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Comparative Evaluation of Tooth Displacement Between Clear Aligners and Fixed Appliance with And Without Mini-Implant Placement During Intrusion of Maxillary Anterior Teeth- A 3-Dimensional Finite Element Analysis

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ABSTRACT

Aim: The present study is a FEM study assessing the amount of displacement of tooth during intrusion of maxillary anterior teeth for correction of gummy smile using clear aligners and conventional brackets with and without the use of mini-implants.

Materials and methods: Cone Beam Computerized Tomography (CBCT) scan which were obtained from DENTSPLY Sirona Ortophos SL 80kv 9500 cone beam 3D Extra oral imaging system with are construction volume of 50x37 mm and are constructed matrix voxel of 0.2x0.2x0.2 um. The equipment had CMOS (Complementary Metal Oxide Semiconductor) sensor technology. The field of view was 11 x 10 mm, exposure parameters for the patients varied from 70k V8mA with a scan time of 14 seconds. All the teeth were assessed by the 3D volume tricimage and 1 mm tomographic sections in sagittal, axial and coronal planes.

Result: The greatest displacement of tooth during intrusion of maxillary anterior teeth was seen clear aligners with e-chain and mini-screws and the least displacement of tooth was seen along with conventional brackets with burstone intrusion arch.

Conclusion: Gummy smile correction using clear aligners and e-chain is the best treatment modality among all four models in planning maxillary anterior intrusion.

Keywords: *Orthodontics, Gummy smile, Intrusion, conventional brackets, clear aligners, mini-screws, TADs*

1. INTRODUCTION

One of the ultimate goals of orthodontic treatment is to achieve an attractive smile. A beautiful smile must have a consonant smile arc, ideally with proportionate tooth sizes and a harmonic gingival line. However, a "gummy smile," or excessive gingival show during a smile, is seen as a drawback for aesthetics. Orthognathic surgery was often thought to be the only treatment for adult patients with gummy smiles. These days, adult patients can have their gummy grins fixed with periodontal surgery and skeletal anchorage, sometimes referred to as temporary anchorage devices (TADs) [1]

Excessive gingival show, sometimes known as the "gummy smile," is a cosmetic concern for dental patients because it is generally considered unpleasant and many of them seek treatment for it[1]. When there is more than 3 to 4 mm of gingival tissue showing when smiling, it gives the illusion of an uneven smile. Anatomical landmarks including the maxilla, lips, gingival structures, and teeth can all affect a gingival grin[1].

To create a lovely grin, all of these anatomical features must cooperate with one another[1]. Alterations in passive tooth eruption, dentoalveolar extrusion, vertical maxillary excess, hyperactive or short upper lip muscles, or a combination of these can all cause a gummy grin [2]. Modified passive eruption can be corrected with crown lengthening surgery, which is achieved via gingivectomy or a flap placed apically. Botulinum toxin injections are a nonsurgical treatment option for gummy grins that are mainly brought on by hyperactive upper lips[3].

However, it is far more difficult to treat gummy grins caused by dentoalveolar and maxillary height aetiologies. In the past, the only treatment for dentoalveolar extrusion and increased maxillary height was orthognathic surgery, which is an intrusive process[3]. However, it has been seen that gummy grins caused by increased maxillary height and dentoalveolar extrusion may occasionally be repaired with the invention of temporary skeletal anchoring devices (TADs)[3, 4].

According to some case reports, a mini-screw can be used to correct a gummy smile with the full incursion of the maxillary arch, which can have the same result as maxillary impaction with Le Fort I surgery[5]. Dental intrusion is often an essential part of orthodontic treatment because it improves the incisors' sagittal and vertical relationships, corrects the angle between the incisors and the gingival line, and restores the smile's aesthetic attractiveness[6].

Burstone defines intrusion as the apical movement of the geometric radicular center with respect to the occlusal plane or a plane defined by the long axis of the tooth, whereas Nikolai defines it as a type of translational tooth movement that move s apically along the longitudinal axis of the tooth [7–9].

The upper and lower lips frame the smile. Within this framework, the components of a smile are the teeth and the gingival scaffold[6–8]. There are three types of lip lines that show up when you smile: low, medium, and high.

The lip line is low when there is no gum showing when you smile. The lip line is medium when there is 1-3 mm of gum visible during a grin; it is high when there is more than 4 mm of gingival display during a smile, which is known as a gummy smile.

With the exception of a few case reports, little study has been done on the significance of using mini-implant absolute anchorages to fully invade the arch and repair the gummy grin brought on by dentoalveolar extrusion and vertical maxillary excess[3–5]. Thus, our goal was to use TADs to simulate four distinct full arch intrusion strategies for the first time and investigate their dynamics, effectiveness, and possible drawbacks (e.g., the risk of root resorption, which is indicated by an excessively high PDL hydrostatic pressure that can collapse the capillaries and impair blood flow[10, 11].

Orthodontic research has made extensive use of the Finite Element Method (FEM), an engineering technology used to compute stress and deformation of complex structures.

FEM offers the benefit of being a precise, non-invasive technique that yields quantitative, in-depth information on potential physiological reactions in tissue. The visualisation of these reactions can be predicted using the FEM by looking at the areas of stress created by applied orthodontic forces. When using various orthodontic device kinds, FEM may evaluate the distribution of stress at the interface between PDL and alveolar bone as well as the shifting trend in various tooth movement types. FEM is a legitimate and trustworthy method for forecasting the movement of teeth that will occur during orthodontic therapy[13].

2. MATERIALS AND METHODS

MATERIAL

1. Cone Beam Computerized Tomography (CBCT) scan which were obtained from DENTSPLY Sirona Ortophos SL 80kv 9500 cone beam 3D Extra oral imaging system with are construction volume of 50x37 mm and are constructed matrix voxel of 0.2x0.2x0.2 um. The equipment had CMOS (Complementary Metal Oxide Semiconductor) sensor technology. The field of view was 11 x 10 mm, exposure parameters for the patients varied from 70k V8mA with a scan time of 14 seconds. All the teeth were assessed by the 3D volume tricimage and 1 mm tomographic sections in sagittal, axial and coronal planes.
2. 3D finite element models simulating

a) Maxillary arch containing Central Incisor, Lateral Incisor, Canine, Second Premolar, First and Second Molar with surrounding period on talligament and alveolar bone.

b) Brackets (0.022x0.028 slot dimensions) on each tooth (OSL M3), 0.016 NiTi (OSL), TAD (1.6x8 mm), Aligner- PET G sheet(0.5 mm) and Power Chain (Ormco Gen 2).

3. Hyper Mesh software (version 11, Altair Engineering, Inc. USA). Hyper Mesh software is a multi-disciplinary finite element pre-processor software which imports STL file format of CBCT CAD-CAM images and processes these images to form meshed finite element models that can be used forvarious problem solving.

4. ANSYS software (version 18.1, ANSYS Inc, Southpointe, Pittsburgh (USA). ANSYS is a software which analyses the meshed finite element models and numerically solves various wide variety of mechanical problems like displacement of teeth when load is applied, stress distribution around the PDL strain energy etc.

METHODS

Exclusion Criteria:

1. Patient with pathologies.
2. Patient having prosthesis
3. Patient with compromised periodontal health.
4. Patient with congenitally missing teeth except for the 3rd molars.

Inclusion Criteria:

1. Patient with permanent dentition.
2. Patient with gummy smile (Gingival display> 4 mm)
3. Patients with deep bite.

A patient with gummy smile with deep bite was undergoing orthodontic treatment in People's Dental Academy's Orthodontics Department, a finite element analysis was performed to compare stress distribution between clear aligner and fixed appliance with and without the use of mini-implants during intrusion of maxillary anterior teeth. Approval for this study was granted by RAC & IEC from Peoples Dental Academy and Peoples University Bhopal. A CBCT of a maxilla with extracted first premolar was obtained from DENTSPLY Sirona Ortophos. In the process of finite element (FE) model construction the Digital Imaging and Communications in Medicine (DICOM) files exported from CBCT which were obtained from DENTSPLY Sirona Ortophos SL 80 kv 9500 cone beam 3D Extra oral imaging system with a reconstruction volume of 50x37 mm and a reconstructed matrix voxel of 0.2 x 0.2 x 0.2 um. The equipment had CMOS (complementary metaloxide semiconductor) sensor technology. Exposure parameters for the patients varied from 70k V8mA with a scan time of 14 seconds.The impacted teeth were assessed by the 3D volumetric image and 1 mm tomographic sections in sagittal, axial and coronal planes. The field of view was 11x10 mm (from the bottom of the chin to the top of the jaw).

All the images were visualized by Sirona Orthophos software on a standard. The DICOM files were converted to stereo lithography (STL) files using the Hyper Mesh software (version 11, Altair Engineering, Inc, USA). The 3D FE models consisted of unilateral maxillary quadrant from central incisor to second molar except first premolar and the constructed PDL for each tooth. The virtual PDL models were constructed around the root surface of each tooth with a 0.25mm, uniform thickness. Each model consisted of a cancellous bone surrounded by a 1mm thick cortical bone.

