# A FINITE ELEMENT ANALYSIS OF MOLAR INTRUSION WITH AND WITHOUT MICROOSTEOPERFORATION AND ITS INFLUENCE IN ROOT RESORPTION

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**ABSTRACT:**
One of the most common iatrogenic effects of orthodontic treatment is orthodontically induced inflammatory root resorption (OIIRR). The etiology of root resorption is multifactorial and yet to be understood completely. Among the known factors, the most common factors are improper orthodontic force and there exists a positive correlation between increased orthodontic force levels and root resorption.
**Aim Of The Study:** The aim of this a finite element study is to analyse the impact of microosteoperforation on miniscrew assisted maxillary posterior intrusion on the stress distribution at PDL, alveolar bone & root surface and its contribution in reducing root resorption.
**Materials & Method:** 3D Model of entire maxilla was constructed from CBCT images. MBT brackets of 0.022” slot dimensions, miniscrews(1.3mm x 9mm) and 019” x 0.025” stainless steel wires, lingual buttons, Niti coil spring(9mm) were reverse engineered. The physical properties of teeth, surrounding structure and materials being used were incorporated to the model. 200gms of force was loaded from miniscrews using Niti coil springs and the stress generated was evaluated on the tooth and surrounding structures by finite element analysis.
**Results**: The von mises stress generated at the experimental side (MOP side) was lower when compared with the control side (Non-MOP side) at the tooth(11.46 MPa vs 18.90 Mpa) and the alveolar bone(0.21MPa Vs 0.24 MPa).Our study also shows that the deformation in the experimental side($2.2 \times 10^{-2}$) was lesser when compared to the deformation attained on the control side($4.0 \times 10^{-2}$)
**Conclusion**: Microosteoperforation had been found to be effective method for rapid orthodontic tooth movement The above study concludes that the stress levels and deformation experienced by tooth and surrounding tissues can be lowered by microosteoperforation procedure and thereby aid in preventing root resorption.
**Keywords** Root resorption, Microosteoperforation, Molar intrusion, Miniscrews, Finite element Analysis

## INTRODUCTION

One of the most common iatrogenic effects of orthodontic treatment is orthodontically induced inflammatory root resorption (OIIRR) (Currell 2019) The etiology of root resorption is multifactorial and yet to be understood completely. Among the known factors, the most common factors are improper orthodontic force and its loading, treatment duration and genetic factors (Roscoe 2015).
The optimum orthodontic force was given by Schwarz in 1932 and any force that exceeds the capillary blood pressure will produce hyanilised zone due to ischemia and necrosis of the periodontal ligament and adjacent alveolar bone and root cementum (Schwarz 1932). There exists a positive correlation between increased orthodontic force levels and root resorption (Chan 2005, Chan 2006).

Miniscrew assisted orthodontic tooth movement had found its application in orthognathic like orthodontics. One among them is intrusion of maxillary posterior segments in case of vertical maxillary excess and there is a need to accelerate orthodontic tooth movement in those cases. Various methods were employed to accelerate orthodontic treatment in such cases of which surgical methods, including corticotomies, piezocisions, and micro-osteoperforations (MOPs) had produced definitive results compared to other methods of acceleration (Venkatachalapathy 2022). The surgical method for accelerating orthodontic tooth movement is based on the regional acceleratory phenomenon (RAP) described by Harold Frost in 1983 as a tissue reaction to any noxious stimulus that increases healing. MOP is a minimally invasive technique that does not require incisions and flaps, unlike conventional corticotomies or piezocision, and it can be performed by the orthodontist, thus considerably reducing treatment costs and providing a more comfortable and less painful postoperative period.
The root resorption is more of a biological phenomenon but it is also a sequelae to the mechanical obstruction of periodontal ligament and stresses generated at alveolar bone, the periodontal ligament and root surface interface(Harris 2006). The biological aspect of microosteoperforation had been studied quite extensively but the mechanical behaviour of MOPs on tooth movement and whether they contribute to reduction in stress levels at the periodontal ligament, alveolar bone and root surface had not been studied extensively.
The aim of this study is to analyse through a finite element study, the impact of microosteoperforation on miniscrew assisted maxillary posterior intrusion on the stress distribution at PDL, alveolar bone & root surface and its contribution in reducing root resorption.

