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ORIGINAL ARTICLE

Bodily labializing lateral incisors: 3D analysis using finite element method

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Abstract

Aim. Among all tooth types and movements, bodily labializing the upper lateral incisors is a challenging one. The main goal of this study is to introduce and analyze a method to labialize palatally erupted lateral incisors. ***Materials and methods.*** Five three dimensional finite element models were designed in SolidWorks 2010 of a segment of maxilla containing the upper left anterior teeth (with the lateral incisor in palatal position), their brackets, their PDLs, the spongy and cortical bone. A segment of 0.016 wire passing through the central incisor and canine brackets (bypassing the lateral incisor bracket) and a designed hook in the lateral incisor bracket (which comprises an inventory approach/design to treat a palatally erupted tooth). The hook and vertical bypassed segment height were 8, 10, 11.5 (stage 1), 9.5 (stage 2) and 9.45 mm (stage 3). Two equal forces (0.15 N each) were applied. Tooth displacements were recorded. ***Results.*** A hook length of 8 mm resulted in a tipping movement (apical = -7.78×10^{-5} mm; incisal = 3.8×10^{4} mm). The other two caused root movement. Stage 2 (hook = 9.5 mm) resulted in root movement (-1.4×10^{-4} mm in incisal; 1.58×10^{4} mm in apical area). Hook length = 9.45 produced bodily movement (incisal = 7.1×10^{5} mm; apical = 6.9×10^{5} mm). ***Conclusion.*** A definite length of the hook was shown to produce bodily movement. This definite length of hook in combination with the same length of bypassed wire can be applied to produce bodily movement of the lateral incisor. An intrusive component can also be added.

Key Words: *orthodontic tooth movement, bodily movement, lateral incisor, finite element method, tooth levelling and aligning*

Introduction

An orthodontic treatment is not completed unless favorable tooth movements are managed in an acceptable consequence to provide a normal/ideal occlusion. According to Proffit et al. [1], physiologic and orthodontic tooth movements are accounted for in treatments. The applied force system triggers a physiological change of the surrounding attachment apparatus. The net result is an inflammatory process and tooth movement.

The first stage of most orthodontic treatments is to align and level the teeth [1]. Light flexible wires are usually used with round (in majority of cases) [1] or rectangular cross-sections (in selected cases of some techniques) [2]. Leveling and aligning is considered to be completed by tipping the involved teeth, which is acceptable in most cases. Palatally displaced lateral incisors are commonly observed in the maxillary arch of patients [3]. One of the shortcomings of orthodontic techniques is their inability to properly treat a palatally positioned lateral incisor if bodily movement is needed. This is because the needed M/F ratio to produce bodily movement is unreachable in this stage of treatment with flexible wires. This inability remains the same during treatment in the lateral incisor region. The center of resistance is a point in a body through which a single force produces bodily movement. Various studies [4–6] have used different methods to examine the characteristics of tooth movement, including the finite element method. Finite element analysis can evaluate the stress distribution in tooth movements and make clear the type of movement when different force systems are applied to the teeth [7–10].

Applying a power arm to move a tooth in a mesiodistal direction is not a new idea and has evidences in the literature [11,12]. Tanne et al. [13] investigated

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the relationship of moment to force ratio (M/F) and the center of rotation using finite element analysis (FEA) in an upper right central incisor. The center of rotation was calculated when applying different M/F ratios. The center of resistance was located 0.24-times the root length measured apical from the alveolar crest level.

Vollmer and Bourauel [14] used FEM to analyze human canine teeth at initial tooth movement to aid in determining the center of resistance. They found that the center of resistance is about two-fifths of the root length from the alveolar margin. However, they concluded that it's very difficult to achieve pure translation in the canine model.

Alveolar bone height and its effects on the center of rotation and resistance of a tooth were assessed by Geramy [7]. It was found that the center of resistance was affected by alveolar bone heights. Greater amounts of bone height loss produced greater amounts of incisal edge and apex displacement and a shift of the center of resistance towards the alveolar crest.

In another study, finite element analysis was used by Geramy [8] to assess different M/F ratios and the different types of tooth movement produced in an upper central incisor. The closest position to the bodily movement was found to be produced by applying M/F = 8.44 mm. The center of rotation of a simple tipping movement located at 6.53 mm incisal to the apex.

