Journal of Neonatal Surgery
ISSN(Online): 2226-0439
Vol. 14, Issue 7 (2025)
https://www.jneonatalsurg.com

"Comparative Evaluation of Torquing Movement of Upper Anterior Teeth Between Fixed Appliance And Clear Aligners With And Without Mini-Implants" - A FEM Study

Dr. Shambhavi Shukla[1], Dr. Amitabh Kallury[2], Dr. Chetan Jayade[3], Dr. Rajesh Kumar Balani[4], Dr. Shashank Jain[5], Dr. Shounak Banerjee[6]

[1,5,6] Post Graduate Resident, Department of Orthodontics and Dentofacial Orthopedics, People's Dental Academy, Bhopal (M.P).

[2]Professor and HOD, Department of Orthodontics and Dentofacial Orthopedics, People's Dental Academy, Bhopal (M.P)

[3]Director, Centre for Orthodontic Research and Education (CORE), Hubli, Karnataka, India.

[4]Professor, Department of Orthodontics and Dentofacial Orthopedics, People's Dental Academy, Bhopal (M.P).

***Corresponding Author:**

Dr. Shambhavi Shukla,

Email ID: shuklashambhavi708@gmail.com

.Cite this paper as: Dr. Shambhavi Shukla, Dr. Amitabh Kallury, Dr. Chetan Jayade, Dr. Rajesh Kumar Balani, Dr. Shashank Jain, Dr. Shounak Banerjee , (2025) "Comparative Evaluation of Torquing Movement of Upper Anterior Teeth Between Fixed Appliance And Clear Aligners With And Without Mini-Implants" - A FEM Study. *Journal of Neonatal Surgery*, 14 (7), 1381-1390

ABSTRACT

Objective-The aim of this study was to compare the torquing movement of the upper anterior teeth between fixed appliance and clear aligners with and without mini-implant.

Materials and Methods- It was a non-linear observational analysis study type. A CBCT scan of a healthy individual with an oversized axial inclination of the upper anterior teeth, along with extracted upper first premolars, was obtained from the CBCT center at People's University, Bhopal.

Results: This analysis has shown that model 3- clear aligner with power ridges on labiogingival and palatoincisal region, exhibited the highest von Mises stress measured at 0.13964 MPa whereas, model 4- clear aligners with mini-implant placed distal to the lateral incisors, recorded the maximum displacement measured at 1.30E-03mm.

Conclusion: Overall, the clear aligners with auxiliaries like (power ridges and mini-implants) demonstrated more effective torque control than fixed appliances, offering a balance between force application and flexibility for controlled torque movement. In model 3, the displacement was measured at 6.61E-04 mm for the upper anterior teeth, and the individual teeth such as— the central incisors measured at 0.000749 mm, the lateral incisors measured at 0.0007295 mm, and canines measured at 0.0006415 mm, respectively. The model 4 exhibited the highest displacement, measured at 1.30E-03 mm for the total anterior teeth. The displacement values for the individual teeth as, the central incisors measured at 0.001615 mm, lateral incisors measured at 0.00146 mm, and canines measured at 0.000914 mm, respectively, were higher compared to the other models. In model 5, displayed second-highest displacement of 1.22E-03 mm for the upper anterior teeth. The central incisors measured at 0.001505 mm, the lateral incisors measured at 0.00137 mm, and the canines measured at 0.0008695 mm respectively

Keyword: torquing movement, continuous tooth movement, fixed appliance, clear aligners, mini-implant, CAT, Finite element (FE).

1. INTRODUCTION

Rauch has defined torque as the force which gives the operator control over the movements of the roots of the teeth. The torque of the edgewise wire is likely one of the most significant and influential forces of the edgewise arch mechanism. A systematic and technical approach enables a clear comprehension of torque, making it relatively straightforward to master. The operator's ability to control torque effectively is the determining factor in achieving an aesthetically pleasing outcome for the finished denture, versus a more standard tooth-straightening result that lacks many of the desired qualities.1

Clear aligner treatment is gaining popularity among both orthodontists and patients due to its comfort, aesthetic appeal, and the ease with which good oral hygiene can be maintained, as opposed to conventional fixed appliance therapy. In CAT, various types of tooth movements can be attained, including intrusion, extrusion, distalization, and root torque. In malocclusions requiring extractions, difficulties can arise from both biomechanical and biological factors, including the “bowing effect” often observed when retracting maxillary anterior teeth without proper torque control. The eventual result may involve challenges in achieving optimal torque control during the retraction of anterior teeth, as the goal is to maintain torque while closing extraction spaces.2

