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ANALYSIS OF STRESS PATTERNS IN THE PERIODONTIUM PRODUCED BY DISTALIZING FORCES ON THE MANDIBULAR MOLARS – A FINITE ELEMENT STUDY

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ABSTRACT **Introduction:** Treatment of Class III malocclusion is a considerable clinical challenge for the orthodontist and commonly includes growth modification involving a chincup to restrain mandibular growth or a facemask to protract the maxilla, dentoalveolar compensation or camouflage involving dental extractions, or orthognathic surgery. **Materials And Methods:** The present study was a Finite Element study. This Study was conducted from 12 months at Department of Orthodontics and Dentofacial Orthopedics, Guru Nanak Institute of Dental Sciences and Research were procured from the departmental archives. **Result:** Increasing the occlusal inclination of the loading force decreased the compressive stresses on the alveolar bone, but an insignificant increase was produced in the compressive stresses on increasing the gingival inclination of the loading force. On comparing the compressive stresses, the horizontal and the 15 degree occlusal force showed greatest compression in the distal surface in the cervical third close to the midline. The 15 degree gingival force also showed greatest compression in the distal surface in the cervical third but it was spread more buccally. The 30 degree occlusal force also showed greatest compression in the distal surface in the cervical third but it was spread more lingually. **Conclusion:** We found that, the 30 degree gingival force shows an increased tendency of the tooth to intrude, as evidenced by the compressive stresses produced around the furcation and either apical regions. Increasing the occlusal inclination of the force shows an increased tendency of the tooth to extrude rather than distalize.

KEYWORDS : Physical properties, Distalizing and Anchorage.

INTRODUCTION

Treatment of Class III malocclusion is a considerable clinical challenge for the orthodontist and commonly includes growth modification involving a chincup to restrain mandibular growth or a facemask to protract the maxilla, dentoalveolar compensation or camouflage involving dental extractions, or orthognathic surgery [1] .While possibly indicated, class III surgical correction has a number of drawbacks or relative contraindications. An interesting possibility would be to camouflage class-III malocclusion by distalizing the mandibular molars while controlling the vertical dimension.[2] Clinicians have attempted to camouflage Class III malocclusion by various methods of distalization of the mandibular dentition. Although this has proved to be one of the most difficult biomechanical problems in traditional orthodontics, particularly in adults, it has now become possible to distalize mandibular molars with the use of various temporary skeletal anchorage devices (TADs).[3]Sugawara and co-workers introduced the Skeletal Anchorage System (SAS) that uses pure titanium anchor plates and screws as absolute orthodontic anchorage units,15-17 making it possible to distalize the mandibular molars with anchor plates placed at the anterior border of the mandibular ramus or mandibular body.[4]

The present study has been designed to measure and study the Stress patterns produced in the periodontium of the mandibular first permanent molars by distally directed forces passing through the buccal surface of the clinical crown of the mandibular first permanent molar delivered from different vertical directions that reciprocate the different anatomical sites in the mandible by means of the finite element method.

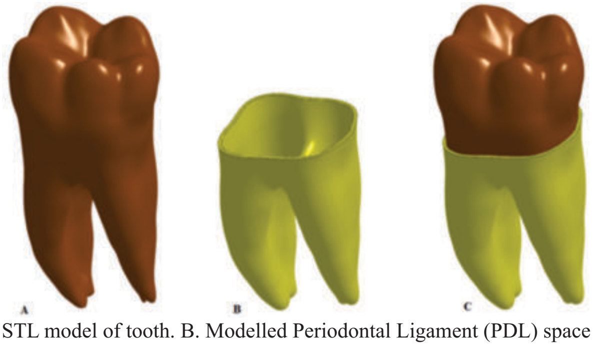
The objectives of this study are to study the patterns of Maximum Principal stress and Minimum Principal stress distribution in the periodontium of the mandibular molars as a result of variation in direction of delivery of distalizing forces to the mandibular first permanent molar in order to establish the regions most susceptible to periodontal resorption during distal orthodontic tooth movement. This study will help to gain an insight into the patterns of root and bone resorption of the mandibular molars under application of distalizing forces from different anatomical sites in the mandible.

MATERIALS AND METHODS

Cone Beam Computed Tomography (CBCT) scans of adolescent and adult patients with fully erupted mandibular first permanent molars who had previously reported to the Department of Orthodontics and Dentofacial Orthopedics, Guru Nanak Institute of Dental Sciences and Research were procured from the departmental archives. Patients with any developmental skeletal anomalies, any immature mandibular teeth with incomplete roots and open apices, previously restored or endodontically treated mandibular first permanent molars, periodontally compromised mandibular dentition, history of trauma to the mandibular bone, or presence of any skeletal pathology in the mandibular bone were excluded from this study.

