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Original Research Article

3D biomechanical intrusion effects of infra zygomatic bone screws and temporary anchorage device on total maxillary dentition in treatment of vertical maxillary excess: A FEM study

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ABSTRACT

Background & Objectives: Many studies have reported on the application and clinical efficiency of full arch maxillary dentition intrusion mechanics; however, studies about biomechanical effects such as stress, strain, and displacements on the teeth and the surrounding tissues are limited. The objectives of study was to evaluate and compare the stress distribution and displacement of total maxillary dentition under intrusion mechanics using a three-dimensional finite element analysis.

Materials and Methods : A three-dimensional finite element model was constructed based on computed tomography scan data, and it served basic model. The geometric model was converted to finite element model using Altair HyperMesh software. Model A with pre-adjusted edgewise appliance (PEA) setup and Model B with occlusal Splint setup was evaluated and compared for von mises stress distribution and displacement of total (full arch) maxillary dentition by using three dimensional finite element analysis; with force delivered from infrazygomatic screws and miniscrew. Force levels for Model A and Model B includes a total of 300grams of intrusive force (each side) on maxillary posterior segment from IZC bone screw and 100grams of intrusive force on anterior segment from miniscrew.

Results: In the model A; with PEA setup reinforced with two trans-palatal arches, highest von Mises stress of 0.970 Mpa was produced on second molar roots followed by molar roots and premolars and central and lateral incisors roots. In the Model A, maximum intrusive values was seen on crown tip of central and lateral incisors (8.671μm), and lowest displacement values on second molars (2.230μm). Similar pattern of von Mises stress distribution and displacement was observed in the Model B.

Conclusions: Model A and Model B provided an effective en masse vertical control of the full arch maxillary dentition. Higher intrusion displacement values were seen in anterior segment than the posterior segments.

1. Introduction

Treatment of vertical dimension of the face is one of the most challenging areas in orthodontics and needs a proper diagnosis and treatment plan.[1] Orthopedic force application during growth to achieve good skeletal relation reduces the complexity of orthodontic treatment mechanics. It also enhances the esthetics; restore good function leading to greater stability.

A gummy smile caused by vertical maxillary excess (VME) cannot be treated satisfactorily with adjunctive surgical approaches such as botulinum toxin injection or a crown lengthening procedure. An ideal treatment option for VME is the reduction of the maxillary vertical dimension by

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LeFort I osteotomy.[2,3] Orthognathic surgery to reposition the maxilla superiorly has been the only way to create significant rotation of the mandible upward and forward, decreasing anterior face height.

Temporary anchorage devices (TADs), including mini-plates and mini-screws, have been used to intrude the maxillary posterior teeth to allow autorotation of the mandible.[4–6] Several cases have been reported for entire maxillary dentition intrusion using TADs. However, they have limited clinical application because of attributes such as too many screws[7] or complicated design,[8] and insufficient amount of attainable intrusion.[9]

More recently an apt balance was achieved with the advent of the OrthodonticBone Screws (OBS) which not only had an extra-radicular site of placement inthe Infra-Zygomatic Crest (IZC) of the maxilla,with significantly less failure rates than regular mini-implants but also doesn'trequire extensive surgical intervention for their placement.[10]

The Maxillary Intrusion Splint (MIS) was also used as an option for correcting maxillary dento-alveolar protrusion and vertical excess in growing patients.[11] The philosophy behind the use of the maxillary splint is that if the force delivered to the upper jaw involved the use of all upper teeth rather than only maxillary first molars, the effect on the jaw would be more orthopedic than orthodontic in nature.[12–14]

Many of the proposed treatments, such as extraction of first molars to bring the second molars out of the wedge, have been reported to have beneficial effects on the vertical dimension.[15,16]

Clinically, VME is classified according to the presence of anterior open bite. When a patient has VME with anterior open bite, intrusion of the posterior teeth is an important component of treatment. A patient having VME with normal overbite should be treated by intrusion of the total maxillary arch.[17–21]

Many studies have reported on the application and clinical efficiency of total full arch posterior intrusion mechanics; however, studies about biomechanical effects such as stress, strain, and displacements on the teeth and the surrounding tissues are limited.[20] Finite Element Analysis (FEA), a common method in engineering, became a valuable option for evaluation of biomechanical factors in orthodontics.[22,23] The purpose of this study was to evaluate and compare three dimensional stress distribution and initial displacement of maxillary dentition under total arch intrusion mechanics for correction of vertical maxillary excess using IZC bone screws and TAD in Pre-adjusted Edgewise Appliance (PEA) setup and occlusal splint setup finite element models.

