

The effects on pdl, tooth and alveolar bone with intrusion of anteriors using round wire utility arch: finite element model analysis

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Abstract

Introduction: Deep bite is common finding in different malocclusions and it is frequently treated by intrusion of incisors. This creates stress areas in the dento-alveolar region. It is important to study the response of dental tissues to orthodontic forces and the resultant effect to minimize risk of tissue damage. Finite element model is an effective method to understand this biomechanical scenario.

Aim: To study the effect of intrusion utility arch in anterior maxillary dento-alveolar region.

Materials and Methods: FEM of maxillary dento-alveolar region. Intrusion scenario of 4 incisors using intrusion utility arch was simulated. The effects on PDL, tooth and alveolar bone were analyzed.

Result: Maximum tensile stresses are in the cervical region of labial surface of incisors, PDL and alveolar bone which are becoming compressive at apices.

Conclusion: Above method is found safe for PDL and alveolar bone but suggested susceptibility to root resorption.

Keywords: Intrusion, FEM, Stresses.

Introduction

In orthodontics, deep bite is a complex problem that is a common feature of many malocclusions. Correction of deep bite is an important part of orthodontic treatment due to the potential deleterious effects on the temporomandibular joint, periodontal health, facial aesthetics and interference with lateral and anterior mandibular movement.^{1,2} Deep bite can be treated orthodontically by intrusion of incisors, extrusion or passive eruption of buccal segments or combination of these.² Treatment of choice depends on variety of factors such as smile line, incisor display and vertical dimension.³ Intrusion of incisor is the main goal in most clinical situations. Various modalities for intrusion includes Burstone intrusion arch, Ricketts utility arch, Connecticut intrusion arch made up of nickel titanium, continuous intrusion arches with segmented arch techniques, and mini-implants.¹⁻⁴

Studies have shown signs of degeneration of cell structures, vascular components and extracellular matrix of cementum and periodontal ligament in all intruded teeth with more severe changes towards an apical direction and in proportion to the magnitude of force applied.⁵⁻⁷ Studies have also shown changes in incisor and molar inclination which are least desirable during attempts of intrusion.^{3,4} Different types of orthodontic tooth movement may produce different mechanical stress at varying locations within the root. The measurement of these stresses is necessary so as to get a detail idea about the response of dental tissues and the resultant effect. This helps us to minimize any risk that could be caused to patient during treatment.

In vivo measurement of such stress is difficult and so development of an effective model for this system is a worthy goal⁸. Finite element model is one such effective method. FEM has many advantages over other methods (such as the photoelastic method), high-lighted by the ability to include heterogeneity of tooth material and irregularity of the tooth contour in the model design and the relative ease with which loads can be applied at different directions and magnitudes for a more complete analysis.⁸

Finite element method studies are being increasingly carried out now days to elucidate the mechanical and biologic system that governs the force needed to produce tooth movement. Finite element analysis, a computer aided numeric method with which stress, strain and deformation of structures with complex geometries can be studied in various loading and boundary conditions. Its philosophy is based on dividing complicated structures into manageable pieces, called elements that can be easily defined with differential equations. These finite number of elements are then assembled to form an approximate mathematic model of the structure.⁹

Aims and Objectives

To study the effect on maxillary arch caused by intrusion of maxillary anteriors using round wire utility arch.

Materials and Methods

A finite element model of all maxillary teeth was simulated with the use of computer (Fig.1&2). The model consisted of PDL, alveolar bone and all the teeth including third molars.

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The bracket simulated was MBT extraction series bracket system 0.022 slot.

Construction of finite element model involves

Construction of geometric model

A mathematical model representing biological properties of the teeth and periodontium was produced. This was represented in terms of points (grids), lines, surfaces (patterns) and volume (hyper patches). A 3 dimensional model of maxillary anterior teeth was produced. As the thickness of PDL is not the same all over, an average thickness of 0.25 mm was assumed and generated around the model of the root. The software used for geometric modeling was ANSYS R15.

Conversion of geometric model to finite element model

This geometric model was converted into finite element model. This process is called discretization. For the 3 dimensional analysis, the finite element were triangular. These elements are considered interconnected at joints which are called nodes or nodal points. The corner nodes are called primary external nodes. The additional nodes which occur at sides of the elements are called secondary external nodes. The secondary nodes have fewer displacements than corner nodes. In the study, Nodes- 30175 and Elements-18935

Material property data representation

The different structures involved in this study include teeth, PDL, and alveolar bone. Each structure has specific material property. These material property used were average values reported in literature.

