APPENDIX A

Proceedings: International Graduate Research Conference (IGRC 2013)

December 20, 2013

The Empress Convention Center, The Empress Hotel,

Chiang Mai, Thailand

Effects of Orthodontic Force Applied for Maxillary Molar Distalization: Finite Element Analysis

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Abstract

Objective: To investigate the effects of the force applied on the buccal side for maxillary molar distalization when either only the first molar is present, or when both the first and second molars are present, using finite element analysis.

Materials and methods:
Three-dimensional finite element (FE) models, including the maxillary first and second molars, the periodontal ligament, and the maxillary bone, were constructed. FE model 1 with only the first molar included and FE model 2 with both first and second molars were generated. A distalizing force of 200 g was applied at 90 deg. (horizontal plane) to the bracket base on the buccal side of the first molar. Stress distributions on the maxillary molar roots as well as tooth displacement were analyzed.

Results: The stress distribution pattern was similar in both FE models. The highest Von Mises stress value was found on the cervical third of the root surface and the stress values were decreased towards to the apex. Stress values on the distal root surface were greater than those on the mesial root surface. The stress values in FE model 1 were greater than those in FE model 2. The tooth displacement in both FE models showed distal tipping, extrusion, and mesial out-rotation of the maxillary molars, but the greater amount of tooth displacement was observed in FE model 1.

Conclusions: The initial tooth displacement after applying the distalizing force on the buccal side for maxillary molar distalization showed distal tipping, extrusion, and mesial out-rotation. FE model 1(the second molar not included) showed greater tipping, extrusion, and mesial out-rotation than FE model 2 (the second molar included).

Keywords: Finite Element Analysis, Maxillary Molar Distalization, Buccal Distalizing Force, First Molar, Second Molar

Introduction

Maxillary molar distalization has become a widely used procedure for non-extraction treatment of Class II malocclusion. The traditional approach to distalizing maxillary molars is the application of extra-oral headgear.[1] However, social and esthetic concerns cause patients to refuse to wear it. Various intraoral appliances have been developed. Kinzinger et al.[2] categorized appliances for molar distalization according to the location of the active components. The first category includes appliances with vestibular force application, such as the Jones Jig appliance,

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repelling magnets, and nickel-titanium (NiTi) coil springs. The second category includes appliances with palatal force application, such as the pendulum, and the distal jet. The First Class appliance, which was described by Fortini et al,[3] has dual forces, a distalizing force on the buccal region and a counteracting force with super elastic NiTi springs on the palatal side.

The force recommended for molar distalization is approximately 180 to 250 cN per side.[2] The direction of the applied force can be either to the buccal side, palatal side, or both sides of the tooth. Applying the force on the buccal side allows the orthodontist to more easily apply and adjust the force directly to the tooth than by applying the force on the palatal side. In addition, it produces a simple force system.

Simultaneous distal movement of both first and second molars has been discussed.[4-8] Several authors reported that the eruption of the second molar had an impact on the distalization of the first molar. On the other hand, Ghosh and Nanda[7] concluded that the position of the second molar during distal movement of the first molar is of little significance.

The finite element method (FEM) is a mathematical method that can be used to simulate force systems and to analyze the biomechanics of tooth movement.[9] Therefore, the purpose of this study was to investigate the effects of distalizing force applied on the buccal side for maxillary molar distalization when either only the first molar is present, or when both the first and second molars are present, using finite element analysis.

Materials and methods

Preparation of FE models

Geometric models including the maxillary first and second molars, the periodontal membrane, and the maxillary bone (cortical and cancellous bone) were established using a three-dimensional computer-aided design program (SolidWorks, SolidWorks Corporation, Waltham, MA, USA). Commercial tooth models (Model-i2lD-400G; Nissin Dental Products, Kyoto, Japan) were three-dimensionally scanned to produce the tooth images. The first and second molars were modeled manually as suggested by Wheeler.[10] Their roots were embedded in the maxillary model which was designed so that the maxillary bone followed the contour of the cemento-enamel junction gingivally. The periodontal membrane was assumed to have a thickness of 0.25 mm. The thickness of the cortical bone was assumed to be 2.0 mm. Models of 0.018 x 0.025 inch brackets and stainless steel archwire with the same dimension were generated. Brackets were attached to the teeth at the midpoint of the buccal surface. The maxillary first and second molars were connected with the archwire on the buccal surface.

