

Comparative Assessment of three Microimplant Assisted Biomechanical Strategies for the Simultaneous Intrusion and Retraction of Anterior Teeth in Relation to Alveolar Bone Stress and Change in Incisor Inclinations – A 3D Finite Element Analysis Study

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Microimplants are widely used to provide absolute anchorage in cases with bimaxillary dentoalveolar protrusion especially in those that require simultaneous retraction and intrusion of anterior teeth. The position of the microimplant significantly affects the build up of stress in the alveolar bone as well as the incisor inclinations, and is therefore a critical factor in treatment planning. Keeping this in mind, this finite element method (FEM) study was taken up to identify the most suitable combination of implant placement sites for cases in which en-masse anterior retraction is done along with intrusion. The geometric model was constructed from a CBCT scan of the maxilla of an adult patient with full permanent dentition. The images were saved as DICOM files and were later exported to the 3D image processing software (Mimics, version 17). The center of resistance for the 6 anterior teeth was 9 mm superiorly and 13.5 mm posteriorly from the midpoint of crown tip of central incisors. The working archwires were assumed to be 0.019 / 0.025-in stainless steel. The three mini-implant placement sites compared were – S1- Midline micro implant between the maxillary central incisors with two placed posteriorly between maxillary 2nd premolar 1st molar roots. S2 – Micro implant placed between the lateral incisor and canine along with posterior mini implants as above. S3- Micro implant placed high up between the maxillary second premolar and first molar roots. The amount of tooth displacement after finite element analysis was compared with central and lateral incisor and canine axis graphs. For the system S1, intrusive components were seen on the archwire mainly in the anterior region with maximum displacement between central incisors and gradually decreasing away from point of force application. In S2, the intrusive component of force was more evenly distributed. In S3, pattern of intrusive component was similar to S2 but the maximum displacement was slightly lower. Greatest value of minimal principal stress was seen on cervical and apical third of central incisors as well as apical third of lateral incisors in S1; and cervical third of lateral incisors and apical and cervical third of canines in S2. Maximum retraction of anterior teeth was seen in S3. In all of the three systems of force application, tooth inclinations were maintained. Maxillary anterior teeth showed more tendency towards retraction in the case where two micro implants were placed posteriorly high up above the roots of maxillary premolars and molars such that the force is directed diagonally having both horizontal and vertical components, and hence eliminating the need for anterior implants. Greater intrusion tendency was seen when implants were placed between the roots of maxillary central incisors.

Keywords: Mini implants, intrusion and retraction, FEM.

Bimaxillary dentoalveolar protrusion is one of the commonest malocclusions encountered by orthodontists worldwide. It is characterized by proclination of maxillary and mandibular anterior teeth with resultant projection of the lips as well as convexity of the profile. It is conventionally treated by therapeutic extraction of the first premolars, trailed by complete anterior tooth retraction to acquire the desired dental and soft tissue profile changes¹. Anchorage requirement is critical in such cases and a successful treatment outcome is often dependent on effective anchorage control strategies.²

There are several extraoral as well as intraoral sources of obtaining anchorage. In recent times, skeletal anchorage has almost replaced all other conventional modes of anchorage reinforcement; as it eliminates all unwanted tooth movement thereby leading to superior treatment outcome and greater patient satisfaction. Skeletal anchorage can also be of various types: anchorage obtained with the help of miniplates and with the help of micro implants being the two important ones. Out of the two, the use of micro implants is widespread due to its advantages like ease of insertion, lower predisposition to infection, shorter procedure times and lesser discomfort to the patient.

Achieving simultaneous intrusion and retraction of anterior teeth has always been a challenge for orthodontists. However, with the use of mini implants obtaining good treatment results is possible and much more predictable. This can be done using a number of biomechanical strategies –

- 1) Either by using one midline mini implant and two posteriorly between maxillary 2nd premolar and 1st molar roots,
- 2) Using two mini implants placed between the lateral incisor and canine along with two posterior mini implants as above,
- 3) Two mini implants placed posteriorly high above between the second premolar and first molar such as the force is directed diagonally with both horizontal and vertical components.

The stress generated in the surrounding alveolar bone as well as amount of intrusion and retraction varies in each scenario. Hence, selection of the mini implant placement site should be done after careful consideration.

Finite Element Analysis (FEA) is a numerical method for solving problems in mathematical physics and helps in finding analytical solutions for stresses of various objects based on mathematical calculations. Qualitative and quantitative reactions of teeth and alveolar bone to orthodontic forces can be evaluated.

