Original Article

A Three-Dimensional Finite Element Study to Assess Intrusion in Clear Aligner Therapy and Conventional Method during En masse Retraction Using Mini-implants

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Abstract

Background: Space closure by en masse intrusion and retraction in orthodontics is of particular interest. **Aims and Objectives:** The aim of this study is to evaluate the amount of intrusion on the anterior teeth as well as the posterior teeth during en masse retraction of maxillary anterior teeth with clear aligners and conventional method using mini-implants after the extractions of maxillary first premolars using three-dimensional finite element analysis. **Materials and Methods:** Two different finite element models of maxillary arch with extracted premolars were constructed to understand the amount of intrusion patterns of anterior teeth during en masse intrusion and retraction on conventional model and aligner model. **Results:** Anterior intrusion was seen more in clear aligner model and posterior intrusion was seen more in conventional model. In anterior intrusion, lateral incisor was involved compared to other anterior teeth in both conventional and aligner model. While during posterior intrusion maxillary second molars are involved and intrusion changes are seen increasing from mesial to distal end. **Conclusion:** Intrusion is a common orthodontic tooth movement which is employed in the cases of deep bite where anteriors are intruded for correction or in anterior open bite where posteriors are intruded to close the bite for correction. The article discusses the biomechanics of intrusion in orthodontic treatment using digital planning and depending least on the patients for the results.

Keywords: Anterior intrusion, Posterior intrusion, Finite element analysis, Clear aligners.

Introduction

In orthodontic treatment, intrusion movement of maxillary incisors is often necessary. One of the major challenges of Class II treatment is the correction of deep overbite. Unfortunately, it is still common for the correction to be determined by the system of mechanics that an orthodontist will employ, rather than the nature of the discrepancy.[1]

The orthodontic correction of deep overbite can be achieved with several mechanisms that will result in true intrusion of anterior teeth, extrusion of posterior teeth, or a combination of both. Deep overbite correction by intrusion of anterior teeth affords a number of advantages including simplifying control of the vertical dimension and allowing forward rotation of the mandible to aid in Class II correction. During intrusion of anterior teeth, optimal magnitudes of force may be delivered constantly using low load deflection springs. Low forces are used during intrusion to minimize root resorption and decrease side effects on the reactive unit.[2]

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The advent of microimplants as skeletal anchorage devices has changed the scenario and has greatly expanded the boundaries of orthodontic tooth movement in all the three planes of space. The popularity of mini-implants is especially due to their ease of placement with less traumatic procedures, less patient discomfort, possibility of immediate loading, independent of patient compliance, and high versatility.[3]

With tridimensional (3D) numeric computer analysis, such as the finite element analysis, valuable information can be obtained since various orthodontic clinical conditions can be simulated, and stress distribution in the individual constituents

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of the periodontium can be evaluated qualitatively and quantitatively.[4]

Therefore, the objective of this investigation is to evaluate the initial distribution patterns and magnitude of compressive stress in the periodontal ligament (PDL) in a simulation of orthodontic intrusion of maxillary incisors, considering the points of force application.

Materials and Methods

A three-dimensional finite element of a maxillary arch was constructed, and the stresses from various types of tooth movement were determined. There are three primary considerations in the development of the three-dimensional finite element model (FEM) tooth model: Geometry of the teeth and periodontal structures, material properties, and loading configuration. Model geometry, the geometry of our three-dimensional FEM of a maxillary incisors, was created by manually designing the tooth (enamel and dentin), PDL, and bone structure according to the dimensions and morphology found in a standard dental anatomy textbook. The outermost boundary of the tooth was defined two dimensionally at first; sectioning the tooth into cross-sections created the third dimension. The model was divided into non overlapping wedge or brick shaped volumes (elements). Nodes are defined as points at which the corners of these elements meet.

The nodes and elements used in this model were manually incorporated into the finite element software that was used for this study (HyperMesh® software (version 11, Altair® Engineering, Inc, United States of America) (Tables 1 and 2). After the model was completed, boundary conditions were defined at all peripheral nodes of the bone with 0° of movement in all directions. Each element was, then, assigned a specific material property. The material properties of enamel, dentin, PDL, and bone used in this study have been experimentally determined. The material properties used were the average values reported in the literature (Table 3).

