Original Article

Is There a Need to Increase Palatal Root Torque of Upper Incisors in Lingual Appliance? A Finite Element Analysis

Abstract

Objectives: To understand the effect of the biomechanical differences by assessing pre and post retraction torque, amount of retraction and arch width changes in both techniques. **Methodology:** A three-dimensional geometric model of maxilla with all upper teeth except first premolar was generated based on computed tomography radiograph of a dry skull using the computer program Hypermesh. 13.0. Virtual models of 0.022 "Roth labial brackets and 0.018 "ORMCO 7th generation lingual brackets; and for labial brackets 0.019 × 0.025" SS archwire and for lingual brackets 0.016 × 0.024" SS archwire were constructed. Sliding mechanics was used during en-masse retraction by applying a 300 g distal force on both sides of the dentition from canine to the second premolar brackets in the labial and lingual simulation. The finite element program ANSYS 12.1 was used to calculate the torque and displacement. **Results:** The results stipulated that in transverse direction there was lingual tipping of anteriors, mild buccal flaring in second premolars and first molars and lingual tipping in second molar in lingual appliance. In the sagittal plane, the greater distal movement of posteriors and an up-righting tendency of molars were observed in lingual appliance. Extrusion of anterior teeth were observed in both appliances. Regarding the premolars and first molars, labial movements and relative intrusion were observed in lingual appliance compared to labial appliance. **Conclusion:** In lingual treatment, it is crucial to increase the lingual root torque. The amount of retraction and arch widening were more in lingual appliance compared to labial technique.

Keywords: *En masse retraction, finite element analysis, labial appliance, lingual appliance*

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Introduction

Aesthetics is an important parameter in contemporary society. Lingual orthodontic appliances enjoy aesthetic advantages over conventional labial orthodontic appliances.[1] Fixed, bonded, lingual appliances have built-in mechanical differences from more widely used labial attachments.

Previous researchers have used different methods i.e., photo-elasticity,[2] laser holography[3] and finite element analysis (FEA) for biomechanical analysis and to verify the pattern of orthodontic teeth movement. Among all of them, FEA was considered to be the best suitable method for biomechanical analysis. The FEA has proved to be effective in simulating tooth movement and optimizing orthodontic mechanics. Previous studies have evaluated the biomechanical effects of various orthodontic treatment modalities with the FEA.[4-6]

A paucity of literature was observed regarding the torque expression capability of lingual and labial appliance. Hence the aim of the present study was to do a comparative evaluation of torque expression, amount of retraction and arch-width changes in maxillary arch following first premolar extraction using labial and lingual fixed appliance.

Methodology

Three-dimensional (3D) geometric model of a normal human skull was generated using a X-force/SH spiral computed tomography (CT) scan of a dry skull. From that maxilla was separated. All the data transfer, modeling and the FEA were performed on a workstation computer (Intel core 2 duo with 2.1 GHz, 2 GB RAM, 2GB graphics card, 320GB hard disk and 17″ monitor). The CT scan images in the DICOM format (Digital Imaging and

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Communications in Medicine) were used as the input and were entered into MIMICS (version 8.11, Materialise NV), Headquartered in Leuven Belgium software.

These data were exported as stereolithographic format and imported into Rapid Form software (Inus Technology Inc, Seoul, Korea) (2004) to convert cloud data points to surfaces. Using this software, the geometric model of the maxilla, was generated, which was considered for Finite element modeling. The geometric model of maxilla, teeth, periodontal ligament, alveolar bone etc., were imported into the meshing software "Hypermesh," then discretized and assembled. Meshed models were called finite element models and it consisted of 3D four noded tetrahedral elements.

Proper material properties were to be assigned to the finite element model to simulate the behavior of the object studied. The material properties assigned were the Young's Modulus (modulus of elasticity) and the Poisson's ratio to assess the behavioral pattern of the maxilla and maxillary dentition. By assigning a set of material parameters to the finite element software, one can readily obtain a set of numeric results. The point of force application, the magnitude, and direction of force application can easily be varied to simulate clinical situation.

In this finite element study, as we considered the static loading of the finite element model, all materials used in this study were defined as homogeneous, isotropic, and linearly elastic. Previous studies had reported the Young's moduli and the Poisson's ratio for compact bone, cancellous bone, sutures, teeth and periodontal ligament, respectively, under isotropic conditions [Table 1].[7,8] These material properties were the average values reported in the literature.

