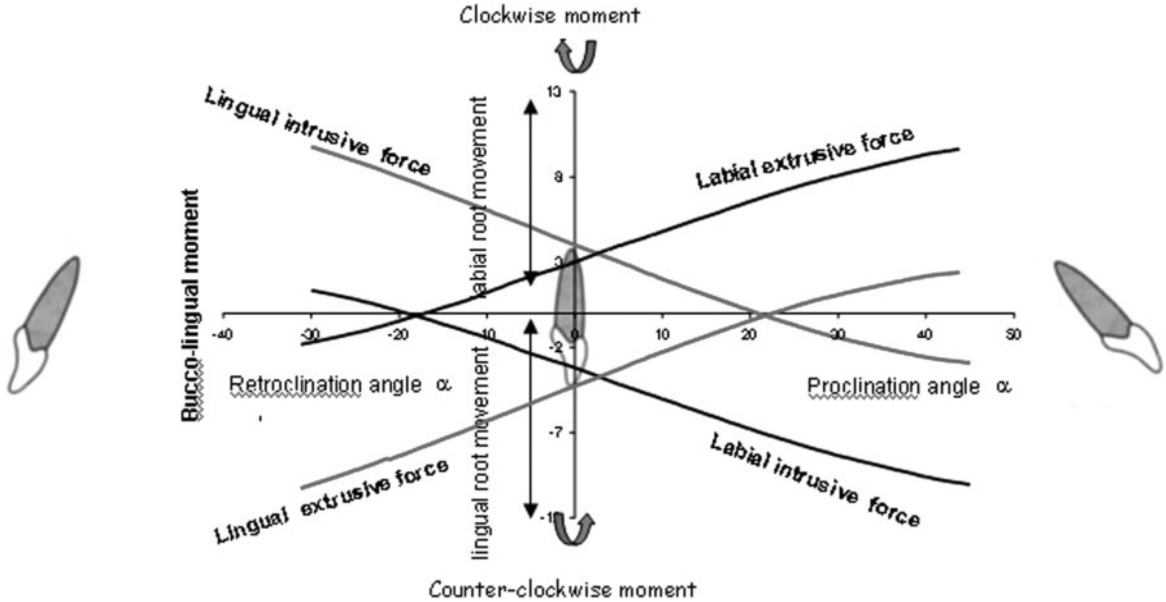

FIGURE 2. Buccolingual moments developed during application of an intrusion and an extrusion force on an incisor with labial and lingual brackets.

$$\overline{OI}_B = \frac{4.5}{\cos\alpha} \qquad \overline{OI}_L = \frac{3.2}{\cos\alpha} \tag{1}$$

Length from the incisal edge to point O, where the index B or L was related to buccal or lingual, respectively,

$$\overline{OC} = 8.5 - \overline{OI} \tag{2}$$

Length between points O and C, where CI was considered as 8.5 mm.

$$\overline{OB} = \frac{2}{\cos \alpha} \tag{3}$$

Length between points B and O, where the distance between B and the long tooth axis was defined as 2 mm.

$$\overline{OL} = \frac{1}{\cos \alpha} \tag{4}$$

Length between points L and O, where the distance between L and the long tooth axis was defined as 1 mm.

$$\overline{OC_{res}} = \overline{IC_{res}} - \overline{OI} \tag{5}$$

Length between O and C_{res}.

$$\overline{OH} = \overline{OC_{res}} \times \sin \alpha \tag{6}$$

Horizontal distance between O and C_{res}.

$$\overline{D_B} = \overline{OB} + \overline{OH} + 1.2 \tag{7}$$

where the distance between the bracket slot and point B for the buccal side was 1.2 mm.

$$\overline{D_L} = \overline{OH} - \overline{OL} - 3 \tag{8}$$

where the distance between the bracket slot and point L for the lingual side was 3 mm.

In both cases,

$$\overline{M} = \overline{F} \times \overline{D} \tag{9}$$

RESULTS

Figure 2 presents the moments developed as a result of the applied intrusion and extrusion forces.

