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Comparison of the Effect of Transpalatal Arch on Periodontal Stress and Displacement of Molars When Subjected to Orthodontic Forces. A Finite Element Analysis

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Authors' contributions

This work was carried out in collaboration between all authors. Author MSB designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors MRD, BCA, RMD, CSP and KSAS managed the literature searches, analyses of the study and author VPS contributed in result analysis, manuscript design and manuscript drafting and performed proof reading. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

Introduction: The transpalatal arch has been used successfully for decades during routine orthodontic treatment for various purposes, including reinforcing anchorage. In the light of current scientific advancements with more precise knowledge of biology of tooth movement, it is prudent to study whether transpalatal arch is effective in preserving anchorage.

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Objectives: The aim of this finite element study was to evaluate and compare the effects of the transpalatal arch on periodontal stresses of molars and displacements when subjected to orthodontic forces.
Methods: Stress patterns and displacements between models with and without a transpalatal arch were investigated by means of 3-dimensional finite element analysis. A finite element model of the maxillary first molars, periodontal ligament, alveolar bone, and transpalatal arch was created, that consisted of 1, 69,036 elements and 29,518 nodes. A simulated orthodontic retraction force of 2N was applied to the maxillary first molar in a mesial direction. Resultant von mises stresses were evaluated and compared in models with and without transpalatal arch, as well as displacement in models with and without transpalatal arch.
Results: Results suggested that the presence of a transpalatal arch has no effect on molar tipping, decreases molar rotations, and reduces periodontal von mises stress magnitudes by less than 1%.
Conclusions: The presence of the transpalatal arch induces only minor changes in the dental and periodontal stress distribution. Alternative methods can be used where absolute anchorage is required however transpalatal arch should not be considered an unnecessary tool in the treatment of orthodontic patients because of its various functions.

Keywords: Finite element model; orthodontic forces; stress analysis; transpalatal arch.

1. INTRODUCTION

The transpalatal arch (TPA) is used widely to change or stabilize the position of the maxillary molars in 3 dimensions, including producing molar rotation and uprighting, stabilizing transverse dimensions posteriorly during treatment, and maintaining leeway spaces during the transition of the dentition. It also is used for additional anchorage during retraction of the anterior segments during extraction treatment [1]. The transpalatal arch has become a routine part of our treatment protocol in both the permanent and late mixed dentitions, with a frequency of use well above 90% [2].

Orthodontic tooth movement can be considered as one of the basic pillars of treatment [3]. Tooth movement occurs as a result of the cellular response within the supporting alveolar structures of the tooth when forces applied to the crowns of the tooth. The tissue response is apparently related to stresses transmitted into these supporting structures by the roots of the teeth. The type of tissue response expected is directly related to the direction, duration, continuity and distance through which forces are applied [3].

It is generally accepted that anchorage is related to periodontal stresses and strains. For a transpalatal arch to modify anchorage, it also must modify the stresses and strains associated with its molars and surrounding tissues. Such modifications could result in the redistribution of stress values to a level below the physiologic threshold at which movement is thought to occur. It is virtually impossible, unfortunately, to measure accurately human periodontal stress distributions *in vivo*. An alternative approach however does exist [4].

Some clinicians theorize that splinting the two maxillary first molars together provides a rigid anchor that can be useful in preventing mesial movement of these teeth. Although this concept seems logical and appears to be commonly accepted, this supposition is based almost entirely on clinical experience rather than on hard science [1]. Hence, a need was felt to use finite element analysis in developing models and subjecting them to orthodontic forces and determine resultant stress patterns and displacements with and without the presence of a transpalatal arch. The objectives of this investigation were to analyze the effects of the transpalatal arch on periodontal stresses and compare the resultant displacements between models with and without transpalatal arch.

2. MATERIALS AND METHODS

This study was done using a workstation computer and an ANSYS Software (version 10.0). The study consisted of developing a finite element model of maxillary molars with and without transpalatal arch with following steps:

1. Construction of a geometric model
2. Conversion of the geometric model to a finite element model
3. Material property data representation
4. Defining the boundary condition
5. Loading configuration
6. Solving the system of linear algebraic equation.
7. Interpretation of the results

2.1 Construction of a Geometric Model

In this study the analytical model of maxillary first molar was developed according to dimensions and morphology found in a standard text book of dental anatomy, physiology and occlusion by Wheeler's [5]. The various aspect of maxillary first molar are constructed using data derived from Wheeler's text book and these aspects are then built, extruded and Boolean operations are carried out to form 3 dimensional geometric model. Individual models of enamel, dentin, periodontal ligament and bone structure are built up.