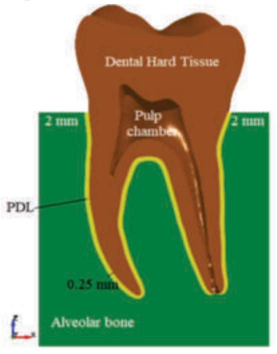
Of the 48 CBCT scans thus available, one scan was selected at random (Patient N.D.) and converted to DICOM (Digital Imaging and Communications in Medicine) images using the iRYS Viewer version 5.6 (Cefla North America Inc., Charlotte, North Carolina, U.S.A). A 3D stereolithographic (.stl) model of the left first permanent mandibular molar was thus obtained, and subjected to Finite Element Modelling using the Hypermesh 14.0 (Altair Engineering Inc., Michigan, U.S.A.) software.

NURBS (Non Uniform Rational Bezier Spline) modelling of the mandibular left first permanent molar was used to construct a Periodontal Ligament (PDL) space of uniform 0.25mm thickness all around the root of the tooth. The average thickness of the PDL space is reported to be 0.25 mm ± 50%, with the range from 0.15 mm to 0.38 mm.

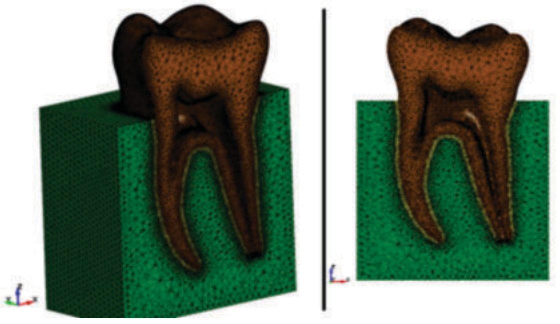


STL model of tooth. B. Modelled Periodontal Ligament (PDL) space of 0.25 mm thickness. C. The Tooth-PDL complex as modelled.

The cervical limit of the PDL space was determined to be the constriction that demarcates the floor of the Pulp chamber, which was clearly evident on the stl model. The Alveolar bone was considered as a composite cuboid box in which the tooth-PDL complex is embedded and was modelled with a uniform thickness of 2.0 mm on the four sides of the tooth-PDL complex.



Cross sectional view of the final model



Discretization of the Tooth-PDL- bone complex into nodes and elements

The entire Tooth-PDL-alveolar bone complex was then discretized into first order tetrahedral solid elements joined by nodes using the Hypermesh v 14.0 software. The meshed model in Hypermesh is exported in the form of LS-DYNA keyword where further pre-processing is carried out. Isotropic elastic material properties - Young's modulus and Poisson's ratio, were assigned to the Tooth, Periodontal Ligament and Alveolar bone in accordance with those assigned in previous studies , shown in Table I.

Material	Young's Modulus (kg/mm^2)	Poisson's ratio
Tooth	2.0 x 10^3	0.15
Peridontal Ligament	6.8 x 10^{-2}	0.49
Alveolar Bone	1.4 x 10^3	0.15

Material properties assigned in this study

The 3 dimensional axes were next defined in order to conduct the FEM study as follows:- X = mesiodistal; Y = buccolingual; Z = axial; The elements in tooth and PDL share the nodes at the PDL-tooth interface, whereas at the PDL-bone interface, the tied contact is prescribed, both signifying the perfect bonding at respective interfaces. Nodes at the mesial and distal surfaces on the outer boundary of the alveolar bone were restricted in all three degrees of freedom.

RESULT AND DISCUSSION

Distalization of mandibular molars presents a unique challenge to the clinician. Movement patterns for mandibular versus maxillary teeth are different due to the anatomic nature of mandibular bone. Hence, mandibular molars distalization is more challenging than distalization of maxillary molars.[5]

Conventional orthodontic appliances have historically tended to elicit tipping rather than bodily movement, before the advent of skeletal anchorage protocols. Various methods of skeletal anchorage have been developed, such as mini-screws and mini-plates, and have enjoyed longtime widespread usage.In addition, other studies have demonstrated the usefulness of skeletal anchorage in improving bialveolar protrusion, or alternatively for protraction of maxillary teeth.[6,7]

Lower molar distalization can generally only occur in smaller increments as compared with maxillary molars. Therefore, it is vital to design and apply the proper vectors of orthodontic force in order to achieve effective treatment results.