Defining the boundary condition

The boundary conditions were defined to simulate how the model would be constrained and to prevent it from free body motion. The nodes attached to the area of the outer surface of the bone were fixed in all directions to avoid free movements. At the connected nodes between the archwire and the brackets, translational degrees of freedom in the two flexural directions of the archwire was coupled to deform together, and translational degrees of freedom in the axial direction of the archwire was un constrained. The contact condition between each structure of the FE model was assigned as tie-contact constraint. The tie-contact constraint was defined as the contact between each part of the model being perfectly bonded, but the surface on each part being separated.

Virtual Models

MODEL 1: Conventional fixed appliance with burstone intrusion arch (Fig.1)

MODEL 2: Clear aligner with power ridge (Fig.2)

MODEL 3: Conventional fixed appliance with Two Mini-implants distal to central incisor (Fig.3)

MODEL 4: Clear aligner with Two Mini-implants distal to central incisors (Fig.4)

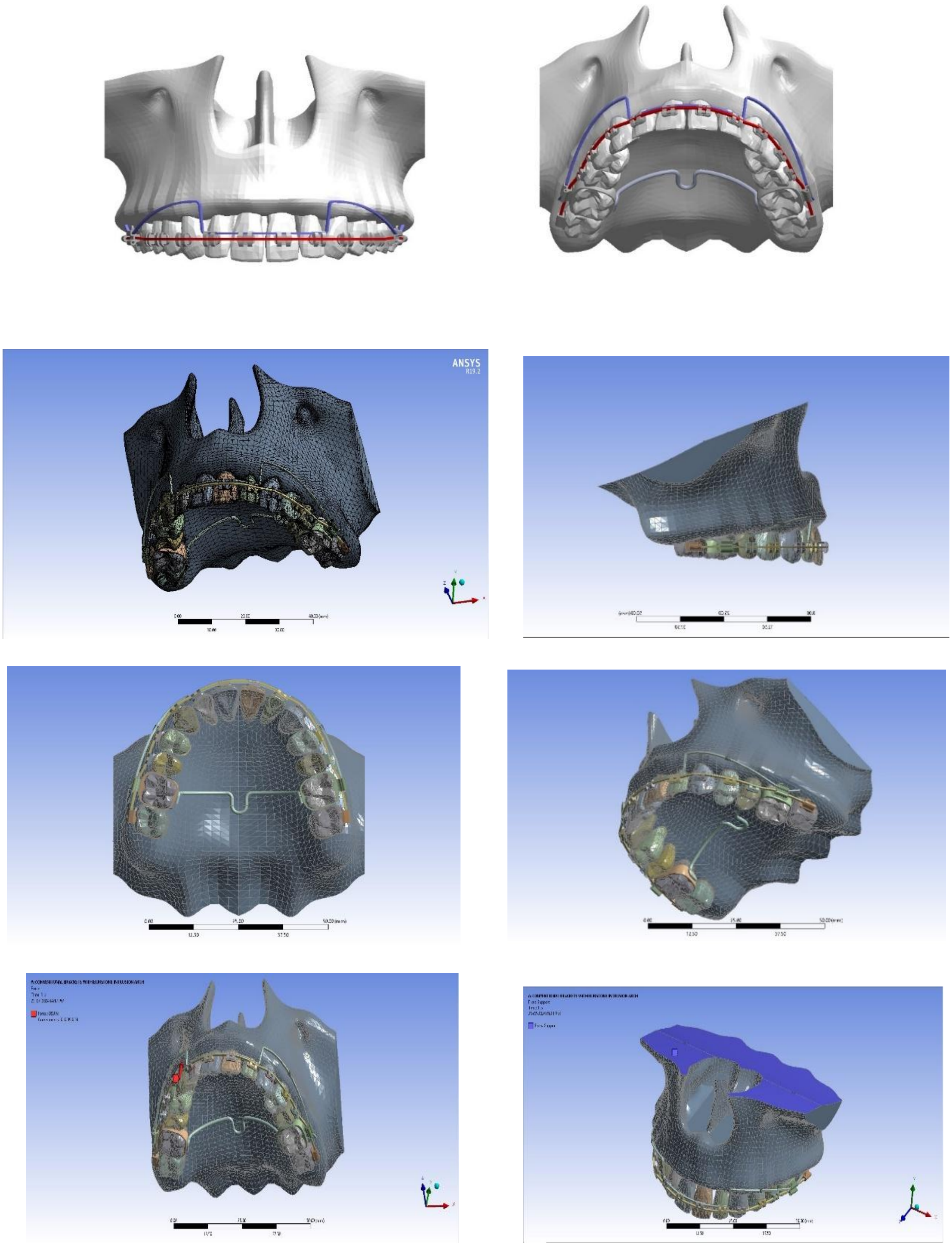
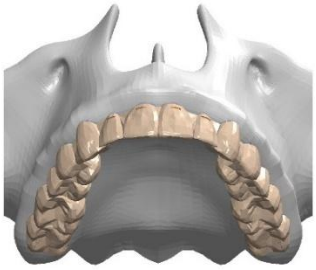
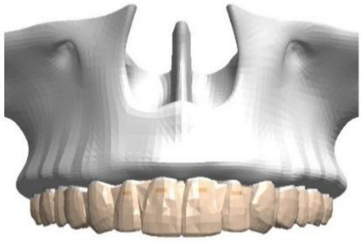
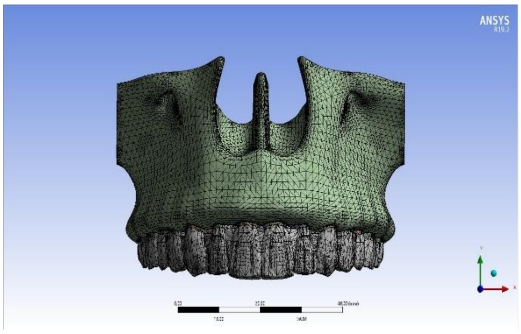


Fig. 1: Conventional fixed appliance with burstone intrusion arch



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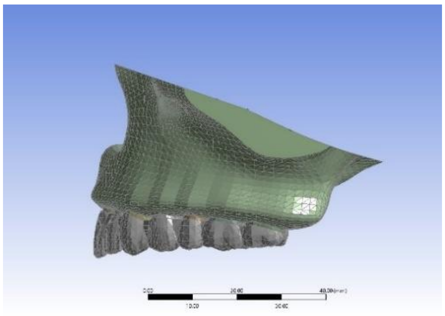
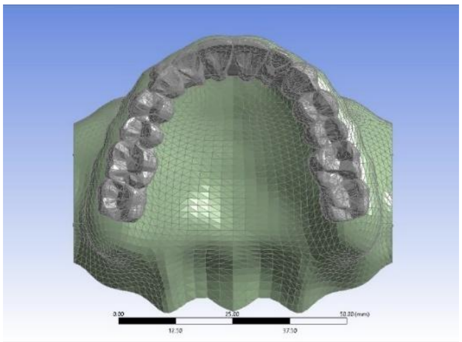
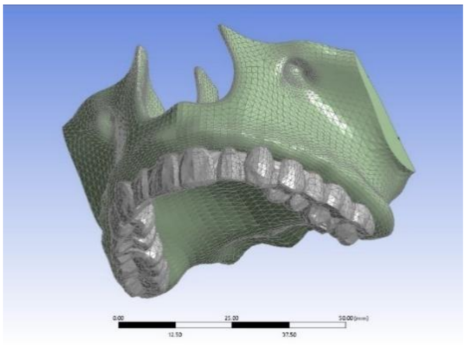
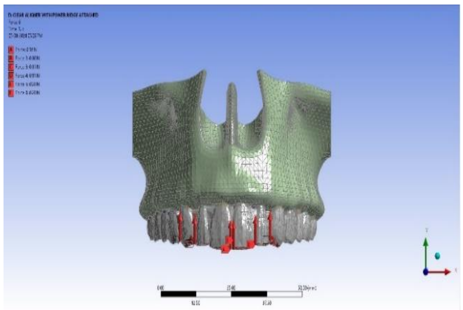
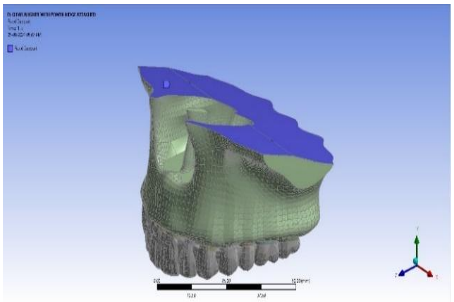
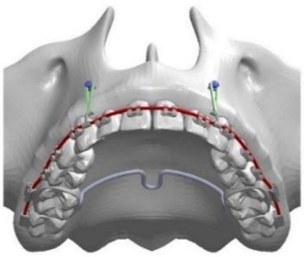


