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DOI: 10.2478/aoj-2008-0014

Comparison of methods used to correct a lingually tilted mandibular molar: 3-D analysis using the finite element method (FEM)

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Background: Methods used to upright lingually tilted mandibular molars frequently result in extrusion and unwanted rotations.
Aim: To use the finite element method (FEM) to compare three springs designed to upright a lingually tilted mandibular first molar.
Methods: A 3-D computer model of a lingually tilted mandibular first molar was designed. The FEM was used to compare movement of the molar during uprighting with either a single horizontal helix, an open vertical loop, or a new spring with two vertical helices wound around and perpendicular to the long axis of the archwire. Each spring was assumed to be part of a continuous 0.016 x 0.022 inch stainless steel archwire, and each spring was placed mesial to the buccal tube on the first molar.
Results: From the mesial perspective, all designs moved the crown of the lingually tilted molar buccally and the root apex lingually. From the occlusal perspective: the horizontal helix uprighted the molar with a disto-buccal rotation; the open vertical loop uprighted the molar with a mesio-buccal rotation; and the new design uprighted the lingually tilted molar around a mesio-distal axis.
Conclusion: Using FEM, the most suitable design was a double helix formed around and perpendicular to the long axis of the archwire and sited mesial to the tilted molar. It was the only spring to upright the lingually tilted molar without an unwanted rotation.
(Aust Orthod J 2008; 24: 96–101)

Received for publication: February 2008
Accepted: June 2008

Introduction

The mandibular second molars frequently erupt in a lingual position due to dental crowding.[1,2] Mandibular molars tilted lingually out of occlusion may cause heavy contacts on the balancing side and may lead to functional disturbances during mastication.[3] Occlusal discrepancies, such as a lingually inclined mandibular molar, in combination with clenching and/or grinding, may lead to temporomandibular joint damage.[4] For this reason, lingually tilted mandibular molars should be intruded and moved into the arch.

Methods of uprighting lingually/palatally tilted molars include: alignment with a light, continuous archwire, use of a continuous, rectangular NiTi archwire or a loop or spring bent into the main archwire.[2] One of the advantages of a loop is that it reduces the load-deflection rate of the archwire and produces a more constant force.[5] Looped archwires may, however, produce forces that extrude a tooth during uprighting and result in occlusal trauma. Other methods of uprighting a lingually tilted mandibular molar use a sectional TMA or stainless steel wire with a helix tied to a passive lingual arch, or a length of elastomeric chain to pull the tooth into position.[2,6,7]

The finite element method (FEM), which subdivides a system into individual components or 'elements' whose behaviour is readily understood, enables one to rebuild the original system so that the behaviour of the system under an applied load can be understood.[8] A 3-D computer diagram of the structure to be modelled is designed and the volumes of the materials in the structure are divided by components or elements specific to each material. The problem is then

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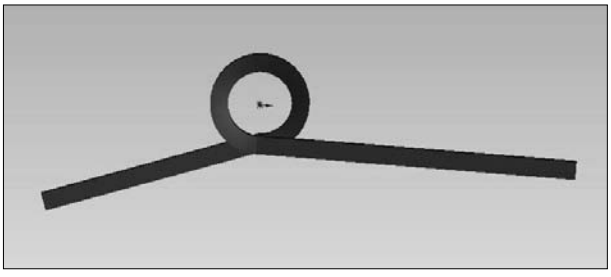


Figure 1a. Activated single horizontal helix.

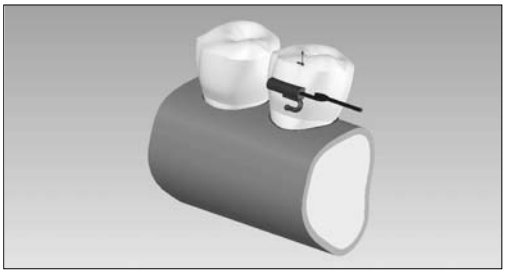


Figure 1b. Pre-activated horizontal helix.

Table I. Mechanical properties of the materials used.

