Stress distribution of maxillary first molar PDL with highpull headgear traction; A finite element analysis

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Statement of the problem: Headgear is most commonly used to correct anteroposterior discrepancies. Headgear can also be used to make more space for teeth to come in. In this instance the headgear is attached to the molars, via molar headgear bands and tubes, and helps to draw these molars backwards in the mouth, opening up space for the front teeth to be moved back using braces and bands. Stress on PDL of molars teeth and soreness of teeth when chewing, or when the teeth touch, is typical. Adults usually feel the soreness 12–24 h later, but younger patients tend to react sooner.

Purpose: Application of heavy forces to maxillary dentition during treatment with headgear, induces high concentration of stresses in periodontal tissue. Quantification of this stress is of great concern in orthodontics. This study was designed to investigate the quantity and quality of stress response in the PDL of maxillary first molar which was subjected to highpull headgear traction using Finite Element Method.

Materials and method: In an experimental study, a three-dimensional finite element model of maxillary dentition, consisting of 17096 elements & 23013 nodes, was developed based on a young human skull. The forces were applied to the maxillary first molar in the stabilized arch by means of a rectangular full size arch wire in (022) slot bracket. Mechanical properties of this model were based on previous studies. A 350 g force was used for high pull headgear to affect the dentition (+30°/C14) and stress distribution was investigated in buccal, palatal, mesial and distal side and in cervical, middle, apical sections of the PDL. The quantity of stresses were expressed as principal stresses, while the negative and positive signs indicated compressive and tensile stresses respectively.

Results: The buccal surface of PDL of mesiobuccal root and the buccal, palatal, and distal surface in cervical regions of PDL of distobuccal root and the distal surface of the PDL of palatal root had received a great deal of stresses, in addition, the over all stress distribution in roots of molar had intrusive nature.

Conclusion: The distribution of high stress concentration areas observed after using high pull headgear is limited to some root surfaces specially the distobuccal root.

1. Introduction

The epidemiologic investigation shows the prevalence of CI II in ages between 12 and 17 the most after CI I malocclusion [1,2]. Meanwhile, there is no doubt that headgear forces need to be used in conjunction with all contemporary mechanotherapy modalities for the highest quality and most stable correction of CI II malocclusion [3]. Since the introduction of orthopedic headgear by the pioneer American orthodontist “Norman W.Kingsly”, Various

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studies have been conducted to investigate morphological, biological and biomechanical changes of the complex area of craniofacial, incident to orthopedic headgear treatment [3,4].

The biological response of PDL is determine by the strain-stress levels induced to tooth [5].

In orthodontics, many attempts have been made to model the reaction of teeth and PDL during application of orthopedic forces. Models such as mathematical — mechanical modeling that the value of such studies is limited by the fact that the mechanical properties of the surrounding tissues could differ from those of actual human tissues. Hence, the results depend on the physical features of the artificial substitute for the PDL [6].

The strain — gauge technique for registration of tooth movement has been demonstrated as a precise and valid method. A disadvantage, however is that the method is invasive [7]. The Finite Element Method is a powerful computer simulation tool in determining Stress—strain level in the mechanics of structures in engineering [8,9]. FEM is an approximation method that divides the entire region of the structure into a set of elements. The application of FEM in dentistry has been found at the late 70’s.

In Rubin et al. studies a 3D finite element model has been developed for analyzing the stress distribution in human mandibular right first molar [10].

Tanne et al. had investigated the stress distribution in PDL of lower first premolar after orthodontic force application, using a 3D

<table>
<thead>
<tr>
<th>Material</th>
<th>Young’s modulus (kg/mm²)</th>
<th>Possion’s ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tooth</td>
<td>$2.031 \times 10^4$</td>
<td>0.3</td>
</tr>
<tr>
<td>PDL</td>
<td>50</td>
<td>0.3</td>
</tr>
<tr>
<td>Alveolar bone</td>
<td>$1 \times 10^4$</td>
<td>0.33</td>
</tr>
<tr>
<td>Steel</td>
<td>$2.031 \times 10^5$</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Fig. 1. Stress distribution in PDL cervical section of mesiobuccal root of first maxillary molar after loading by headgear.

Fig. 2. Stress distribution in PDL middle section of mesiobuccal root of first maxillary molar after loading by headgear.
The highest stresses were observed on the root, secondly on the alveolar bone, and finally in the PDL, which was caused by the differences in the mechanical properties of them [11].