Therefore, this study was taken up with the aim of evaluating and comparing the efficacy of the above mentioned mini implant sites for intrusion and retraction of anterior teeth.

Aims and objectives

To graphically display the pattern and magnitude of stress distribution along the alveolar bone of maxillary anterior teeth on application of intrusive and retraction forces using microimplants and analyse the efficacy of the three techniques.

MATERIALS AND METHODS

It was a 3D finite element analysis study for which prior ethical clearance was obtained from the Institutional Ethics committee, Manipal College of Dental Sciences, Mangalore. The study was conducted in collaboration with the CAD Lab, Department of Mechanical Engineering, Manipal Institute of Technology.

The FE-analysis consisted of the following steps

- Construction of geometric model: This step involved creation of geometric representation of maxillary teeth, alveolar bone, wires and brackets.
- Meshing: The geometric model was subdivided into discrete elements and the resulting set was called mesh. ANSYS provides various options to produce 3D mesh on solid geometry of tooth model.
- Materials, Loads and Boundary Conditions: In this step, material and element properties along with loads and boundary conditions were defined on discretized model of complete model in ANSYS.
- Analysis: In this step FEA solver ANSYS Workbench is used to calculate displacement and stress due to the loading conditions.
- Visualisation of the results: This step involves visualization of various results such as displacement, Von-Mises stress and comparison of stress with the design admissible limits of materials.

Construction of geometric model

The geometric models of the maxillary central and lateral incisors, canines, second

premolars and first molars were constructed using the CBCT scan of the maxilla of an adult patient with full permanent dentition, obtained with Planmeca Promax 3D MID. The images were saved as DICOM files and were later exported to 3D image processing software (Mimics, version 17).

A 3D solid model was constructed encompassing of maxillary dentition, alveolar bone, mini implants, brackets and arch wire (Fig 1,2). First premolar was not constructed in order to simulate retraction as seen in 1st premolar extraction cases. Brackets with slot size 0.022"/0.028" were modelled with the Roth prescription and attached to the crowns of the teeth, such that the facial axis point was coinciding with the center of the bracket slot (base point and slot point). Stainless steel arch wire of dimension 0.019" × 0.025" was designed with hook of 8mm between the lateral incisor and canine, for the purpose of retraction. The tooth model was then exported in STL format.

Conversion of geometric model to finite element model

STL (Stereo Lithography) model data was used to generate suitable mesh. STL is a file format native to the stereo lithography computer aided design programming created by 3D Systems. 3MATIC supports this file format and is also generally utilised for rapid prototyping in dentistry. After meshing, the file was exported to ANSYS Workbench where material properties, load and boundary conditions were defined. (Fig 3-5)

There were 172265 tetra elements and 280942 nodes (Table 1). It is highly impossible to achieve perfect quality parameters for the mesh generated for such complex geometry. However, reasonably good quality parameters were maintained in the model in order to get quality results. Also, special care was taken to model contact between different parts in the model such as contact between arch wire and bracket, contact between teeth and bracket, contact between teeth and the alveolar bone.

Material Properties and Data Representation

Non-living mechanical structures for example implants, abutments, and restorations can be mimicked in detail and can significantly impact the computed stress and strain values,

similar to living structures. These materials can be carefully demonstrated in FEA templates utilising already decided isotropic, transversely isotropic, orthotropic, as well as anisotropic properties. In an isotropic material, the pertinent material properties are the same every way, bringing about just 2 autonomous material constants, for example, Young's modulus and Poisson's proportion. Young's modulus (MPa), otherwise called the tensile modulus, is a quantity that is used to characterise materials and it is a measure of the stiffness of an elastic material. Young's modulus is also called the elastic modulus or modulus of elasticity, since Young's modulus is the most ordinarily used elastic modulus. Poisson's ratio is the ratio of the contraction or transverse strain (perpendicular to the applied load), to the extension or axial strain (in the direction of the applied load) when a sample object is stretched. When a material is compressed in 1 direction, it has a tendency to expand in the other 2 directions perpendicular to the direction of compression. This phenomenon is called the Poisson effect and Poisson's ratio is a measure of the Poisson effect.