	Young's modulus (MPa)	Poisson's ratio
Tooth	20 300	0.26
PDL	66.7	0.49
Spongy bone	13 400	0.38
Cortical bone	34 000	0.26
Stainless steel	210 000	0.28

defined in detail, and the manner by which the structure responds in the real situation (e.g. in the oral cavity) is completed by defining nodes, lines or faces that are either free to move or are restricted. The latter is called the boundary condition. The behaviour of each element under the applied load is then calculated and assembled for the model as a whole. The FEM has been used to study a number of different problems in orthodontics and dentistry, such as alveolar bone resorption during tooth movement, extra oral force application and orthodontic mechanotherapy.[9–18]

Movement of teeth in unwanted directions may prolong treatment and compromise the outcome. The ideal treatment of a lingually inclined mandibular molar would be to rotate the tooth into position around the mesio-distal axis passing through the centre of resistance without extrusion or rotation around other axes. Additional time and effort can be spent neutralising unwanted tooth movements, which may increase the duration of orthodontic treatment. The aim of this study was to use the FEM to compare three springs designed to upright a lingually tilted mandibular first molar.

Materials and method

A 3-D computer model of the first and second mandibular molars, with the first molar tilted lingually, was designed in SolidWorks 2006 (SolidWorks, Concord, Massachusetts, USA). The teeth were modelled according to Ash's dental anatomy.[19] The model contained compact and cancellous alveolar bone and the first and second mandibular molars. The mechanical properties of the materials in the model are given in Table I. The roots of the molars were given a periodontal ligament with a uniform thickness of 0.25 mm. Three different methods of uprighting the tilted first molar were used.

1. A spring with a single horizontal helix placed mesial to the tipped molar (Figure 1). The diameter of the helix was 2 mm, and the spring was activated by toeing out (30 degrees) the archwire distal to the helix.

2. An open vertical loop placed mesial to the first molar (Figure 2). The height of the loop was 5 mm. This spring was activated by bending the distal leg of the loop buccally: the short horizontal section of the archwire was parallel to and 3 mm buccal to the molar tube on the first molar.

3. A spring with two complete helices wound around the line of the archwire, and placed mesial to the first molar (Figure 3). The helices were 2 mm in diameter, and the spring was activated by inserting the end of the wire into the buccal tube on the displaced molar and twisting the archwire (30 to 45 degrees) to engage the brackets on the remaining teeth.

All loops were modelled in 0.016 x 0.022 inch stainless steel wire. The 3-D models were designed to be as realistic as possible, without using any symmetries in modelling. Each design was added in turn to the

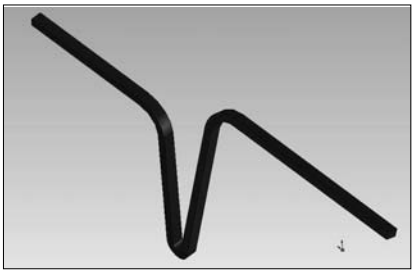


Figure 2a. Activated vertical open loop.

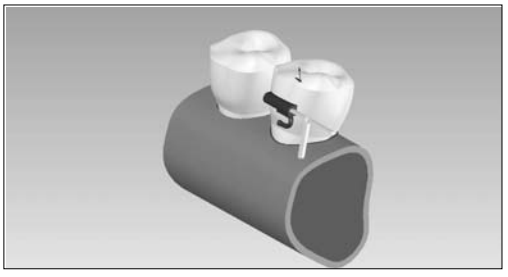


Figure 2b. Pre-activated vertical open loop.

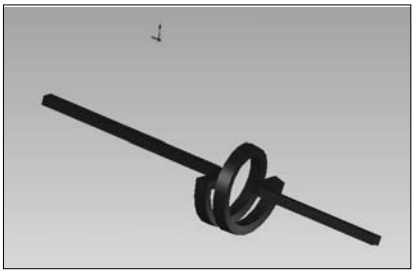


Figure 3a. Spring consisting of two complete helices perpendicular to and wound around the line of the archwire.

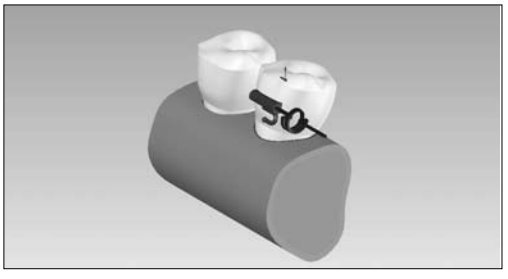


Figure 3b. Activated spring with two complete helices.