The main goal of this study was to assess the possibility of bodily movement of the lateral incisor when aligning the anterior teeth by a newly designed hook by the finite element method. The other goal was to show other tooth movement types produced by this hook. To the author's knowledge this is the first time that the bodily labializing of the lateral incisors is being introduced and assessed.

Materials and methods

Five 3D computer models of an upper left lateral incisor were designed in SolidWorks 2010 (SolidWorks, Concord, MA). The tooth was modeled according to Ash's [15] dental anatomy. The models contained cortical and spongy bone, an upper left central and lateral incisor, canine, their PDLs, the brackets, a segment of round arch wire (0.016" diameter) passing through the central incisor and canine brackets while bypassing the lateral incisor one. This part of the wire is placed at the same vertical height with the designed hook. The models were the same except for their hook and the bypassed wire heights. The bracket of the lateral incisor was attached 3.93 mm cervical to incisal edge. The hook height was 8 mm (model 1), 10 mm (model 2), 11.5 mm (model 3), 9.5 mm (model 4), and 9.45 mm (model 5). The analyses were prepared in three stages; models 1–3 were used in the first stage, model 4 in the second and model 5 in the third stage. The second and third stage was designed based on the results of the previous model(s)/stage. The 3D models were designed to be as realistic as possible, without using any symmetry. The models were transferred to the ANSYS Workbench Version 12.1 (ANSYS Inc, Southpointe, Canonsburg, PA). Boundary conditions restricted displacements of the nodes at the upper and lateral surfaces of the models to prevent rigid body motion. The manner of restriction was based on the anatomy of the maxilla. The wire segment was restricted from displacements in mesio-distal direction to simulate the continuity of the arch wire. The wire segment was left free to rotate around its long axis (not producing any moment in the other brackets due to its cross section shape). Mechanical properties (Table I) were then applied and the models were meshed with 52470 nodes and 16659 elements (Figure 1).

The applied force system contained a 0.3 N force divided to two equal force vectors on each hook tip towards the bypassed wire and the same in the bypassed wire towards the hook tip, simulating a piece of elastic thread tied between the hook and the wire.

At each stage of the study, the incisal, cervical and apical displacements of the lateral incisor were recorded to be used as a guide to the next stage and the lengths of the arm was considered in a sequence to produce bodily movement. Reviewing the results at stage one, it was decided to reduce the hook length in stage two and the same for the third stage.

Results

In the numeric findings, positive ones refer to labial and negative ones to palatal displacement.

- *Stage 1*: In model 1, with hook length of 8 mm, the displacement of the incisal edge was 3.3×10^{-4} mm; 1.65×10^{-4} mm for the cervical area; 7.78×10^{5} mm in the apical area (representing a tipping movement). Hook length of 10 mm resulted in -2.1×10^{-4} mm in the incisal region, -8.11×10^{-6} mm in the cervical area and 2×10^{4} mm in the apical area (Root movement). When the hook extended more in model 3 (= 11.46 mm), the root movement was more than

Table I. Mechanical properties of the materials used in models.

	Young's Modulus (MPa)	Poisson's Ratio
C bone	34000	0.26
S bone	13400	0.38
PDL	0.667	0.49
Tooth	20300	0.26
SS bracket	200000	0.3