Most of the elastic properties of selected living and non-living materials are widely available in different material properties database. Young's modulus and Poisson's ratio are used in models to reproduce reality as closely as possible. For instance, alveolar bone (both cortical and cancellous portions), implant, abutment, metal framework, and porcelain can be included in the model properties. In the numerical simulation that was performed, stainless steel orthodontic wires and brackets with the above material properties was used. (Table 2)

Defining the boundary condition

In order to make the connected nodes between the brackets and archwires deform together, translational degrees of freedom of the arch wire in the two flexural directions were coupled; and in the axial direction of the arch wire, translational degrees of freedom remained unconstrained. This allowed free axial rotation movement of the arch wire, while the friction between the arch wire and brackets along the axial direction was ignored⁴. To simulate the constraints of the model, the boundary conditions of alveolar bone was defined to prevent it from free bodily

motion. The nodes which were attached to the outer surface area of the bone were fixed in all directions to avoid free movement.

Application of forces

Three point of force (Loading situation) application were chosen in view of simulated clinical circumstances and focusing on what a clinician for the most part would choose to intrude and retract maxillary incisors. Thus, the points of force application were:

- LOAD 1: 120 gm in Z direction (8 mm from the arch wire) and 100 gm parallel to arch wire (S1)
- LOAD 2: 60 gm in Z axis (8 mm from the arch wire) and 100 gm parallel to the arch wire (S2)
- LOAD 3: 13.5 mm posteriorly and 9 mm superiorly to the incisal edge of upper central incisors at an angle to generate both vertical (60 gm each) and horizontal components (100 gm each) (S3)

Frictional coefficient between the bracket and arch wire slots was assumed to be 0.2^{45, 46}

RESULTS

Stress pattern and deformation in x, y and z axis as well as total displacement were analysed

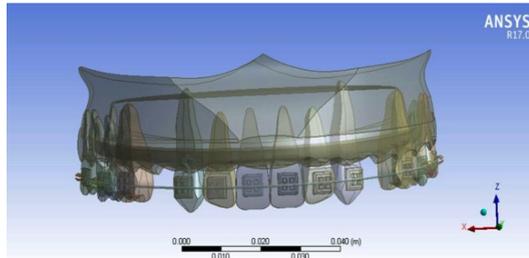


Fig. 1. Frontal view of the geometric model

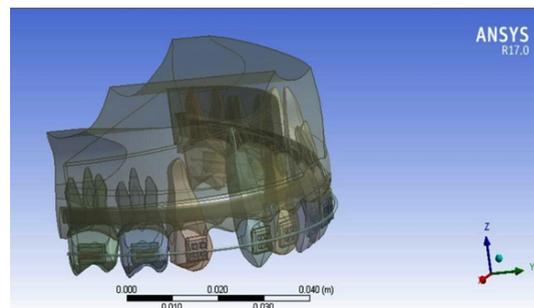


Fig. 2. Lateral view of the geometric model

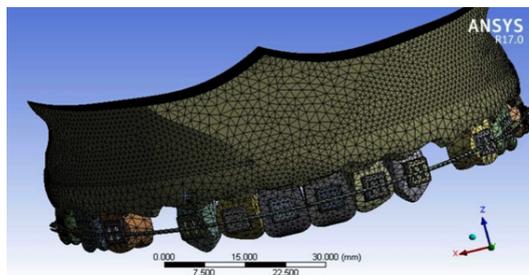


Fig. 3. FE model from frontal view

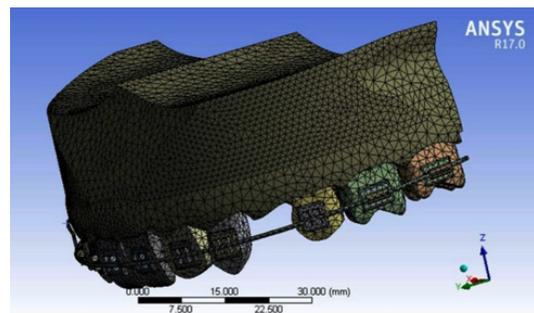


Fig. 4. FE model from left lateral view

along the alveolar bone of maxillary incisors on application of intrusive and retraction forces using micro implants, using ANSYS workbench.

Because of the action of various components of stresses on the teeth and alveolar bone the results obtained consisted of displacement (Table 3), minimum principal stress (Table 4) and Von Mises or equivalent stress (Table 5).