Figure 4. A spring with two complete helices uprighting a lingually inclined mandibular second molar.

tooth model, and the force system 'activated' using information gained from clinical experience with the springs (Figure 4). In the models the short horizontal section of the archwire distal to the springs did not engage the second molar. The plastic deformations in the first and second models produced the required activation force systems when the loops were engaged. The springs did not exceed their elastic limits when engaged.

Each model was transferred to the Ansys Workbench Version 10 (Ansys Inc., Southpointe, Canonsburg, PA, USA). The wire was considered to fit in the molar tube without any relative displacement. The contact element between the inner surface of the buccal tube and the outer surface of the rectangular wire bound the wire and tube together. Boundary conditions restricted displacements of the nodes at the mesial and distal parts of the model. Solid bodies are free to move in 3-D space while under load in FEM. This rigid body motion was restricted by preventing definite nodes from moving along the 3-D space axis. The manner of restriction was based on information obtained from use of the springs in the clinic. All nodes at the mesial and distal surfaces of the model were prevented from being displaced bucco-lingually, mesio-distally and occluso-apically. Mechanical properties were then applied and the models were meshed (Figure 5). After solving the problems, the displacements were derived and shown as vectors.

Results

From the mesial perspective, all loops moved the crown of the lingually displaced molar buccally and

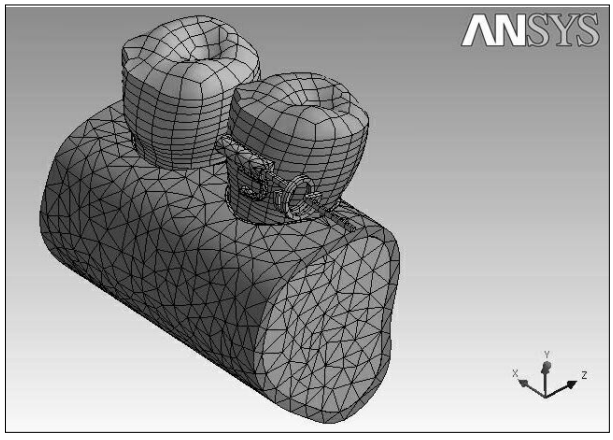


Figure 5. The meshed 3D model.

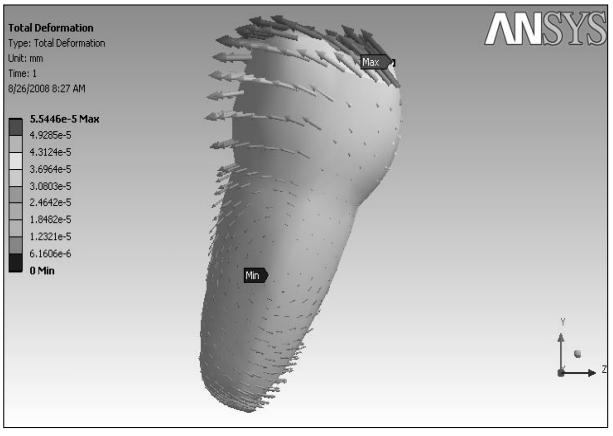


Figure 6. Uprighting movement viewed from the mesial aspect, all springs.

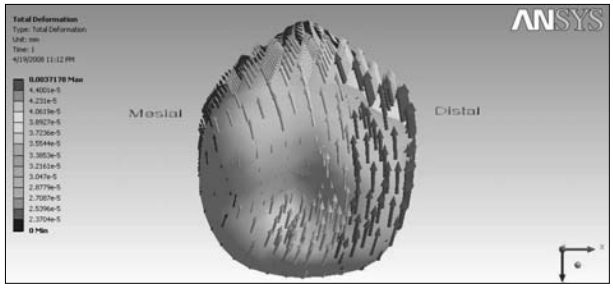


Figure 7a. Movement from the occlusal aspect, the spring with the single horizontal helix.