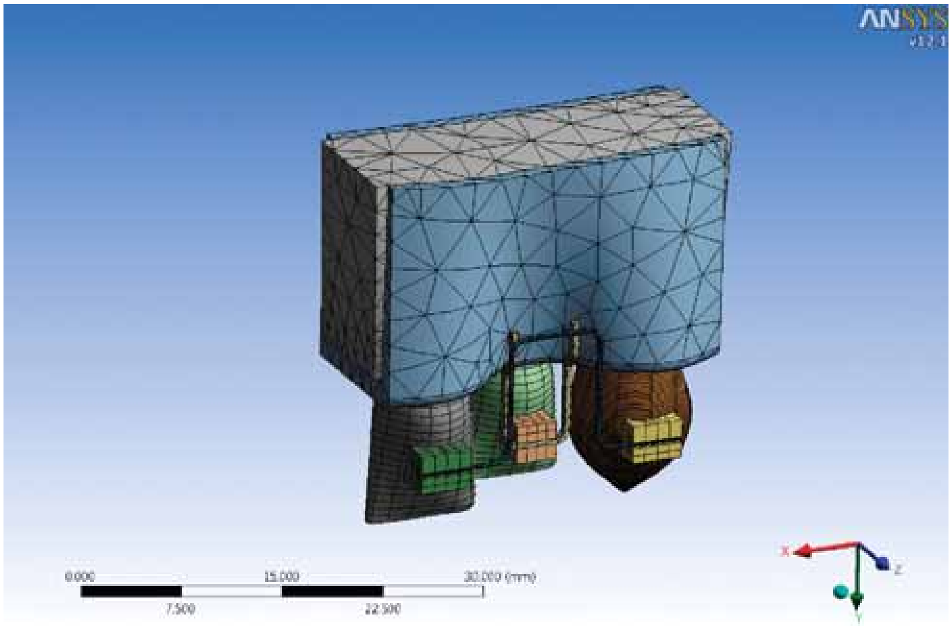

Figure 1. The meshed model with cortical and spongy bone, the teeth and their PDL; the bypassed arch wire and the hook.

the cervical and incisal area; -3.64×10^{-4} mm in the incisal area, -2.99×10^{-5} mm in the cervical area, and 2.24×10^{-4} mm in the apical region (The root movement) (Figures 2A–C).

- *Stage 2*: In the second stage (in model 4), the hook length was reduced to 9.5 mm and displacements results were, 1.4×10^{4} mm in the incisal area, 7×10^{-6} mm in the cervical area and 1.58×10^{-4} mm in the apical area (Root movement) (Figure 2C). This necessitated a decrease in hook length.
- *Stage 3*: In model 5 (the last stage), with a hook length of 9.45 mm, the displacements were 7.1×10^{-5} mm for the incisal edge; 7.7×10^{-5} mm in the cervical area and 6.7×10^{-5} mm (The nearest situation to the body) (Figure 2D).

Clinical application

An 18-year-old boy with a chief complaint of unaesthetic and crowded anterior teeth was referred for orthodontic treatment. His treatment plan included extraction of the first premolars, leveling and aligning, canine retraction, and the next step was to align the palatally erutpted lateral incisors. Palatal eruption of the lateral incisors was managed using the hook after a radiographic evaluation of the teeth to estimate the location of the center of resistance. (Almost 0.3-times the root length measured from the alveolar crest.) Hooks were made of 0.017" × 0.025" SS wire in October 2010 and the force application was started. The desired tooth movement was to labialize them by bodily movement without any vertical component. The displacement in the left one was acceptable, but the right one was judged to need a longer arm due to the presence of degrees of tipping. The new hook was designed on January 2011 and the final form was achieved on July 2011 (Figures 3A–E).

Discussion

For the first time, a method is introduced to deal with palatally erupted lateral incisors in maxillae needing bodily movement. Although the duration of orthodontic treatments can be a strong motivation in looking for new methods to reduce the total time needed in treating a case, it is not the case in bodily labializing of the upper lateral incisors in some cases, as we cannot correct the tooth positions acceptably without a high risk for the tooth health. Bodily movement is the most desirable one among tooth movement types due to its decreased stress levels in root surface [16]. A decrease of the stress is provided by the highest root surface area available to compress the PDL in the displacement direction [1,16].

Proper positioning of the anterior teeth is a prerequisite of aesthetics in orthodontic treatments.

The real challenge in aligning the upper lateral incisor is to bring it bodily to an acceptable position. There are two alternative strategies in the contemporary orthodontic treatments to align this tooth: leaving it unmoved in the aligning and leveling phase and engaging it after reaching an acceptable leveled arch either by a NiTi section of wire or by an elastic tread/chain. The other method is to start the correction from the beginning of the leveling and aligning phase by engaging the lateral incisor to the wire. The main shortcoming is the lack of required M/F ratio to produce a bodily movement. The applied force in