Sugawara et al.[3] proposed the Skeletal anchorage system (SAS), a safe and useful system for skeletal anchorage that uses titanium anchor plates and monocortical titanium screws, which provide rigid anchorage units for distalizing the mandibular molars.The monocortical bone screws in the SAS are fixed on the anterior border of the mandibular ramus or the mandibular body beyond the root apices or outside the alveolar region and never interfere with root movement in orthodontic therapy.

Stress Patterns in the Periodontal Ligament space

The apical third of the lingual surface of the mesial root consistently demonstrated the highest tensile stresses. Of these, the 30 degree gingival force produced the lowest, and the 30 degree occlusal force produced the highest tensile stress. The stress values increased as the force was directed increasingly occlusally. The exact reverse of the above phenomenon was observed in the compressive stresses, with the 30 degree gingival force producing the highest compressive stress, and the 30 degree occlusal force producing the lowest compressive stress. The horizontally and gingivally directed forces produced greatest compression at the medio-lingual surface of distal root in apical third, the occlusally directed forces produced greatest compression at the distal root surface in the cervical third on the PDL-tooth junction.

Stress patterns in the Alveolar bone

Increasing the gingival inclination of the loading force decreased the tensile stresses and increasing the occlusal inclination of the loading force also showed a decrease in tensile stresses, with the 15 degree occlusal force producing the highest tension among the five variables, followed by the horizontally directed force. The horizontally, gingivally and 15 degree occlusally directed forces produced greatest tensile stresses at the mesial surface in the cervical third spread more buccal to the midline. The 30 degree occlusally directed force was unique in producing greatest tensile stress at the lingual surface of the mesial root in its middle third.

Increasing the occlusal inclination of the loading force decreased the compressive stresses on the alveolar bone, but an insignificant increase was produced in the compressive stresses on increasing the gingival inclination of the loading force. On comparing the compressive stresses, the horizontal and the 15 degree occlusal force showed greatest compression in the distal surface in the cervical third close to the midline. The 15 degree gingival force also showed greatest compression in the distal surface in the cervical third but it was spread more buccally. The 30 degree occlusal force also showed greatest compression in the distal surface in the cervical third but it was spread more lingually. The 30 degree gingival force was unique as it produced greatest compression on the medio-lingual surface of the distal root close to the apical foramen.

The stress patterns produced in all force directions demonstrate the tendency of the tooth to tip under a distalizing force. This can be attributed to the fact that the force directions pass occlusal to the centre of resistance of the tooth, which lies close to the furcation.The stress patterns produced also demonstrate the tendency of the tooth to rotate under a distalizing force. Again, this can be attributed to the force directions passing buccal to the centre of resistance of the tooth.

Due to this rotational and tipping tendency, the maximum tensile stresses in the PDL for the five different force directions are concentrated around the lingual surface of the mesial root in its apical third, and the maximum compressive stresses around the medio-lingual surface of the distal root in the apical third. Only the 30 degree occlusally directed force produces greatest compression on the distal surface in the cervical third, but the magnitude is almost half of that produced by the other force directions.

Contrasting results are seen in the alveolar bone. Maximum tensile stresses are distributed around the mesial surface in the cervical third; only the 30 degree occlusally directed force produces greatest tension in the lingual surface of the mesial root surface in the apical third.

Maximum compressive stresses are distributed around the distal surface in the cervical third; only the 30 degree gingivally directed force produces greatest tension in the medio-lingual surface of the distal root surface close to the apical foramen.

The stresses produced in the alveolar bone are approximately $x10^3$ times greater than those produced in the PDL, which may be attributed to the difference in physical properties of the two components. It is well worth noting that the stresses produced in the apical regions are significantly lesser than the stresses produced in the cervical regions on either mesial or distal surface for all force directions. Thus, it can be expected that remodeling of periodontal fibres and bone will be much higher in the cervical regions than in the apical regions.

Jeon PD et al.[8] observed higher stress concentrations around the maxillary molar root furcation region. The maxillary molar with three roots is likely to undergo resorption on the root surface at the furcation level that is difficult to see radiographically. On the contrary, this study shows only moderate stress concentration in the furcation regions in both the PDL and alveolar bone. This would suggest that the mandibular molar with two roots is unlikely to undergo significant periodontal remodeling at the furcation.