2. Materials and Methods

A dry adult skull of a healthy person with intact maxillary dentition and no craniofacial anomaly was procured. Computed Tomography (CT) images of dry skull (slice thickness, 0.5mm) were used for generating CAD Model. The obtained CAD model was used to construct the geometric model of the tooth in Geomagic Modelling Software. The geometric model was converted to finite element model using Altair HyperMesh software. The finite element modelling is the representative of geometry in terms of finite number of elements and nodes. This process is called discretization. The main idea behind discretization is to improve the accuracy of the results.

The different structures involved in this study include teeth, the periodontal ligament and alveolar bone. Each structure has specific material property. These materials properties of the tooth cortical bone, cancellous bone, suture periodontal ligament, stainless steel, nickel-titanium were the average values reported in literature. The mechanical properties are listed in the Table 1.

The boundary conditions were defined to simulate how the model was constrained and to prevent it from free body motion. The nodes attached to the area of the outer surface of the bone are fixed in all directions to avoid free body movement of the tooth. The 3D coordinates were based on the occlusal plane: X (antero-posterior plane), Y (transverse plane), and Z (vertical plane). Positive values for X, Y, and Z indicated forward, left, and upward displacement.

Maxillary model was converted into two finite element models (Model A and Model B). Maxillary Model A: Design consists of PEA setup reinforced with two trans-palatal arches (Figure 1). Maxillary Model B: Design consists of maxillary intrusion splint setup with hooks (Figure 2). The computer-aided design model of 0.019×0.025-in arch wires and 0.022×0.028-in brackets were generated with a laser surface scanner (Next Engine, Santa Monica, Calif) and 3ds Max software. Brackets were attached to the teeth so that the midpoint of the brackets overlapped the midpoint of the facial surface of the crowns. Bone screws and Mini-implants were modelled manually with the 3ds Max software.

In both models IZC bone screw measuring 2×12 mm, placed at IZC above first molar and TAD 1.2×8 mm above the roots of central incisors. Two closed coil nickel titanium spring on right buccal segment and two on left was used for the application of intrusive force from IZC bone screws. One closed coil nickel titanium spring was used for the application of intrusive force from TAD on anterior segment.

Force application: Force levels for Model A and Model B includes total of 300grams of intrusive force on each side was applied on maxillary posterior segment from IZC bone screw (150gms from each coil springs) and 100grams of intrusive force on anterior segment from TAD.

Interpretation of results: Von Mises stresses were presented as different color bands, which represented different magnitude. Red column of the spectrum indicated maximum level followed by different shades of orange, yellow, green, blue, while dark blue represented the minimum level. Initial tooth displacement was measured with numerical values in micro-millimetres.

3. Results

Two basic models were considered, Model A with PEA setup and Model B with occlusal splint setup, the results were divided under two sections. Von Mises stress distribution and displacement of total maxillary dentition produced after the intrusive forces applied from IZC bone screws and mini-screw on posterior segment and anterior segment respectfully, through the closed nickel titanium coil springs.

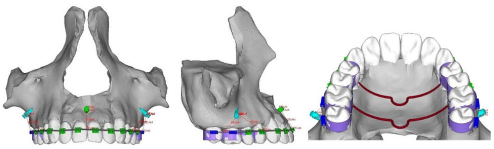

Fig. 1: Model A: Maxillary model withpre-adjusted edgewise fixed appliance setup; reinforced with two trans-palatal arches.

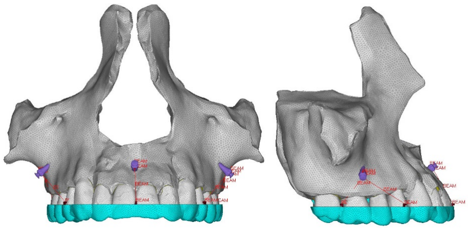

Fig. 2: Model B: Maxillary model with acrylic occlusal intrusion splint with hooks.

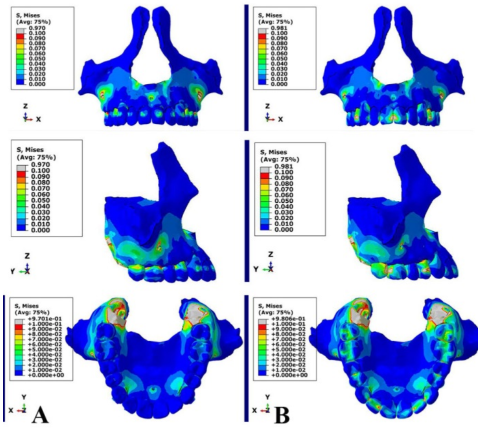

Fig. 3: Frontal, sagittal and occlusal view of Model A and Model B showing Von Mises stress distribution of teeth and bone assembly.