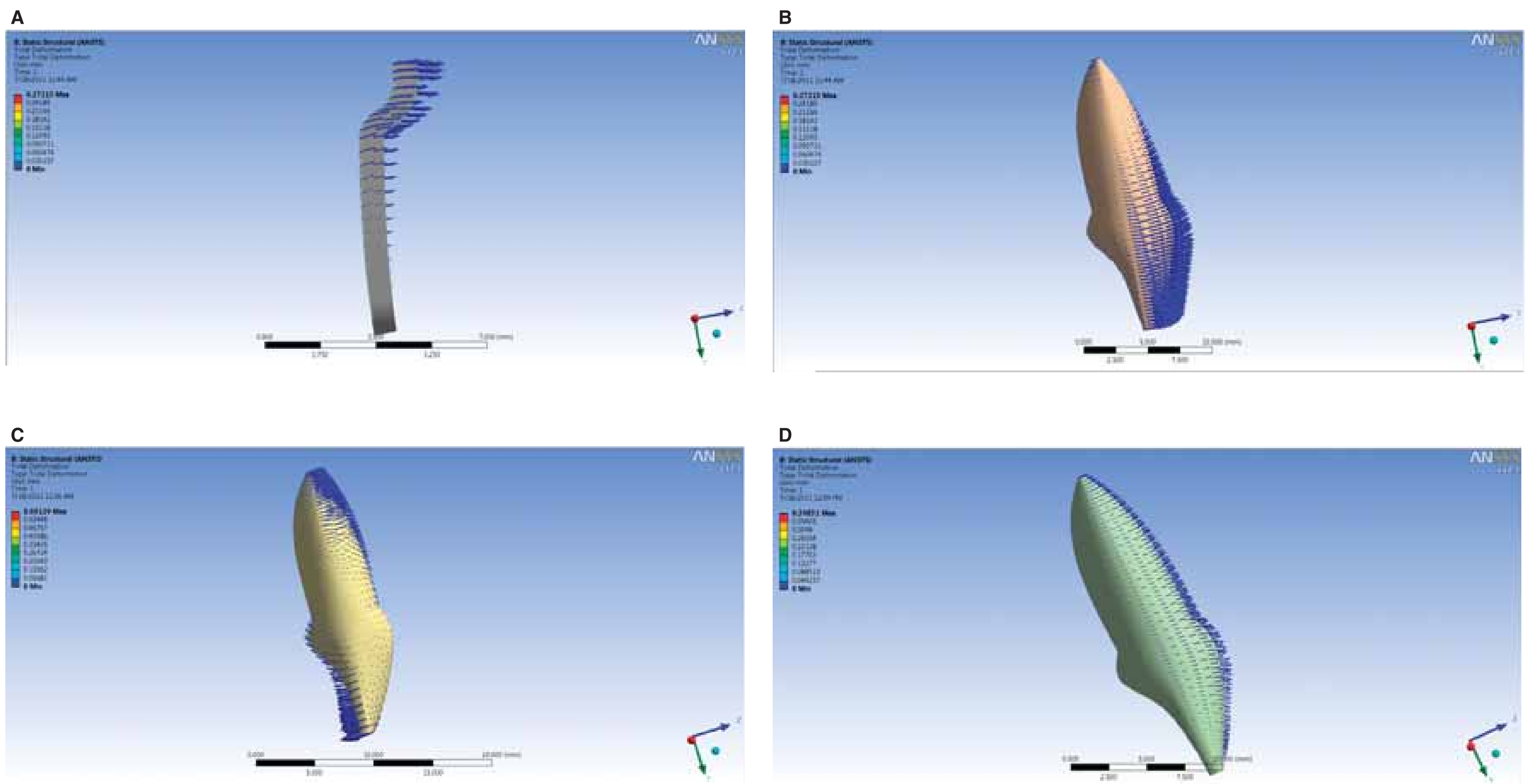

Figure 2. (A) The vector display of hook displacement. (B) Tipping movement. (C) Root movement. (D) Bodily movement.