The boundary condition represents the load imposed on the structures under the study. Here the model was restrained at the superior border of the maxilla to avoid any motion against the loads imposed on the dentition. Once the boundary conditions were defined, separate models were constructed for labial and lingual appliance. The type of finite element used in the analysis was 3D tetrahedral elements and the mathematical model comprised a total of 34,4654 elements (75,359 nodes) and 317,967 elements (69,172 nodes) for lingual and labial appliance models, respectively. The finite element model generated was restricted to a certain zone beyond the cortical bone. The cancellous bone has been extended horizontally approximately 1/3rd of the tooth length below the tooth roots, making an artificial lower boundary. After the model was completed, boundary conditions were defined at all peripheral nodes of the bone, giving them 0° of freedom in all directions. Virtual models of 0.022" Roth (ORMCO) labial brackets and 0.018" ORMCO 7th generation lingual brackets; and for labial brackets 0.019 × 0.025" SS archwire and for lingual brackets 0.016 × 0.024" SS archwire were constructed. The constructed brackets and archwires were placed in their proper positions according to the technique.

Table 1: Material properties of components[7,8]

Material	Young's modulus (N/mm)	Poisson's ratio
Cancellous bone	1370	0.30
Cortical bone	13,700	0.26
PDL	0.6668	0.49
Tooth	20,000	0.30
Bracket and SS wire	214,000	0.30
NiTi coil spring	110×10^3 N/mm	0.35

PDL: Periodontal ligament, SS: Stainless steel

For consolidating the maxillary teeth, using en masse retraction, anterior and posterior teeth are ligated as separate unit via figure of eight virtual ligation. Sliding mechanics were used during en masse retraction of the anterior dentition, using 0.019 × 0.025" SS and 0.016 × 0.024" SS labial and lingual mushroom arch wires, respectively, in the respective slots.

To simulate the bracket ligation, link elements were defined between the nodes on the mesial and distal ends of the bracket in both models. A distal force of 300 g was applied using NiTi coil spring[9-12] to simulate consistent light force on both sides of the dentition from the distal wing of canine bracket to the mesial wing of the second premolar bracket in the labial simulation [Figure 1] and between the hooks on the canine and second premolar brackets [Figure 2] in the lingual simulation.

The linear static analysis was carried out using the ANSYS software (Analysis System Software version 12.1, Ansys, Inc. Canonsburg,Pennsylvania, United States) and the response of applied loads was interpreted. ANSYS is a FEA code widely used in the computer-aided engineering that allowed us to construct computer models of structures, machine components or systems; apply operating loads and other design criteria; and study physical responses, such as stress levels, temperature distributions, pressure, displacement etc., In this study, torque expression, arch width changes and amount of retraction in both techniques were assessed.

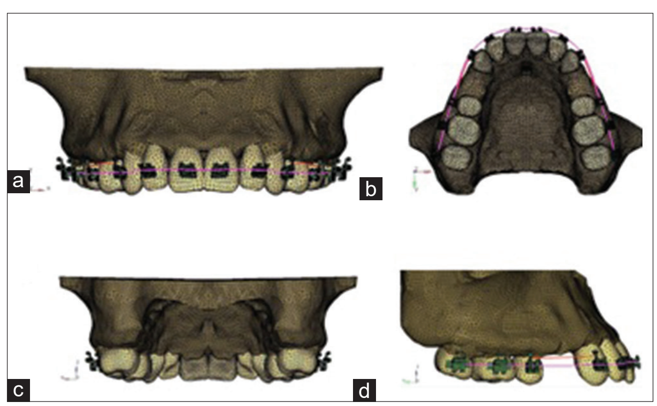


Figure 1: Creation of finite element model of maxilla for labial appliance. (a) Front view, (b) occlusal view, (c) rear view, (d) side view