The coordinates defining the shape of the periodontal ligament was simulated as a 0.20 mm thick ring around the model of the tooth, bone, and transpalatal arch was simulated as 0.036 inch in diameter, 36mm in width with a 5 mm omega loop were calculated and inputted in the model also. Two geometric element models were developed, model without and with the presence of transpalatal arch. The software used for the geometric modelling was ANSYS 10 (Figs. 1 and 2).

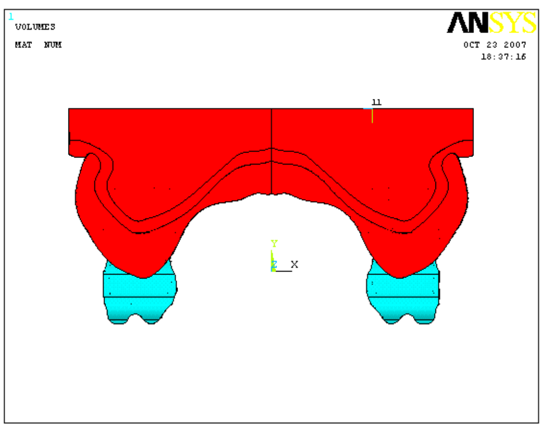

Fig. 1. The symmetric geometric model comprises of tooth, periodontal ligament and alveolar bone

2.2 Conversion of Geometric Model to Finite Element Model

Individual models of enamel, dentin, periodontal ligament and bone structure were converted to finite element models using hypermesh 7.0 (Figs. 3 and 4). The finite element model generation was achieved with the help of ANSYS 10 software. So, finite element model was constructed, which approximately consisted of 1, 69,036 elements and 29,518 nodes.

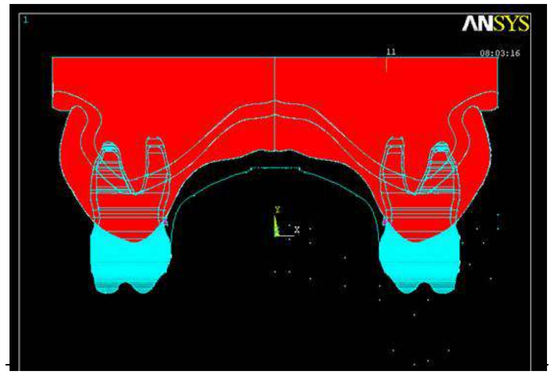

Fig. 2. The symmetric geometric model comprises of tooth, periodontal ligament, alveolar bone and transpalatal arch

2.3 Material Property Data Representation

The different structures in the finite element models are enamel, dentin, periodontal ligament, alveolar bone and steel (transpalatal arch). Each structure was then assigned a specific material property [4,6]. These material properties were the average values reported in the literature. Each material was defined to be homogenous and isotropic (Table 1).

Table 1. Material parameters used in the finite element model

Material	Young's modulus (Gpa)	Poisson's ratio
Enamel	65.00	0.32
Dentin	15.00	0.28
Periodontal ligament	0.05	0.30
Alveolar bone	10	0.33
Steel	200	0.30

2.4 Defining the Boundary Condition

The boundary condition, in the finite element models was defined at all the peripheral nodes of the bone with 0 degree of movement in all directions (the nodes of the base of the models were fixed to prevent free body displacement of the model). The final model was confirmatory from an engineering point of view for this study.

2.5 Application of Forces

Once the models with and without the presence of a transpalatal arch were constructed a force of 2 Newton (204 gm) was applied in a mesial direction of the molar.

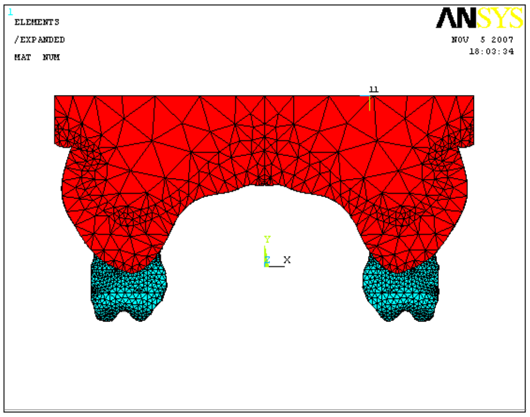

Fig. 3. The geometric model was converted into the 3-dimensional finite element model without transpalatal arch