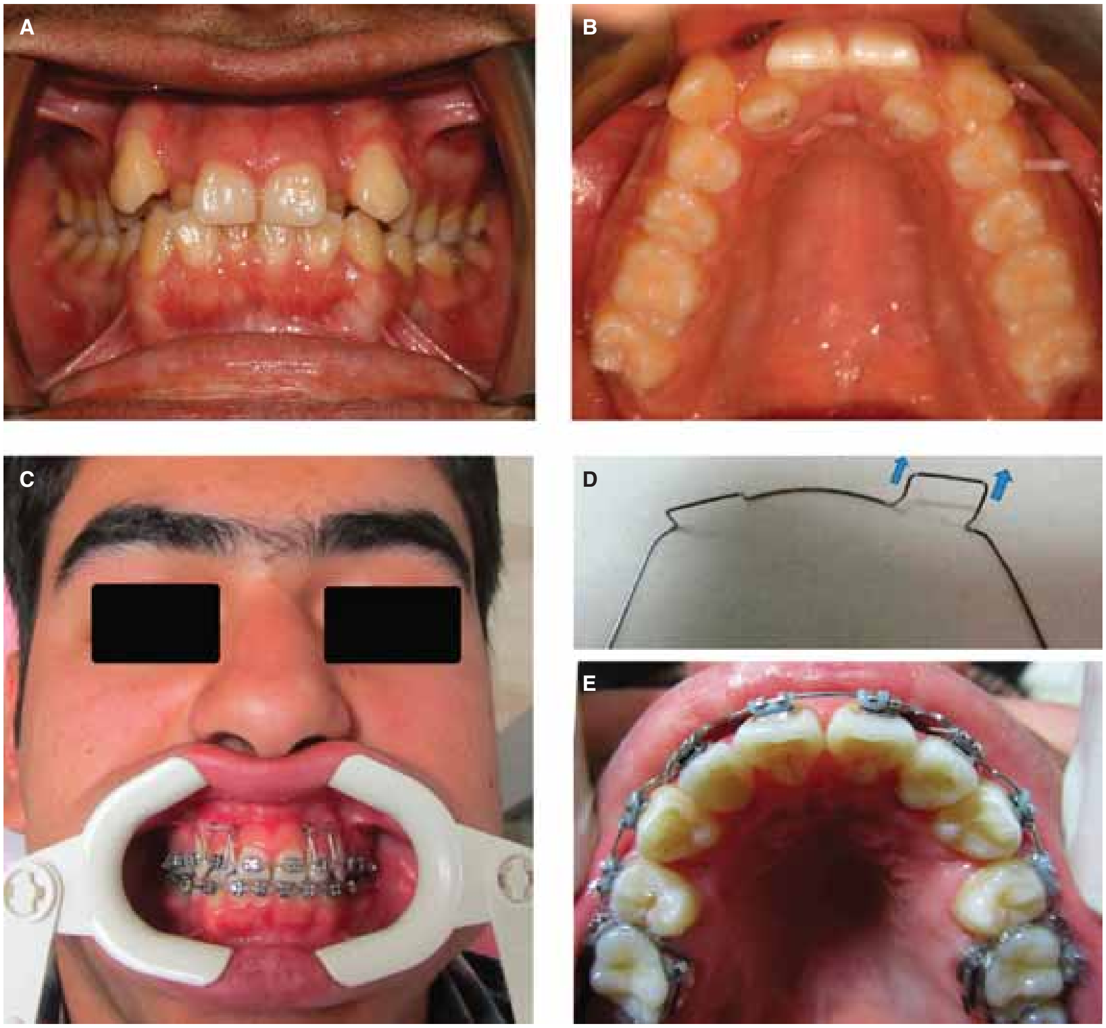

Figure 3. (A) Frontal view of the dental arch before treatment. Palatal eruption (cross-bite) of the lateral incisors is noticed. (B) Upper dental arch before treatment. Palatal eruption of the lateral incisors and the uneven form (concavity) of the gingivae between the central incisors and canines is noticed. (C) The bypassed arch wire and the hook in place before force application. Please note the gingival form. (D) The bypassed arch wire; activated in one side to serve as an additional source of labial driving force on the lateral incisor (the other side will be bent afterwards). (E) The alignment of the lateral incisors has been completed. Please note the alignment produced in the cingulum of the incisors.

these methods is a light, somehow continuous one without needed moment to produce a desirable M/F ratio. A round cross-section of the wire cannot produce moment and in the second method the tread or chain can only apply a single force. The resulting movement is tipping in both ways.

There is no need to explain the disadvantage of applying force systems with lower M/F ratios. They can produce a tipping movement, worsening the apex position (more palatally) and leaving the gingival form uneven (in occlusal and frontal view) between the central incisor and canine and this is considered a non-aesthetic appearance. To complete the tooth movement, a phase of torque correction is needed. Torque correction in this area is a high risk one due to two main reasons: the weakest single-root tooth is going to undergo a long-term stress concentration in its apical part in torque correction [16] after a history of stress concentration in the tipping phase in palatal movement [16] and also a reverse (root palatal torque as a side-effect) is produced on the two adjacent teeth (the central incisor and canine).