For the system S1 with micro implants placed between the central incisors, intrusive component of force was maximum in the anterior region, which gradually decreased away from the force application point (Figure 6). In the second scenario S2 with the micro implant placed between the lateral incisor and canine, the intrusive force was more evenly distributed (Figure 7). In the third scenario S3, pattern of intrusive component of force in the archwire was similar to S2, but the maximum displacement was lesser than in S2 (Figure 8)

DISCUSSION

One of the major challenges faced by orthodontists is understanding and predicting the complexities involved in the response of teeth to

forces and moments³⁰. Finite element analysis was selected for this study because of its advantages like it is non invasive, three dimensional, can simulate the actual physical properties of the materials involved, visualisation of the actual tooth displacement, measurement of stresses at any point as well as the possibility of infinite magnification^{3,34}.

In order to accomplish an amicable profile in patients with protusive lips, extraction of premolars and retraction with critical anchorage is often necessary^{6,45}. In such cases, it is important to ensure there is no torque loss with respect to the maxillary anterior teeth. This can be done by incorporating additional torque in the the arch wire, using high torque brackets or by adjusting the length of the anterior retraction hook⁴⁷. Another effective way is to use micro implants at appropriate sites. These can be used to control anterior torque as well as conserve posterior anchorage.

During enmasse retraction of maxillary anterior teeth, it is necessary to apply an intrusive component of force to prevent extrusion as well as to maintain the labial crown torque. This can be achieved with the help of micro implants and ARH in sliding mechanics. It is thus important to bring light to the best technique requiring minimum number of micro implants. The best combination of position of OMI and point of force application that can generate optimum intrusive force is required to

control incisor inclination and bring about active intrusion. Initially, there was a need to explore the CR for 6 anterior teeth in the model so that force can be applied at or in vicinity of CR. The centre of resistance varies among patients, depending on alveolar bone support, root length and number of teeth⁴⁹⁻⁵³.

It is desirable for the line of action of force to pass through CR for the bodily retraction of 6 anterior teeth in en-masse retraction appliances⁴. Rigid splinting of incisors and canines should be included in the design to prevent deformation between the main arch wire and the ARH^{49,52} and a rigid palatal lever arm which is bilaterally connected that can enable force application around the center of resistance without deflection of the ARH and gingival impingement^{52,53}

Sang - jin Sunget et al in their study applied the intrusive force component of 30 to 60 gms to the tooth centre of resistance of 6 anterior teeth to expect simultaneous movement³. In our study, 20gms/tooth of intrusive force was used.

Maximum compressive stress on the alveolar bone was found at the cervical and apical third of central incisors in S1, cervical third lateral incisors and canines in S2, apical third of lateral incisors in S1 and apical third of canines in the S3. The torque loss was calculated by measuring the difference between initial and final displacement of crown tip and root apex, if both the crown tip and root apex moved equally it showed the translation

Table 1. Finite element details of each component of the model

Teeth	Number of Nodes	Number of Elements
Central Incisor	5019	2887
Lateral Incisor	1682	874
Canine	13122	7889
Second Premolar	2977	1665
First molar	6298	3678
Second Molar	7838	4748
Alveolar bone	190029	121423
Archwire	5009	1993

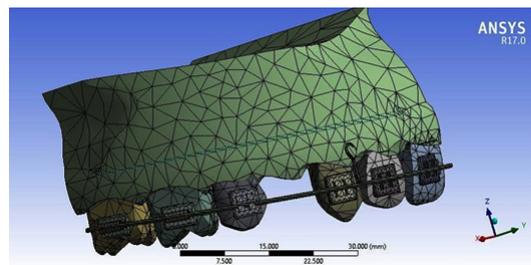


Fig. 5. FE model from right lateral view

Table 2. Material Properties

	Young's modulus (g/mm ²)	Poisson's ratio
Teeth	3E6	0.3
Alveolar bone	2E5	0.3
Stainless steel	2E7	0.3

E- times ten raised to the power, as (scientific) E notation.

i.e. the bodily movement. Inclination of tooth was maintained in all of the three cases described in our study.

In Y axis, crown tip of anteriors showed maximum displacement in S3 showing a greater tendency of retraction. Similarly, displacement at root apex is highest in S1 showing greater tendency towards intrusion as compared to the S2 and S3. Among the anterior teeth, canines showed greatest intrusive tendency.

Maximum total displacement was seen at the crown tip of maxillary anteriors was seen in S2. Root tip of maxillary canines showed maximum total displacement among the anteriors. Extrusion of central incisors, lateral incisors and canines is prevented maximum in S1. Torque loss with the root moving in Y direction was not seen in any of the case. Compressive stress on the labial alveolar bone was seen maximum on the cervical and apical third of central incisor in the S1, apical third of lateral incisor in S1 and apical third of canine in S3.