Table 1: Number of elements and nodes in the models

Models	Number of elements	Number of nodes
Conventional group	476,932	699,568
Aligner group	336,112	434,042

Table 2: Number of elements and nodes of individual components of the models

Components	Elements	Nodes
Maxillary arch	80,292	137,820
Cortical bone	31,022	60,462
Cancellous bone	148,640	231,328
Arch wire	440	882
Bracket	67,544	118,544
Retraction hook	14	30
Niti closed coil spring	650	1302
Miniimplant	11,958	22,020
Aligner	14,242	28,688
Attachment	21,540	38,184

In first model, cone-beam computed tomography (CBCT) scan of maxillary arch with extracted first premolars was recorded using Acteon X-MIND® PRIME 3D (Aceton India Pvt. Ltd, Gandhinagar, India) with slice thickness of 1 mm. These CBCT scan were used to construct FEM models. Three-dimensional finite element models were designed. Model one shows the conventional mechanics of en masse retraction using titanium mini-implants size 1.6 × 8 mm, (FavAnchor skeletal anchorage system), archwire 0.019 × 0.025 SS (Ormco), brackets MBT 0.022" (Ormco), niti closed coil springs 10 mm (Orthotech), retraction hooks 6 mm × 2 mm (Orthotech) (Figure 1) with forces in horizontal and vertical direction for en masse retraction, and intrusion of anterior segment of maxilla. Intrusion force used was 100 g and retraction force used was 200 g which was applied on the models (Figure 2).

In second model, it shows the retraction mechanics by clear aligners using aligner of thickness of 0.38 mm, horizontal rectangular attachments (2 mm height, 3 mm width, and 1 mm thickness) for lateral incisors, vertical rectangular attachments (3 mm height, 2 mm width, and 1 mm thickness) for teeth other than central incisors, friction coefficient of $\mu = 0.2$, and forces in horizontal and vertical direction for en masse retraction and intrusion of anterior segment of maxilla. Intrusion force used was 100 g and retraction force used was 200 g which were applied on the models (Figure 3).

Results

Anterior intrusion

The maximum amount of intrusion was seen on the incisal area of lateral incisor on the Y-axis with a value of 0.0000913 Model-1 (Table 4) and on the apical most area of canine on Model-2. The amount of intrusion was seen minimum on the incisal area of central incisor of Model-2 and on the middle III of the canine of Model-1. On the lateral incisor of Model-1, the changes were gradually decreasing until the cervical III of the crown followed by moderate distribution until the middle III of the root and slight increased change was observed on the apical area. Similarly, an increased change was seen on the apical area of canine in Model-1. The anterior intrusion

Table 3: Mechanical properties of the materials used in modeling

Components	Poisson's ratio	Young's modulus
Teeth	0.26	20,300
PDL	0.49	0.667
Cortical bone	0.26	34,000
Cancellous bone	0.38	13,400
Aligner	0.36	528
Attachments	0.36	125,000
Niti closed coil spring	0.33	83,000

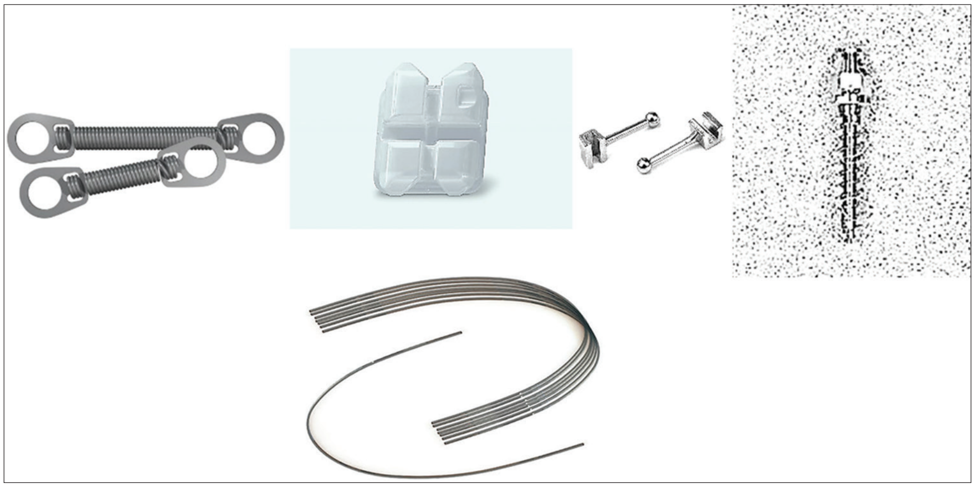


Figure 1: Geometric model of bracket (Ormco), closed coil spring (orthotech), orthodontic arch wire (Ormco), implant (Fav anchor), and retraction hook (orthotech)