Once the bodily movement is reached (the line of action of the force passes through the center of resistance (CRes)), the direction can be adjusted to combine bodily movement and vertical displacements (extrusion or intrusion). The direction of the force is determined by the vertical position of the hook end and the bypassed wire. An equal length of the hook and the bypassed wire is recommended for a bodily movement without vertical component; however, intrusion can be easily produced by a longer bypassed wire than the hook length.

Selecting the round cross-section as the base arch wire makes it possible for the wire segment to move towards the hook when the force application is started to the lateral incisor while avoiding any moment (torque) to the adjacent teeth, leaving

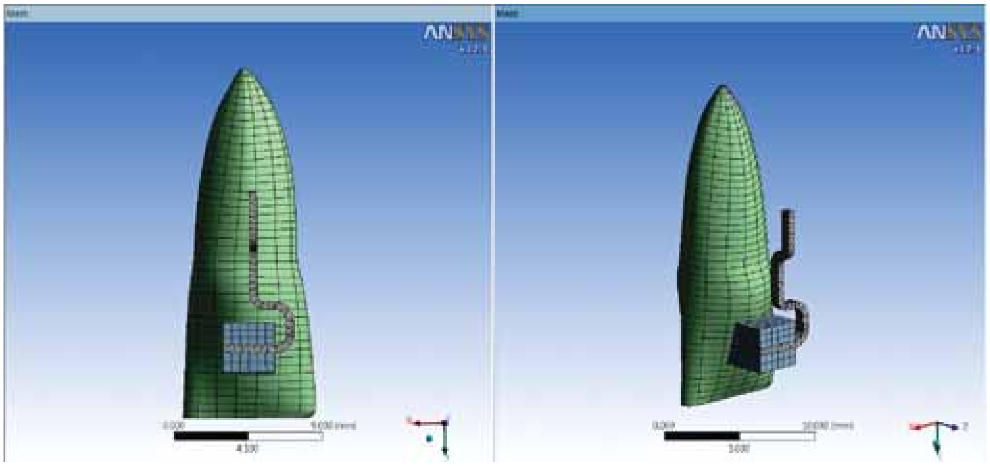

Figure 4. Modified model with one leg. (Any misjudgment in the mesio-distal location of the tooth long axis will cause a rotation due to the moment arm present).

them almost unloaded (unless the vertical component is added).

Another point to mention is the continuity of force application manner. In this approach, the labial driving force is a combination of elastic thread force (or a ring elastic inserted in the main arch wire before being placed on the dental arch) and a force produced by the bypassed wire after engagement. The bypassed segment of the arch wire can be bent labially before being attached to the hook ends with a piece of elastic thread to serve as an additional source of labial force to the lateral incisors (Figure 3D). This combination is hoped to provide a light continuous force on the lateral incisor.

The other benefit from a two legged hook is to provide an ability to apply unequal forces in legs to correct the rotated tooth while bringing it to its proper position. Unequal bending of the bypassed wire segment can also be another approach to deal with rotated lateral incisors.

An upper Hawley removable appliance with anterior bite plane can be fabricated. This is not going to be used during treatment as an auxiliary but can serve as a visual aid to monitor the tooth movement type. This can be used as a template to monitor the distance of the palatal aspect of the lateral incisor(s) from its (their) counterpart in the acrylic. The monitoring can be facilitated by grinding the acrylic in the distal half (halves) of the lateral incisor(s). A parallel separation of the palatal aspect of the crown and acrylic in consequent visits is interpreted as bodily movement. Any variation to this should be noticed and interpreted to reach a bodily movement by adjusting the hook length.

A modification to this design may be applied, which is to delete one leg and bring the hook leg in front of the tooth long axis (Figure 4). This design necessitates further consideration which is to avoid any mesio-distal distance between the hook tip and the CRes (viewed frontally to coincide with the long axis of the tooth). It is worth mentioning that the presence of such horizontal distance results in a moment [M = F (labializing force) $\times$ d (horizontal distance between the hook and the tooth long axis)]. This judgment may be difficult in some cases (in the case of normal variations in crown form) causing rotation and increasing treatment duration.

Conclusion

Bodily displacement of lateral incisors was shown to be practical both clinically and analytically using this new design.

A vertical component of force can be easily added to the design if diagnosed necessary. This component is added by considering a difference between the hook ends and the height of the bypassed part of the wire. Viewed laterally, this difference causes an angle to be formed between the force vector and the horizontal plan.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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