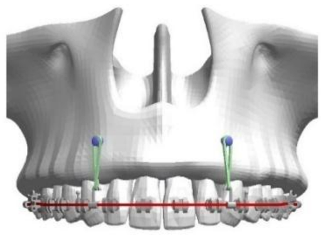












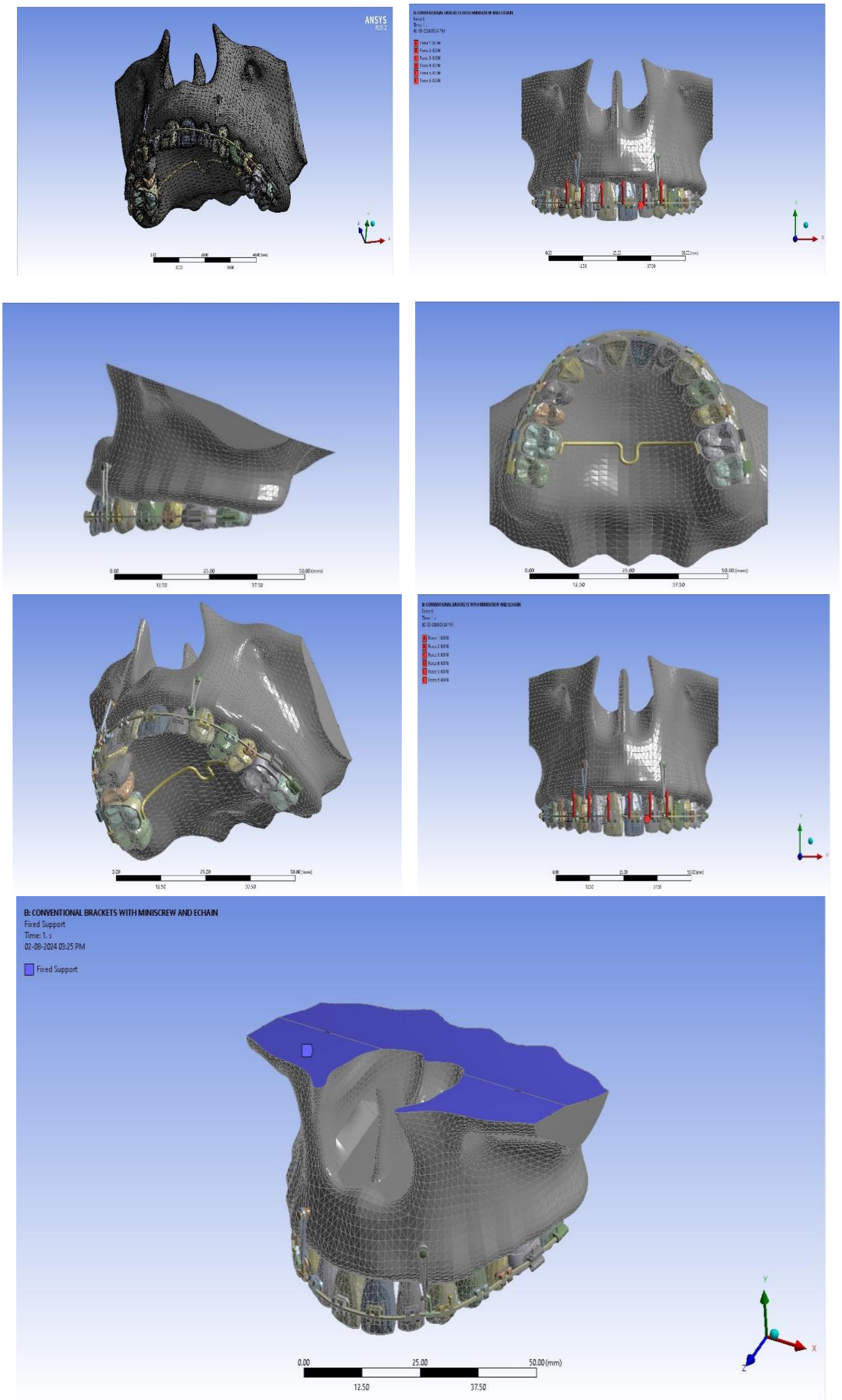


Fig. 3: Conventional fixed appliance with Two Mini-implants distal to central incisors

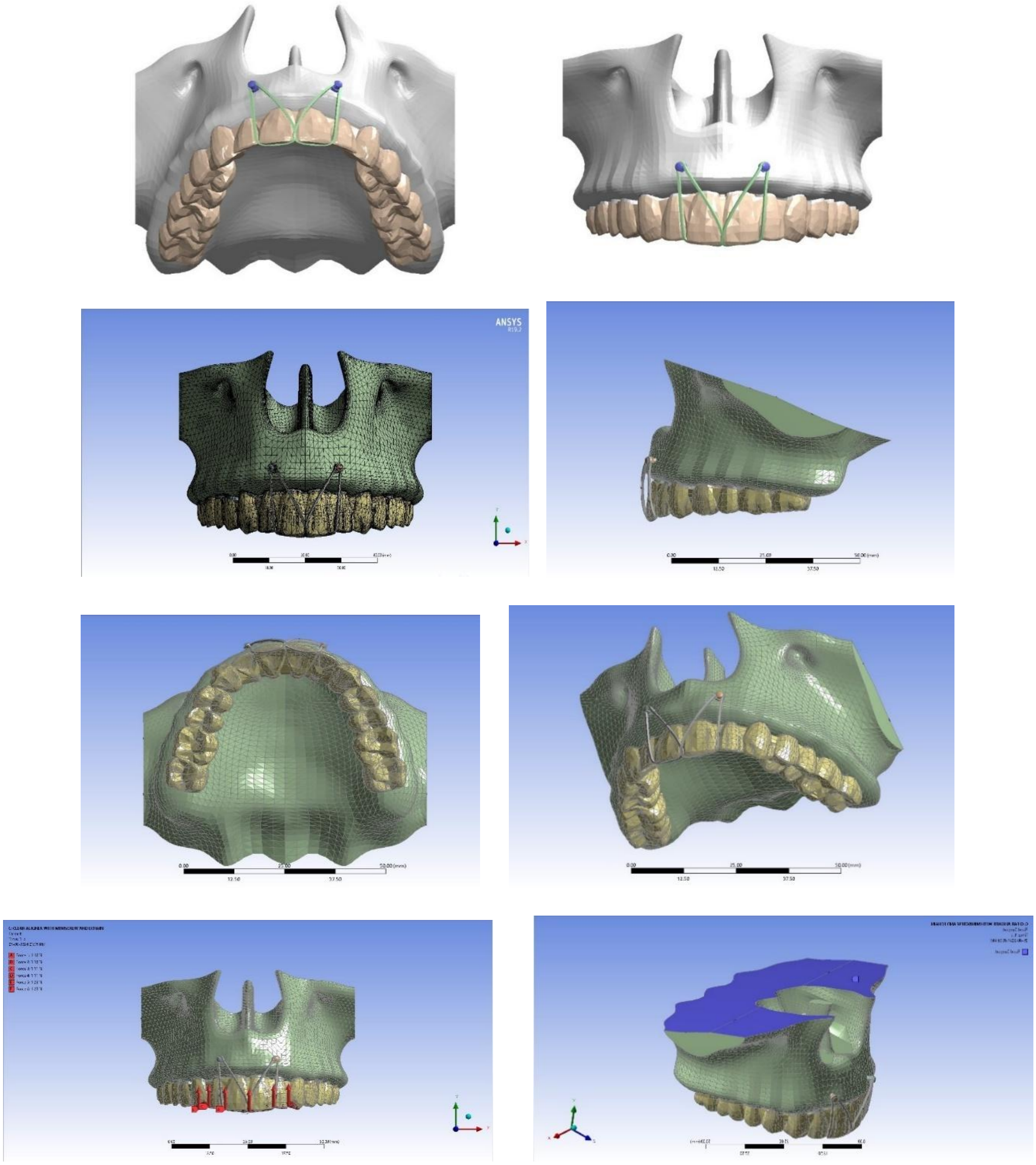


Fig. 4: Clear aligner with Two Mini-implants distal to central incisors

MODEL 1: Conventional brackets (3M Unitec) along with banding of 1st molars were done. The wire used was 0.019x0.025 stainless steel secured into brackets using 0.20 stainless steel ligation wire. TPA (Trans palatal arch) was placed engaging the 1st molars made up of 0.9 stainless steel wire. Burstone intrusion arch (0.017x0.025 TMA) was placed distal to laterals for intrusion of maxillary anterior teeth. For intrusion of maxillary anterior teeth 100 grams of force was applied per side.

MODEL 2: Aligners (0.5 mm) were engaged to maxillary arch till 2nd molar. Power ridge attachment was placed onto gingival 3rd of the buccal surface of maxillary anterior teeth.