In this study, two different FE models were produced to simulate the effects of the distalizing force in the buccal direction for maxillary molar distalization. FE model 1, which included the first molar, was generated to simulate the condition in which the second molar has not yet erupted or has already been extracted (Figure 1A). FE model 2 included the first and second molars (Figure 1B).

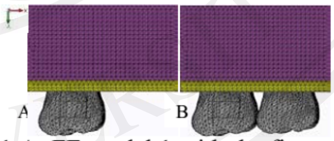

Figure 1 A: FE model 1 with the first molar; B: FE model 2 with the first and second molars

The mechanical properties of the materials have been described in previous studies,[11, 12] as shown in Table 1. All materials were considered to be homogenous, isotropic, and have linear elasticity.

Table 1 Mechanical properties of the material

	Young's modulus (MPa)	Poisson's ratio
Cortical bone	13700	0.26
Cancellous bone	1370	0.3
Tooth	19613.3	0.15
PDL	0.6668	0.49
Stainless steel	200000	0.3

Determination of axes

In this study, the x-axis was constructed as the mesio-distal direction, the y-axis as the supero-inferior direction, and the z-axis as the bucco-palatal direction, and -x was defined as the mesial direction, -y as the apical direction, -z as the buccal direction, and x-y as the occlusal plane of the teeth.

Loading configuration and boundary conditions

All the nodes on the lateral and bottom outermost surfaces of the cortical and cancellous bone were constrained in all directions. To simulate the maxillary molar distalization, a distalizaing force of 200 g was applied at 90 deg. (horizontal plane) to the bracket base of the first molar.

Finite element analysis was performed using the SolidWorks program. The stress distribution pattern along the root surfaces and the tooth displacement of the four cusps and the three root apices of the maxillary molars were analyzed.

Results

In FE model 1, the Von Mises stress distribution pattern and stress values on the root surface of the first molar are shown in Figure 2, A and B. On the root surface, the highest stress value was found on the cervical third of the root surface, with the stress values decreasing (?) towards to the apex. The stress values on the distal root surface were higher than those on the mesial root surface. The first molar showed distal tipping, extrusion, and mesial-out rotation (Figure 3).

In FE model 2, the Von Mises stress distribution pattern and stress values on the root surface of the first and second molars are shown in Figures 4 and 5. On the root surface, the stress distribution pattern was similar to that in FE model 1. The highest stress value was found on the cervical third of root surface with the stress values decreasing towards to the apex. In FE model 2, the first molar showed distal tipping, extrusion, and mesial out-rotation. The second molar showed less distal tipping, extrusion and mesial out-rotation than did the first molar (Figure 6). The amount of distal movement of the maxillary first molar in FE model 2 was less than that in FE model 1. In addition, the maxillary first molar showed greater distal tipping and extrusion when the second molar was excluded.

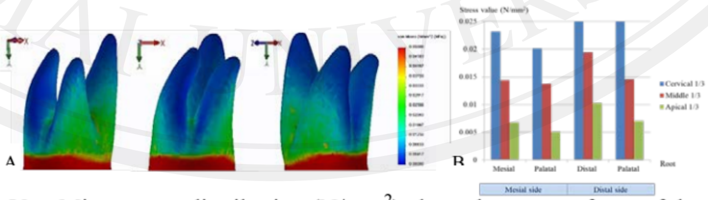

Figure 2 A: Von Mises stress distribution (N/mm^2) along the root surfaces of the first molar in FE model 1; B: Stress value (N/mm^2) on the root surface (mesial and distal side)

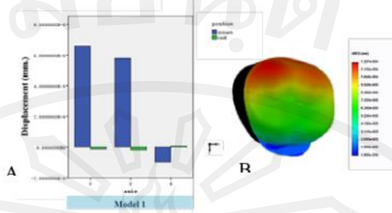

Figure 3 A: Displacement of the maxillary first molar crown and root in FE model 1; x-axis, distal direction; y-axis- vertical direction; z-axis - lateral direction B: Occlusal view (x-z axis)