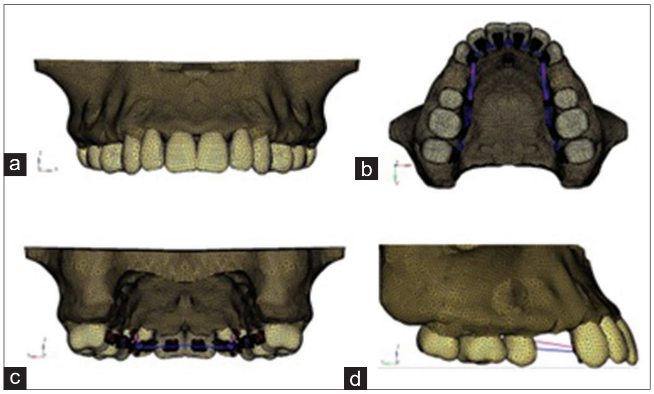


Figure 2: Creation of finite element model of maxilla for lingual appliance. (a) Front view (b) occlusal view, (c) rear view, (d) side view

For the assessment of torque change, angle between perpendicular to occlusal plane and facial axis of clinical crown was taken for labial appliance [Figure 3a], as mentioned by Andrews,[13] and angle between tangent to the prominent portion of lingual surface and LA plane [Figure 3b] was taken for lingual appliance.[14]

A coordinate system with X, Y, and Z axes perpendicular to one another was used. The X axis represented the bucco-lingual direction (+lingual, −buccal), the Y axis the mesiodistal direction (+distal,-mesial), and the Z axis the vertical direction (+ intrusion,-extrusion). To simplify the expression of tooth displacements, reference nodes were placed on the cusps and root apex. The amount of initial displacement of these landmark nodes on the X, Y, and Z axes after orthodontic force application was analyzed by FEM. For ease of interpretation, the values obtained were magnified by 10,000. Teeth movement was measured in "mm."

The tooth movement pattern was analyzed and compared and displacements were interpreted by various colors. Finally, the results were processed and documented.

Results

In Labial appliance, central incisor palatal root torque, decreased from + 13° to + 11.4° and from 12° to 11.1° in lateral incisor. In canine, labial root torque decreased by 1°. The torque difference in second premolar was −0.5°, from a palatal crown torque of 9°-8.5°. In first molar and second molar torque difference was −0.8°, indicated that decrease in buccal root torque of 14°–13.2° [Graph 1].

Torque changes observed for Lingual appliance [Graph 2] is as follows; In central incisor torque value decreased from 57° to 55° indicating that labial crown torque, decreased by 2°, the palatal root torque decreased by 1.2° for lateral incisor. In the case of canine labial crown torque decreased by 1.5° from an initial value of 55°–53.5°. There observed a torque difference of 0.4° in second premolar from a buccal crown torque of 9°–9.4°. In first molar and second molar, torque difference was 0.5° and 0.4°, respectively, indicated that mild palatal root torque in first molar and buccal root torque in second molar.

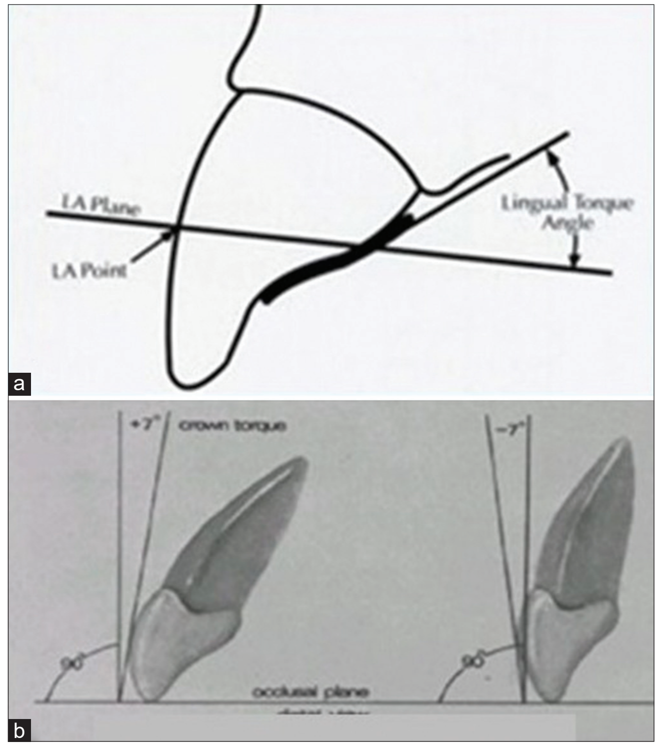


Figure 3: Torque assessment (a) labial appliance,[13] (b) lingual appliance[14]

The initial displacement [Figures 4 and 5] of the reference nodes (X, Y and Z coordinates) caused by retraction force applied [Table 2] were the following**:**

Central and lateral incisors: Central incisor and lateral incisor showed lingual tipping (+X) extrusion (−Z) and distal tipping (+Y) of crowns in both groups, although greater tipping and extrusion occurred with lingual technique in central incisor and less extrusion in lateral incisor compared to labial.

