# Efficacy of transpalatal arch as an anchorage reinforcing unit during orthodontic space closure: A three-dimensional finite element study

**Vishal Shrishail Kudagi, N. Vijay[1], H. C. Kiran Kumar[1], K. Sadashiva Shetty[1]**

*Department of Orthodontics, JSS Dental College and Hospital, Mysore, [1]Department of Orthodontics, Bapuji Dental College and Hospital, Davangere, Karnataka, India*

## Abstract

**Background and Objectives:** Connecting the contralateral upper molars by means of a transpalatal arch (TPA) is thought to decrease the tendency of the molars to move mesially in response to orthodontic force (i.e., provide orthodontic anchorage). This study was hence conducted to investigate the effects of the TPA on the displacement of the molars and stresses generated in the periodontium during orthodontic tooth movement using the finite element method (FEM). **Materials and Methods:** A three-dimensional (3D) model was generated using medical modeling software (Mimics) using the computed tomography slice images of the skull which were obtained at a slice thickness of 1 mm. From this, the finite element model was built using HyperMesh and analysis was performed using PATRAN software (MSC Software Corporation, 4675 MacArthur Court, Newport Beach, California 92660). The 3D finite element models were fabricated in two versions such as maxillary first molars including their associated periodontal ligament and alveolar bone one with TPA and another without TPA. Both were subjected to orthodontic forces, and the resultant stress patterns and displacements between the models with and without TPA were determined. **Results:** The stress and displacement plots in this study failed to show any significant differences in stress and displacement within the periodontium of molars, between the two models – one with TPA and the other without, in response to the orthodontic force. **Interpretation and Conclusion:** The results of the current finite element analysis, therefore, suggest that the presence of a TPA brings about no change in the initial dental and periodontal stress distribution and displacement.

**Key words:** Anchorage, finite element method, space closure, transpalatal arch

## INTRODUCTION

Ever since its introduction by Dr. Robert A. Goshgarian in the year 1972, the transpalatal arch (TPA) and its modified versions have been applied widely in clinical orthodontics. One such application is to increase the resistance of molars to unwanted movement or in other words to provide orthodontic anchorage.[1] It is hypothesized that the TPA by splinting the two molars prevents their movement and thus reinforces anchorage.[2] Since anchorage is related to periodontal stresses and strains, the TPA must also be modifying these parameters around the molars and surrounding tissues. It is virtually impossible to quantify or detect these stress distribution patterns within the human

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**Address for Correspondence:**
Dr. Vishal Shrishail Kudagi, Department of Orthodontics, JSS Dental College and Hospital, Mysore - 570 015, Karnataka, India.
E-mail: drvishalsk@yahoo.com



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periodontium accurately by *in vivo* methods.[3] However, mathematical methods which replicate the biological system accurately in both anatomy and physical characteristics such as the finite element method (FEM) are available in engineering, which can be applied to orthodontics as well.[4-6]

Finite element analysis (FEA) is the mathematical method in which the shape of complex geometric objects and their physical properties are modeled using a computer software. Physical interactions of various components of the model are then calculated in terms of stresses, strains, and deformation.[5,6] Over the past few years, FEA has been used to simulate various orthodontic scenarios and to quantify stress, strain, and displacement patterns of pertinent tissues (e.g., dental roots, the periodontal ligament, and alveolar bone).

### Objectives

To construct two appropriate, three-dimensional (3D) finite element models of the maxillary first molars with their associated periodontal ligament and alveolar bone-one with TPA and another without TPA and to determine the resultant stress patterns in periodontium and displacement of molars with orthodontic force application in both models.

## MATERIALS AND METHODS

Steps involved in this study using FEA were as follows:

1. Construction of geometric model
2. Assigning material properties
3. Defining the boundary conditions
4. Application of forces and
5. Analysis and interpretation of results.