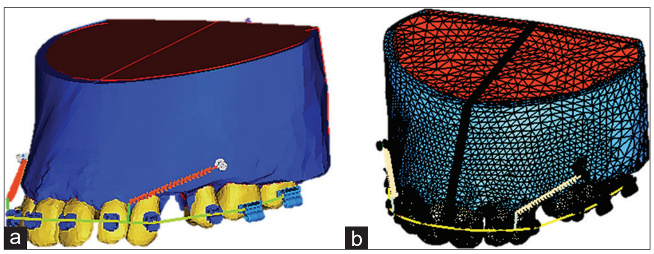


Figure 2: Finite element models with defined boundary conditions. (a) Geometric model of the maxillary arch with extracted 1st premolar and implants and (b) meshed model

was seen increasing from the incisal to apical area in Model-2 and was moderately distributed in Model-1. In Model-2, central incisor has least change on the incisal area and kept on increasing till the apical III of the root. Lateral incisor of Model-2 shows even and moderate distribution effect of intrusion, while the canine shows maximum change in the apical most region and gradually decreasing until the incisal area of the crown.

Posterior intrusion

The amount of posterior intrusion was maximum on the distal surfaces of maxillary second molars in both Model-1 and Model-2. In Model-1, the area of maximum intrusion was covering complete distal surface of the second maxillary molar tooth including its incisal, middle, and cervical areas and the distobuccal root on the Y-axis with a value of 0.00000968 (Table 5). The minimum change was seen on the mesial surface of second premolar covering coronal and until middle third of the root in Model-1 on the X-axis. In the Model-2, the minimum change was seen also on the mesial most area of the second premolar including coronal and cervical III of the root on the X-axis. The palatal root of first molar in Model-1 shows more changes than the mesial and distal root on the Z-axis. In Model-2, the posterior intrusion on maxillary second molar was observed on the higher end compared to Model-1 on maxillary second molar on the Y-axis.

Inferences of the Result

a. The anterior intrusion was seen increasing from the incisal to apical area in Model-2
b. The anterior intrusion was seen more in Model-2
c. The anterior intrusion was seen maximum on the incisal surface in Model-1
d. The anterior intrusion was seen maximum on the apical surface of canine in Model-2
e. The anterior intrusion was observed increasing from incisal to apical in Model-2
f. The amount of posterior intrusion was maximum on the distal surfaces of maxillary second molars in both Model-1 and Model-2
g. The posterior intrusion kept on increasing from mesial to distal surfaces of posterior teeth on x-axis
h. The posterior intrusion was seen more in Model-1
i. On comparison, Model-1 showed more posterior intrusion than Model-2
j. On comparison, Model-2 showed more anterior intrusion than Model-1.

Discussion

The finite element method was a numerical method for mechanical analysis. With structural discretization as the heart, it used a finite range of easy-to-analyze elements to express and address complex objects. The finite element approach was an efficient method of mechanical analysis with good numerical precision. It was specifically suited to stress-strain problems in engineering structure and solid mechanics, such as dental biomechanics. The finite element approach was currently the only *in vivo* research method for en masse retraction biomechanics that requires periodontal tissue for assessment. Moreover, the stress and displacement of any portion of the model loaded can be calculated. This research, therefore, followed a three- dimensional finite element approach to investigate the biomechanical effects of