In the case of Canine, lingual (+X) and distal tipping (+Y) and extrusion (−Z) of crowns were evident in both groups, although less lingual tipping, more distal tipping and extrusion occurred with the lingual modality.

Second Premolar: Lingual (+X) and distal tipping (+Y) with extrusion (−Z) observed with labial retraction, whereas in lingual technique labial (−X) and distal tipping (+Y) with extrusion (−Z) was noted. Even though difference in transverse, anteroposterior and vertical displacements were smaller between the techniques rotation movement was greater with lingual appliance.

First molar: Lingual (+X) movement of the crown with distal (+Y) tipping, extrusion (+Z) and mesiolingual rotation was seen with labial appliance, whereas labial (+X) tipping with mesiolabial rotation, distal (+Y) tipping and extrusion (+Z) observed with lingual appliance.

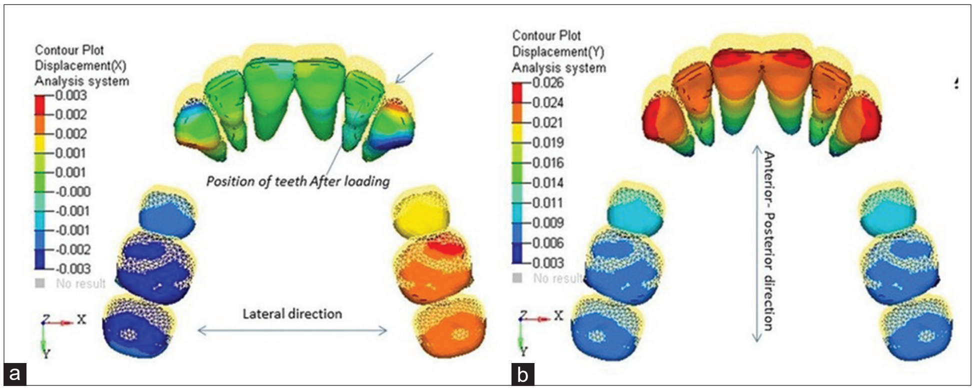


Figure 4: Position of teeth before and after loading in X direction: (a) Labial appliance and (b) Lingual appliance

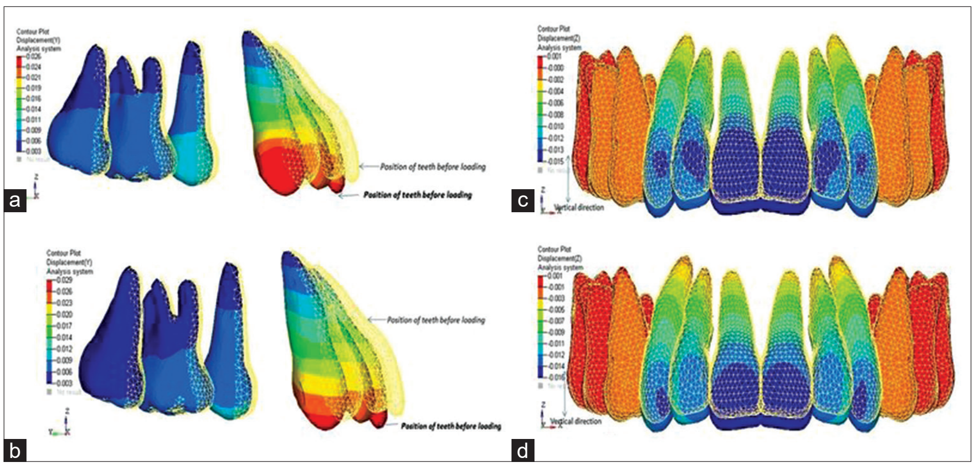


Figure 5: Position of teeth before and after loading in Y-direction: (a) Labial appliance and (b) lingual appliance; position of teeth before and after loading in Z-direction, (c) labial appliance and (d) lingual appliance

Second molars: Lingual movement (+X) of the crowns with mesiolingual rotation, distal tipping (+Y) and extrusion (−Z) of lingual cusps and intrusion (−Z) of mesiobuccal and disto-buccal cusp were observed with labial appliance, as compared to lingual (+X) tipping accompanied by mesiolingual rotation, distal tipping (+Y) and intrusion (+Z) in the lingual technique.