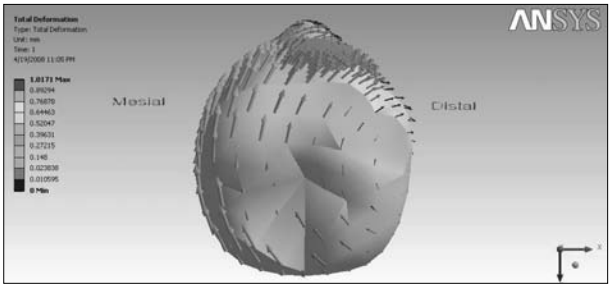


Figure 7b. Movement from the occlusal aspect, the spring with the open vertical loop.

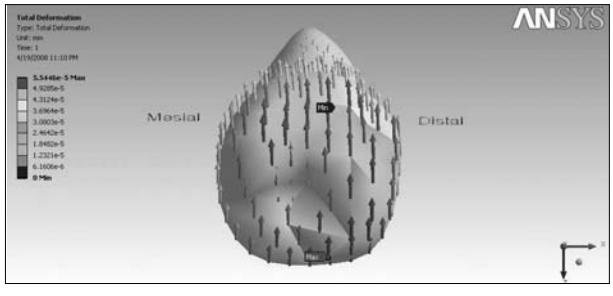


Figure 7c. Movement viewed from the occlusal aspect, the spring with two complete vertical helices.

the root apex lingually (Figure 6). From this perspective all designs were acceptable. The centre of rotation of the molar can be visualised from the direction and curve in the vectors in Figure 6.

Viewed from the occlusal perspective, the springs had different vector patterns. The spring with the single horizontal helix rotated the distal surface buccally, with the centre of rotation some distance from the mesial surface of the molar (Figure 7a). The open vertical loop rotated the mesial surface buccally, around a centre of rotation sited near the distal surface of the molar (Figure 7b). The spring with the double helix perpendicular to the long axis of the archwire uprighted the tipped molar with no rotation (Figure 7c). This may be considered ideal movement.

Discussion

In the present study we used FEM to investigate how a lingually tilted mandibular first molar might move with three different uprighting springs: one spring had a single horizontal helix, a second spring consisted of an open vertical loop, and the third spring had two helices wound around and perpendicular to the line of the archwire. All three springs were designed to be part of a continuous archwire. Viewed from the mesial perspective all springs rotated the molar into position, but from the occlusal perspective

only the third spring, with two helices perpendicular to the line of the archwire, uprighted the molar without any unwanted clockwise or anticlockwise rotations. The single horizontal helix and vertical loop springs, which are relatively straightforward to fabricate, resulted in unwanted rotations around vertical axes that could prolong treatment. Furthermore, because of the bracket-wire relationships in a continuous archwire system, the anchor teeth could move and their correction may further prolong treatment.

The three springs we investigated uprighted the tilted molar into occlusion with a small amount of extrusion. Methods that extrude a lingually tilted mandibular molar during uprighting can result in increased tooth mobility and premature contacts, which may lead to pain, a displacement of the mandible during closure and prolonged treatment. To avoid these complications a lingually tilted molar should be uprighted without extrusion.

Short inter-bracket distances in continuous archwires can produce large load-deflection rates with less than optimum forces and moment to force ratios. The latter determine the centre of rotation of the tooth. The position of the centre of rotation relative to the centre of resistance determines the type of tooth movement that will take place, and when both coincide pure rotation occurs. The load-deflection rate varies inversely with the cube of the length of the wire: a small increase in the inter-bracket distance can dramatically reduce the load-deflection rate. For this reason the springs we tested incorporated either a loop or a coil to reduce the load-deflection rates.

From the mesial perspective, the springs with a single horizontal helix and the open vertical loop uprighted the tilted molar by moving the crown buccally and the apices lingually. From the occlusal perspective, however, both springs resulted in unwanted rotations around vertical axes. The spring with two vertical helices may have been more difficult to fabricate, but it was easy to activate. Furthermore, the vertical helices were opposite the embrasure between the second premolar and molar and were unlikely to interfere with tooth movement. It was the only spring to upright the tilted molar without unwanted rotations. Our clinical experience with these loops supports the FEM findings.