Intrusion

Labial bracket. Application of an intrusion force using a labial bracket created a counterclockwise moment and a labial crown movement when the incisor inclination was −20° up to 45°.

Lingual bracket. Application of an intrusion force using a lingual bracket created a clockwise moment and a lingual crown movement when the incisor inclination was −30° up to 20°. A counterclockwise moment was developed with the intrusive force using a lingual bracket only when the incisor inclination was more than 20°. The point of transition for the moments was 20°. At this point, pure intrusion without any moments was developed.

Extrusion

Labial bracket. Application of an extrusion force using a labial bracket created a clockwise moment and a lingual crown movement when the incisor inclination was −20° up to 45°.

Lingual bracket. Application of an extrusion force using a lingual bracket created a counterclockwise moment and a labial crown movement when the incisor inclination was −30° up to 20°. A clockwise moment was developed with an extrusive force using a lingual bracket only when the

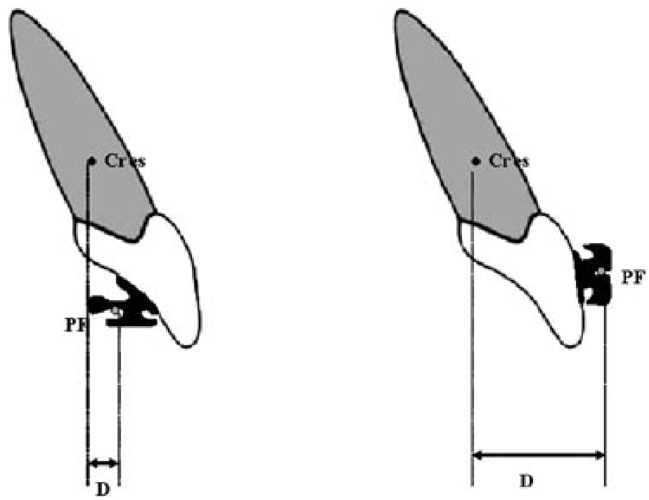

FIGURE 3. Distance between center of resistance and point of force application in an incisor with labial and lingual brackets.

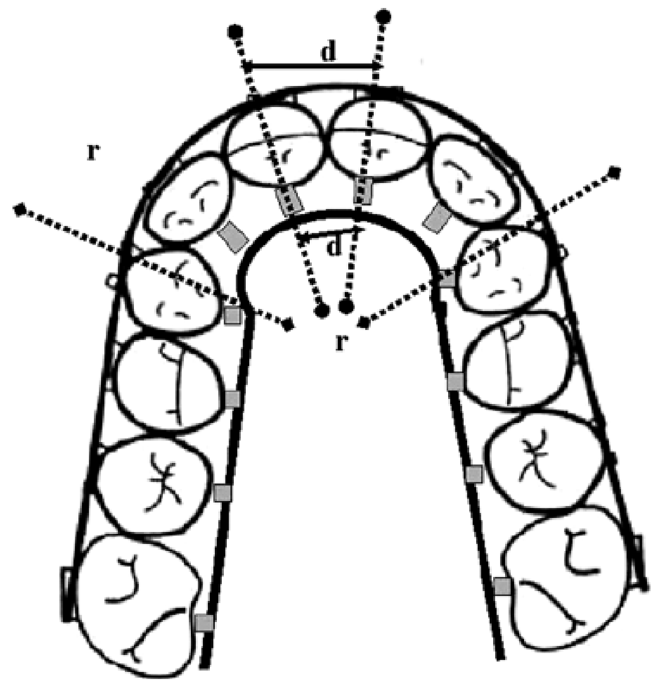

FIGURE 4. Arch perimeter and interbracket distance in a labial and lingual bracket system. Lateral shift of lingual brackets has a greater effect on the final tooth position than when the same shift is applied on labial brackets.

incisor inclination was more than 20°. The point of transition of the moments was 20°. At this point, pure extrusion without any moments was developed.