In labial technique, arch width [Table 3 and Figure 4a] decreased by 0.296 mm in canine region, 0.33 mm in premolar area, 0.427 mm in first molar region and 0.359 mm in second molar region. In lingual technique [Figure 4b], arch width decreased by 0.082 mm in canine region, increased by 0.338 mm in second premolar region and first molar region and decreased by 0.359 mm in second molar region.

Anterior teeth moved to the distal by 0.026 mm [Figure 5a] and extruded to the extent of 0.015 mm [Figure 5c] in labial appliance. At the same time, in lingual appliance, anterior teeth moved distal by 0.029 mm [Figure 5b] and extruded 0.016 mm [Figure 5d].

Discussion

Torque changes

Anterior teeth root had an overall tendency toward labial root torque or otherwise torque loss, indicated by reduced palatal root torque in lingual appliance. This can be explained by the direction of applied force to the lingual brackets which passes lingual to the center of rotation of the teeth, resulting in increased lingual crown torque on the anterior teeth.

Second premolar showed more of a buccal crown torque, first molar roots also showed a palatal torque and second molars exhibited buccal crown torque. Even though labial appliance also had a tendency toward torque loss, compared to lingual appliance, it was less. However, first molar and second molar expressed a reduction in buccal root torque.

This study is in agreement with another study by Liang *et al.*,[4] in which they stated that, when retracting incisors, controlling the torque is important. It can produce lingual crown tipping of incisors. Because of the contour of the lingual surface, the height of bracket positioning, the point of force application would be more occlusal than labial. This leads to the generation of an additional lingual crown torque,

Table 2: Overall changes- displacement in X, Y and Z axis

Location	X - direction (×10⁻⁴ mm)		Y - direction (×10⁻⁴ mm)		Z - direction (×10⁻⁴ mm)	
	Labial	Lingual	Labial	Lingual	Labial	Lingual
Central incisor						
Occlusal	6.3	8.7	2.5	2.8	−1.5	−1.6
Apex	−2.6	−3	0.67	0.72	−0.28	−0.22
Lateral incisor						
Occlusal	13.1	17.29	2.35	2.62	−1.4	−1.34
Apex	−3.2	−2.3	0.61	0.67	−0.23	−0.14
Canine						
Occlusal	29.2	28.53	2.64	2.85	−1.4	−1.49
Apex	−25.2	−26.91	0.43	0.46	−0.14	−0.07
Second Premolar						
Buccal cusp	17.2	−19.44	1.01	0.97	−0.21	−0.17
Lingual cusp	16.5	−15.32	0.91	0.91	−0.18	−0.15
Apex	−5.1	−6.13	0.43	0.39	−0.046	−0.067
First molar						
Mesiobuccal Cusp	24.1	−18.46	0.83	0.69	−0.04	−0.082
Disto -Buccal Cusp	22.3	17.22	0.78	0.66	−0.06	−0.026
Mesiolingual Cusp	18.7	−14.75	0.73	0.63	−0.12	−0.068
Disto - Lingual Cusp	17.8	14.31	0.69	0.59	−0.14	−0.012
Mesial Apex	−13.8	−10.16	0.46	0.42	−0.04	−0.04
Distal Apex	−12.3	8.41	0.42	0.39	0.045	0.043
Second molar						
Mesiobuccal Cusp	22.8	19.42	0.76	0.62	0.04	0.023
Disto -Buccal Cusp	21.4	19.07	0.71	0.59	0.035	0.011
Mesiolingual Cusp	17.7	15.08	0.69	0.55	−0.015	0.021
Disto - Lingual Cusp	16.5	14.71	0.65	0.51	−0.013	0.01
Mesial Apex	−12.6	10.97	0.39	0.35	0.015	−0.012
Distal Apex	−11.2	10.03	0.35	0.32	0.011	−0.006

Table 3: Arch width changes pre- and post-retraction width in labial and lingual appliance