Young's modulus (n/mm^2) value as per average values reported in literature for tooth, PDL, alveolar bone, stainless steel and implant.⁸⁻¹⁴ (Tooth – 20300, PDL- 0.667, Alveolar bone-13700, Stainless steel- 19200)

POISSON'S RATIO VALUES as per average values reported in literature for tooth^{8,10,15} PDL, alveolar bone,¹²⁻¹⁷ Stainless steel¹⁴ and implant¹⁸ (Tooth- 0.3,PDL- 0.45, Alveolar bone - 0.3, Stainless steel - 0.3)

Defining the boundary condition

Boundary conditions were defined to simulate how the model was constrained and to prevent it from free body motion.

Application of forces

Intrusion of maxillary 4 incisors was simulated with a force of approximately 80 gms. Utility intrusion arch made up of 0.018 inch stainless steel wire placed in 0.022 slot size MBT bracket with tip back to molar section was to perform intrusion of maxillary 4 anterior and the effects on periodontal ligament, tooth and alveolar bone in maxilla were analyzed (fig.3&4).

Evaluation of stress distribution

The stresses were calculated and represented in color band diagram so as to carry out the analysis (fig.5&6)

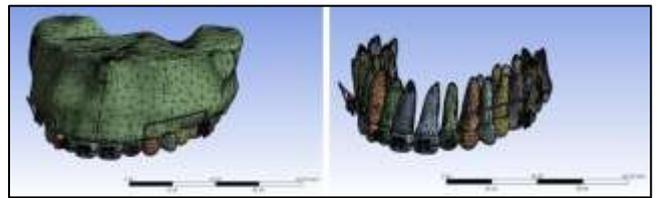


Fig. 1 and 2: Finite element model with utility arch made up of 0.018 inch S.S wire with and without bone.

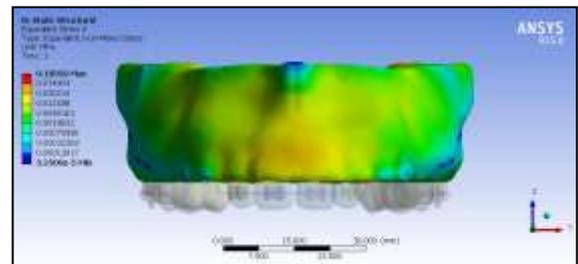


Fig. 3: Von Mises stress distribution along bone with utility arch made up of 0.018 inch S.S wire

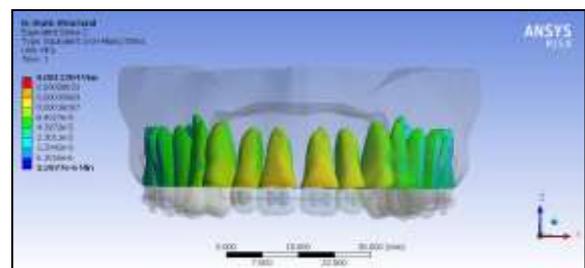


Fig. 4: Von Mises stress distribution along PDL with utility arch made up of 0.018 inch S.S wire

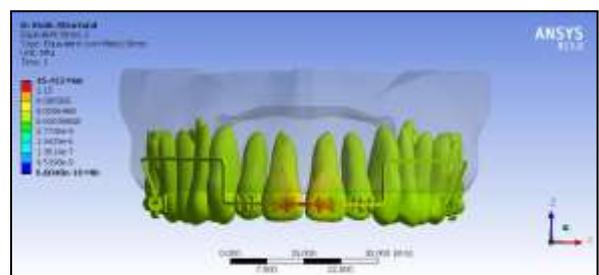


Fig. 5: Von Mises stress distribution along teeth with utility arch made up of 0.018 inch S.S wire