DISCUSSION

- Differences between the labial and lingual techniques have an important impact on the biomechanics of LiO. First, the relationship between the PF and the C_{res} is different between LaO and LiO because of the different position of the brackets (Figure 3). Because the distance (D) between C_{res} and PF is smaller in LiO than in LaO, the moments of forces in LiO are smaller (moment = force × distance). As a consequence, torque is more difficult to control in LiO, and first-, second-, and third-order movements (in-out, extrusion-intrusion, and torque) are also influenced.
- Second, the arch perimeter in the anterior region of the lingual tooth aspect is smaller than in the labial aspect (Figure 4). Consequently, the load deflection rate (L/D of the wire) in LiO is higher, which will make it more difficult to apply light optimal forces. Activation range and force constancy are reduced. Because increasing the wire length for reducing the L/D rate is impossible in LiO, the preferable options are to decrease the modulus of elasticity by using shape memory alloys and to reduce the cross section of the wire.[16]
- Third, the lingual tooth aspect is more complex and versatile, and, therefore, every change in the bracket position on the lingual side may cause unpredictable and extensive change in the torque and vertical tooth height[17] (Figure 5).
- Fourth, the lingual brackets are bonded distally from the labial surface that has to be aligned. Changing a bracket position on the lingual side will have a greater effect on

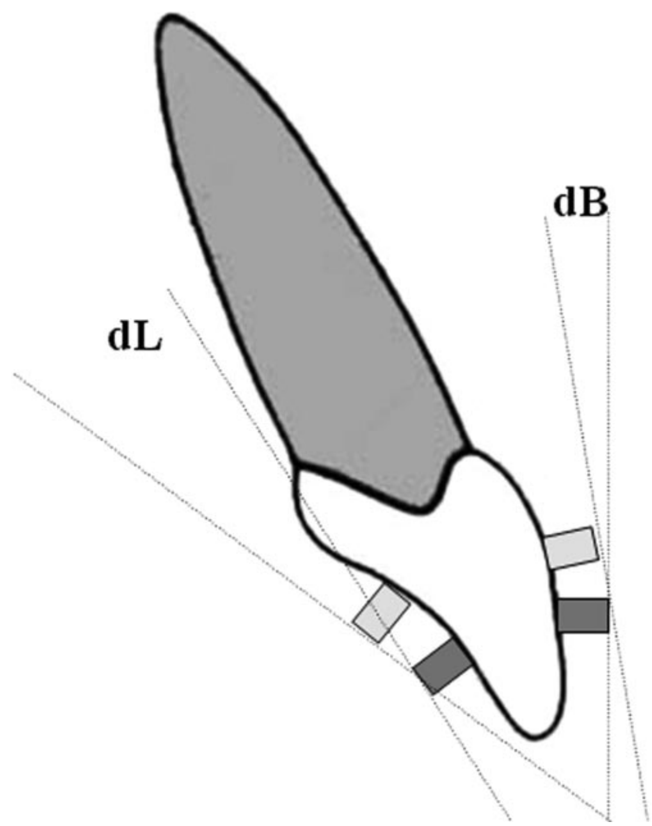

FIGURE 5. Changing the bracket position on the lingual side creates unpredictable and extensive change in the torque and vertical tooth height.

the final tooth position than the same change when applied on labial bracket (Figure 4).

These differences between the labial and the lingual technique can influence tooth movement, even small movements. Because wire bending is always needed in LiO and it is difficult to sustain a desired movement over a significant distance, it may be more accurate and straightforward to view most tooth movements as combinations of linear translation with rotation around the C_{res}.[12] The results of this study open a window to the complexity of tooth movement with the lingual technique.

In another study,[18] the biomechanical response of maxillary incisors was compared with labial and lingual force applications with a three-dimensional finite element model; apically directed vertical forces applied at the lingual points produced more uniform tooth displacements and stress distributions. It was concluded that lingual force application could produce more optimal tooth movement in terms of intrusion and subsequent stress distributions in the periodontal ligament.

In this study, the same results were obtained only when referring to the transition point, at which pure intrusive or extrusive movements occurred when vertical forces were applied. However, this transitional point cannot be accurately identified because it depends on tooth inclination, tooth width, and bracket base width, which determines the distance between the PF and the C_{res}.