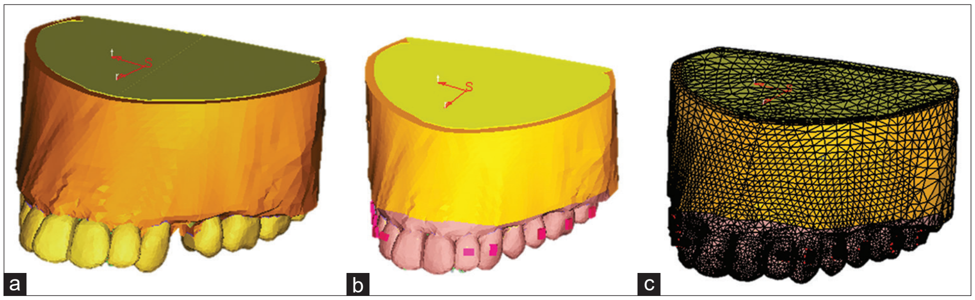
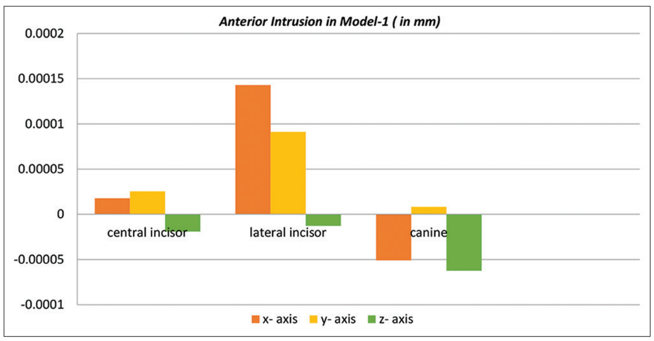
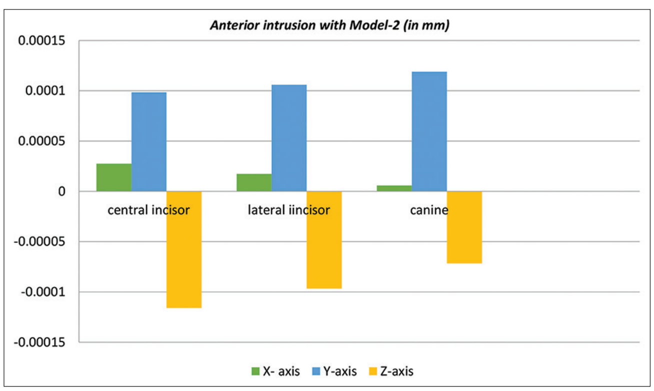


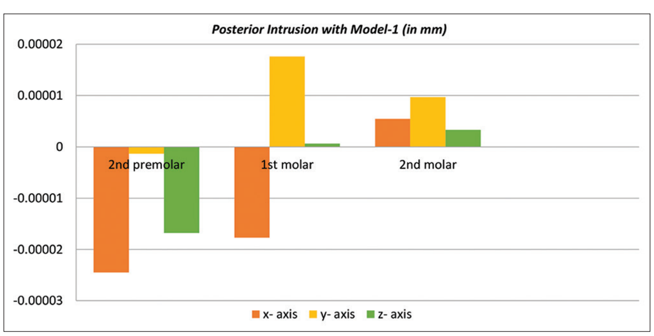
Figure 3: Three-dimensional finite element model for incisor retraction in a 1st premolar extraction case. (a) Maxillary arch with 1st premolar removal and attachments on the vestibular surfaces of crowns. (b) Geometric model of the clear aligner. (c) Mesh division on the model assembly with the aligner on dentition



Graph 1: Anterior intrusion with implant model

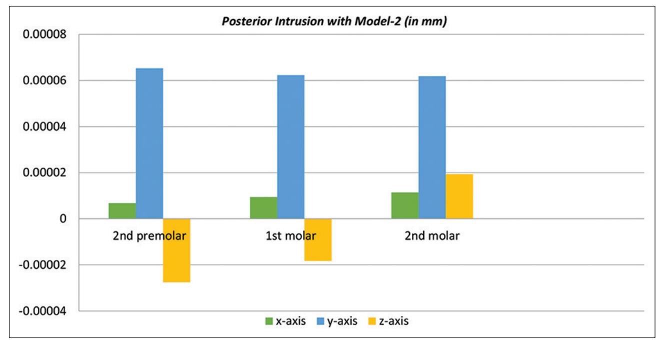


Graph 2: Anterior intrusion with aligner model



Graph 3: Posterior intrusion with implant model

CAT and conventional biomechanics on en masse retraction of maxillary anterior teeth.



Graph 4: Posterior intrusion with aligner model

Table 4: Anterior intrusion of maxillary anterior teeth of the right quadrant in both the models (all values expressed in mm)

Ateriors	Model 1 (Conventional)	Model 2 (Aligner)
Central incisor		
X-axis	0.0000178	0.0000276
Y-axis	0.0000254	0.0000985
Z-axis	−0.0000191	−0.000116
Lateral incisor		
X-axis	0.000143	0.0000174
Y-axis	0.0000913	0.000106
Z-axis	−0.0000127	−0.0000967
Canine		
X-axis	−0.0000509	0.00000582
Y-axis	0.00000818	0.000119
Z-axis	−0.0000624	−0.0000716

In extreme cases of root resorption, intrusive forces have always been suspected clinically. According to the current FEM study, there was a concentration of stress at the PDL of the root apex. The most effective predictors of EARR, according to Shaw, Sameshima, Vu, Parker, and Harris, were intrusive movement and an increase in incisor proclination.[4]