Finite element method is a powerful tool for the analysis of complex structures, however its outcome is dependent on formulation of the

problem.⁵¹When any numerical model is used, choosing the right material properties, such as elastic modulus and Poisson's ratio, as well as presenting alveolar bone's characteristics and teeth are the most critical factors in obtaining precise results.

In this study, the greatest value of minimum principal stress was seen on cervical and apical third of central of S1, cervical third of lateral incisors and canines of S2, apical third of lateral incisors of S1 and apical third of canines of S2. Maximum retraction of maxillary anteriors was seen in S3. A significant finding is that torque loss was not seen in any of the three models.

Displacement in Y axis

Force in Y direction (Fy) causes tensile and compressive stresses on the lingual and labial aspect of teeth and alveolar bone. Maximum displacement of the crown tip of central incisors, lateral incisors and canines was seen in S2. This shows a greater tendency of retraction with all anterior teeth showing similar displacement values.

In a study done by *Teasoo Kim et al*¹², it was found that despite applying the line of action of force close to the centre of resistance of 6 anterior

Table 3. Recorded directional deformation at crown and root tips in Y and Z axes from different force systems(mm)

Tooth	Position	Axis	First system	Second system	Third system
Central incisor	Crown tip	Y	-2.4883e-5	-4.1313e-5	-4.1051e-5
		Z	-4.1107e-6	-9.8535e-6	-9.8038e-6
	Root tip	Z	-4.1107e-6	-8.4937e-6	-9.8038e-6
Lateral incisor	Crown tip	Y	-1.4983e-5	-4.1313e-5	-4.1051e-5
		Z	-1.4806e-6	-7.1337e-6	-7.071e-6
	Root tip	Z	-4.1107e-6	-7.1337e-6	-7.071e-6
Canine	Crown tip	Y	-3.4782e-5	-4.1313e-5	-4.1051e-5
		Z	1.1494e-5	-1.6934e-6	1.1273e-6
	Root tip	Z	1.1494e-5	-1.6934e-6	1.1273e-6

Table 4. Recorded minimum principal stress values on alveolar bone near crown and root tips from different force systems (MPa)

Tooth	Position	First system	Second system	Third system
Central incisor	Cervical third	0.012256	0.00035374	0.00195165
	Apical third	0.012256	0.00035374	-0.0003049
Lateral incisor	Cervical third	-0.0010665	0.00035374	-0.0003049
	Apical third	0.00559475	0.00035374	-0.0003049
Canine	Cervical third	-0.02771125	-0.00168628	-0.00255895
	Apical third	-0.0010665	-0.00168628	-0.0003049

Table 5. Recorded equivalent stress/Von Mises stress values on alveolar bone near crown and root tips from different force systems(MPa)

Tooth	Position	First system	Second system	Third system
Central incisor	Cervical third	0.00041097	0.00049281	0.000070572
	Apical third	0.00041097	0.00049281	0.000070572
Lateral incisor	Cervical third	0.00041097	0.0060953	0.000070572
	Apical third	0.00041097	0.00049281	0.000070572
canine	Cervical third	0.018927	0.0060953	0.00038074
	Apical third	0.00041097	0.00049281	0.000070572

teeth along with adequate amount of intrusive force, the central and lateral incisors were not bodily retracted. In our study, with similar force application, slight labial tipping of the crowns of maxillary anterior teeth were seen.

Displacement in Z axis

Force in Z direction (F_z) causes tension and compression stresses on teeth and alveolar bone in both the occlusal and apical direction