## MATERIALS AND METHODS

### Geometry Preparation

3D model of Maxilla, and teeth surfaces have been extracted from 3d scanned CBCT files and processed via Mimics software as *.STL files. The *.stl file were imported into hypermesh 14.0 software for Geometry cleanup and assembly creation where the small surface and redundant features in the scanned model were removed and all surface data were converted in to solid model using material properties as given in Wheeler's Anatomy(Nelson 2014). This step is very important to have a clean geometry to develop an error free FE model.
MBT brackets (3M Unitek) of 0.022" slot dimensions, miniscrews of dimensions 1.3mm diameter x 9mm in length and 019" x 0.025" stainless steel wires, lingual buttons were reverse engineered and modelled using SolidWorks 2020 software and the part geometries were converted to *.stl file. All these files were imported in to hypermesh to create the complete assembly. Once the assembly is completed with hypermesh, then it is exported as *.X_T (Parasolid) format to process only solid geometry data.
FE Model
Once the geometry cleanup and assembly were completed using hypermesh, *.xt (Parasolid) file was imported to Ansys design modeller for creating holes and final checks were done. Holes on the alveolar bones were created to replicate microosteoperforation in maxilla using design modeler by creating different planes at required locations. In this study 1.5mm diameter and 6mm depth holes have been made on maxilla at the level of 3mm, 6mm and 9mm from the crest of alveolar bone in the interdental space(figure 1)

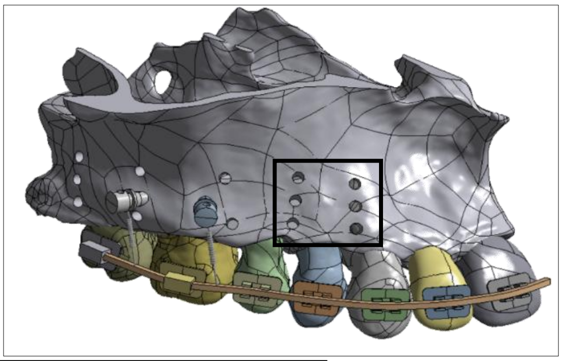


Figure 1: FE Model

Once the holes are created then the geometry fed in to static structural mechanical editor window for further processing. The tooth segments , alveolar segments and periodontal tissue are constructed. A 1 mm mesh size has been used as global mesh size to capture all features of the geometry and at critical zones 0.5mm mesh size has been used. The Niti coil spring was connected from the miniscrew to the arch wire on buccal side and from miniscrew to palatal button on the palatal side. All springs have been assigned with a stiffness value of 0.5 N/mm in longitudinal directions to replicate the actual conditions. In addition to spring, a beam connection was also established with a diameter of 0.3mm to apply pretension values. An intrusive force of 100 gms on buccal and 100 gms on palatal side was applied. Solid 187 tetrahedral type element has been used to capture all parts except wire, Solid 186 Hexahedral type element has been used to capture the wire. COMBIN 14 element has been used to capture spring and Beams created for loading purpose. Full assembly has been captured with 148306 total no. of elements and 241422 nodes. (figure 2)

Material Model

Geometries which are considered for the analysis have been assigned with linear isotropic material model as follows

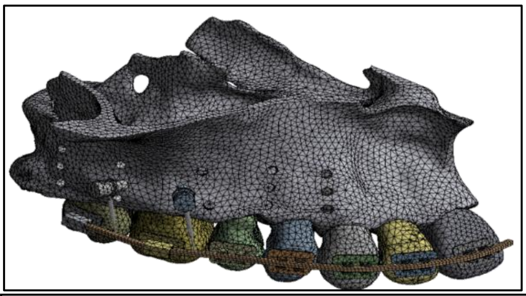


Figure 2 Geometric Material Model

Table 1: Material properties assigned for the generated model

| Sl. No | Part | Young's modulus (E), Mpa | Poisson's ratio (μ) |
|---|---|---|---|
| 1 | Alveolar bone | 16000 | 0.26 |
| 2 | Dentine | 19613 | 0.16 |
| 3 | PDL | 0.6668 | 0.49 |
| 4 | Stainless steel | 200000 | 0.3 |

All brackets, screws and wire have assigned with stainless steel property, Maxilla has been assigned with alveolar bone property. Tooth crown and root portion has been assigned with Dentine property and the periodontal ligament surrounding root portion had been assigned with PDL properties.(Table 1)

Analysis methodology

To perform non-linear static structural analysis, symmetry model has been considered In this analysis geometrical nonlinearity has been considered, since it is assumed to be large strain problem due to highly deforming materials present in the assembly.