When the intrusion force was applied under various boundary conditions, the anterior intrusion was seen more in Model-2 (Figure 5) compared to Model-1 (Figure 4). The anterior intrusion was seen severe on the apex of the lateral incisor of Model-2. In general, the anterior intrusion was seen more

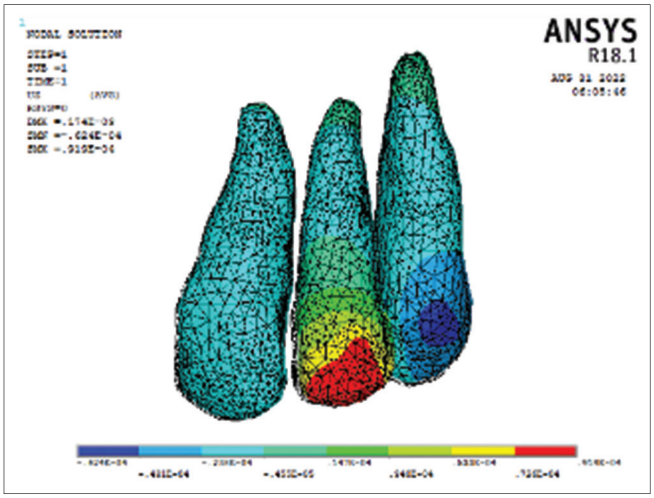


Figure 4: Anterior intrusion with conventional model

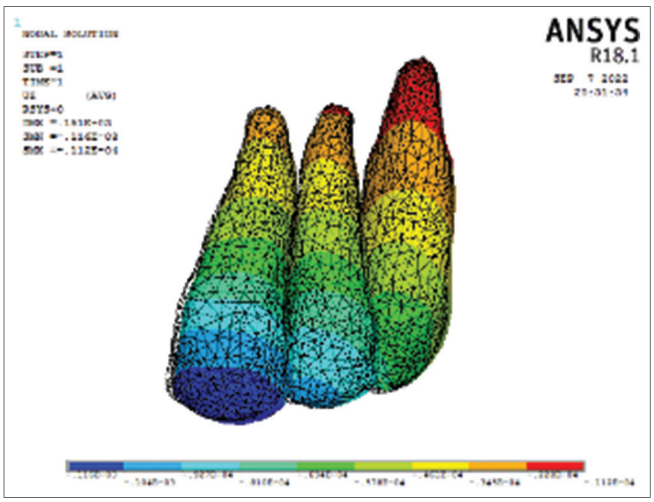


Figure 5: Anterior intrusion with aligner model

in both lateral incisor of Model-1 and Model-2. The changes during anterior intrusion were seen increasing toward the apex for Model-1 and Model-2.

During the posterior intrusionm maximum changes were observed on the distal surface of the maxillary second molar in both Model-1 and Model-2. Comparitively, more changes were distributed on the distal surface of Model-1. The impact was found to be increased when moving from mesial to distal end.

Limitations of the study

Limitations of the finite element study, analytical results of FEM, are highly dependent on the models developed; therefore, they have to be constructed to be equivalent to real objects in various aspects. The results of this study were obtained from simulated models, from which biologic variabilities may occur. Similar to previous studies, the PDL was modeled as a layer of uniform thickness and was treated as linear elastic and isotropic, even though the PDL exhibits anisotropy and non-linear viscoelastic behavior due to tissue fluid. There is no reliable and adequate data that pertain to anisotropic and nonlinear properties of the PDL. Another limitation of this study is the inability to directly predict long-term tooth