Anderson et al. in a study investigated the distribution of stress around teeth after loading, with FEM and discussed that the results were dependent on the load, the boundary condition, and the material parameters [12].

McGuiness et al. in a study, using a 3D finite element model of a human maxillary canine, examined series of forces applied to the teeth. It has been demonstrated that the highest stress concentration in the PDL was at the cervical margin. In all cases, the distribution over most of the PDL was less than the upper limit of 0.026 N/mm² proposed as optimal [13]. Tanne et al. investigated the nature of initial tooth displacement associated with varying root length and alveolar bone heights. The results showed that moment to force values at the bracket level for translation of a tooth decreased with shorter root length and increased with lower alveolar bone height [14].

Middleton et al. studied the role of the PDL in the bone remodeling process by application of the FEM and concluded that the PDL shows the highest strain close to the cervical margin [15].

Jeon et al. studied the stress response in the PDL of a maxillary first molar to different amounts of moment to force ratio, and determined the moment of force ratio for translational movement of the tooth, using FEM [16].

Chaudhry et al. evaluated the effect of a fixed functional appliance on mandible with a FE analysis and they showed that this fixed appliance increases the maximum force more than 2 times [17].

The aim of this study was to investigate the stress distribution in PDL of a maxillary first molar after application of high pull headgear by means of the FEM in a certain circumstance that maxillary dentition is fully aligned and leveled by a full size arch wire. The long term effects of high pull headgear have found that it may cause stress on roots of teeth and lead to resorption of roots and also...

**Fig. 3.** Stress distribution in PDL apical section of mesiobuccal root of first maxillary molar after loading by headgear.

**Fig. 4.** Stress distribution in PDL cervical section of disto buccal root of first maxillary molar after loading by headgear.
inhibit the natural growth of the jaw, which relate to the size of the maxilla and the mandible.

2. Materials and method

In an experimental study, a 3D(3-dimensional) model of the craniofacial complex was used in this study. A 3D analytical model was developed from a dry skull of a young human at one-to-one magnification.

For accurate modeling, sections of the skull were cut at approximately 1.5 mm intervals in facial and 3 mm in calvaria. By scanning, the graphic data of CT scan(computed tomography) were transferred to computer and they were restored in Auto Cad software by dwg format. This model was divided into 17096 iso-parametric elements & 23013 nodes under the preprocessing check of NISAII, which was the 3D analytical program that had the possibilities such as, linear elastic analysis, non linear static analysis, and displaying. For orthodontic appliance simulation, the angulation and length of the appliance were measured by profile projector and data analyzed by NISAII software. (Cranes Software Inc, Troy, USA).

In NISAII, each element was consisted of two characteristic, NKTP (the type of element) & NORDR (the number of node). For subdivision and discretization, 3D elements such as, cubic, wedge and pyramidal type were used.

The values for Young’s modulus and Poisson’s ratio used in this study (Table 1) were those used by Tanne (1991).

The model was fixed at the foramen magnum. A posteriorly-directed force of 350 gr was applied in each side to the maxillary first molar in the direction 30 superior to the occlusal plane.

For precise evaluation of stress distribution in PDL(Periodontal ligament), the tooth was divided in three equivalent occlusogingival section, from CEJ(Cemento-enamel Junction) to apex and midway of each section studied. In horizontal plane, four points around the circumference of the root (buccal, mesial, distal, palatal) were defined and stress values were calculated at these points.

![Fig. 5. Stress distribution in PDL middle section of disto buccal root of first maxillary molar after loading by headger.](image1)

![Fig. 6. Stress distribution in PDL apical section of distobuccal root of first maxillary molar after loading by headgear.](image2)
Three principal stresses, maximum (◆, 1 princ), intermediate (■, 2 princ) and minimum (▲, 3 princ) measured for all reference points at the occlusogingival levels. A minus sign in this instance signified a tensile stress, while a plus sign indicating compressive stress. The output from these loading conditions presented in the form of graphs of stress.

The stress distribution graphs in (cervical, middle, apical) sections of each root of the first molar (mesiobuccal, distobuccal and palatal) were designated.

3. Results

The stress pattern in periodontium are shown in Figs. 1–9 through presented graphs.

In Fig. 1, at 1. Princ all the regions showed tensile stresses, at 2. Princ all the regions experienced compressive stresses, except buccal surface, at 3. Princ the stress distribution was compressive in all regions.