The 6 degree distal offset force produces similar stresses to the buccal horizontally directed force in all regions in both the PDL and alveolar bone. The lingually directed force produces lower tensile stress in the PDL on the mesial cervical margin.On comparing the stresses at the specified elements in the periodontium, it is observed that all stresses are tensile on the mesial cervical margin and compressive on the distal cervical margin in the PDL (Graphs I, II). The horizontal force exerts both the most tensile and the most compressive stresses on either cervical margin. While all other force directions produce tensile stresses in the mesial root apex region as well as in the furcation, the 30 degree gingival force is unique in producing compressive stresses in these regions. (Graphs III, V). The 30 degree gingival force also produces the lowest tensile and compressive stresses on either cervical margin. The stresses tend to become increasingly compressive as the force direction moves more gingivally, and increasingly tensile as the force direction moves occlusally, with the 30 degree occlusal force producing the greatest tensile stress in both the furcation and mesial root apex regions in the PDL.

The 15 degree gingival force produces only minor tensile stresses in the furcation region. The 15 degree occlusal force produces minor tensile stresses in the distal root apex while all other forces produce compression (Graph IV). The 30 degree gingival force produces the greatest compressive stresses on the distal root apex region in the PDL. Similar to the PDL, all force directions produce tensile stresses in the mesial cervical margin of the alveolar bone, and compressive stresses on the distal cervical margin (Graphs VI, VIII). The 30 degree gingival force is again unique in producing compressive stresses in the furcation region, while all other stresses produce tensile stresses in the furcation. Of these, the 15 degree gingival force produces the least tensile stresses. The stresses tend to become increasingly compressive as the force direction moves more gingivally, and increasingly tensile as the force direction moves occlusally, with the 30 degree occlusal force producing the greatest tensile stress in the furcation region (Graph VII).

Increasing the occlusal inclination of the force shows a tendency of the tooth to extrude, as observed by greatest tensile stresses on the PDL and alveolar bone produced by the 30 degree occlusal force in the apical and furcation regions. The stresses produced on the mesial and distal surfaces, though, are lower than the stresses produced by the horizontal and 15 degree occlusal force in these regions. Thus, the total distalizing potential of the 30 degree occlusal force is also lower. Increasing the gingival inclination of the force shows a tendency of the tooth to intrude, as observed by the compressive stresses on the PDL and alveolar bone produced by the 30 degree gingival force in the apical and furcation regions, compared to the progressively decreasing tensile stresses produced by the horizontal and 15 degree gingival force in these regions, respectively.

Park M et al. [9]observed that orthodontic forces at the level of the cemento-enamel junction resulted in a greater biomechanical bodily movement in distalization of the mandibular molars compared to when the orthodontic forces were applied at the level of the bracket. Applying orthodontic forces to the cemento-enamel junction also resulted in unwanted greater extrusive movements in distalization of the mandibular molars compared to the bracket level. On the contrary, the results of this study show that the most effective distalization of the mandibular molar takes place when the force is applied at 15 degree gingival direction from the level of the bracket. Unwanted intrusive forces are generated when the force is directed further gingivally. Unwanted extrusive stresses are produced when the force is applied in an occlusal direction. Thus, distalization of the mandibular molar would be most effective with skeletal anchorage from the region of the external oblique ridge or mandibular ramus below the occlusal plane. A TAD placed in the alveolar region between the roots of the two molars would lead to unwanted intrusion and periodontal resorption around the furcation region. Any TAD placed above the occlusal plane would lead to extrusion of the molar. This is especially contraindicated in cases with hyperdivergent growth patterns.

CONCLUSION

From the results of this study, it can be concluded that:
The 30 degree gingival force shows an increased tendency of the tooth to intrude, as evidenced by the compressive stresses produced around the furcation and either apical regions. Increasing the occlusal inclination of the force shows an increased tendency of the tooth to extrude rather than distalize.

Overall, the 15 degree gingival force produces lowest stresses in the periodontium around the furcation and apical regions, and sufficient stresses on the mesial and distal surfaces. Thus, the 15 degree gingival force would be the most effective force to avhieve bodily distalization of the mandibular first permanent molar.

30 degree Gingival

Element	Location	Max P Stress MPa	Min P Stress MPa
A 738504	Mesial cervical margin	0.0171	0.00822
B 809302	Distal cervical margin	-0.00648	-0.0153
C 832541	Mesial Root Apex	-0.000527	-0.00169
D 716157	Distal Root Apex	-0.00157	-0.00421
E 667192	Furcation	-0.0073	-0.0079

15 degree Gingival

Element	Location	Max P Stress MPa	Min P Stress MPa
A 738504	Mesial cervical margin	0.0193	0.00952
B 809302	Distal cervical margin	-0.00725	-0.0172
C 832541	Mesial Root Apex	0.00498	0.00382
D 716157	Distal Root Apex	-0.00155	-0.00302
E 667192	Furcation	0.00078	0.0002

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