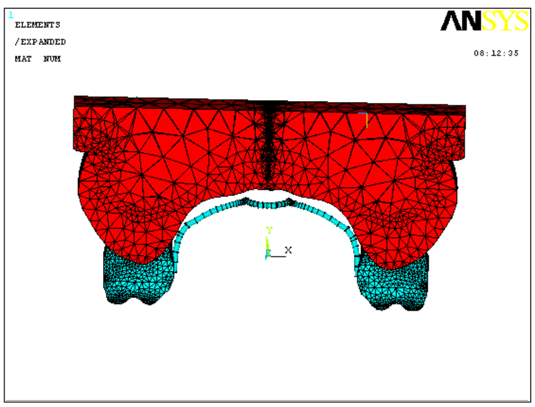

Fig. 4. The geometric model was converted into the 3-dimensional finite element model with transpalatal arch

2.6 Solving the System of Linear Algebraic Equations

The sequential application of the above steps leads to a system of algebraic equations where the nodal displacements are unknown. These equations are solved by frontal solver technique present in the ANSYS software.

3. RESULTS

The two finite element models with and without the transpalatal arch were subjected to retraction forces the following resultant stresses were obtained. The resultant stresses can be subdivided into two types: normal, those acting in a direction perpendicular to their associated surfaces, and shear, those acting in a direction parallel to their associated surfaces. The principal stresses are composed of three types: minor principal, intermediate principal, and major principal, depending on their magnitudes. The intermediate principal stresses were found to qualitatively and quantitatively best depict areas of tension and compression.

Qualitatively, as shown in Figs. 5-8, the fringe plots revealed patterns consisting of areas of positive and negative stresses, corresponding to areas of tension and compression. Stress magnitudes were denoted by a series of colors, as shown in the spectrum display to the bottom of the plot. In general, dark blue, light blue, green, represent progressively greater compressive stress values whereas yellow, orange, and red represent progressively greater magnitudes of tension.

Resultant stress patterns at the periodontal ligament and alveolar bone (Table 2). Results analyzed for von mises stress for periodontal ligament in model without transpalatal arch showed 0.02469 N/mm^2 and von mises stress for periodontal ligament in model with transpalatal arch showed 0.00999N/mm^2. Results analyzed for von mises stress for alveolar bone in model without transpalatal arch showed 1.576N/mm^2 and von mises stress for alveolar bone in model with transpalatal arch showed 0.81316N/mm^2.

Resultant von mises stress distribution in the model with and without transpalatal arch (Table 2, Fig. 5). The model without transpalatal arch represents maximum von mises stress of about 14.417 N/mm^2 and the model with transpalatal arch represents maximum von mises stress of about 14.413 N/mm^2.

Resultant displacements in the model with and without transpalatal arch in x-direction, transverse plane (Table 3, Fig. 6). The resultant displacement in the model with transpalatal arch showed 0.43 microns and without transpalatal arch was 1.2 microns. Resultant displacements in the model with and without transpalatal arch in y-direction, vertical plane (Table 3, Fig. 7). The resultant displacement in the model with transpalatal arch showed 0.05 microns and without transpalatal arch was 0.27 microns.

Resultant displacements in the model with and without transpalatal arch in z-direction, antero-posterior plane (Table 3 and Fig. 8). The resultant displacement in the model with transpalatal arch showed 0.04 microns and without transpalatal arch was 0.16 micron.

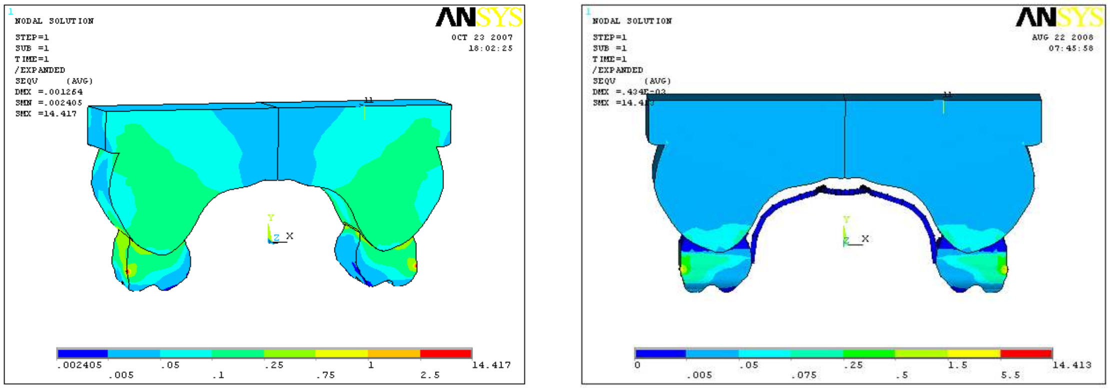

Fig. 5. Von mises stress distribution in model without and with transpalatal arch