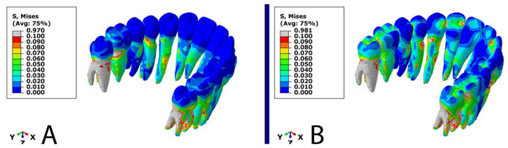

Fig. 4: Posterio-occlusal viewof Model A and Model B showing Von Mises stress distribution of maxillary dention assembly.

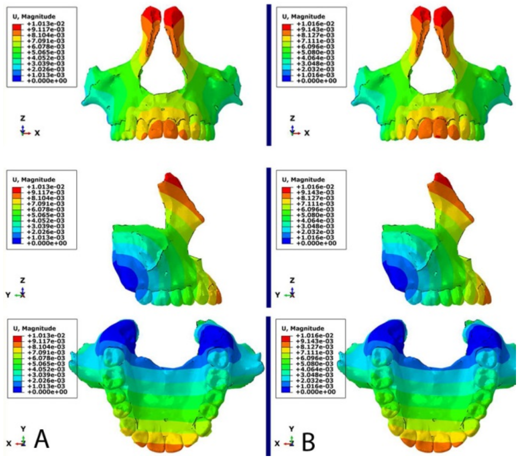

Fig. 5: Frontal, sagittal and occlusal view of Model A and Model B showing displacement of teeth and bone assembly.

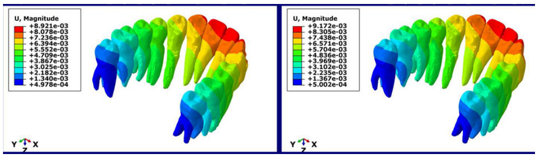

Fig. 6: Posterio-occlusal view of Model A and Model B showing displacement of maxillary dentition.

3.1. Von Mises stress distribution

In the model A; with PEA setup reinforced with two trans-palatal arches, highest von Mises stress of 0.970 MPa was observed on second molar roots followed by molar roots and premolars and central and lateral incisors roots.

Similar pattern of stress distribution was observed in the model B, with occlusal splint; highest von Mises stress of 0.981Mpa was produced on second molars roots followed by first molar roots and premolar roots and central and lateral incisors roots. Moderate amount of stress was observed on crowns of maxillary dention.

3.2. Displacement

In the Model A, maximum intrusive values was seen on crown tip of central and lateral incisors 8.671μm, followed by canines (7.360μm) and premolars (4.342 μm) first molars (3.905μm) and lowest displacement values on

Table 1: Mechanical properties applied to structures and materials.[23]

Material	Young's modulus (MPa)	Poisson's ratio (Psi)
Cortical bone	1.37×10^4	0.30
Cancellous bone	7.90×10^3	0.30
Palatal bone	1.05×10^5	0.33
Miniscrew	1.05×10^5	0.33
Occlusal splint	2.7×10^2	0.35
Tooth	19613.3	0.15
Stainless steel	2.00×10^5	0.30
PDL	0.6668	0.49

Table 2: Displacement values in vertical plane on left side maxillary dentition.

Models		Displacement of tooth in vertical plane (E-3mm)						
		Second Molar	First Molar	Second Premolar	First Premolar	Canine	Lateral Incisor	Central Incisor
Model A With PEA setup	**At crown tip**	2.230	3.905	4.977	5.939	7.015	8.031	8.633
Model B With Occlusal splint	**At crown tip**	2.321	3.953	5.057	5.991	7.322	8.225	8.873

Table 3: Displacement values in vertical plane on right side maxillary dentition.

Models		Displacement of tooth in vertical plane (E-3mm)						
		Second Molar	First Molar	Second Premolar	First Premolar	Canine	Lateral Incisor	Central Incisor
Model A With PEA setup	**At crown tip**	2.627	4.324	5.378	6.304	7.360	8.175	8.671
Model B With Occlusal splint	**At crown tip**	2.721	4.384	5.449	6.383	7.611	8.461	8.887

second molars (2.230 μm).

Similar pattern of stress distribution was observed in the Model B with maximum intrusion values was seen on crown tip of right maxillary central incisors of 8.861μm and lowest intrusion values on second molars.

Buccal displacement values in transverse plane were minimal with 2.275 μm and 2.272 μm in Model A and Model B respectively.

4. Discussion

Intrusion of the teeth has been a difficult issue in orthodontics and was associated with side effects of root resorption; because of the lack of control of force and anchorage. However, in recent years with the advent of IZC bone screws and TAD's have allowed to achieve anchorage from different locations of maxillofacial areas for balanced intrusion with minimal side effects provided that the magnitude and direction of force are carefully monitored. But there are still unclear data concerning the biomechanical issues on the accuracy of the models.