Symmetry boundary condition has been applied on the red highlighted faces and it is assigned as X-axis symmetry for this orientation. Fixed support has been assigned at the blue faces . In addition to springs deployed with appropriate stiffness at molars, 1D beam also deployed, to apply pretension / pulling load of 2N on first molars. Pretension load applied on the beam depicts the actual scenario/physics happens between screws and connected tooth. Nonlinear analysis has been solved with minimum increment of 10% i.e., results shall be extracted for every 10% of loading.

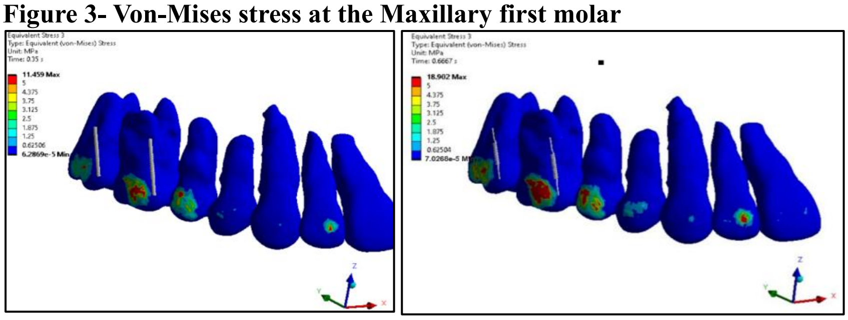
## RESULTS

The results were analysed after post processing. The calculated stresses were represented by colorful bands of different colors for different level of stresses. Red column of spectrum indicates maximum level of stress and blue as minimum with colors orange, yellow and green in between. The results were obtained as distribution of stresses in the teeth, periodontal ligament and surrounding alveolar bone after the application of 200 g of intrusive force by three mini-implants, two of which were placed on mesial and distal aspect of buccal surface of first molar and one in palatal surface between 1st and 2nd molar connecting the first molars.

Von-Mises stress at the maxillary first molar

The von mises stress generated at the tooth structure is less 11.46(maximum) in MOP group compared to that in the control group with a value of 18.90(maximum). Both these were observed at the bracket teeth interface in molar region. The von mises stress generated at the root were observed to be less in MOP group (6.0269e-5min) as against that in control group (7.0268e-5 min).(Figure 3 & Table 2)

**Figure 3- Von-Mises stress at the Maxillary first molar**

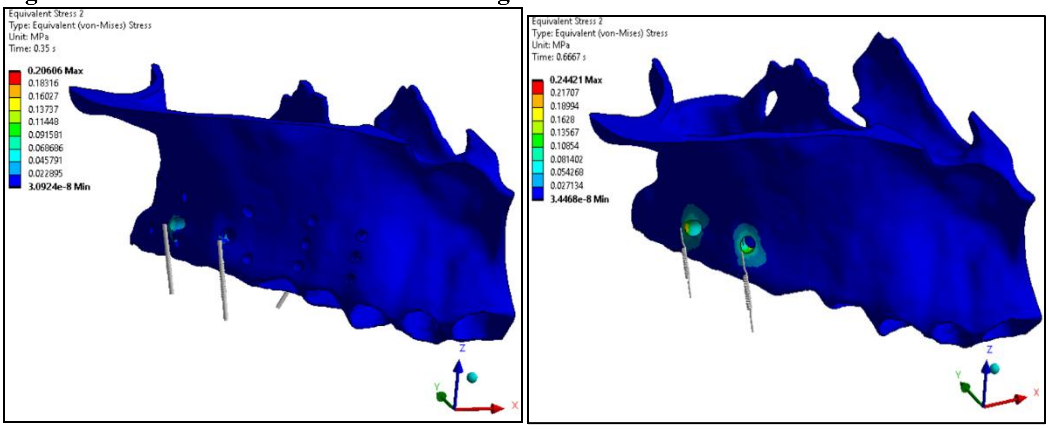


| Table 2. Von mises stress at tooth structure(MPa) | | |
|---|---|---|
| | Microosteoperforation group | Control group |
| Maximum | 11.46 | 18.90 |
| Minimum | 6.0269e-5 | 7.0268e-5 |

Von-Mises stress at the surrounding alveolar bone

The von mises stress generated at the alveolar bone is less 0.20606 (maximum) in MOP group compared to that in the control group with a value of 0.24421(maximum). Both these were observed at the bracket teeth interface in molar region. The von mises stress generated at the root were observed to be less in MOP group (3.092e-8 min) as against that in control group (3.4468e-8 min).(Figure 4 & Table 3)