### Construction of geometric model

Computed tomography (CT) slice images of the skull of a cadaver were obtained at a slice thickness of 1 mm [Figures 1-3]. The FEA model was then created in two broad steps of generation of 3D model using the CT slices in a medical modeling software Mimics [Figure 4], and conversion of 3D model into the finite element model using CAD through the preprocessor software Altair HyperMesh (Altair Engineering,Troy, Michigan) [Figures 5-7]. Nastran was the solver used to perform the analysis in the present study.

Two types of models were generated for comparative investigation:

- Model 1: Consisting of maxillary first molars, their associated periodontal ligament, and alveolar bone segments with TPA [Figure 8]
- Model 2: Consisting of maxillary first molars, their associated periodontal ligament, and alveolar bone segments without the TPA [Figure 9].

Solid tetra elements were used to model the teeth, periodontium, bone, and TPA [Figure 7], which had three degrees of freedom (translation) at each node. TPA with Blue Elgiloy (0.9 mm diameter) wire was also modeled with tetra elements. The entire model comprised a total of 172,236 elements and 31,868 nodes.

### Assigning material properties

The assignment of proper material properties to a FEM is necessary to simulate the behavior of the object being studied. The material properties assigned were the Young's modulus (or modulus of elasticity) and the Poisson's ratio – both derived from literature review [Table 1].[6-19]

### Defining the boundary conditions

The boundary conditions in FE models basically represent the load imposed on the structures under study and the area of the model which is restrained. In this study, the model was restrained from free body displacement by fixing the nodes at the superior border of the model [Figure 10].

### Application of forces

Force of the magnitude 1 N (102 g) was applied on the buccal attachment of each molar band simultaneously, analogous to that seen clinically, when Class I elastics are used to create a distal force on anterior teeth during space closure [Figure 11].

### Analysis and interpretation of results

A linear static evaluation was carried out. The model was divided into two cases. Case 1 comprised both models for which resultant stresses were calculated at nodes in response to force of 1 N magnitude and in case 2 the resultant displacements were calculated at the nodes for both models. The stress and displacements were determined at mesial, distal, and occlusogingival levels. They are presented in colorful contour bands, where different colors represent different stress levels in the deformed state. Positive and negative values in the column of stress spectrum indicate tension and compression, respectively. Results were expressed in stresses and displacements as follows:

- Case 1: Stress plots of model with and without TPA and their periodontium when subjected to a force of 1 N [Table 2]
- Case 2: Deformation plots of model with and without TPA when subjected to a force of 1 N [Table 2].

## RESULTS

To simplify the results, calculations were performed from maximum amount of stresses and displacements in each