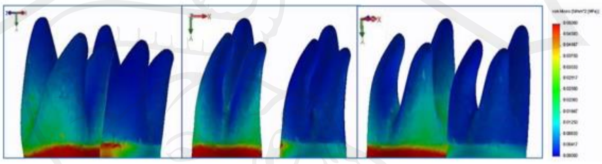

Figure 4 Von Mises stress distribution (N/mm^2) along the root surfaces in FE model 2

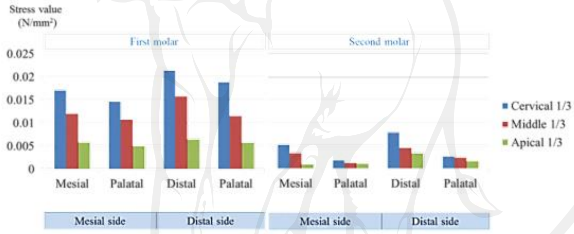

Figure 5 Stress values (N/mm^2) on the root surface of first and second molars in FE model 2

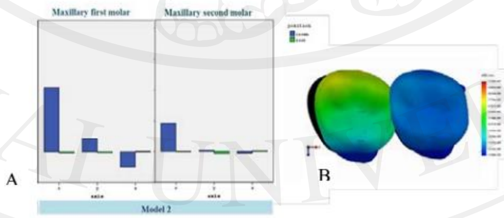

Figure 6 A: Displacement of the maxillary first molar crown and root in FE model 2; x-axis, distal direction; y-axis- vertical direction; z-axis - lateral direction
B: Occlusal view (x-z axis)

Discussion

The accuracy of the results relates to the accuracy of the FE model, including the anatomic accuracy of the geometric model, and of the specifications of the virtual dental material properties, the virtual clinical tissues and the boundary conditions.[9, 13] In this study, 3D laser scanning and CAD technology were used to produce the tooth models. In addition, we used mechanical properties of tissue materials that have been calibrated and published.[11, 12, 14] Tetrahedron elements with high mesh quality were used for discretization of the teeth, the PDL, and the alveolar bone in the model.

In FE model 1, the Von Mises stresses of the maxillary first molar root were distributed along the cervical third of the root surface to the apex. This pattern indicates tipping movement of the tooth, as suggested by Tanne et al.[11] They concluded that in FE analysis, stress values that varied nonuniformly with a large difference from the cervix to the apex of the root indicated tipping movement. In addition, principal compressive stresses were observed on the distal root surface and varied from the cervix to the apex. On the mesial root surface, the principal tensile stresses varied from the cervix to the apex. This result agreed with the pressure-tension theory of tooth movement.[15]

The tooth displacement of the maxillary molar included distal tipping, extrusion, and mesial out-rotation. These results corresponded with the results of previous studies using similar distalizing modalities with nickel-titanium coil springs.[8, 16, 17] Because the distalizing force was applied through a bracket level below the center of resistance of the first molar, the result was distal tipping of the tooth. When the first molar was tipped distally, the mesial cusp tips of the crown were extruded, whereas the distal cusp tips were intruded. Mesial out-rotation occurred because the distalizing force was applied buccal to the center of resistance of the first molar and there was no counteracting force to control tooth movement on the palatal side.

In FE model 2, the first and second molars were distalized simultaneously. Displacement of the first molar showed less distal tipping, mesial out-rotation, and extrusion than did the first molar in FE model 1. The second molar showed less distal tipping, mesial out-rotation, and extrusion than did the first molar in the same FE model. Our results are similar to those of Kinzinger et al.[6], and Bondemark et al.[4, 8], who observed the effects of the simultaneous distal movement of maxillary first and second molars in their patients. They concluded that the distal movement was more difficult if the first and second molars were distalized simultaneously. When the second molar was combined with the first molar, the resistance to distal movement was then increased because of a large root surface area increased in the bone. In addition, to prevent tipping of the first and second molars, second-order antitip bends might be added to the archwire.[5, 6] When minimal tipping of the first molar is needed, orthodontists can wait for simultaneous distal movement of the maxillary first and second molars.