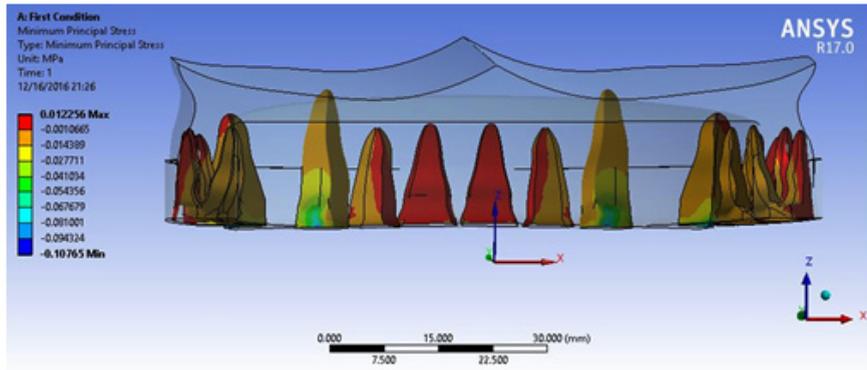


Fig. 6. Minimum principal stress on alveolar bone in S1

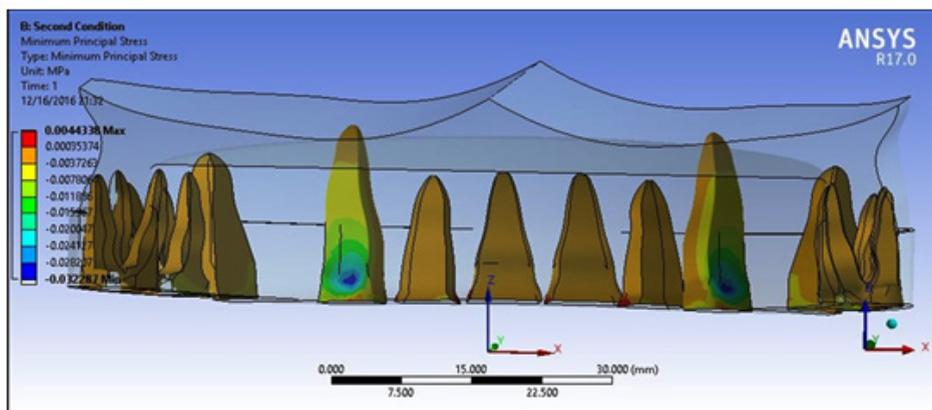


Fig. 7. Minimum principal stress on alveolar bone in S2

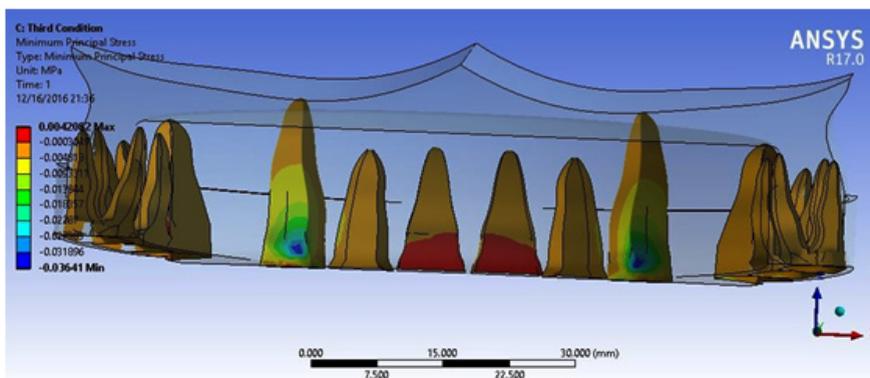


Fig. 8. Minimum principal stress on alveolar bone in S3

which tends to move teeth in these directions. Apical displacement of root apex was highest in S1 showing greater intrusive tendency. Canines among the anterior teeth showed greater intrusive tendency.

In a similar study done by *Quiang Zhang et al¹⁴*, it was found that loading on lateral incisors was greater than other teeth while retracting the 6 anterior teeth with their force passing near the centre of resistance. In our study, a similar result was found.

Limitations of FEM study

FEM is not an actual simulation, there might be some degree of variation from clinical situation. The result of this study is only valid with patients exhibiting similar bone density, root lengths and angulations, crown sizes etc. also, placing implants very high above the arch wire is not always possible in clinical situations.

CONCLUSION

This study was carried out to analyse the efficacy of three micro implant assisted biomechanical strategies for simultaneous intrusion and retraction of maxillary anterior teeth.

A three-dimensional finite element model of the maxillary dentition with alveolar bone was created using ANSYS Workbench. Load was applied to the model in three different ways to bring out the desired result.

Conclusions drawn from this study are

- In all of the three systems of force application, tooth inclinations were maintained.
- Maxillary anterior teeth showed more tendency towards retraction in the case where two micro implants were placed posteriorly high up above the roots of maxillary premolars and molars such that the force is directed diagonally having both horizontal and vertical components, and hence eliminating the need for anterior implants.
- Greater intrusion tendency was seen when implants were placed between the roots of maxillary central incisors.

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