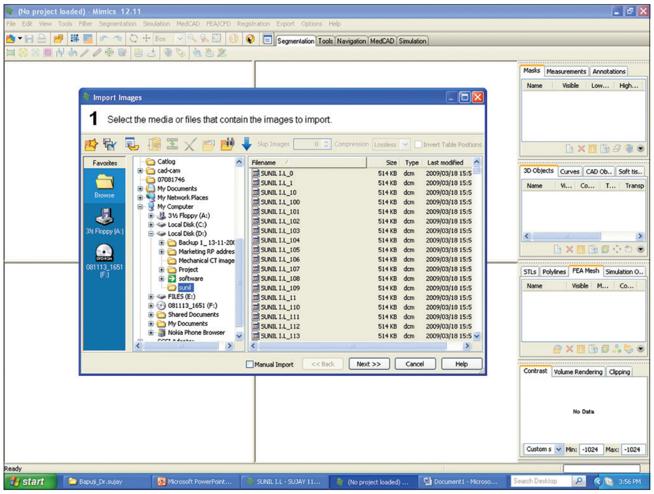

**Figure 1:** Importing of two-dimensional format computed tomography data to Mimics medical modeling software

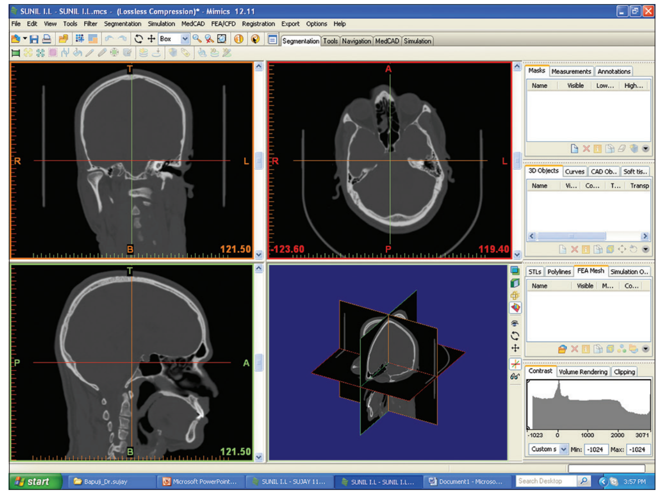

**Figure 2:** Selection of slices of interest to generate three-dimensional model

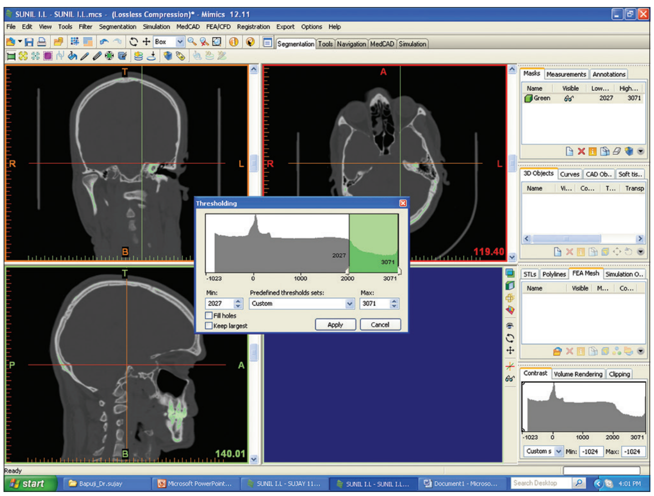

**Figure 3:** Thresholding to separate teeth from full-face three-dimensional model

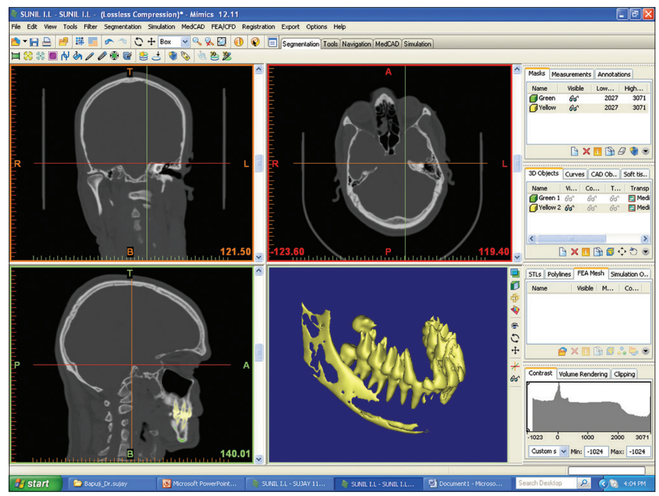

**Figure 4:** Separation of teeth from rest of the three-dimensional model

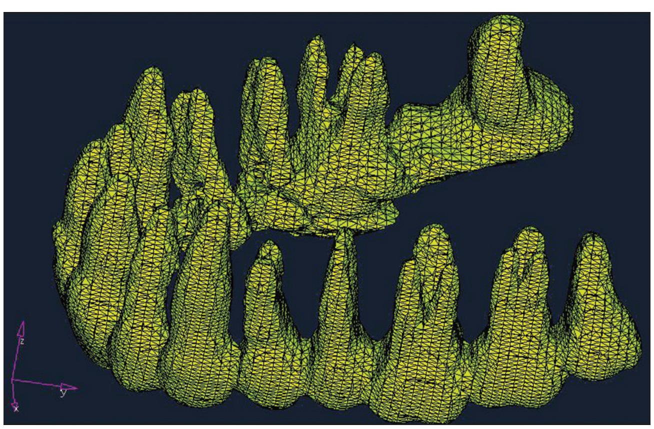

**Figure 5:** Remeshing and triangular reduction of the model

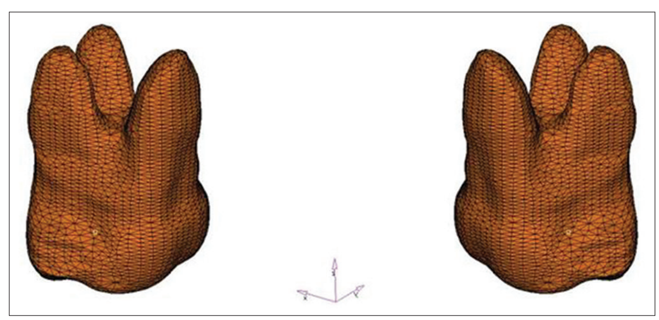

**Figure 6:** Final three-dimensional molar models after cropping objects other than area of interest

model. Qualitatively in Figures 12-17, the plots reveal patterns consisting of areas of positive and negative stresses located