MODEL 3: Conventional brackets (3M Unitec) along with banding of 1st molars were done. The wire used was 0.019x0.025 stainless steel secured into brackets using 0.20 stainless steel ligation wire. TPA (Trans palatal arch) was placed engaging the 1st molars made up of 0.9 stainless steel wire. TADs (1.6x8 mm) were placed distal to lateral incisors and connected to arch wire using 3.5 oz elastics.

MODEL 4: Aligners (0.5 mm) were engaged to maxillary arch till 2nd molar. TADs (1.6x8 mm) were placed distal to lateral incisors and connected to aligner cut present lingual to maxillary central incisor using 3.5 oz elastics.

Material properties

Materials in the models were assigned the properties explained in Table 1. A elastic chain was used for the intrusion of 3.5 ounces.

Table. 1

Material properties	Material Elastic modulus (MPa)	Poisson ratio
Cortical bone	1000	0.3
Cancellous bone	500	0.3
Dentine	18600	0.3
PDL	0.15	0.45
Stainless steel	200000	0.3
NiTi	34000	0.3
Miniscrew titanium G5	115000	0.33

Materials in the models were assigned the properties explained in Table 1. The simulated elastic chain was used of 3.5 ounces in Model 2 and Model 4.

Meshing

After applying the properties of the components, their meshing, which is one of the main parts of finite element analysis, was performed. To do this, the model was divided into smaller three-dimensional parts called elements, which were made up of a number of nodes. The total number of elements in all the models were 16,60,697 tetrahedral elements, and the number of nodes were 36,38,347.

Table. 2

NUMBER OF NODES AND ELEMENTS			
S. No.	CASE	NODES	ELEMENTS
1	CONVENTIONAL BRACKETS WITH BURSTONE INTRUSION ARCH	782380	429994
2	CLEAR ALIGNER WITH POWER RIDGE ATTACHED	874799	483853
3	CONVENTIONAL BRACKETS WITH MINISCREW AND ECHAIN	836150	482220
4	CLEAR ALIGNER WITH MINISCREW AND ECHAIN	1118018	651630

Boundary Conditions

In the next step, boundary conditions were applied: in this step, the fixed parts of the model were identified and forces were applied to the model. The maxilla was immobilized at its upper surface.

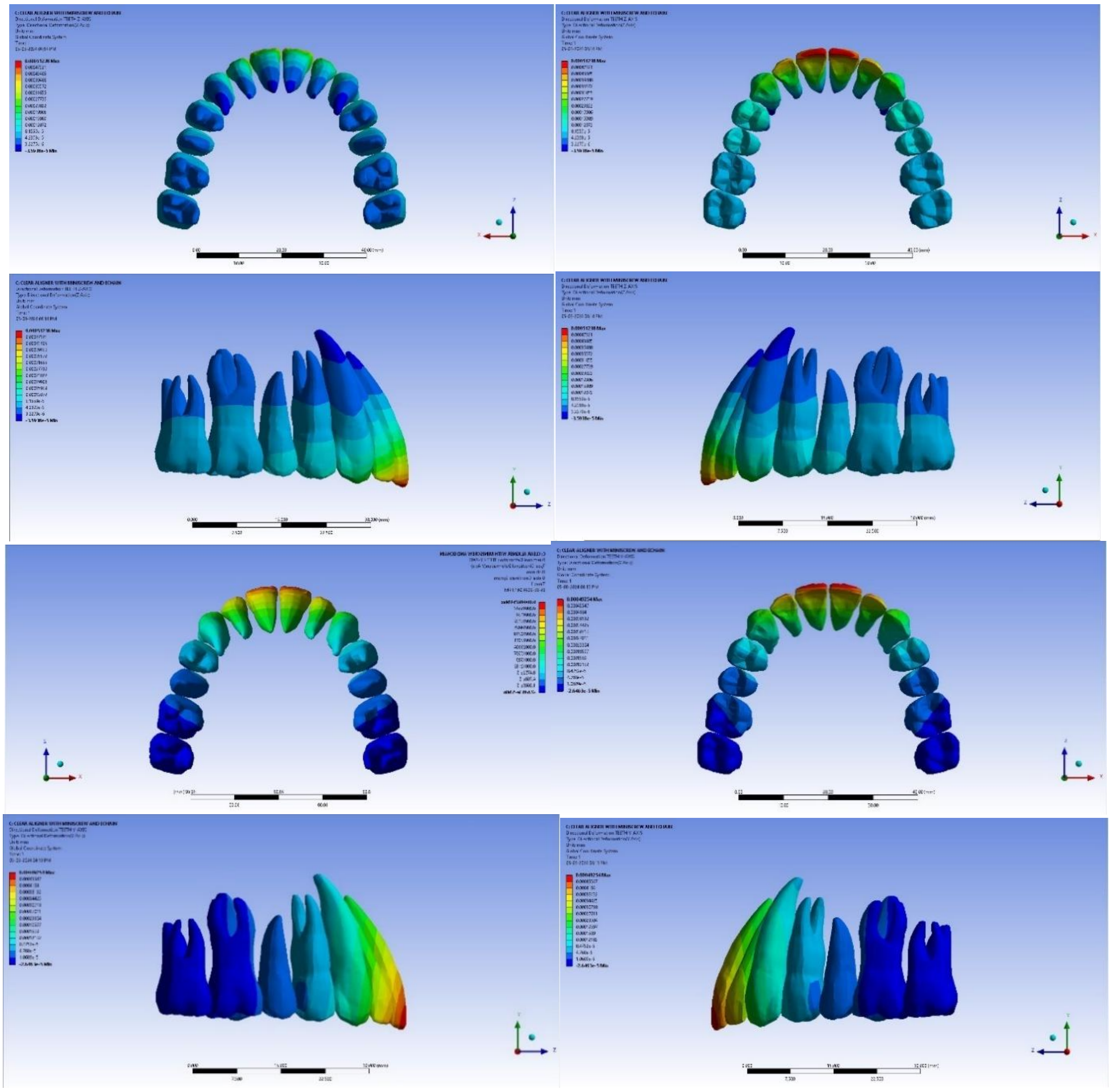
Outcomes

The duration for finite element simulations was 1 second. The created and loaded models were compared regarding displacement of PDL in x-axis, y-axis and z-axis.

Statistical Analysis

Data was entered in a Microsoft Excel spreadsheet and descriptive data were analyzed using SPSS software Version 26.0 (SPSS Inc., Chicago, IL, USA). Descriptive statistics and the Wilcoxon signed-rank test were used to analyze the results. For statistical purposes, a p-value of ≤0.05 was considered significant.