Teeth	Preretraction width (×10⁻⁴ mm)		Postretraction width (×10⁻⁴ mm)	
	Labial	Lingual	Labial	Lingual
Canine	36.652	26.444	36.356	26.362
Second premolar	48.693	31.152	48.363	31.49
First molar	55.352	32.785	54.925	33.123
Second molar	60.074	38.525	59.678	38.166

leading to exaggerated lingual crown movement in lingual treatment. They also pointed to the fact that biomechanical effects in labial orthodontics were 15% more than in lingual orthodontics with the same torque. These findings suggest that more torque force is needed to compensate the loss of torque control during retraction in lingual orthodontic treatment. The inclination of incisors will be reduced, if torque is not controlled during the retraction of the teeth. Also the amount of retraction will be increased.[15]

The current study showed adverse transverse and vertical bowing effects in the entire dentition with the lingual setup indicated by buccal flaring of second premolars and first molar, leading to increased arch width in premolar and first molar region and more lingual tipping and extrusion of the anterior dentition.

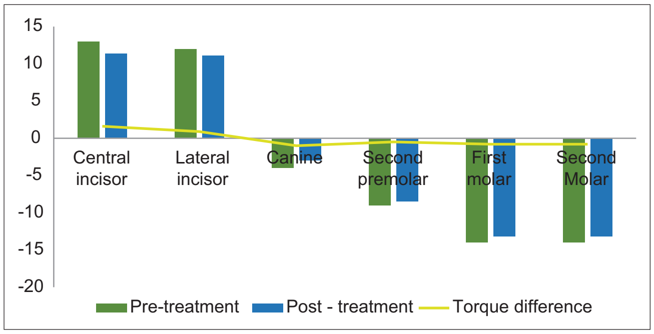
Mascarenhas *et al.*[16] used finite element model of right maxillary central incisor. In their study they applied vertical and horizontal forces labially and lingually at 3 different heights 4 mm, 5 mm, and 6 mm from the incisal edge and found that intrusion and retraction force resulted in tipping of incisors reflected as "vertical bowing" effect in lingual orthodontics and intrusion in labial orthodontics.

Arch width changes

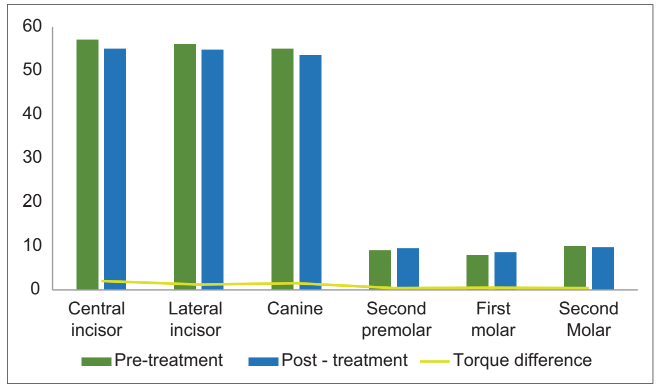
Displacement along the X-axis

In the present study, central incisor and lateral incisor showed lingual tipping of + 6.3 and + 13.1, respectively, in labial appliance model [Figure 4a]. At the same time, in lingual appliance [Figure 4b] model central and lateral incisor demonstrated more lingual tipping of + 87, +17.29, respectively, than the labial appliance. In the case of canine, labial appliance had lingual (+X) tipping of + 29.2 and lingual appliance demonstrated lesser value of + 28.53.

It was evident that, on an average lingual tipping of anteriors was more for lingual appliance as compared to labial appliance. This confirms the result obtained by Liang



Graph 1: Graphical representation of torque changes observed in labial appliance



Graph 2: Graphical representation of torque changes observed in lingual appliance

et al.,[4] which stated that loads of the identical magnitude produced greater maxillary incisor crown tipping in lingual mechanics as compared to labial orthodontics. In addition to this in this study instead of the whole maxilla and dentition, finite element model of maxilla and incisors were used. Here horizontal retraction force, vertical intrusion force and lingual root torque were applied to simulate retraction force instead of horizontal retraction force alone.

Second premolar demonstrated lingual tipping of (+17.2) for buccal and (+16.5) lingual cusp with labial appliance, whereas in lingual technique labial tipping of buccal (-19.44) and lingual (−15.32) cusps were evident. In first molar, lingual (+X) movement of the cusps were evident with labial appliance whereas in lingual retraction, mesiobuccal (−18.46) and mesiolingual (−14.75) cusp tipped buccaly, and distobuccal (+17.22) and distolingual (14.31) cusps tipped palatly, along with that distal apex tipped palatally (8.41) and mesial apex buccaly (−10.16). This indicated the occurrence of mesiobuccal rotation of first molars. Second molars tipped palatally (+X) in labial retraction, whereas in lingual technique palatal tipping was less compared to labial technique. These values implied that in the posterior segment reduction in arch width was greater with labial appliance. Transverse bowing effect and the prominent premolar offset in the archwire might be a reason for increased arch width in the premolar region of lingual appliance.