The removable nature of aligners limits their capacity for consistent torque generation, even with the most advanced artificial intelligence, despite improvements in material stiffness and attachment technology.3 The inability of clear aligner appliances to effectively control torque in anterior teeth increase the risk of torque loss, extrusion, and deepening of overbite during the retraction process.4 The "power ridge" feature is incorporated into clear aligners, particularly in relation to the incisors, in orthodontic treatments following extraction, in order to enhance control over the torque applied to incisors.5

Mini orthodontic screws provide an effective technique for achieving the intrusion of maxillary incisors and addressing the issue of a gummy smile. One or two mini orthodontic screws can be inserted either between the central incisors, or central and lateral incisors, or between the lateral incisors and canines, with a favourable outcome and minimal incisor protrusion achievable if the mini-screws are placed in the correct position.6

The aim of this study was to compare the torquing movement of the upper anterior teeth between fixed appliance and clear aligners with and without mini-implant.

2. MATERIALS AND METHODS

It was a non-linear observational analysis study type. A CBCT scan of a healthy individual with an oversized axial inclination of the upper anterior teeth, along with extracted upper first premolars, was obtained from the CBCT center at People’s University, Bhopal. The scan was used to simulate the digital model, and finite element analysis was performed to compare the torquing movement of upper anterior teeth between fixed appliances and clear aligners with and without mini-implants.

Data Collection Procedure-

A Cone Beam Computerized Tomography (CBCT) scan (Carestream CS 9600, CBCT machine, Kodak Carestream Health, Rochester, NY, USA) was obtained from a healthy individual with informed consent. The individual had a well-aligned maxillary arch with an oversized axial inclination of the upper anterior teeth and extracted first premolars, prior to the closure of the extraction spaces. The corresponding brackets, molar tubes, PDL, 0.019x0.025 base stainless-steel wire, and elastomeric chain had been modelled and imported into ANSYS Workbench 19.2 software (version 19.2, ANSYS Inc, Southpointe, Pittsburgh (USA). An extra oral imaging software at 150 µm Voxels was used. The FOV (Field of view) used was at 5x5cm². The equipment had CCD (Charged Couple Device) with exposure parameter showing the dosage area product at 500-640 mGy.cm², the potential difference at 120 kVp, tube current at 8 mA and timing which ranges between 10-30 seconds. These Computed Tomography scans served as the pattern for the construction of the mathematical model. A 3D reconstruction was done; images were evaluated on CS 3D imaging v-3.10.45. The DICOM file (Digital Imaging and Communications in Medicine) was generated through CBCT evaluation and was imported into SolidWorks 2023 software for semi-automatic edge detection, followed by meshing of surface elements using ANSYS 19.2 (version 11, Altair Engineering, Inc. USA) software constructed the 3D analytical model of the dentition by thresholding the growing region and calculating 3D operations.

A) Inclusion Criteria

1. Patient with all healthy permanent teeth upto the 2nd molars.

2. Patients with completely levelled and aligned arches with 0.019x0.025 stainless steel archwire in 0.022x0.028’’ bracket slot.

3. Patient requiring extraction of 1st premolars for correction of proclination of anterior teeth.

B) Exclusion Criteria:

1. Patient with other pathologies (Ankylosis, Peg laterals, Fractures).

2. Patient having prosthesis

3. Patient with compromised periodontal health.

4. Patient with congenitally missing teeth except for the 3rd molars

Materials used:

3D FEM models of maxillary dentition.

1.CBCT Scan

2. DICOM/STL file

3. Solidworks 2023

4. ANSYS workbench 19.2 software

Material Property Data Representation- Teeth, PDL, alveolar bone was considered as isoperimetric and homogenous. The different structures involved in this study had different specific material properties.

The approval for this study was granted by RAC/2023/006/03 & IEC/2023/600/03 from People's Dental Academy, People's University, Bhopal.

Construction of Geometrical models: The geometric models of the maxillary central incisor, lateral incisor, canine, second premolar, first molar and second molar were constructed using the dimensions and morphology found in Wheeler's text book. These teeth were arranged in ovoid arch form. To determine the mesio-distal angulations and labio-lingual inclinations of the teeth, the maxillary dentition was aligned in accordance with MBT guidelines.

Construction of Geometric Model into a Finite Element Model-

Geometric models were converted into finite element model i.e., finite number of elements and nodes. 4-node tetrahedron elements were used. These elements form the essential building blocks of the numerical representation of the model.