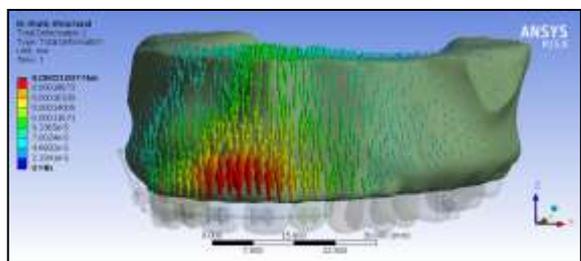


Fig. 6: Deformation along bone with utility arch made up of 0.018 inch S.S wire

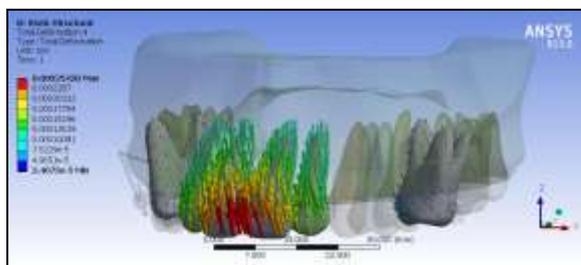


Fig. 7: Deformation along teeth with utility arch made up of 0.018 inch S.S wire

Results

The results were viewed in post processor of analysis software. The effects were studied in the form of Von Mises stress and deformation that developed on application of forces. The stresses and deformation were presented in a colour band diagram (fig.7) with different colours representing different levels of stresses and deformation. Red colour indicated maximum value and blue indicated minimum value with orange, yellow and green showing the values between red and blue. The units of Von Mises stress are Megapascal. The units of deformation are Millimeter. The patterns of stress distribution & deformation in each of the above methods obtained are explained in tables.

Table 1: Maximum Von Mises stress among teeth, PDL and alveolar bone with 0.018 inch S.S wire utility arch

Area	Maximum Von Mises stress
Teeth	0.23765 MPa
Periodontal ligament	0.0008454 MPa
Alveolar bone	0.18546 MPa

Table 2: Maximum deformation among teeth, PDL and alveolar bone with 0.018 inch S.S wire utility arch

Area	Maximum deformation
Teeth	0.00025428 mm
Periodontal ligament	0.00021007 mm
Alveolar bone	0.00021007 mm

Table 3: Maximum Von Mises among individual teeth with 0.018 inch S.S wire utility arch

Tooth no.	16	12	11	21	22	26
Max. Von Mises	0.02346 6	0.138 3	0.2376 5	0.19536	0.11989	0.02145

Table 4: Maximum deformation among individual teeth with 0.018 inch S.S wire utility arch

Tooth no.	16	12	11	21	22	26
Max. deformation	6.36 e-5	0.000169 53	0.000254 28	0.00026 37	0.00017 43	6.32 e-5

The study results becomes important for treating deep-bite in adult cases, the results suggested the following in relation to stress values in PDL & alveolar bone. The utility arch made of 0.018 SS wire, 0.017x0.025 SS & mini-implant placed between the roots of two central incisors showed that Von Mises stress in PDL & Alveolar bone was below their ultimate tensile strength, suggesting this method to be safe for PDL & alveolar bone, however the stresses on tooth suggest susceptibility to resorption.

As wire is placed & forces are applied, stress gets dissipated into cervical region before reaching the apical region. Thus maximum stress is found in cervical region of labial surface of tooth, PDL, & alveolar bone. More stress & deformation was seen with centrals followed by laterals. Unlike utility arches, molars were not subjected to stress & deformation with mini implants. Thus the study suggests that all methods used were suitable for intrusion but the forces are to be kept lighter & mini-implants should be used whenever molar anchorage is needed.

Discussion

Any tooth movement requires knowledge of biomechanics and the manner in which the tooth and its supporting structures react to forces. Deep bite can be treated orthodontically by intrusion of incisors, extrusion or passive eruption of buccal segments or combination of these. Intrusion is the treatment of choice in most cases depending on clinical situations.¹⁹ Continuous arch wire treatment predominantly cause correction of the deep overbite by extrusive tooth movement in posterior segment. Studies have shown that with segmental arch technique, overbite can be reduced mainly by intrusion of anteriors with minimal effect on molars.^{2,4} Utility arch is one such mean and is commonly used mechanics for intrusion.⁴