Lombardo *et al.*[7] carried out a similar FEM study to assess the displacement on application of retraction force. The displacement pattern of teeth in transverse direction was similar to the present study, except that it was done in FEM of mandible.

On the contrary, Papageorgiou *et al.*,[17] reported in a systematic review and meta-analysis about the treatment effects of lingual versus labial appliance which stated that compared to labial appliance, lingual appliance were associated with decreased inter-molar width and increased inter canine width. The present study result stipulated that in transverse direction there was lingual tipping of anterior and mild buccal flaring in second premolar and first molar region and lingual tipping in second molar in lingual appliance. Along the X axis, this different tipping trend of premolar and first molar may result from the transverse bowing effect of the lingual retraction forces, specified in literatures,[18-20] which deliver some amount of expansion on the lateral side of the archwire.

Amount of retraction

Displacement along the Y-axis

Along the Y axis, there was a tendency toward distal tipping (+Y) of anteriors and posteriors in both techniques. But the lingual retraction mechanics showed more distal tipping than the labial. This is indicated by the amount of distal movement of anterior teeth by 0.026 mm in labial [Figure 5a] and 0.029 mm in lingual appliance [Figure 5b]. The premolars and molars were tipped distally and rotated buccally in the lingual arch wire. On the contrary, they were rotated lingually in labial arch wire. Sung *et al.*,[6] noticed that during canine retraction with the lingual technique, vertical bowing can result from lingual tipping of the incisors and mesial tipping of the molars. But in the present study a distal tipping and mesiobuccal rotation of molars was observed.

Displacement along the Z-axis

In labial retraction [Figure 5c] method all teeth had extrusion (−Z) tendency, same as that of lingual appliance, except second molar, in which intrusion (+Z) was observed in lingual retraction [Figure 5d]. The built-in bite planes on the upper incisor and cuspid brackets in the Kurz 7th generation lingual bracket (Ormco Corp), resulted in a posterior open bite, facilitating deep bite correction and molar verticalization.[21] Increased extrusion observed in premolars and first molars in the present study can be interpreted due to this effect. In a clinical study Fulmer and Kuftinec[22] conducted a cephalometric analysis was conducted to assess lingual treatment effect. They found that lingual appliance appears to cause incisor intrusion and molar extrusion. In the present study, incisor and molar extrusion was observed (−Z). In this investigation, the incisor torque was maintained such that they were slightly upright. On the other hand, the present study indicated greater torque loss in the anterior segment when lingual appliance is used.

Depending only FEA results may deceive the orthodontist due to blemish in computer aided geometrical modeling and biomechanical analysis. The present study could uphold, the results and facts about the biomechanical characteristics that differentiate the lingual technique from the labial appliance.

Conclusion

A FEA, comparing changes in torque, arch width and amount of retraction between labial and lingual preadjusted edgewise appliance revealed the following findings;

- This study demonstrated that when retracting incisors with the same load, lingual crown tipping was more with the lingual appliance. Hence, retraction force should be reduced and well controlled for lingual appliance
- Torque control is more crucial in lingual appliance, which manifested as lingual tipping of incisor crown. Hence, lingual root torque should be increased in lingual appliance
- An adverse vertical bowing effects of the lingual appliance was observed for the entire dentition
- Increased arch width in second premolar and first molar region, due to buccal flaring of second premolars and first molar, in lingual appliance is indicative of transverse bowing effect
- Amount of retraction is more with the lingual appliance as compared to labial appliance
- First molars had a tendency for mesiolabial rotation and a distal uprighting effect, stipulate that movements were more rotational and distal in lingual appliance, while with the labial technique movements were less rotational.

The present study is not an actual representation of long-term effect of force application on tooth movement, but it demonstrates the tooth movement in sagittal, vertical, and transverse direction immediately after force application. Hence, clinical translation of the FEM findings should be done with caution.

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Conflicts of interest

There are no conflicts of interest.

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