on the tooth and periodontal ligament, corresponding to areas of tension and compression, respectively. Stress magnitudes were denoted by a series of colors as shown in the spectrum display to the left of the stress plot. In general, yellow–red represent progressively greater tensile stress values, whereas the green–blue represent progressively greater magnitudes of compression.

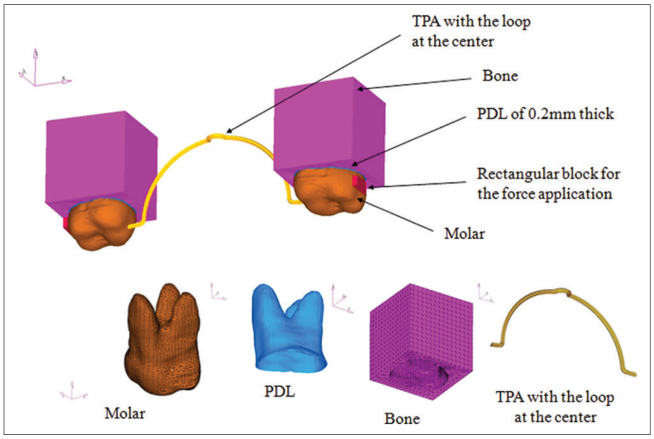


**Figure 7:** Final three-dimensional model with molars with transpalatal arch, including periodontium and alveolar bone around it

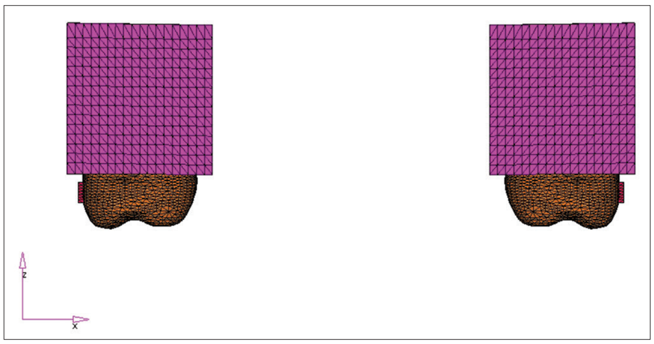

**Figure 9:** Geometric model of maxillary first molars and its associated periodontium and alveolar bone segments without the transpalatal arch

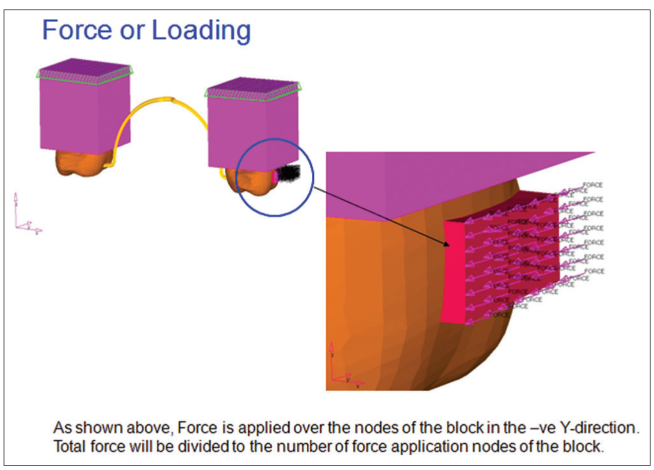


**Figure 11:** Simulation of orthodontic force application on the model

The following results were observed:

- Case 1 (Stress at Nodes): Figures 12 and 13 show that maximum stresses of 0.2578 MPa were associated with both models where forces of 1N were applied in the area of molar tube. Similarly, in Figures 14 and 15 maximum stresses of 1.083 E-02 MPa in periodontium of both models, with and without TPA, were seen [Tables 3 and 4].

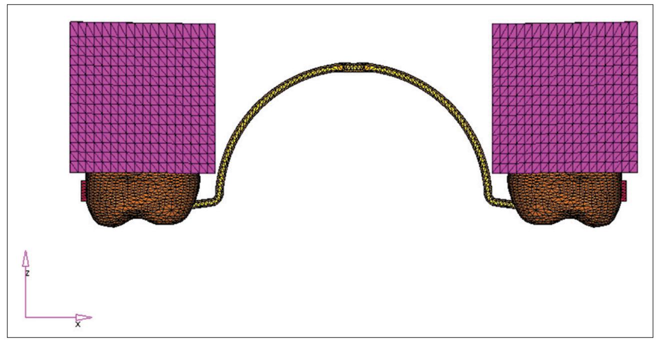

**Figure 8:** Geometric model of maxillary first molars and its associated periodontium and alveolar bone segments, with transpalatal arch

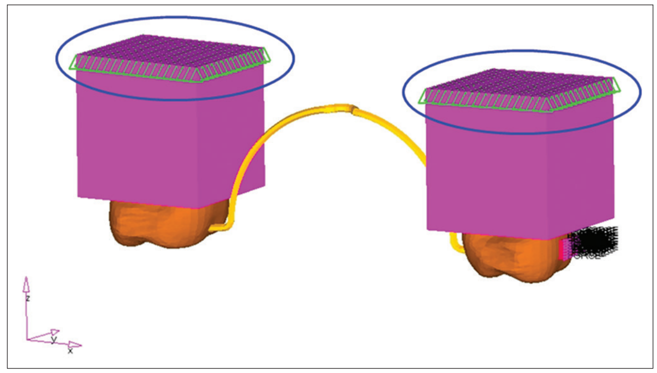

**Figure 10:** Setting the boundary conditions for the model

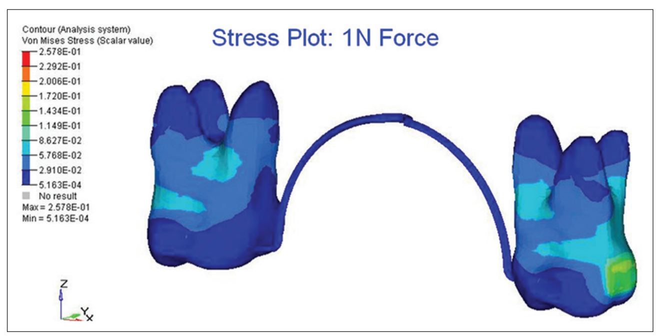


**Figure 12:** Stress plot for the molar in model with transpalatal arch

- Case 2 (Displacement at Nodes): Figures 16 and 17 show maximum displacement of − 0.000149 mm associated with both models in the area of molar tube, where the forces of 1N were applied [Table 5].