**Figure 4 Von-Mises stress at the surrounding alveolar bone**

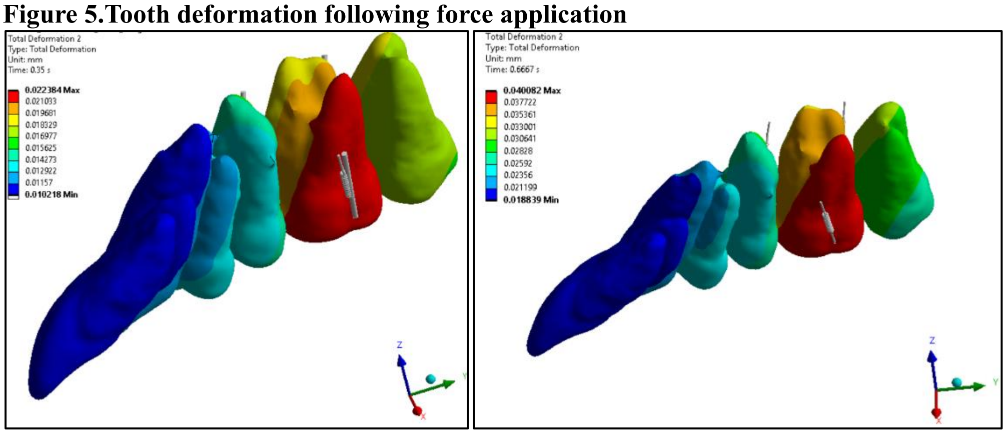



| Table 3. Von mises stress at alveolar boneMPa) | | |
|---|---|---|
| | Microosteoperforation group | Control group |
| Maximum | 0.20606 | 0.24421 |
| Minimum | 3.092e-8 | 3.4468e-8 |

Tooth deformation following force application

The tooth deformation observed is less in MOP group ($2.2 \times 10^{-2}$ maximum to $1.2 \times 10^{-2}$ minimum) compared to that in the control group ($4.0 \times 10^{-2}$ maximum to $1.8 \times 10^{-2}$ minimum) for the same amount of force delivered.(Figure 5 & Table 4)

**Figure 5.Tooth deformation following force application**




| Table 4. Tooth deformation following force application | | |
|---|---|---|
| | Microosteoperforation group | Control group |
| Maximum | $2.2 \times 10^{-2}$ | $4.0 \times 10^{-2}$ |
| Minimum | $1.2 \times 10^{-2}$ | $1.8 \times 10^{-2}$ |

The intrusion of teeth is one of the most difficult tooth movements as it needs minimal amount of force to be delivered and it may induce iatrogenic orthodontic root resorption(Han 2005, Parker 1998). The advent of temporary anchorage device had created biomechanically effective ways of intrusion without affecting the adjacent teeth. True intrusion was made possible in posterior dental arch by which orthognatic surgeries can be avoided. It is proven that the clinical application of TADs provides added advantage in intrusion. However, the biomechanical effects of intrusion effects on roots at fem level still lacks clarity and also clinically intrusive forces have been traditional suspect in severe cases of root resorption.

This FEM study analyses the stress pattern on roots of molars and surrounding alveolar bone during temporary anchorage device assisted posterior intrusion with or without microosteoperforation.

The analytic model used in this study such as brackets, wire, and mini-implants was developed using reverse engineering technique extracting the dimensional details of the physical parts using precision measuring instruments. The present finite element model was created based on material parameters taken from Wheeler's anatomy(Nelson 2014). The assumption was made that the materials were homogenous and linear and that they had elastic material behavior characterized by two material constants viz. Young's modulus and Poisson's ratio. Young's modulus and Poisson's ratio of the Nickel Titanium closed coil spring were assigned as 36, 0.33 as per Sana et al in 2021. Maxillary model was generated with one side of the maxilla from the central incisor to the second molar served as the experimental side while the other side served as the control side. The fixed orthodontic appliance was constructed with stainless steel metal brackets and molar bands. Full strap up with MBT prescription 0.022 slot was designed in the model. A rectangular 0.46 × 0.64 mm (0.019 × 0.025 inches) stainless steel wire was passively inserted into the bracket slot. This design was adapted to the whole maxilla as found in the previous experimental studies. Similar models were used in various finite element model study done by Pekhale in 2016.