Defining the boundary condition: Boundary conditions refer to the constraints applied to an element constructed on a computer. When a force is applied to this element, it behaves like a free-floating rigid body, undergoing translational or rotational motion, or a combination of both, without experiencing any deformation. To analyse its deformation, it is necessary to restrict certain degrees of freedom — specifically, the movement of nodes in each direction (X, Y and Z) for some nodes. These constraints are known as boundary conditions. The study of force application at various points in geometric configurations is essential for understanding their structural behavior is known as loading configuration.

Grouping of FE models-

After the construction of geometric FEM models, they were divided into five groups for further analysis, namely- Five models were generated: -

Model 1: Fixed appliance with 0.019x0.025 stainless-steel wire with curve of Spee with 5-7 ° torque in wire.

Model 2: Fixed appliance with 0.019x0.025 stainless-steel wire with curve of Spee with 5-7 ° torque in wire with mini-implants placed distal to the lateral incisors.

Model 3: Clear aligners with power ridges on labiogingival and linguoincisal region on anterior teeth for palatal root torque.

Model 4: Clear aligners with power ridges on labiogingival region on anterior teeth for palatal root torque with mini- implants placed distal to the lateral incisors.

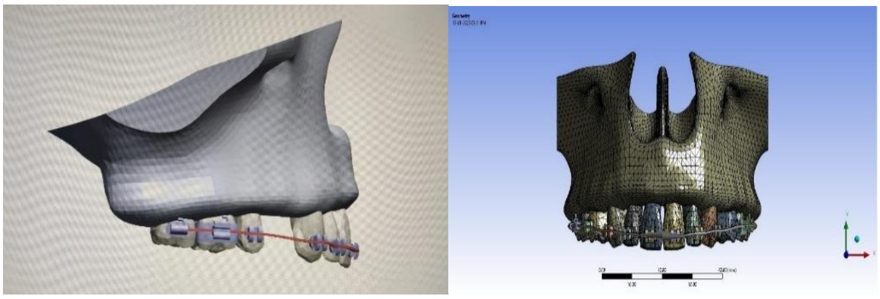
Model 5: Clear aligner with power ridges on labiogingival region on anterior teeth for palatal root torque with mini-implants placed distal to central incisors.

In material properties and data presentation process equations are formulated for each element in the FEM mesh and then assembled into a set of global equations that represent the properties of the entire system. The minimum material properties required are the Poisson's ratio and Young's modulus.

Virtual placement of materials and assignment of material properties taken in this study:

Table 1- Mechanical properties of the materials used in modelling

Materials	Density (kg/m^3)	Youngs Modulus	Poisson's Ratio
Tooth	1960	20000	0.3
Cortical	1300	13700	0.3
Cancellous	1300	1500	0.33
PDL	1100	68.9	0.45
Stainless steel	8000	193000	0.25
Titanium	4540	200000	0.3
Rubber	95	100	0.5
PMMA/ Acrylic	1190	2800	0.37