## DISCUSSION

The current study has used the FEM of analysis to investigate the effectiveness of the use of the Blue Elgiloy TPA by quantifying the stresses generated in the periodontium-the physical property on which anchorage is thought to be dependent. From the analysis (of case 1–2) of the stress and displacement values of the two models, the presence of a TPA did not bring about any significant

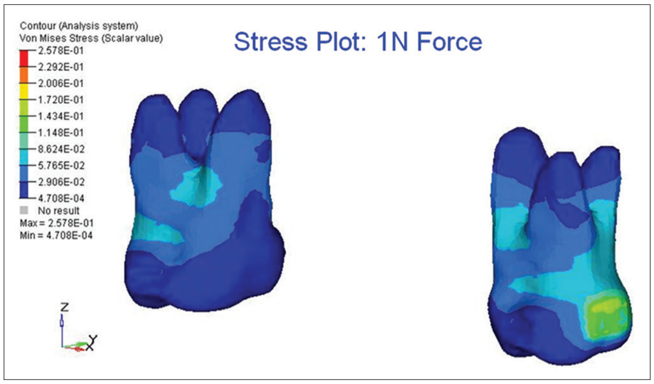


**Figure 13:** Stress plot for the molar in model without transpalatal arch

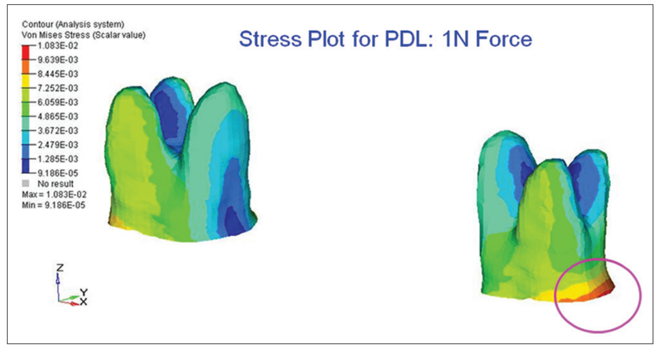


**Figure 14:** Stress plot for the periodontium in model with transpalatal arch

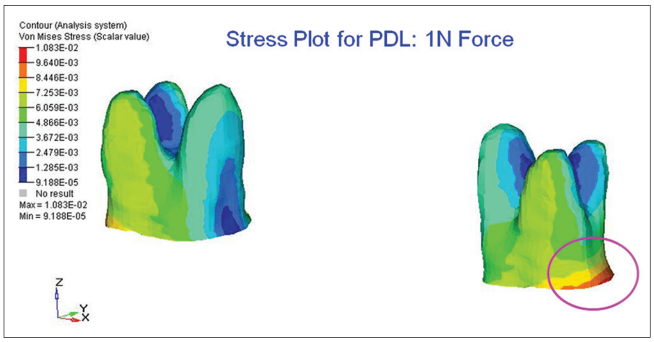


**Figure 15:** Stress plot for the periodontium in model without transpalatal arch

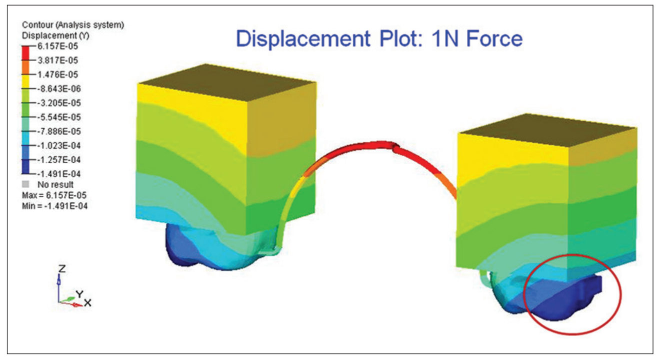


**Figure 16:** Displacement plot for model with transpalatal arch

difference in stress distribution or displacement of the molars in response to the forces applied. In other words, in all the cases the maximum difference between any of the principal stresses between cases with and without a TPA was zero. If one accepts the belief that orthodontic anchorage is based on periodontal stresses, then the current results suggest that the TPA virtually has no effect on anchorage in the initial stages of the tooth movement.