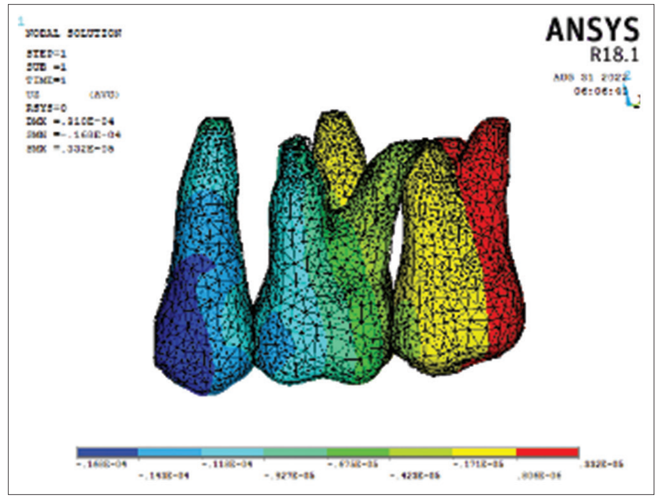


Figure 6: Posterior intrusion with conventional model

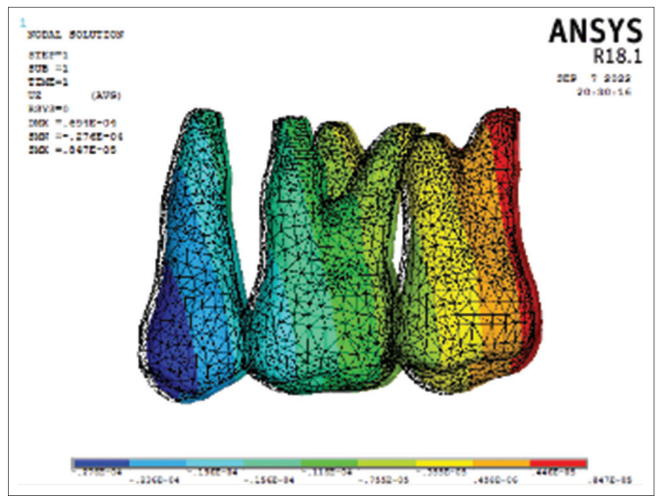


Figure 7: Posterior intrusion with aligner model

Table 5: Posterior intrusion of maxillary posterior teeth of the right quadrant in both the models (all values expressed in mm)

Posterior	Model 1 (Conventional)	Model 2 (aligner)
2nd Premolar		
X-axis	−0.0000245	0.00000682
Y-axis	−0.00000133	0.0000653
Z-axis	−0.0000168	−0.0000276
1st Molar		
X-axis	−0.0000177	0.00000941
Y-axis	0.0000176	0.0000623
Z-axis	0.000000629	−0.0000183
2nd Molar		
X-axis	0.00000546	0.0000114
Y-axis	0.00000968	0.0000619
Z-axis	0.00000332	0.0000194

movement quantitatively through simulation. FEM can only calculate initial tooth displacement and stress distribution after force application. The biological and time-dependent reaction is still unpredictable and requires more clinical evidence.[5]

Conclusion

Early studies of treated patients saw little intrusion of incisors, because the mechanics used tended to extrusion of posterior teeth with the mechanics used. It has been shown that the use of light constant forces enables the intrusion of teeth with minimal disruption of posterior anchor units. It has also been shown that as the forces for intrusion are increased, more root resorption but not necessarily a greater rate of intrusive movement may result. The upper incisors commonly must be intruded more than lower incisors to maintain the original cant of the plane of occlusion. The typical patient who requires intrusion also requires minimization of extrusion of the posterior teeth. Understanding the basic biomechanical principles involved in effecting controlled tooth movement enables achieving successful orthodontic treatment outcomes which are more predictable and consistent.[6]

Digital planning and the digital technology can be extremely beneficial for orthodontists, as well as can induce them to prescribe very unpredictable movements since the virtual environment does not necessarily reflect *in viv*o conditions.[7]

References

1. Burstone CJ. The segmented arch approach to space closure. Am J Orthod 1982;82:361-78.
2. Shroff B, Lindauer SJ, Burstone CJ, Leiss JB. Segmented approach to simultaneous intrusion and space closure: Biomechanics of the three-piece base arch appliance. Am J Orthod Dentofacial Orthop 1995;107:136-43.
3. Naqeed MA, Ponnada SR, Ganugapanta VR. Three-dimensional finite element analysis for stress distribution during intrusion and retraction using orthodontic mini-implants. Int J Dent Med 2021;7:1-9.
4. Saga AY, Maruo H, Argenta MA, Maruo IT, Tanaka OM. Orthodontic intrusion of maxillary incisors: A 3D finite element method study. Dental Press J Orthod 2016;21:75-82.
5. Bohara P, Kumar M, Sharma H, Jayprakash PK, Misra V, Savana K. Stress distribution and displacement of maxillary anterior teeth during en-masse intrusion and retraction: A FEM study. J Indian Orthod Soc 2017;51:152-9.
6. Sahu S, Samantaray S, Sahoo N, Mohanty P, Gowd S, Srinivas B. Orthodontic intrusion: An insight. Int J Oral Health Med Res 2017;3:137-40.
7. Machado RM. Space closure using aligners. Dental Press J Orthod 2020;25:85-100.