In Fig. 2, at 1. princ all the regions were under tensile stresses, at 2. princ expect for mesial, the other regions showed compressive stresses, at 3. princ the PDL experienced compressive stresses.

In Fig. 3, at 1. princ we observed tensile stresses in all regions, at 2. princ buccal and palatal surfaces were under tensile stresses while the others were under compressive stresses, at 3. princ we observed compressive stresses in all regions.

In Fig. 4, at 1. princ, there were tensile stresses in all regions, at 2. princ buccal and mesial surfaces were under tensile stresses while the others were under compressive stresses, at 3. princ all of the regions showed compressive stresses.

In Fig. 5, at 1. princ the stresses were tensile in all regions, at 2. princ except for buccal surface, in other regions we observed compressive stresses, at 3. princ all the regions were under compressive stresses.

In Fig. 6, at 1 princ all the stresses were tensile in nature, at 2. princ, in mesial surface we observed compressive stresses while the others showed tensile stresses, at 3. princ, all the stresses were

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**Fig. 7.** Stress distribution in PDL cervical section of palatal root of first maxillary molar after loading by headgear.

**Fig. 8.** Stress distribution in PDL middle section of palatal root of first maxillary molar after loading by headgear.
compressive in nature.

In Fig. 7, at 1. princ we observed tensile stresses in all regions, at 2. princ the buccal and palatal were under compressive stresses, at 3. princ all regions showed compressive stresses.

In Fig. 8, at 1. princ all the stresses were tensile in nature, at 2. princ the tensile stresses reduced and they were only observed in buccal and distal surfaces, at 3. princ all the stresses were compressive in nature.

In Fig. 9, at 1. princ all the regions were under tensile stresses, at 2. princ the palatal and buccal surfaces were under compressive stresses and the others experienced tensile stresses, at 3. princ we observed compressive stresses in all four regions.

4. Discussion

In this study, the Finite Element Method provided a mathematical model that allowed quantification of the stress & strain in the PDL of the maxillary first molar. High pull headgear is often used for the vertical, intrusive force which can be applied to the maxillary molars. Maxillary molar buccal tubes can be either occlusal or gingival. Advantage of placing the tube gingivally is that the tube is closer to the center of rotation of the molar, which may lead stress to PDL. The mechanical influence of the high pull headgear produces a reaction in the biologic system under stress. Local response can be anticipated in the affected tissues. If force is applied during growing period, a modification of growth dynamics is evident. Force systems a headgear can deliver depends on the magnitude, direction, point of application and its line of action. To determine the effect of the headgear force, the line of action of the force with respect to the body to which it is applied — tooth, arch or the maxilla has to be examined. Hence, knowledge of the approximate location of the body’s center of resistance is essential to choose the force system desired in treatment mechanics. The stress patterns in the PDL were displayed in separate illustration, so that the complex responses of it to different types of loading were compared. Stress distribution in three sections of mesiobuccal root showed that at buccal surface, there were less tensile stress in apical section at 1. princ, implying intrusive displacement (Fig. 10).

At 2.3 princ considering the compressive nature of stresses, in middle & cervical section, we observed the compression of fibers into buccal alveolar bone. In palatal, distal & mesial surface of this root the stress pattern indicated intrusive displacement, approximately in all principal stresses.

In distobuccal root, in middle section, the stress pattern totally elaborated a rotational movement of this area. In apical section of this root, there was a superior — posterior displacement, with both tensile & compressive stresses that resulted rotational movement of this root. Stress distribution in three sections of distobuccal root showed intense compression of apical section of distobuccal root toward the opposite alveolus.

In palatal root the stress pattern implied the tooth displacement in the direction of loading, although we had not noticeable difference between stress pattern of three sections, but the palatal surface showed the greatest intrusive displacement.

Fig. 9. Stress distribution in PDL apical section of palatal root of first maxillary molar after loading by headgear.

Fig. 10. 3D model of Stress distribution on roots of first maxillary molar after loading by headgear.
5. Conclusion

The buccal surface of PDL of mesiobuccal root & the buccal, palatal and distal surface in cervical region of PDL of distobuccal root and the distal surface of the PDL of palatal root, had received a great deal of stresses, in addition, the overall stress distribution in roots of molar had intrusive nature. The distribution of high stress concentration areas observed after using high pull headgear is limited to some root surface specially the distobuccal root.

Conflicts of interest

The authors deny any conflict of interests.

References