The horizontal distance between the bracket slot and the tooth surface in a lingual system was assumed to be 3.0 mm. This distance is greater in many clinical cases because of the bracket-positioning system, which includes rebasing of the lingual brackets with composite material, creating an individual custom base.[19] Therefore, the point of transition of the moments can extend beyond 20° of inclination. Pure intrusion or extrusion using a lingual bracket may develop when incisor inclination is at the transitional point. This is not accurately defined and could be 20° or more depending on the width of the bracket base. Different moments develop above or below the transitional point. Depending on the initial tooth inclination and the width of the bracket base, an intrusive force applied using a lingual bracket can develop a clockwise or counterclockwise moment. Although these moments are small, the crown movement followed by application of an intrusive or extrusive force cannot be predicted.

Contrary to the above study,[18] our results suggest that lingual force application may produce much more complicated and unpredictable tooth movement in terms of intrusion and extrusion. This conflict can be explained because the authors did not refer to different incisor inclinations or to a different bracket base thickness.

Clinical Implications

Periodontal cases with reduced bone level—application of intrusion and extrusion bends in LiO and LaO. Where bone level is reduced, the C_{res} moves apically, and the distance between PF and C_{res} increases, resulting in higher moments. Marginal bone loss increases the moment-to-force ratio (M/F) required for translation at 65% of bone loss (M/F increases by 0.65 mm for every 1 mm of bone loss).[20]

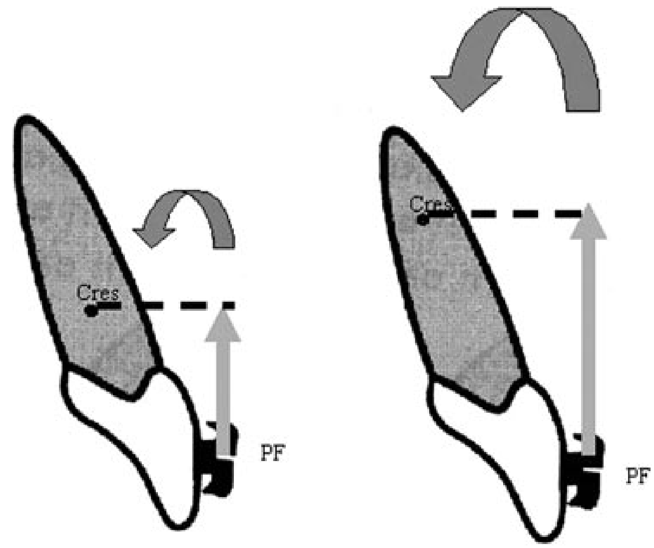

FIGURE 6. Center of resistance (C_{res}) is moved apically in cases of reduced bone level. The distance between the C_{res} and the point of force application is increased, resulting in increased moments.

Application of an intrusion force in cases of reduced bone level with a labial bracket creates counterclockwise moments that are larger than in normal cases because of the greater distance between the PF and the C_{res} (Figure 6). Therefore, the crown moves more labially. With a lingual bracket, different root moments are created depending on the initial tooth position, as described previously. The transitional point at which pure intrusion movement is created (without any labial or lingual movement of the crown) is smaller than in normal cases and depends on the bone level as well as on tooth inclination and bracket width.

Moments created with a lingual bracket as compared with a labial bracket are always smaller, with less side effects of proclination or retroclination of the crown. When the bone level is reduced and the incisors are proclined, the counterclockwise moments developed with intrusive forces are smaller than those developed with the labial bracket. There is also less labial crown movement (Figure 7).

Because the C_{res} and PF cannot be changed, the magnitude of forces applied to teeth with reduced periodontal support must be reduced to maintain the stress and strain at physiologic levels[21] and to reduce the moments.