Çifter in 2011 analysed various combinations of mini-implants and transpalatal arches and found that the posterior intrusion systems with force application from counterbalancing sites lead to a more uniform stress distribution and balanced intrusion than the mechanics with a transpalatal arch alone. Their findings confirmed that true intrusion was observed using three mini-implants and a transpalatal arch with maximum forces acting on the site of delivery force to the crown and in the middle one-third region for the periodontal ligament. However in our study, three mini-implants were used without transpalatal arch so as to avoid force dissipation from the opposing arch and also to keep the force application separately for control and experimental side.

Usage of mini-implants for molar intrusion had various advantages but the main disadvantage is root resorption. Still, now the optimal force for intrusion with mini-implants is not known. Several authors had done experiments with intrusion forces ranging from 50gms -200 gms (Umemori 1999, Paik 2003, Xun 2007, Park 2001) According to the study by Uysal in 2019, 1.96 Newton, 200 grams of force was used for molar intrusion in our study.

The safe zone for implant placement was selected in accordance with the study by Poggio in 2006. The mini-implants were placed at the height of 6mm from the crest of the alveolar bone in the interradicular space between the second premolar and first molar and first and second molars. Two titanium mini-implants of dimension 9mm length, 1.3 millimeters in diameter were used for molar intrusion. The dimension of the mini-implant was decided based on the criteria mentioned by Poggio in 2006 for increasing the effectiveness of the mini-implant.

Nickel Titanium closed coil springs were used for generating the 200grams of force required for molar intrusion. NiTi coil springs were used to obtain a constant force delivery as per Cox et al in 2014. The elastomeric chain was not used due to the possibility of force decay necessitating frequent activation as per Halimi et al in 2012.

Hyeon Shik Hwang in 2001 used corticotomy procedure to speed up the rate of molar intrusion. The results showed that by corticotomy procedure the resistance to tooth movement was reduced, hence both treatment time was reduced, also root resorption was prevented. In our study micro-osteoperforation has been done to reduce the resistance to tooth movement. This is minimally invasive when compared to the corticotomy procedure. Since this is a minimally invasive procedure micro- osteoperforations can be repeated in a clinical scenario to generate the RAP phenomenon. In our study total of 6 micro – osteoperforations were simulated in the model. For the success of the mini-implants, 1.5mm space around the mini implant must be left untouched according to Poggio in 2006. Hence the 3 micro – osteoperforations were placed in the interradicular region between the first molar and the second molar at a height of 3 mm, 9mm, 12mm from the crest of the alveolar bone, and 3 micro – osteoperforations were placed in the interradicular region between the first molar and the second premolar at a height of 3 mm, 9mm, 12mm from the crest of the alveolar bone.

The Von Misses stress experienced by the experimental side and the control side were compared. In our study, the experimental side (MOP side) experienced lower stress levels when compared with the control side (Non-MOP side) at the tooth, root and the surrounding alveolar bone. This was due to the interruption in the transmission of stress at the region of micro –osteoperforation. This led to reduced resistance to tooth movement. Chung et al have stated that corticotomy cuts reduced the resistance of the alveolar bone to tooth movement by breaking the integrity of the bone. Our study results are in agreement with the studies by Chung in 2009 and Yang in 2015.

Our study also shows that the deformation in the experimental side was lesser when compared to the deformation attained on the control side This decreased amount of deformation for the same amount of force shows that the resistance to tooth movement has decreased in the experimental side as given by Chung in 2009.

The above findings clearly explain that microosteoperforation reduces the stress levels and deformation experienced by teeth & surrounding structure thereby reducing the chances for root resorption.

**Limitations:**

Any theoretical model of a biological system has its limitations. All the mechanical properties of the materials were assumed to be isotropic and homogenous, which is different from the clinical scenario. Also, the outcome can be affected by the patient's age, bone quality, and the complexity of the problem. Finite element analysis can simulate the stress distribution only, under initial forces acting on the supporting structures. In a clinical scenario, the ongoing tooth movements and related biological response of bone remodeling may affect the results. Hence, further human clinical trials may be required to apply the above results on a daily basis in orthodontic treatment

## CONCLUSION

Microosteoperforation had been proven method for rapid orthodontic tooth movement. The above study concludes that the stress levels and deformation experienced by tooth and surrounding tissues can be lowered by microosteoperforation procedure and thereby aid in preventing root resorption.

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