3. RESULT



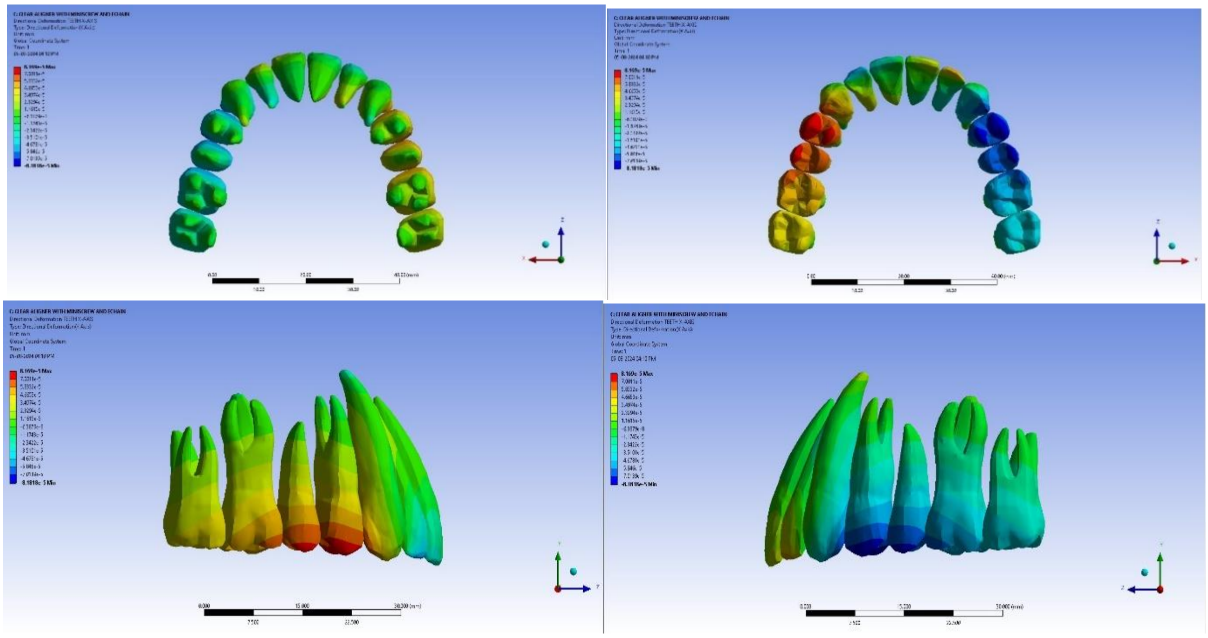
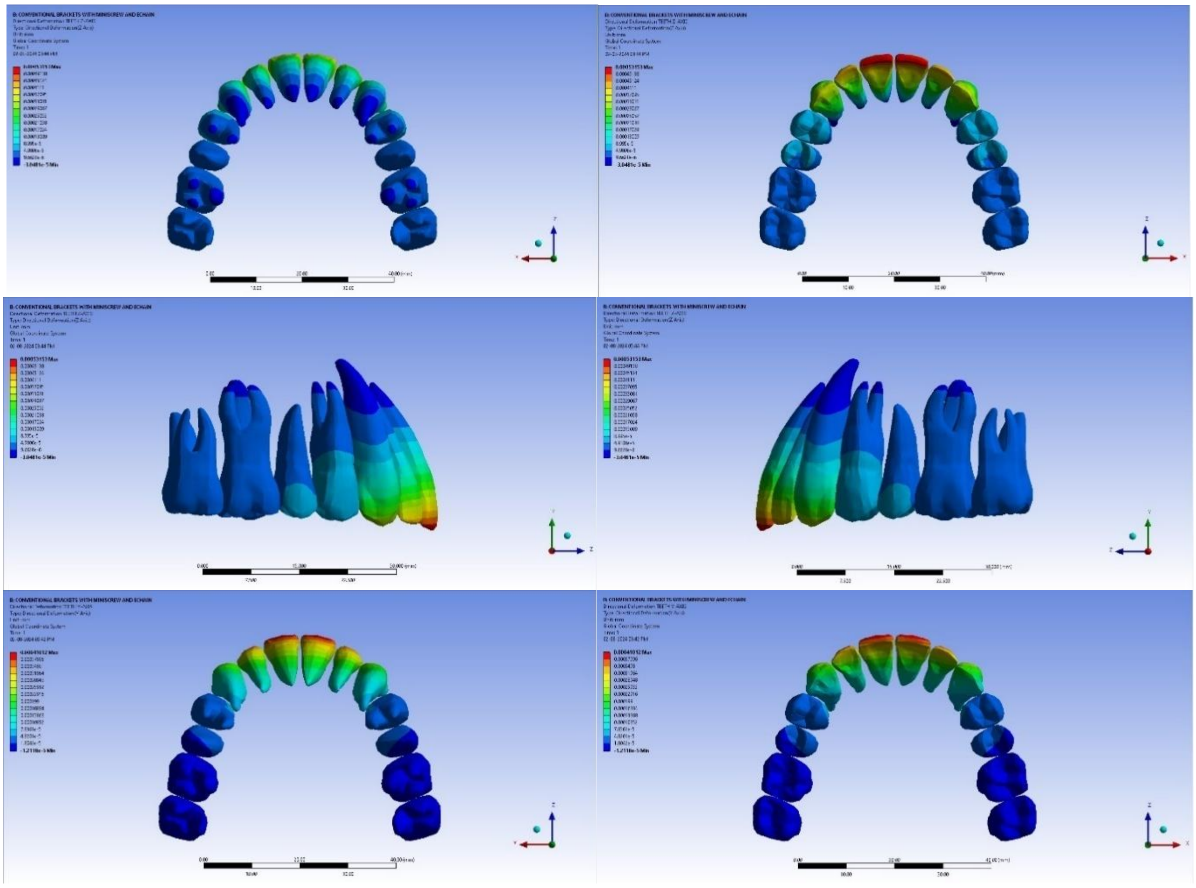


Fig 5. Directional displacement of tooth in x, y and z-axis in clear aligners with e-chain and mini-screws



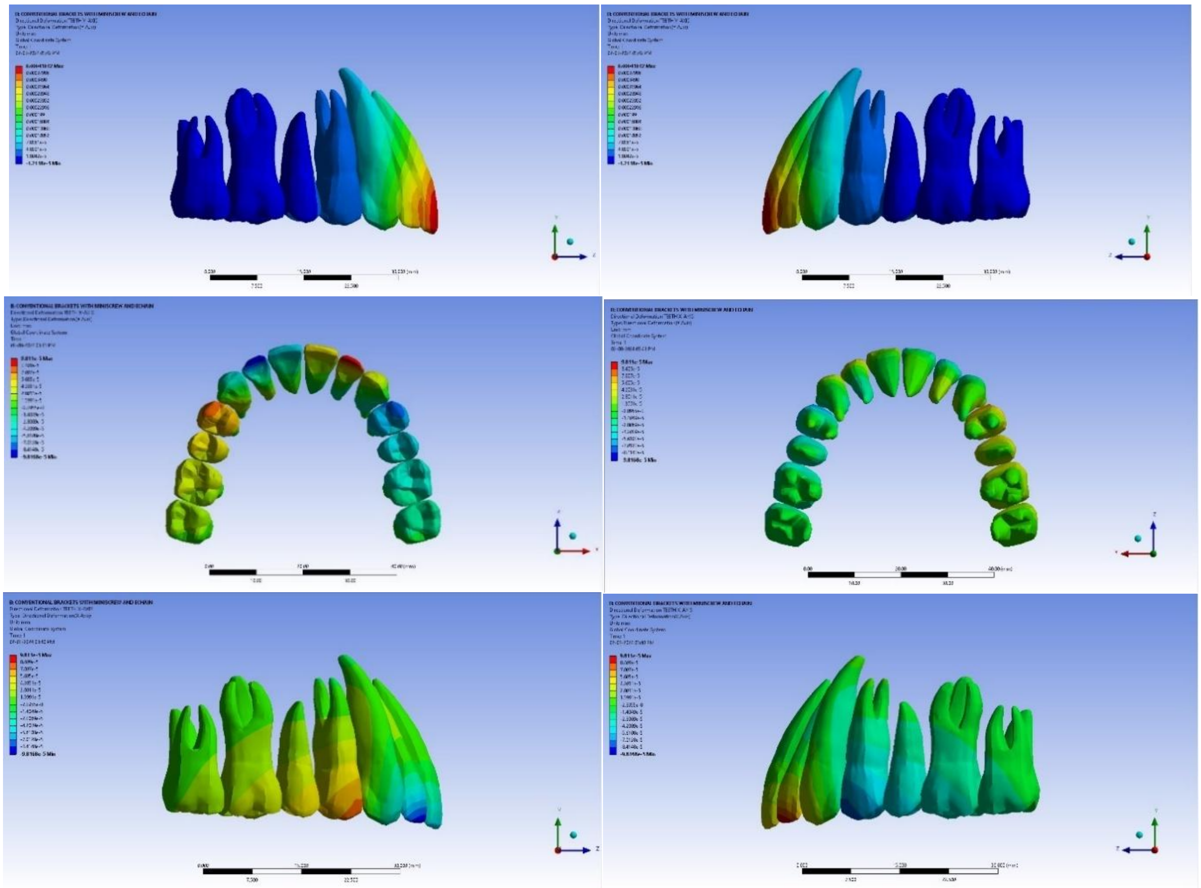
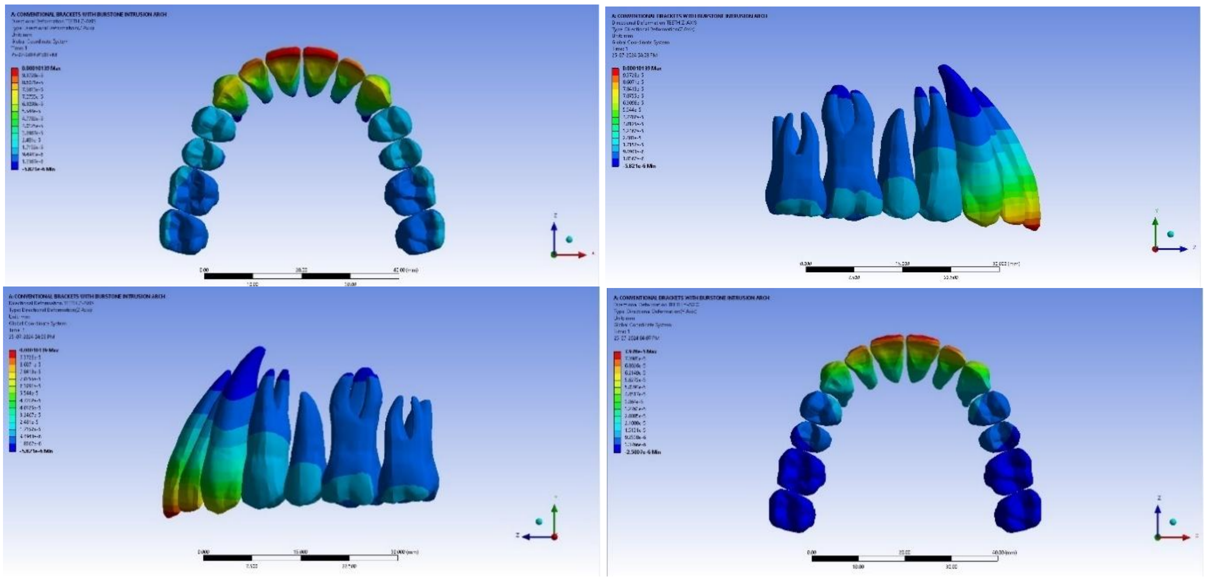