The current analysis was not time-dependent. The results, therefore, may only be applicable to the initial stages of the tooth movement. With respect to the described limitations, the general validity, in terms of physical properties, model geometry, and element shape, of the current model was sufficiently enough to provide insight into the interactions of orthodontic forces, tissues, and appliances related to this investigation.[10,17] The results of the present study were in accordance with the studies done by Kojima and Fukui who also found that in orthodontic movement, the TPA had almost no effect in preserving anchorage for mesial movement.[6] However, the TPA prevented rotational, transverse, and vertical movements of the anchor teeth.[7,9,11,15,18] Our results were also similar to those in the study carried out by Zablocki *et al.* who concluded that the TPA does not provide a significant effect on either the anterioposterior or the vertical position of the maxillary first molar during extraction treatment.[8] Kojima *et al.* also found that the presence of a TPA had no effect on molar tipping, but it did decrease molar rotations and affected periodontal stress magnitude by <1%.[6]

**Table 1: Material properties used in the current study based on review of literature**

| Material | Young's modulus (GPa) | Poisson's ratio |
|---|---|---|
| Enamel | 65 | 0.32 |
| Dentin | 15 | 0.28 |
| Periodontal ligament | 0.1 | 0.45 |
| Alveolar bone | 10 | 0.33 |
| Stainless steel | 170 | 0.3 |
| Elgiloy blue | 175 | 0.3 |

## CONCLUSION

This investigation was carried out to examine the effects of the TPA on stress patterns and displacements and the findings are as follows:

1. The stress plots failed to show any significant difference in the effects due to the presence of a TPA on the area of highest stress in both models
2. The displacement plots also failed to show any significant differences in the area of maximum displacement in both models in response to the applied orthodontic force.

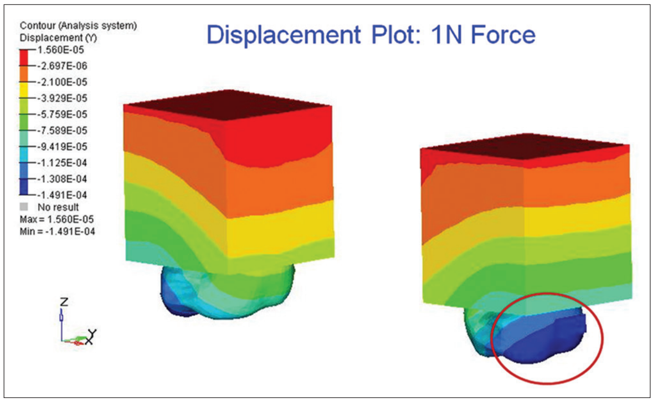


**Figure 17:** Displacement plot for model without transpalatal arch

**Table 2: Cases analysis summary**

| Number | Transpalatal arch | Stress or displacement calculation position in response to 1 N of force |
|---|---|---|
| 1 | Model with TPA | Stress at node (molar) |
| 2 | Model without TPA | Stress at node (molar) |
| 3 | Model with TPA | Stress at node (PDL) |
| 4 | Model without TPA | Stress at node (PDL) |
| 5 | Model with TPA | Displacement at node |
| 6 | Model without TPA | Displacement at node |

TPA – Transpalatal arch; PDL – Periodontal ligament

**Table 3: Maximum stresses generated at molar tube on force application in both models**

| Force value (in N) | Model with TPA (stress in MPa on the molar) | Model without TPA (stress in MPa on the molar) | Difference |
|---|---|---|---|
| 1 | 0.2578 | 0.2578 | Nil |

TPA – Transpalatal arch

**Table 4: Maximum stresses generated in periodontium on force application in both models**

| Force value (in N) | Model with TPA (stress in MPa in PDL) | Model without TPA (stress in MPa in PDL) | Difference |
|---|---|---|---|
| 1 | 0.01083 | 0.01083 | Nil |

TPA – Transpalatal arch; PDL – Periodontal ligament

**Table 5: Maximum displacement associated with both models in the area of molar tube**

| Force value (in N) | Model with TPA (displacement in mm) | Model without TPA (displacement in mm) | Difference |
|---|---|---|---|
| 1 | −0.000149 | −0.000149 | Nil |

TPA – Transpalatal arch

The results of the current FEA, therefore, suggest that the presence of a TPA brings about no changes in the dental and periodontal stress distributions.

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## Conflicts of interest

There are no conflicts of interest.

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