Original Article

Analysis of initial movement of maxillary molars submitted to extraoral forces: a 3D study

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Abstract

Objective: To analyze maxillary molar displacement by applying three different angulations to the outer bow of cervical-pull headgear, using the finite element method (FEM). **Methods:** Maxilla, teeth set up in Class II malocclusion and equipment were modeled through variational formulation and their values represented in X, Y, Z coordinates. Simulations were performed using a PC computer and ANSYS software version 8.1. Each outer bow model reproduced force lines that ran above (ACR) (1), below (BCR) (2) and through the center of resistance (CR) (3) of the maxillary permanent molars of each Class II model. Evaluation was limited to the initial movement of molars submitted to an extraoral force of 4 Newtons. **Results:** The initial distal movement of the molars, using as reference the mesial surface of the tube, was higher in the crown of the BCR model ($0.47x10^{-6}$) as well as in the root of the ACR ($0.32x10^{-6}$) model, causing the crown to tip distally and mesially, respectively. On the CR model, the points on the crown ($0.15\ x10^{-6}$) and root ($0.12\ x10^{-6}$) moved distally in a balanced manner, which resulted in bodily movement. In occlusal view, the crowns on all models showed a tendency towards initial distal rotation, but on the CR model this movement was very small. In the vertical direction (Z), all models displayed extrusive movement (BCR 0.18 $x10^{-6}$; CR 0.62 $x10^{-6}$; ACR $0.72x10^{-6}$). **Conclusions:** Computer simulations of cervical-pull headgear use disclosed the presence of extrusive and distal movement, distal crown and root tipping, or bodily movement.

Keywords: Headgear. Finite Element Method (FEM). Tooth Movement.

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INTRODUCTION

Angle Class II malocclusion is characterized by anteroposterior dental discrepancy, which interferes with patients' maxillomandibular relationship. It is a rather significant condition whose prevalence ranges from 35% to 50% of the Brazilian population.[10] Although currently several methods are available to correct it, such as intraoral appliances (Jones jig, Distal Jet, Pendulum, etc.), skeletal anchorage devices and headgear, treatment choice will depend on case-by-case assessment, patient compliance and professional skills. Despite its esthetic limitations and the need for compliance, headgear (HG) is a conventional, still widely used appliance that enables different force lines to be applied. HG can assist in correcting skeletal problems and achieving distal movement of permanent maxillary molars.[3] Its use requires knowledge of basic biomechanical concepts, such as center of resistance, tooth rotation and force action lines[14] for monitoring tooth movement during treatment.[20,25] When symmetrically changing the length and/or angulation of its outer arch, or when applying different force vectors, the impact on dental and skeletal structures can be altered.[20,29] The effects are often undesirable and it is up to orthodontists to reduce such effects by predicting the possible force action line angulations and their relationship with the center of resistance of the tooth to be moved.[25] The viewing of these side effects has been extensively reported in literature,[1,4,9,17,21,26,29] usually by superimposing profile X-rays. Some studies have shown that a major limitation of this method lies in the difficulty to isolate molar movement without allowing the growth of the basal bones to interfere with the analysis.[18] Thanks to technological advances, studies have been conducted through computer simulations, some with a view to analyzing tooth movement in dental casts and others to evaluate the impact of masticatory forces on the tooth, and its stability.[2,5] The effects of force vectors applied to mini-implants have also been investigated[6] as well as the response of different facial patterns to extraoral forces.[8] None of these, however, addressed the influence of these forces on the movement of permanent first molars by the finite element method (FEM). The authors of this study aimed to analyze the displacement of maxillary molars by tipping the outer arch of cervical-traction headgear in three different directions and using FEM.

MATERIAL AND METHODS

Maxillary models were reproduced using teeth set up in Class II malocclusion and cervical-traction headgear with the outer bows modified at three different heights, thereby determining force lines that, although different, had the same length. The imaginary line that resulted from the force vectors ran above, below and through the

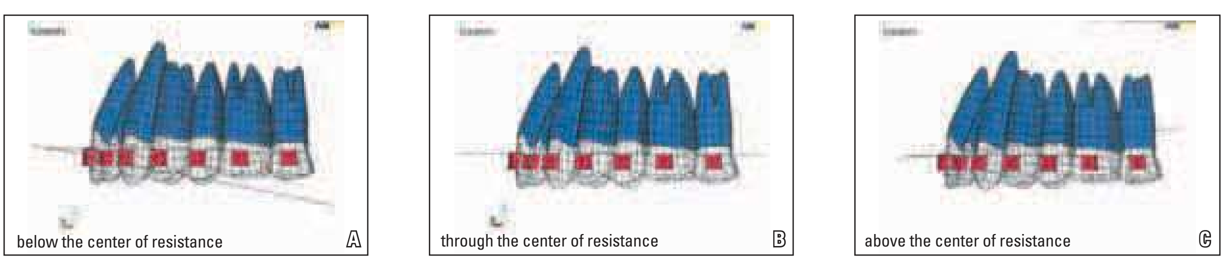


FIGURE 1 - Reproduction of the three models of cervical headgear with different outer bow inclinations in relation to X, Y and Z coordinates, using the Ansys 8.1 program: **A**) BCR (below the center of resistance); **B**) CR (through the center of resistance) and **C**) ACR (above the center of resistance).