Fig 6 . Directional displacement of tooth in x, y and z-axis in conventional brackets with mini-screws and e-chain



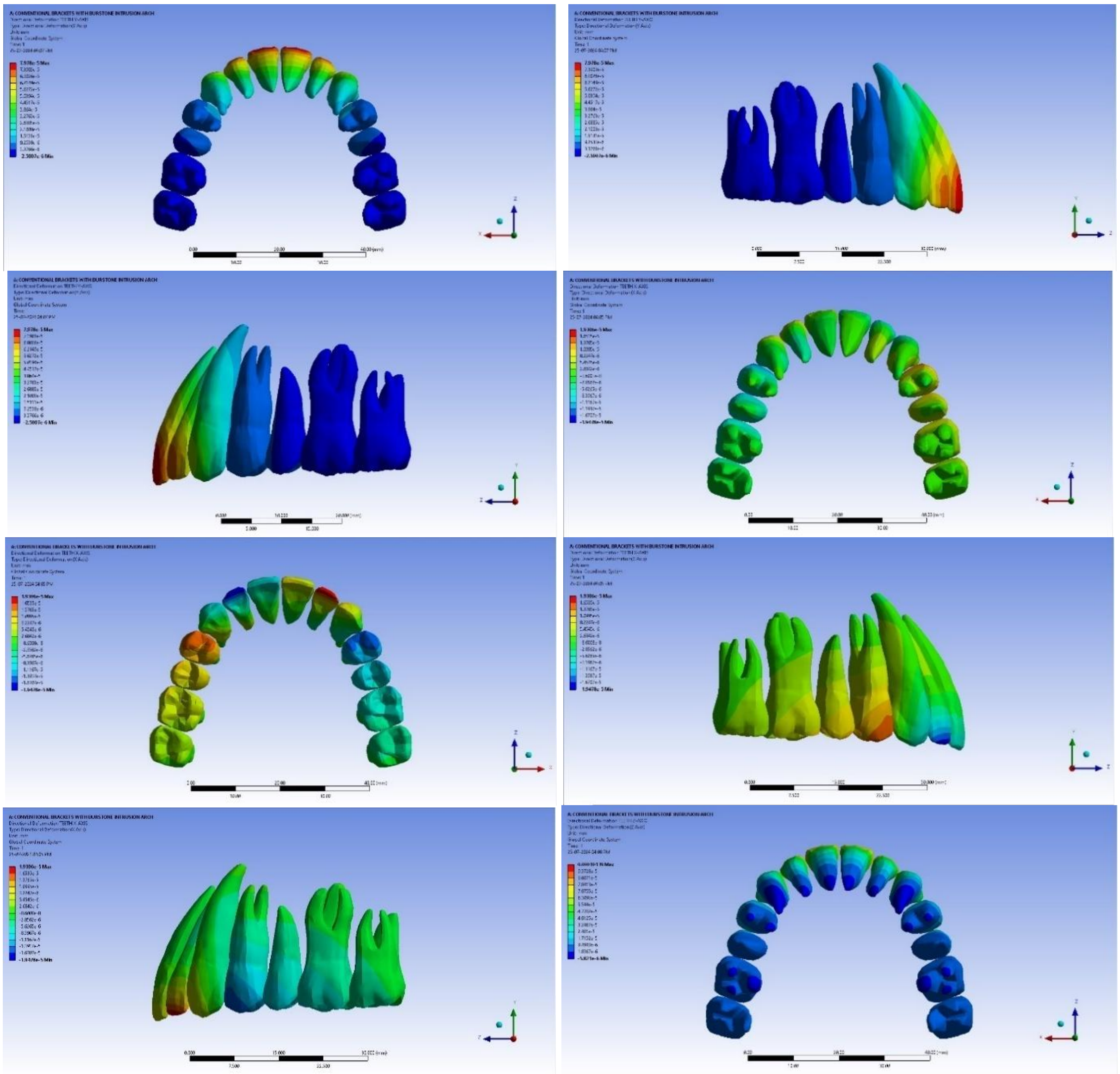
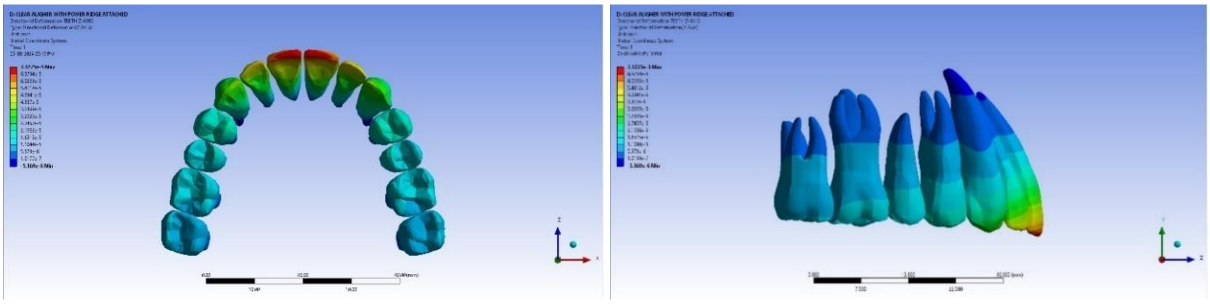


Fig 7. Directional displacement of tooth in x, y and z-axis in conventional brackets with burstone intrusion arch



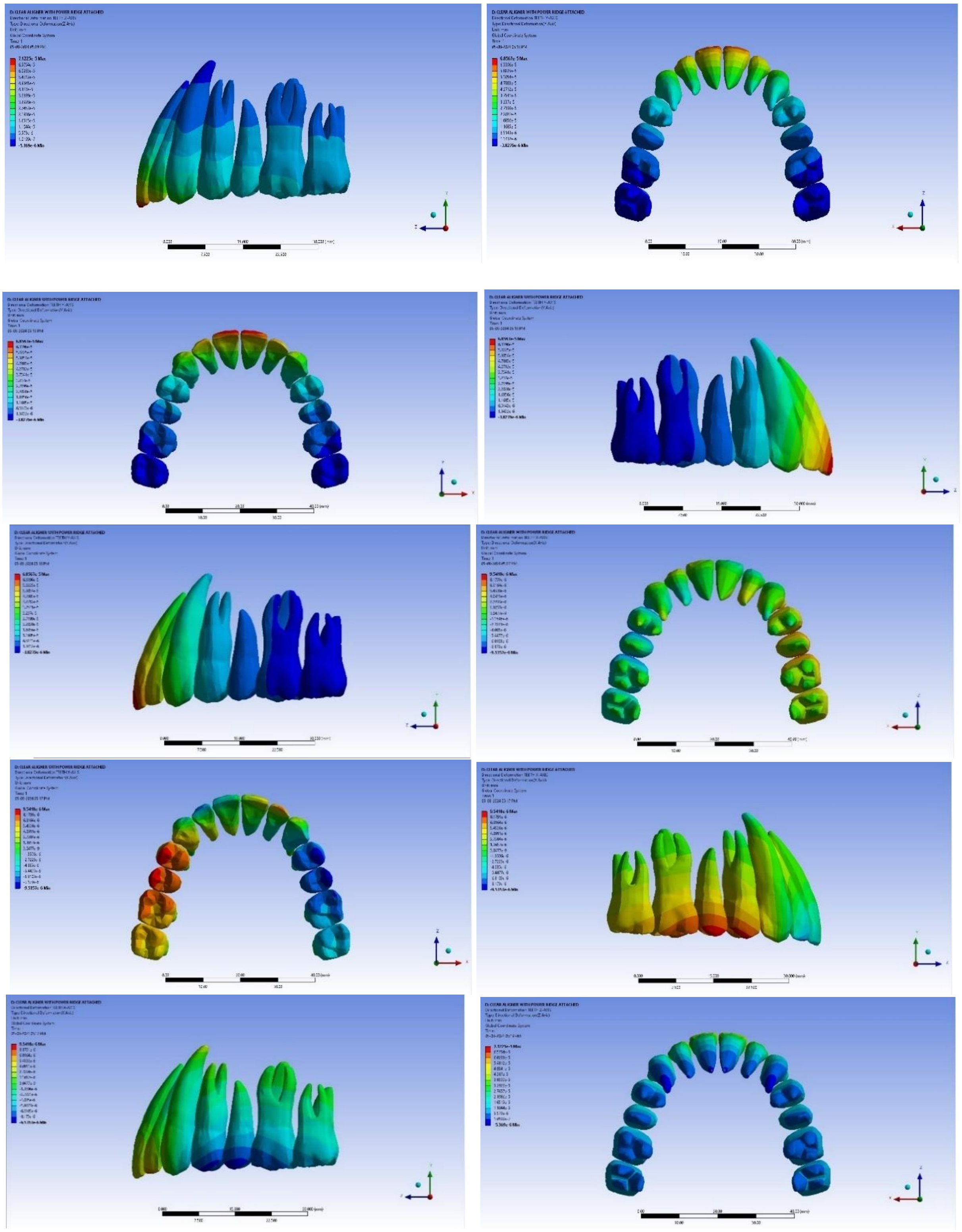


Fig 8. Directional displacement of tooth in x, y and z-axis in aligners with power ridges