The first area of contact between a pre-activated spring and the inner surface of the molar tubes can explain the unwanted rotations produced by the first two springs. In the case of the open vertical loop, the first area of contact occurred between the pre-activated archwire and the mesio-buccal surface of the buccal tube. However, the opposite occurred when the pre-activated spring with a single horizontal helix was inserted into the buccal tube. When engaged, the toed out distal end of the archwire contacted the disto-buccal surface of the buccal tube, and moved the first molar buccally with a disto-buccal rotation. Our spring design with the two vertical helices was passive before insertion, and it was activated by inserting the end of the archwire into the buccal tube on the displaced molar and then twisting the archwire to engage the brackets on the remaining teeth. The first two spring designs contain a force and a moment, but the spring with the two vertical helices had only a moment if applied correctly.

Conclusions

FEM can be used to determine the behaviour of springs designed to upright a lingually tipped lower molar.

Of the three springs tested, a recent design incorporating a double helix wound around and perpendicular to the long axis of the archwire was the only spring to upright a lingually tilted molar without unwanted rotations.

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References

1. Chipman MR. Second and third molars: their role in orthodontic therapy. Am J Orthod 1961;47:498–520.
2. Cureton SL. Second molar biomechanics. J Clin Orthod 1995;29:500–8.
3. Ramfjord SP. Dysfuctional temporomandibular joint and muscle pain. J Prosthet Dent 1961;11:353–74.
4. Sadowsky C, Polson AM. Temporomandibular disorders and functional occlusion after orthodontic treatment: results of two long-term studies. Am J Orthod 1984;86:386–90.

5. Graber TM, Vanarsdall RL, Vig KWL. Orthodontics: Current principles and techniques. 4th edn. St Louis: Mosby, 2005:322–7.
6. Nakamura S, Miyajima K, Nagahara K, Yokoi Y. Correction of single-tooth crossbite. J Clin Orthod 1995;29:257–62.
7. Yoon YJ, Kim KW. Posterior crossbite appliance to correct the lingually ectopic eruption of mandibular second molar. J Korean Dent Assoc 1997;35:80–1.
8. Zienkiewicz OC, Taylor RL. The finite element method. 4th Edn. London: McGraw-Hill, 1989:1–4.
9. Geramy A. Harmonious translation of the Cres in different tooth movements while the force is remained constant. J Dent, Shiraz University of Medical Sciences 2002:3;59–65.
10. Geramy A, Faghihi SH. Secondary trauma from occlusion: 3-D analysis using the Finite Element Method. Quintessence Int 2004;35:835–43.
11. Geramy A. Moment/Force ratio and the center of rotation alteration: 3-D analysis by means of the Finite Element Method. J Dent, Shiraz University of Medical Sciences 2000;1;26–34.
12. Geramy A. Alveolar bone resorption and the center of resistance modification: 3-D analysis by means of the Finite Element Method. Am J Orthod Dentofacial Orthop 2000; 117:399–405.
13. Geramy A. Initial stress produced in the periodontal membrane by orthodontic loads in the presence of alveolar bone loss of varying extent: three dimensional analysis using the Finite Element Method. Eur J Orthod 2002;24:21–33.
14. Geramy A. Stress tensor modification in alveolar bone resorption: 3-D analysis using the Finite Element Method. J Dent, Shiraz University of Medical Sciences 2002:3;39–49.
15. Geramy A. Cervical headgear force system: 3-D analysis by means of the Finite Element Method. J. Dent, Shiraz University of Medical Sciences 2001;2;21–30.
16. Geramy A. Optimization of unilateral overjet management: 3-D analysis using Finite Element Method. Angle Orthod 2002;72:585–92.
17. Geramy A, Morgano S. Finite element analysis of three designs of an implant-supported molar crown. J Prosthet Dent 2004;92:434–40.
18. Geramy A.V-bend force system: 3-D analysis using the Finite Element Method. Iranian J Orthod 2006;1:12–17.
19. Ash MM. Dental anatomy, physiology, and occlusion. 6th edn. Philadelphia: W.B. Saunders Co. 1984:245–86.