center of resistance of each permanent maxillary molar. Measurements of the center of resistance of the maxillary first molar, activation point of the appliance (tube), neck pad hooks and outer bows of the headgear where the force had been applied, were made using a volumetric model, in Class II pattern,with the aid of a digital caliper. The resulting values were represented through X, Y, Z coordinates, considering as zero point the midway point tangent to the distal surface of the second molars.

Computer simulations were performed on an Intel Pentium 4 Personal Computer with 2.8 GHz processing power, 80 GB hard disk and 1 GB RAM. For the simulations, the computer software ANSYS (Ansys Inc. Canonsburg, PA, USA) version 8.1 was utilized. This program relies on the finite element method (FEM) for quantification of forces, moments and tensions. The activations were simulated for molar distalization, thus allowing the parameters involving orthodontic biomechanics to be determined quantitatively.

In numerical models, the regions representing the alveoli had their movements restricted in all directions, allowing only movement due to deformation of the periodontal ligament.

The computer simulations represented only the initial movement resulting from the 4N force (Newton) delivered to the first permanent molars, considering the presence of the second permanent molars. Measurements were made from the points marked on the root, crown and center of resistance region of the first permanent molar. The value of all points prior to force delivery was zero (Fig 2).

The initial movement, resulting from the force delivered by the headgear, caused deformation of the periodontal ligament, whose elastic modulus was 0.05 N/mm^2 and Poisson's ratio 0.49. The force was considered static load[23,28] to allow tooth movement in its respective alveolus, with a modulus of elasticity of 20,000 N/mm^2 and Poisson's ratio of 0.30.[7,23]

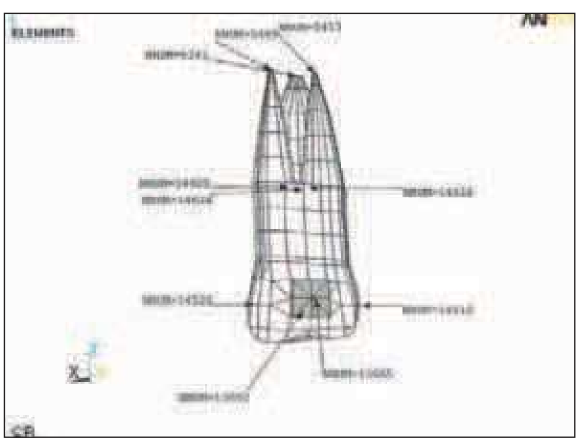


FIGURE 2 - Points analyzed after simulating force application to the first permanent molar on each model.

RESULTS

The initial distal movement of maxillary first molars (Ux) on the model in which the resultant of forces ran below the center of resistance (BCR) caused greater distal tipping in the crown than in the root, producing a tip back movement. In the center of resistance (CR) model, distal bodily movement occurred, causing displacement of the distal root as far as the middle third. On the model in which the resultant of forces ran above the center of resistance (ACR), the displacement was greater in the distal root, tipping the tooth forward (Fig 3). All models, in occlusal view, tended initially towards distal crown rotation (Fig 4). However, this movement was very small on the CR model.

Results for the vertical direction (Uz) revealed that all models exhibited extrusion, which was higher on the ACR model. The CR model exhibited mild extrusion at all points, unlike BCR and ACR, which showed slight intrusion at distal and mesial points of the crown, respectively.

The values shown in Table 1 and 2 confirmed the initial molar displacement in each HG model, displaying its direction and orientation at each maxillary molar point.

DISCUSSION

Finite element method (FEM) was employed through variational formulation and the mechanical properties of organic tissues and orthodontic materials were obtained in the orthodontic literature,[7,19,23,28] which enabled the characterization of the elements and the geometry of the body using numerical modules.

The effects of forces applied to the first molars examined in these models are virtually the same as those observed in clinical practice. Figure 4 illustrates the differences that occur at key points (root and crown) of the first permanent molar on the BCR and ACR force line models in the anteroposterior orientation (X coordinate). A uniform distal movement can also be observed on the CR model. Points 1 and 2 are located in the mesiobuccal and palatal roots of the molar. Points 3 and 4 are in the distal and mesial surfaces of the buccal tube bonded to the molar crown. Thus, reverse tipping can be noted, depending on the force lines of the two models (BCR and ACR).