Table. 3 CONVENTIONAL BRACKETS WITH BURSTONE INTRUSION ARCH DIRECTIONAL DISPLACEMENT (mm)

SR NO.	TOOTH		X - AXIS	Y- AXIS	Z- AXIS
			AVERAGE	AVERAGE	AVERAGE
1	RIGHT	SECOND MOLAR	2.11E-06	-5.74E-07	5.68E-06
2		FIRST MOLAR	3.66E-06	1.30E-06	5.75E-06
3		SECOND PREMOLAR	6.40E-06	3.75E-06	7.92E-06
4		FIRST PREMOLAR	7.01E-06	7.08E-06	8.20E-06
5		CANINE	5.61E-08	2.41E-05	2.90E-05
6		LATERAL INCISOR	-4.20E-06	4.40E-05	4.33E-05
7		CENTRAL INCISOR	-1.81E-06	5.06E-05	4.61E-05
8	LEFT	SECOND MOLAR	-2.11E-06	-5.74E-07	5.67E-06
9		FIRST MOLAR	-3.67E-06	1.29E-06	5.79E-06
10		SECOND PREMOLAR	-6.37E-06	3.75E-06	7.86E-06
11		FIRST PREMOLAR	-7.07E-06	7.06E-06	8.17E-06
12		CANINE	-7.25E-08	2.39E-05	2.90E-05
13		LATERAL INCISOR	4.15E-06	4.41E-05	4.34E-05
14		CENTRAL INCISOR	1.68E-06	5.03E-05	4.56E-05

Table. 4 CONVENTIONAL BRACKETS WITH MINISCREW AND ECHAIN DIRECTIONAL DISPLACEMENT (mm)

SR NO.	TOOTH		X - AXIS	Y – AXIS	Z-AXIS
			AVERAGE	AVERAGE	AVERAGE
1	RIGHT	SECOND MOLAR	1.03E-05	-2.82E-06	2.74E-05
2		FIRST MOLAR	1.77E-05	6.20E-06	2.78E-05
3		SECOND PREMOLAR	3.08E-05	1.81E-05	3.84E-05
4		FIRST PREMOLAR	3.34E-05	3.42E-05	3.98E-05
5		CANINE	4.20E-07	1.18E-04	1.39E-04
6		LATERAL INCISOR	-2.28E-05	2.15E-04	2.13E-04
7		CENTRAL INCISOR	-1.20E-05	2.57E-04	2.40E-04
8	LEFT	SECOND MOLAR	-1.03E-05	-2.80E-06	2.74E-05
9		FIRST MOLAR	-1.78E-05	6.16E-06	2.80E-05
10		SECOND PREMOLAR	-3.07E-05	1.80E-05	3.81E-05
11		FIRST PREMOLAR	-3.36E-05	3.42E-05	3.98E-05
12		CANINE	-3.52E-07	1.18E-04	1.38E-04

13		LATERAL INCISOR	2.29E-05	2.15E-04	2.13E-04
14		CENTRAL INCISOR	1.16E-05	2.55E-04	2.37E-04

Table. 5 CLEAR ALIGNER WITH MINISCREW AND ECHAIN DIRECTIONAL DISPLACEMENT (mm)

SR NO.	TOOTH		X - AXIS	Y – AXIS	Z-AXIS
			AVERAGE	AVERAGE	AVERAGE
1	RIGHT	SECOND MOLAR	2.18E-05	-6.52E-06	4.35E-05
2		FIRST MOLAR	2.79E-05	9.25E-06	4.60E-05
3		SECOND PREMOLAR	4.07E-05	3.05E-05	6.51E-05
4		FIRST PREMOLAR	3.30E-05	6.93E-05	6.58E-05
5		CANINE	2.15E-05	1.50E-04	9.60E-05
6		LATERAL INCISOR	1.43E-06	2.63E-04	1.83E-04
7		CENTRAL INCISOR	-2.20E-06	3.22E-04	2.13E-04
8	LEFT	SECOND MOLAR	-2.17E-05	-6.48E-06	4.35E-05
9		FIRST MOLAR	-2.81E-05	9.17E-06	4.63E-05
10		SECOND PREMOLAR	-4.05E-05	3.05E-05	6.48E-05
11		FIRST PREMOLAR	-3.31E-05	6.93E-05	6.60E-05
12		CANINE	-2.14E-05	1.50E-04	9.60E-05
13		LATERAL INCISOR	-1.34E-06	2.63E-04	1.84E-04
14		CENTRAL INCISOR	1.85E-06	3.20E-04	2.11E-04

Table. 6 CLEAR ALIGNER WITH POWER RIDGE ATTACHED DIRECTIONAL DISPLACEMENT (mm)

SR NO.	TOOTH		X - AXIS	Y – AXIS	Z-AXIS
			AVERAGE	AVERAGE	AVERAGE
1	RIGHT	SECOND MOLAR	3.04E-06	-9.09E-07	6.55E-06
2		FIRST MOLAR	3.70E-06	1.60E-06	6.96E-06
3		SECOND PREMOLAR	5.02E-06	5.25E-06	9.95E-06
4		FIRST PREMOLAR	3.62E-06	1.15E-05	1.01E-05
5		CANINE	1.70E-06	2.36E-05	1.45E-05
6		LATERAL INCISOR	-6.11E-08	3.67E-05	2.54E-05
7		CENTRAL INCISOR	-3.25E-07	4.45E-05	2.94E-05
8	LEFT	SECOND MOLAR	-3.03E-06	-9.08E-07	6.54E-06
9		FIRST MOLAR	-3.72E-06	1.60E-06	6.99E-06
10		SECOND PREMOLAR	-4.98E-06	5.24E-06	9.92E-06
11		FIRST PREMOLAR	-3.64E-06	1.16E-05	1.02E-05

12		CANINE	-1.69E-06	2.35E-05	1.45E-05
13		LATERAL INCISOR	6.18E-08	3.68E-05	2.55E-05
14		CENTRAL INCISOR	2.81E-07	4.43E-05	2.90E-05

MODEL 1:

In this model, the highest amount of intrusion was seen in the lateral incisor (maximum intrusion: 0.00045 mm/ $4.5x10^{-5}$ mm). The least amount of intrusion of seen in central incisor (minimum intrusion: 0.00029 mm/ $2.9x10^{-5}$ mm). The average intrusion placed on the anterior segment was 0.00039 mm/ $3.9x10^{-5}$ mm (Figures 1, 7 and Table 3).

MODEL 2:

In this model, the highest amount of intrusion was seen in the central incisor (maximum intrusion: 0.00029 mm/ $2.9x10^{-5}$ mm). The least amount of intrusion of seen in canine (minimum intrusion: 0.00014 mm/ $1.4x10^{-5}$ mm). The average intrusion placed on the anterior segment was 0.00023 mm/ $2.3x10^{-5}$ mm (Figures 2, 8 and Table 6).