This finite element method study was carried out to evaluate the efficiency of intrusion mechanics in maxillary dention using combination of infra-zygomatic bone screws for posterior intrusion and a mini-screw for anterior intrusion, in two different scenarios comparing PEA setup (Model A) and occlusal splint setup (Model B) for total maxillary intrusion.

The present study simulated the initial intrusive tooth movement on maxillary dentition in both the models. In the Model A with PEA setup; maximum intrusive values was seen on crown tip of central and lateral incisors 8.671μm, and lowest intrusion values on second molars (2.230 μm). Similar pattern of stress distribution was also observed in the Model B with occlusal splint setup. In clinical studies by Deguchi et al.[24] reported 2.3 mm of maxillary molar intrusion in a study of 15 patients and Baek et al.[7] reported 2.4 mm for 9 patients. Akan et al.[25] In a more recent report of 19 patients in whom intrusion force was delivered to an occlusal splint, reported a mean intrusion of 3.4 mm and a decrease in the mandibular plane angle.

Iftera and Sarac[23] calculated the intrusive forces according to the root surface area ratios. The applied forces according to the selected root surface area ratios gave a virtually uniform intrusion movement, They also stated variations in tooth morphologies and root angles, inclination differences of the vestibular and palatinal slopes of the alveolar bone, and anisotropic and nonlinear properties of the tissues also can have significant effects on the stress distribution and the path of the intrusion movement. In the present study we divided the posterior intrusive force of 300 grams into 150 grams on two premolars and 150 grams on two molars to achieve uniform intrusion posterior maxillary segment.

Iftera and Sarac[23] intruded maxillary posterior segment; both right and left segments with 4 mini-implants and a trans-palatal arch was used to balance the produced moments and inhibit buccal tipping movements. They stated in clinical situations, extrusion of the palatal cusps can create interferences between the antagonist teeth and lead to a decreased overbite. In clinical situations, if a trans-palatal arch with sufficient resistance is used, it will exhibit its uprighting effect through a long-term process of bone remodelling, and most of the initial interferences will disappear with time by intrusion of the palatal cusps. The other side effect of the vestibular tipping movement identified in the second and third models was the increase in overall stress magnitudes, which clinically increase the probability of root resorption. Thus, in most open-bite patients, it is crucial to prevent buccal tipping during posterior intrusion.

In the present study in model A; 2 trans-palatal arches were modelled, one connecting the first molars and second connecting premolars; In accordance with the clinical applications, trans-palatal arches were adapted evenly 5 mm from the palatal bone to achieve clearance for the intrusion movement and inhibit buccal tipping movements. Buccal displacement initial values in transverse plane were lowest with 2.275 μm and 2.272 μm in Model A and Model B respectively. Both models showed similar pattern of buccal posterior displacement. It has been hypothesized that an intrusion appliance that includes a transpalatal arch passing 3 to 5 mm away from palatal mucosa, similar to that used in the present study, has the additional advantage of an intermittent intrusive force of the tongue on the posterior teeth and avoids irritation of the palatal mucosa during intrusion (Erverdi et al.[26]; Park et al.[27]; Kravitz et al.[28]; Xun et al.[29]).

In the present study a total 300grams of intrusive force were applied on each side on maxillary posterior segment IZC bone screws through two nickel titanium coil springs (150gms from each coil springs) and 100grams of intrusive force on anterior segment from TAD below anterior nasal spine. In Model A maximum intrusive values were seen on crown tip of central and lateral incisors, followed by canines and premolars first molars and lowest displacement values on second molars. Similar pattern of tooth displacement was observed in the Model B with occlusal splint.

Both treatment modalities provided effective en masse vertical control of the maxillary dentition. Higher intrusion displacement values were seen in anterior segment which will help to correct gummy smile; in patients with vertical maxillary excess

4.1. Limitations of the study

Because of variations of individual geometry, it is neccessary to use unique mechanics and force systems for each patient. Even with perfect mechanics and exact force systems, after the initial tooth movement, the biomechanical effect of the force system changes, and modifications are required during treatment.[30,31]

5. Conclusion

In the Model A; highest von Mises stress of 0.970 MPa was observed on second molar roots followed by first molar roots and premolars, canines, central and lateral incisors roots. Similar pattern of stress distribution was observed in the Model B.

Model A and Model B provided an effective en masse vertical control of the full arch maxillary dentition. Higher intrusion displacement values were seen in anterior segment than the posterior segments.

Buccal displacement of teeth in transverse plane was minimal in Model A and Model B. Both models showed similar pattern of buccal posterior displacement.

6. Source of Funding

None.

7. Conflict of Interest

None.

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