Melsen and Dalstra[18] demonstrated, by superimposing patients' X-rays, that the type of tooth movement that occurs while wearing headgear with a downward or upward outer bow angulation was dependent on the force action line in both groups. Patients who wore headgear with

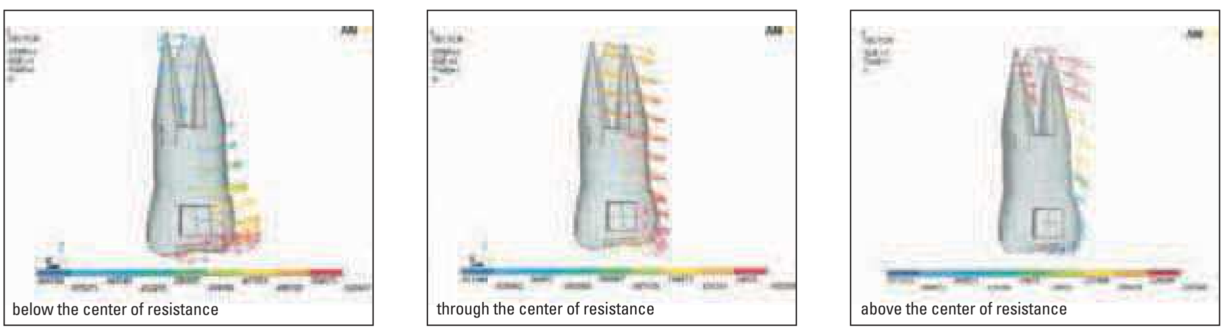


FIGURE 3 - Figure showing the initial distal movement of the first molar in the three computer simulation models. (**A**) BCR illustrates posterior (distal) tipping of the crown; (**B**) CR, uniform distal movement of the crown and root; (**C**) ACR illustrates posterior (distal) tipping of the root.

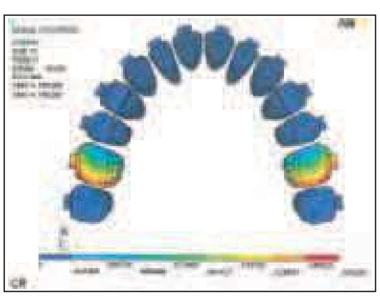
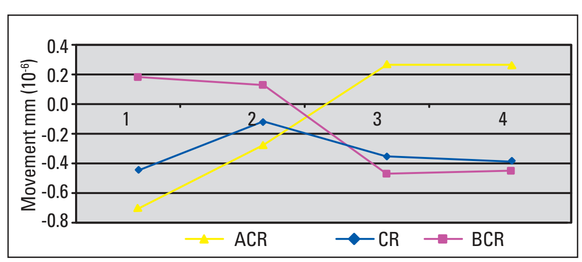


FIGURE 4 - Occlusal view showing initial distal rotation of the crown on the CR model.



GRAPH 1 - Graph showing the initial movement of the first molar (anteroposterior direction) at points in the palatal (1) and mesiobuccal (2) roots, and at mesial (3) and distal (4) points of the tube bonded to the crown, as observed in all three computer simulation models (ACR, CR and BCR).

TABLE 1 - Values in mm (x10^{-6}) reflecting the initial movement of the first permanent molar in the anteroposterior direction (X coordinate), on the three models.

Nodes / coordinates	Ux BCR	Direction	Ux CR	Direction	Ux ACR	Direction
mesial root (5413)	0.06821	M	0.12336	D	0.32432	D
distal root (5489)	0.05468	M	0.13153	D	0.32687	D
tube B (13665)	0.52272	D	0.13128	D	0.09499	M
tube M (14510)	0.47447	D	0.14887	D	0.01425	M
tube D (14528)	0.45748	D	0.16665	D	0.02567	M
D region of CR (14609)	0.13785	D	0.14141	D	0.28577	D
D region of CR (14618)	0.16082	D	0.13761	D	0.18142	D
D region of CR (14624)	0.13875	D	0.12894	D	0.26128	D

Captions: M (mesial), D (distal), Ux (resultant of initial movement in the anteroposterior direction), V (buccal) and CR (center of resistance).

TABLE 2 - Values in mm (x10^{-6}) reflecting the initial movement of first permanent molars in the vertical direction (Z coordinate) on the three models. Negative values represent extrusive movement at such points.