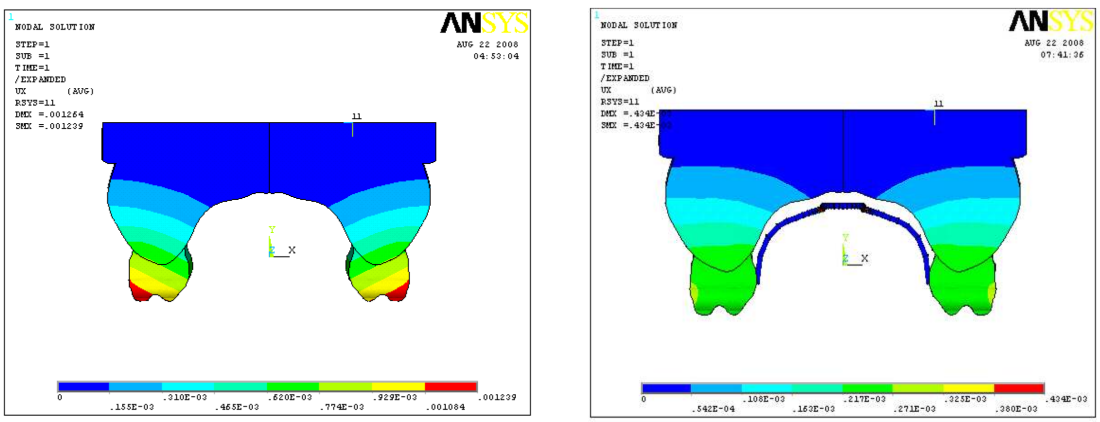

Fig. 6. Displacement in x-direction in the model without and with transpalatal arch

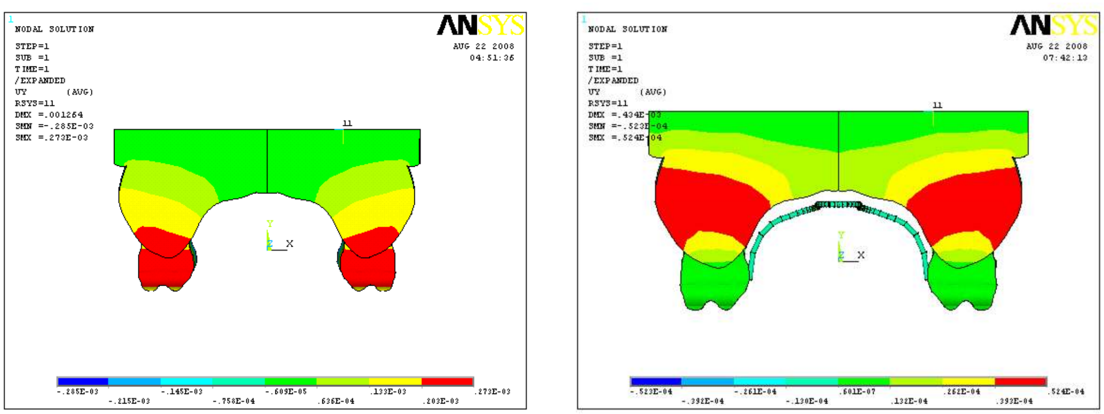

Fig. 7. Displacement in y-direction in the model without and with transpalatal arch

Table 2. Resultant Von Mises stresses at the alveolar bone, periodontal ligament and in models without and with transpalatal arch

Serial no.	Results analyzed for Von Mises stress	Periodontal ligament	Alveolar bone	Stress value
1	Model without TPA	0.024695	1.576	14.417 N/mm^2
2	Model with TPA	0.00999	0.813163	14.413 N/mm^2