Class II division 2 cases with incisor retroclination—application of intrusion and extrusion bends in LiO and LaO. Intrusive force applied on a retroclined incisor using a lingual bracket could aggravate the initial tooth position, making the tooth more retroclined. A clockwise moment develops, aggravating the initial retroclination by labial root

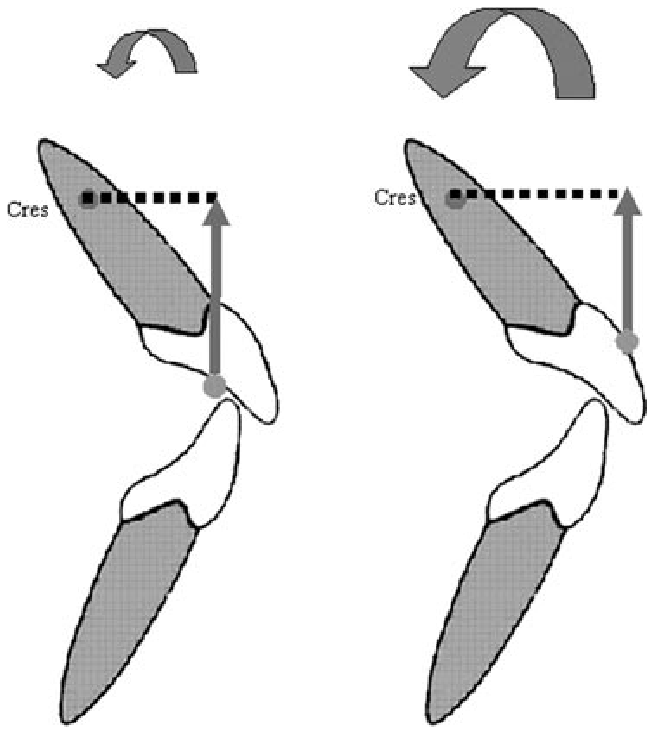

FIGURE 7. Distance between center of resistance and point of force application is shorter when using lingual brackets.

movement (Figure 8). The opposite occurs when an extrusive force is applied with a lingual bracket. An extrusive force on a retroclined tooth creates a counterclockwise moment, which may improve the incisor inclination.

Intrusion-extrusion bends with rectangular wire vs round wire. Intrusion-extrusion bends produce labial and lingual root moments. Labial and lingual crown tipping movements are observed when round wires are used for these bends. Tipping movements produce localized high-stress areas in the PDL, (periodontal ligament) and root, which increase the risk of tissue damage.[21]

When bending wires, a rectangular archwire should be used to avoid crown movements and to allow pure intrusion or extrusion. Using a full-size rectangular wire may control the moments because of the opposite moments developed by the rectangular wire. Consequently, only small labial or lingual crown movements will be observed when extrusion-intrusion bends are applied. The use of full-size TMA wires is recommended for this purpose in LiO (Ormco 0.0175- × 0.0175-inch lingual wire for 0.018-inch slot size).

CONCLUSIONS

A vertical force applied with labial and lingual appliances has different clinical effects on tooth movement. With a lingual force, it is more complicated, and its effect on tooth movement cannot be accurately anticipated because it depends on bracket position and initial tooth inclination. The effect of intrusive or extrusive force with the lingual appliance should be examined before application in any clinical situation to avoid side effects and to prevent creating the opposite of the desired movement.

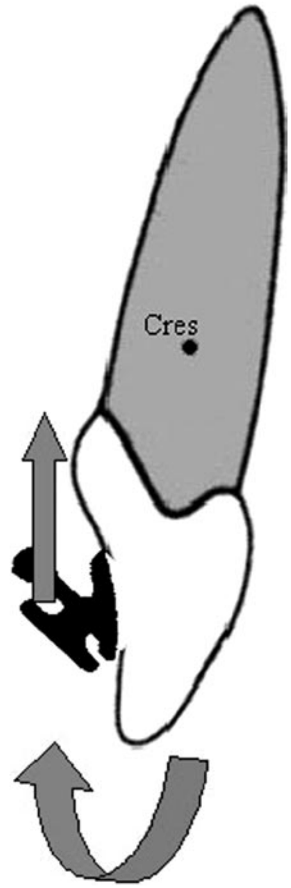

FIGURE 8. Intrusion force applied with a lingual bracket in case of a retroclined incisor creates lingual root movement and aggravation of the retroclination.

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