In our study, static finite element analysis simulated only the initial tooth displacement and initial stress distribution along the root surface. The pattern of long-term orthodontic movement and the stress distribution can differ from those of the initial tooth displacement because of the changes in force systems and individual biologic responses. This study had some limitations, including the constant values used for the mechanical properties of the tissues in the virtual models, which might be different from those prevailing clinically through the various histologic processes.

Conclusions

The initial tooth displacements when applying distalizing force on the buccal side for maxillary molar distalization were distal tipping, extrusion, and mesial out-rotation. FE model 1 (the second molar not included) showed more tipping, extrusion, and mesial out-rotation than did FE model 2 (the first and the second molars included).

Acknowledgement

The authors are grateful to Faculty of Dentistry, Chiang Mai University, for the support in financial aid of this research. The authors wish to thank Dr. M. Kevin O Carroll, Professor Emeritus of the University of Mississippi School of Dentistry, USA and Faculty Consultant at Chiang Mai University Faculty of Dentistry, Thailand, for his assistance in the preparation of the manuscript.

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APPENDIX B

Poster: International Graduate Research Conference (IGRC 2013)

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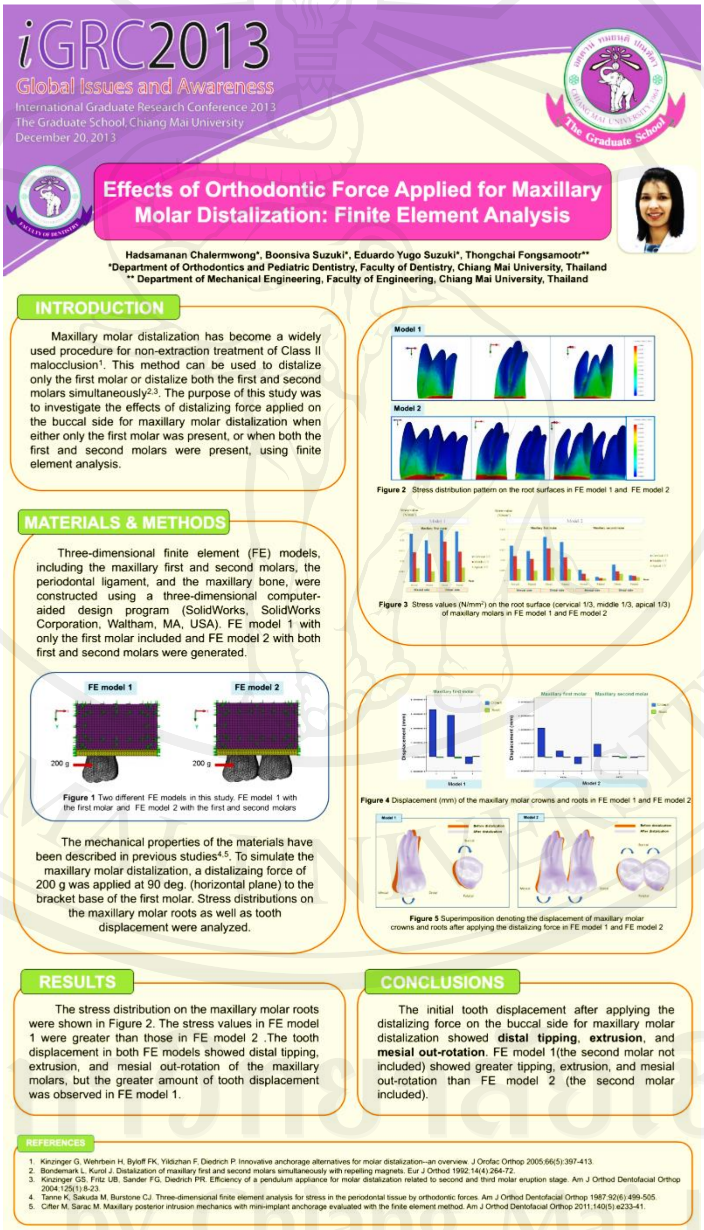

APPENDIX C

Certificate of presentation: International Graduate Research Conference (IGRC 2013)


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The Graduate School, Chiang Mai University
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