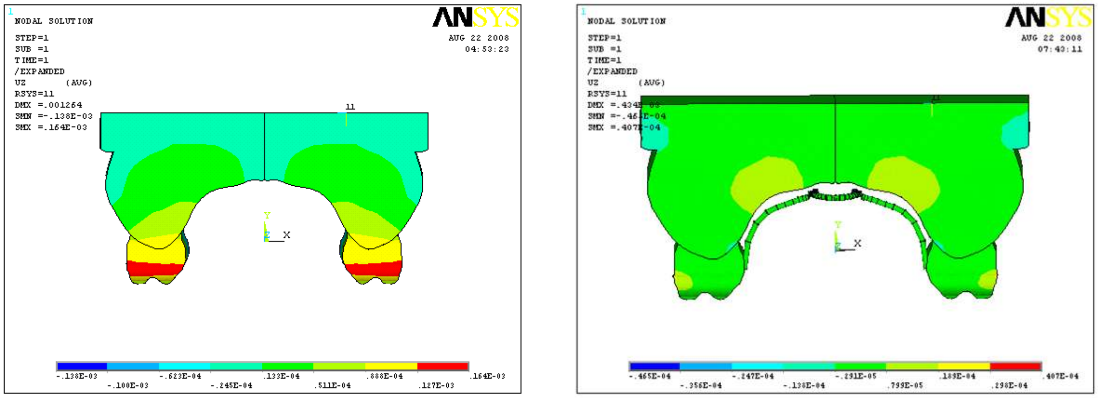

Fig. 8. Displacement in z-direction in the model without and with transpalatal arch

Table 3. Resultant displacements in a model without & with transpalatal arch in x, y, z-direction

Model	**Displacement value x-direction (Transverse direction)**	**Displacement value y-direction (Vertical direction)**	**Displacement value z-direction (Antero-posterior direction)**
Model without TPA	0.001264 mm (1.2 Microns)	0.00027 mm (0.27 Microns)	0.00016 mm (0.16 Microns)
Model with TPA	0.000434 mm (0.4 Microns)	0.00005 mm (0.05 Microns)	0.00004 mm (0.04 Microns)

4. DISCUSSION

There is a great deal of subjective justification for the use of many orthodontic appliances, partly because of the lack of understanding into the fundamental cause of orthodontic tooth movement (i.e. periodontal stress & strain). The current investigation has used the finite element analysis to investigate the effectiveness of the transpalatal arch in reinforcing anchorage by qualifying & quantifying stress, the physical properties on which anchorage thought to be dependent [4].

Comparative stress patterns were used to contrast any stress differences between models with and without the presence of a transpalatal arch. A comparison of these patterns revealed minute differences in any of the principal (e.g., minor, intermediate, or major) stress distributions. Likewise, an inspection of periodontal ligament and bone stress patterns also showed minute differences between the two models. In this analysis, the presence of a transpalatal arch changed stress distributions by less than 1%.

Displacement of the tooth with transpalatal arch is 0.43 microns and without transpalatal arch is 1.2 microns which is approximately 1:3 ratio, suggesting anchorage in the transverse plane may be enhanced with the presence of transpalatal arch which will reduce the buccal tipping and prevent molar rotation.

In an established study [4] it states that a rigid, thicker transpalatal arch may have effect on the stress distributions. However, the transpalatal arch modeled in that studyhad effectno effect on controlling molar displacements (ie. rotation or tipping). The results of the same showed that transpalatal arch does have an inhibitory effect on molar rotation.

In an interesting investigation of similar nature demonstrated that during the initial movement produced by elastic deformation of the periodontal ligament, stress magnitude in the periodontal ligament was not changed by the transpalatal arch. In the orthodontic movement produced by bone remodeling, the mesial force tipped the anchor teeth irrespective of the transpalatal arch. The tipping angles of anchor teeth with and without the transpalatal arch were almost the same. The anchor teeth without the transpalatal arch were rotated in the occlusal plane and moved transversely [6].

Displacement of the tooth with transpalatal arch is 0.05 microns and without transpalatal arch is 0.27 microns which is approximately 1:5 ratio, which suggests that in the vertical plane anchorage may be enhanced with the presence of transpalatal arch which will reduce the extrusion of the molars.

Displacement of the tooth in the antero-posterior plane with transpalatal arch is 0.04 microns and without transpalatal arch is 0.16 microns which is approximately 1:4 ratio, which suggests that anchorage may be enhanced with the presence of transpalpatal arch which will reduce the anchor loss.

As with any theoretical model of a biological system, there are some limitations with finite element method. The physical characteristics of tissue vary from site to site, further the density, trabeculation, thickness of alveolar bone and periodontal ligament is not uniform throughout the root surface and also differs with age and between individuals [7,8]. The type of study done was static analysis and is not time dependent. As a result this study is applicable in initial stages of tooth movement.

5. CONCLUSIONS

1. In presence of transpalatal arch only minute differences of less than 1% in stress values were observed suggesting only minor changes in periodontal stress distribution.
2. Tooth displacement levels in the model with transpalatal arch when compared to a model without transpalatal arch confirmed the ability of the transpalatal arch to control molar rotation; however minimal buccal tipping was noted which was not significant.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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