One of the challenges in intrusion of teeth is precise control of forces, least damage to the tooth and surrounding structures. A very light force is recommended for intrusion. Literature have documented that use of heavier forces will not increase rate of intrusion but may lead to root resorption.^{6,7,19,20} Burstone recommends 25 gms for upper central and lateral incisors.²¹ Nanda advocates 12-15 gms for upper central 8-10 gms for upper lateral incisors.²² Utility intrusion arches there is no good documentation on their effect on dental tissues. In the present study, analysis of the effect in the form of stress and deformation with intrusive force of 80 gms (20 gms per tooth) applied with utility arch (0.018 stainless steel) was performed. FEM makes it possible to analyze stress in response to a force system at any point and in any direction, when accurate modeling and material properties are utilized.²³ The aim of studying the stress distribution along the root, periodontal

ligament and surrounding bone was to localize their susceptibility to adverse effect of intrusion. FEM gives us detail knowledge about the deformation contour, principal stress concentration that is nature of stress distribution – compressive or tensile stress and the Von Mises stress following the application of an external force. The Von Mises stress of a material when compared to the ultimate tensile strength of that material gives an idea whether the material is going to fail corresponding to load applied¹³.

The results with round wire utility arch have shown maximum deformation of 0.00025428 mm at tooth followed by PDL 0.00021007 mm and alveolar bone 0.00021007 mm. The deformation is confined in cervical region on the labial side for bone and PDL and on labial side of the crown of the tooth at the site of wire bracket interface. The maximum stress was with teeth 0.23765 MPa followed by bone 0.18546 MPa and PDL 0.00068309 MPa. The stress and deformation was more with central incisor than on lateral incisor probably because they were the first ones to be loaded and more area for wire bracket interface. Also maximum stress was found along the cervical region of labial side of incisors in accordance to deformation.

Maximum stress was found along cervical region of labial side of central incisor followed by laterals similar to study by Sagar S Padmawar et al^{8,10} probably because the point of force application is between central incisors and away from the lateral incisors.

In this method maximum Von Mises stress on tooth was at the site of bracket – wire interface. The nature of stresses is tensile at cervical region and is comparatively compressive towards apex similar to study by Yan et al.¹⁷ This is also in accordance to study by Vikram et al where stress pattern on a maxillary incisor following orthodontic loading was maximum towards the mid –root region and minimum towards apex²⁴ This may be due to the reason that following load application, the stress gets dissipated into the alveolar crest and mid root region before it reaches the apical region. The maximum Von Mises stress value in alveolar bone in above method is far below the ultimate tensile strength of alveolar bone 8 MPa¹³. Also The maximum Von Mises stress value in PDL in above methods is below the ultimate tensile strength of PDL which is 2.4 MPa²⁵. Hence both alveolar bone and PDL are safe with the above method of intrusion without any deteriorating effect.

Studies have also shown that range of stresses exerted by the blood in capillary vessels (0.0026N/mm²) help us to determine the changes in tooth structure at apex leading to root resorption.^{8,10} Few literature consider 0.0047 MPa as the range of capillary blood pressure²⁶. All the values of Von Mises stress on tooth in above method are found to be above the capillary blood hydrostatic pressure suggesting the possibility of root resorption.

The finding that with 80 gms of force, the teeth are susceptible to root resorption necessitates the need for further studies using various intrusive force ranges suggested by literature. So intrusion should be carried out

under light continuous force capable of producing intrusion without harming the dental tissues concerned.^{6,7,19,20,26}

Limitations

The results have been obtained from simulated model from which biologic variability may occur. In the present study, the PDL was treated as a linear, elastic and isotropic even though PDL exhibit anisotropic, non linear and viscoelastic behavior. Because of this, results obtained in this work are not representative of the long-term effects and long-term displacements for which more complex material models are required. Further researches to study the time dependent stress and deformation are required. The resultant values should be interpreted as reference values to aid clinical judgment.

Conclusion

With utility arch made up of 0.018 inch stainless steel wire, the maximum deformation that occurred was in accordance to the maximum Von Mises stress distribution. Also, Von Mises stress in PDL and alveolar bone was below their ultimate tensile strength suggesting the method to be safe for PDL and alveolar bone. However, the stresses on tooth suggested susceptibility to resorption. Maximum stress is found in cervical region of labial surface of tooth, PDL and alveolar bone which is tensile in nature becoming comparatively compressive at apices. More stress and deformation was with centrals followed by lateral incisors.

Source of Funding

None.

Conflict of Interest

None.

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