Nodes / coordinates	Uz BCR	Direction	Uz CR	Direction	Uz ACR	Direction
mesial root (5413)	-0.24398	ex	-0.46214	ex	0.23297	in
distal root (5489)	-0.99368	ex	-0.23581	ex	-0.63052	ex
tube V (13665)	-0.18231	ex	-0.62664	ex	-0.72586	ex
tube M (14510)	-0.11875	ex	-0.63811	ex	0.31449	in
tube D (14528)	0.17873	in	-0.19519	ex	-0.10243	ex
D region of CR (14609)	-0.51664	ex	-0.26472	ex	-0.39593	ex
D region of CR (14618)	-0.13161	ex	-0.41045	ex	-0.26438	ex
D region of CR (14624)	-0.54192	ex	-0.32091	ex	-0.18191	ex

Captions: in (intrusion), ex (extrusion), Uz (resulting initial movement in the vertical direction), V (buccal), M (mesial), D (distal), P (palatal) and CR (center of resistance).

a downward angulation displayed extrusion and distally tipped crowns, while those with an upward angulation exhibited translatory (bodily) movement.[18] The authors used the center of resistance as a reference, as in the present study, which found distally tipped crowns on the BCR model, distally tipped roots on the ACR model and bodily movement on the CR model.

Extrusion evidence found in the three models can be explained by the point of origin of force application, which was located low in the patients' cervical region.[20,29] This movement, however, is not necessarily undesirable, since in some cases, e.g., patients with a reduced lower facial third, extrusion is expected, given its impact on their facial profile as a whole.[24,29] Care should be taken in cases where it is necessary to raise the outer bow in order to achieve an action line that is better suited for the effect desired in the molar, since any elevation in the outer bow will increase the extrusive component (Table 2, reference node tube V).

Ashmore et al[2] described the movement of first permanent molars during treatment with headgear (combined traction) on plaster models analyzed in 3D. The results showed little extrusion due to the fact that the high-pull force used in their study ran through the CR, producing bodily movements. Despite the reduced amount of movement and the cervical traction, the same results were found in this study: uniform distal movement of the crown and root, and mild extrusion on the CR model.

Oosthuizen et al[20] reported that the center of resistance of the maxillary first molar is positioned approximately at the trifurcation of the roots, at the mid-height of the cervical third. When the action line of a force does not go through the center of resistance, the tooth being moved tips under its center of rotation, i.e., depending on the position of this line, the molar will display a tipping movement.[20] The mechanical function explained above further reinforces the clinical findings as well as the findings of this study, based on finite elements.

The center of resistance of the tooth or skeletal unit to be moved provides the rationale for the organization of a force system.[27] The effects caused by varying the outer bow can also be applied to orthopedic movements since the reasoning behind the distribution of forces through vectors is similar. The only difference lies in the location of the center of resistance.

According to Klein's superimposition cephalometric studies, molar movement could be observed free from the influence exerted by the patient's growth[15]. He found that in 17 of 23 cases molars experienced distal bodily movement.[15] Unlike Piva et al[22], Schiavon Gandini et al.[24] demonstrated in cephalometric radiographs that even in cases where the maxilla was rotated downwards, the axial inclination of the molar remained unchanged and there was greater distal tipping of the root, even when the force line ran through the center of resistance. Schiavon Gandini et al[24] standardized outer bow angulation while Klein[15] resorted to cervical traction only.

Several authors have stated that it is possible to prevent undesirable displacements, such as mesial or distal crown tipping, through changes in the outer bow of the headgear ,by either raising or lowering it, but that depends more on the operator than on the patient.[15,16] Traction line angulation can be changed only by varying outer bow angle and length.[20,25] It is possible, however, with such changes, to cause extrusive movements that undermine vertical control mechanics, especially when the outer bow is raised to correct distal molar tipping (tip back). In this situation, it is advisable to employ combined traction.

Similarly to the findings of this study, Haas believes that the tendency displayed by molars to rotate around their own axis in the lingual direction only occurs because force application derives from a low position in the outer bow (patient's cervical region). He therefore proposes that the inner bows of the headgear be expanded, thereby improving molar positioning.[12] Other authors recommend the use of a removable palatal bar to control vertical movement and correct undesirable rotations and torques during treatment.[11,13,30] Besides, rectangular archwires can obviously be used to control torque when a patient is in this treatment phase.

Piva et al[22] suggest that 3D studies be conducted given the limitations of radiography, which does not disclose pure molar movement through overlays (superimposition) due to changes in growing patients. Thanks to the use of the finite element method (FEM), the results of this research succeeded in reflecting maxillary molar movement in isolation by varying the outer bows of the headgear.

CONCLUSIONS

It was shown that the use of cervical-traction headgear causes extrusive and distal movement. Force line orientation is important to control maxillary molar movement, which can be translatory (bodily), tip back or tip forward, when distal movement occurs through the use of a headgear. Determining this approach depends on the clinical situation and on orthodontic treatment planning.

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