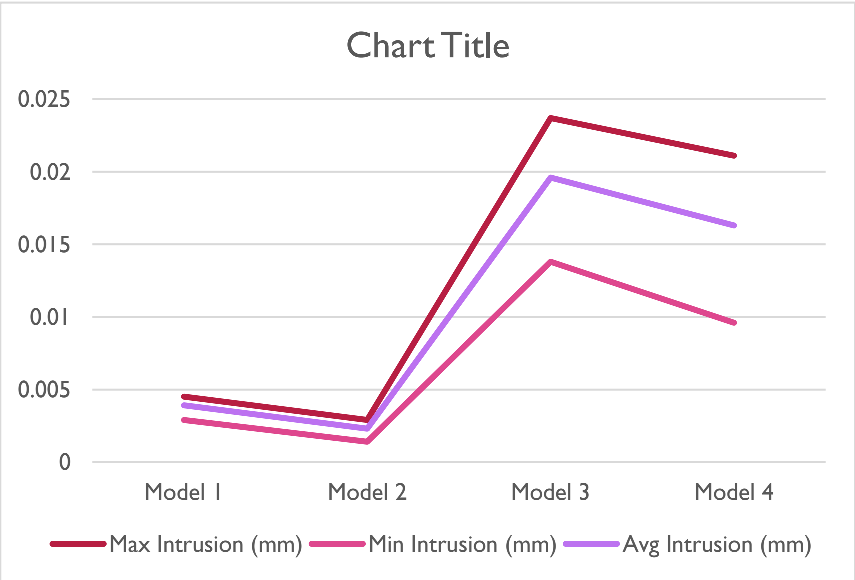
MODEL 3:

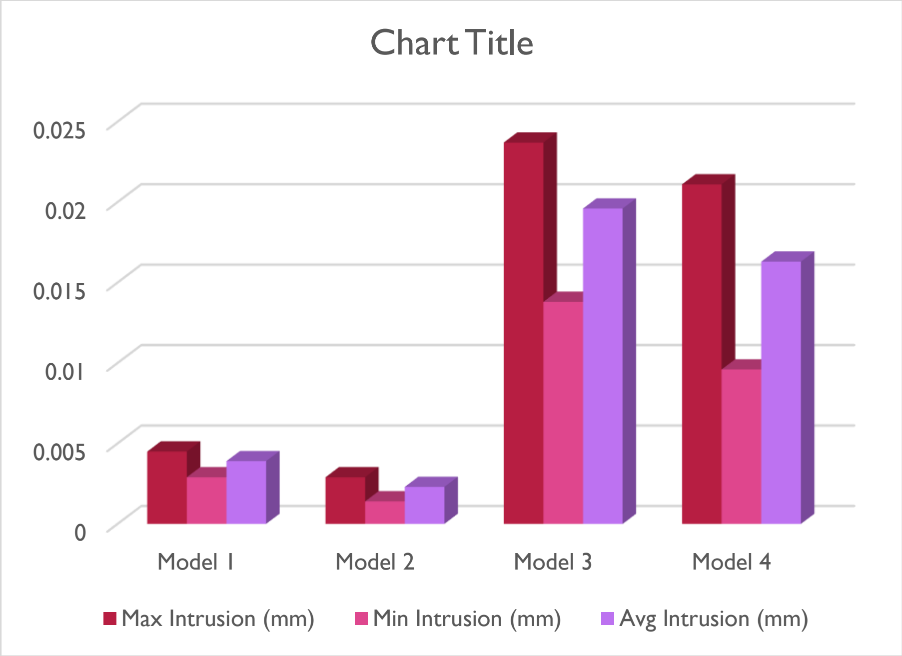
In this model, the highest amount of intrusion was seen in the central incisor (maximum intrusion: 0.0237 mm/ $2.3x10^{-4}$ mm). The least amount of intrusion of seen in canine (minimum intrusion: 0.0138 mm/ $1.38x10^{-4}$ mm). The average intrusion placed on the anterior segment was 0.0196 mm/ $1.96x10^{-4}$ mm (Figures 3, 6 and Table 4).

MODEL 4:

In this model, the highest amount of intrusion was seen in the central incisor (maximum intrusion: 0.0211 mm/ $2.11x10^{-4}$ mm). The least amount of intrusion of seen in canine (minimum intrusion: 0.00096 mm/ $9.6x10^{-5}$ mm). The average intrusion placed on the anterior segment was 0.0163 mm/ $1.63x10^{-4}$ mm (Figures 4, 5 and Table 5).

Model	Max Intrusion (mm)	Min Intrusion (mm)	Avg Intrusion (mm)
Model 1	0.00045	0.00029	0.00039
Model 2	0.00029	0.00014	0.00023
Model 3	0.0237	0.0138	0.0196
Model 4	0.0211	0.00096	0.0163





4. DISCUSSION

TADs, or temporary anchoring devices, have expanded the options for orthodontic treatment by allowing teeth to move in three dimensions while maintaining bone support. Whole arch displacement, molar distalization, incisor segment control, and molar control are all areas in which TADs are employed[14]. Additionally, skeletal problems are treated with TADs. People with vertical maxillary excess who have significant alveolar orgival appearance are treated with total arch intrusion[15-16]. It is both practical and beneficial to use miniscrews to reduce gingival appearance and improve gingival smiles, according to recent review research[16].

Using a miniscrew to treat gingival hyperplasia can be done with or without prolonging the periodontal crown. Lower risks, simpler orthodontic biomechanics, reduced patient discomfort, more cost-effectiveness, and the avoidance of alar base broadening are some advantages of this approach over orthognathic surgery[17].

One of the primary causes of TADs is the anterior teeth in gummy smile patients: The deep overbite correction is one of the most difficult orthodontic treatment challenges. In most instances, this correction is caused by extrusion. The combination of anterior intrusion and posterior teeth in patients with posterior extrusion, which is unfavourable with vertical growth. In these situations, absolute anterior intrusion is required, particularly when there is excessive incisors display.

Various models seen in this study were taken from cases having gummy smile due to excessive incisor display (gumminess in anterior region). Similar FEM study was done with four models for whole maxillary arch intrusion with different positions of TADs, while in this study models were compared only for the anterior segment intrusion where intrusion of posterior segment is not needed.

In model 1, the amount of intrusion with an average of $3.9x10^{-5}$ mm was the second lowest among the four models. Anterior movement/labial tipping of centrals were more when compared to lateral incisors and canines with average anterior movement of $3.6x10^{-5}$ mm. The centrals and lateral incisors moved towards left side while canines towards the right side.

In model 2, the amount of intrusion with an average of $2.3x10^{-5}$ mm was the lowest among all the four models. Labial tipping of centrals were more when compared to lateral incisors and canines with average anterior movement of $3.4x10^{-5}$ mm. The centrals and lateral incisors moved towards left side while canines towards the right side similar to model 1.

In model 3, the amount of intrusion with an average of $1.96x10^{-4}$ mm was the highest among all the four models. Labial tipping of centrals were more when compared to lateral incisors and canines average anterior movement of $1.9x10^{-4}$ mm which is still more when compared to model 2 and model 1. The centrals and lateral incisors moved towards left side while there was negligible movement of canines towards the right side.

In model 4, the amount of intrusion with an average of $1.6x10^{-4}$ mm was the 2nd highest among all the four models. Buccal movement/ labial tipping of centrals were more when compared to lateral incisors and canines average anterior movement of $2x10^{-4}$ mm being the highest anteroposterior movement among all four models. The central incisors moved towards right side while the laterals and canines showed movement towards left side while in other three models centrals and lateral incisors moved towards left side while canines towards the right side.

In the sagittal dimension, the highest amount of palatalization/ posterior movement of anterior was seen in our fourth model followed by the third model. Therefore, when the amount of palatalization/ posterior movement is required more, it seems more practical to not use third and fourth model.

In the vertical dimension, the highest amount of intrusion was seen in our third model followed by the fourth one. Therefore, when the amount of intrusion is crucial, it seems more practical to use these two methods.

There are 3 similar FEM studies regarding the intrusion of anterior tooth segment using only the mini-screws at different position and varying the lengths of the power arms, but no studies have compared the different modalities used for intrusion of anterior segment in the same study. In our study we have compared four different treatment modalities used to correct gummy smile and compared the displacement of anterior tooth segments in all the directions.

This study's design has certain drawbacks. The goal of the study was to use finite element analysis to mathematically visualise the initial displacement of the PDL during intrusion; as a result, the results might not precisely match clinical outcomes, which are impacted by the cumulative effects of ongoing bone reactions and arch wire rebounding from secondary tooth displacement. Stated differently, it is not advisable to forecast final clinical results using the arithmetic computations of the initial response. Furthermore, because of technological issues, it was unable to quantify how the amount of alveolar bone loss affected the placement of each tooth's CR. The impact of bone loss on the pattern of tooth displacement under intrusive force should be better explained by quantitative analysis. The study's other limitations include the assumption that the periodontal membrane was homogeneous, isotropic, and uniform in thickness, as well as the constant values used for the tissues' physical characteristics (these values would typically vary clinically due to the histologic process).

5. CONCLUSION

The following conclusions can be summarized:

(1) The highest amounts of anterior segment intrusion was seen in third model.

(2) The highest amount of labial tipping was seen in fourth model which showed second highest amount of intrusion in vertical dimension.

(3) The least or minimal amount of intrusion was seen in second model.

Hence, it seems that the use of the third model is more effective in correction of gummy smile when anterior teeth intrusion is required.

6. CONFLICT OF INTEREST

None of the authors declares a conflict of interest regarding this research project.

7. ETHICAL STATEMENT

This study was conducted in the Department of Orthodontics and Dentofacial Orthopedics, People’s Dental Academy, Bhopal, Madhya Pradesh. The research was initiated after obtaining approval from the Institutional Ethical Committee (IEC/2024/700/03).

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