Figures 1 and 2 depicting Geometric and meshed Model 1

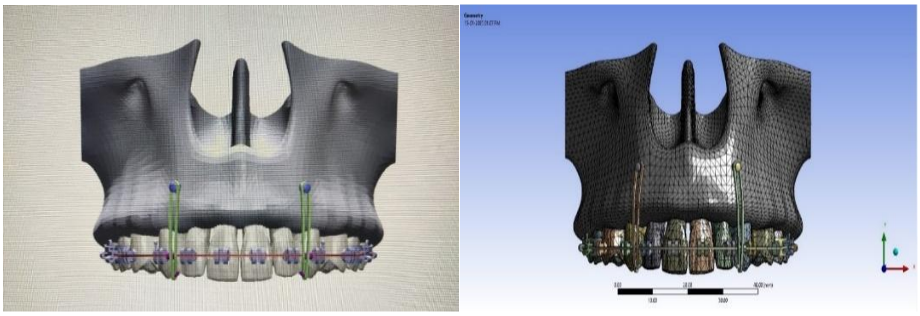


Figure 3 and 4 depicting Geometric and meshed Model 2

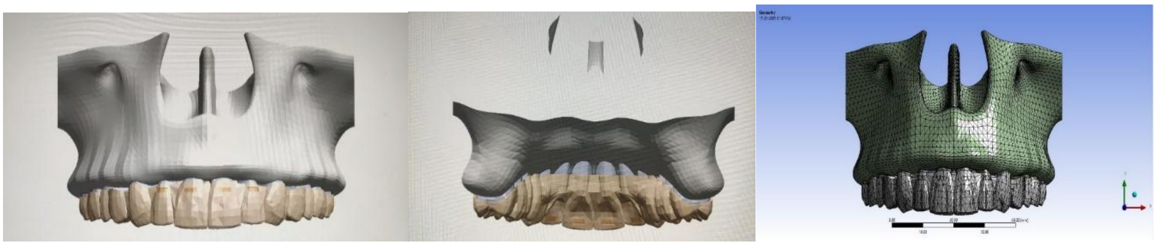


Figure 5, 6 and 7 depicting Geometric and meshed Model 3

Figure 8, 9 and 10 depicting Geometric and meshed Model 4

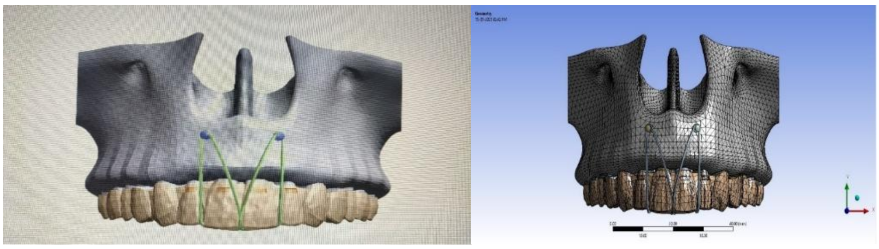


Figure 11 and 12 depicting Geometric and meshed Model 5

Analysis

For FEM analysis, ANSYS 2019 software was used to compare the torquing movement between fixed appliances and clear aligners with and without mini-implants.

3. RESULTS AND DISCUSSIONS

Table 1: The von Mises stress in (Model 3- Clear aligners with horizontal attachment on labio-gingival and palato-incisal region)

S.No.	Entity	von Mises Stress (MPa)
	Central Incisor	0.0803725
	Lateral Incisor	0.214485
	Canine	0.0653
	Anteriors (6 teeth)	0.13964

Table 2: The von Mises stress in (Model 4- Clear aligners with horizontal attachment on labio-gingival region and mini-implants placed distal to lateral incisors)

S.No.	Entity	von Mises Stress (MPa)
	Central Incisor	0.114465
	Lateral Incisor	0.126755
	Canine	0.0988
	Anteriors (6 teeth)	0.11286

This analysis has shown that model 3- clear aligner with horizontal attachments on labiogingival and palatoincisal region, exhibited the highest von Mises stress measured at 0.13964 MPa whereas, model 4- clear aligners with mini-implant placed distal to the lateral incisors, recorded the maximum displacement measured at 1.30E-03mm.

Table 3: The average displacement recorded in maxillary anterior teeth are as follows: Average displacement recorded in Model 1

S.No.	Entity	Displacement (mm)
	Central Incisor	0.000120925
	Lateral Incisor	0.000135415
	Canine	0.000103225
	Anteriors (6 teeth)	0.00011932

Table 4: Average displacement recorded in Model 2

S.No.	Entity	Displacement (mm)
	Central Incisor	0.000285
	Lateral Incisor	0.000316
	Canine	0.0002215

	Anteriors (6 teeth)	2.72E-04

Table 5: Average displacement recorded in Model 3

S.No.	Entity	Displacement (mm)
	Central Incisor	0.000749
	Lateral Incisor	0.0007295
	Canine	0.0006415
	Anteriors (6 teeth)	6.61E-04

Table 6: Average displacement recorded in Model 4

S.No.	Entity	Displacement (mm)
	Central Incisor	0.001505
	Lateral Incisor	0.00137
	Canine	0.0008695
	Anteriors (6 teeth)	1.22E-03

In model 3, the displacement was measured at 6.61E-04 mm for the upper anterior teeth, and the individual teeth such as—the central incisors measured at 0.000749 mm, the lateral incisors measured at 0.0007295 mm, and canines measured at 0.0006415 mm, respectively. The model 4 exhibited the highest displacement, measured at 1.30E-03 mm for the total anterior teeth. The displacement values for the individual teeth as, the central incisors measured at 0.001615 mm, lateral incisors measured at 0.00146 mm, and canines measured at 0.000914 mm, respectively, were higher compared to the other models. In model 5, displayed second-highest displacement of 1.22E-03 mm for the upper anterior teeth. The central incisors measured at 0.001505 mm, the lateral incisors measured at 0.00137 mm, and the canines measured at 0.0008695 mm respectively.

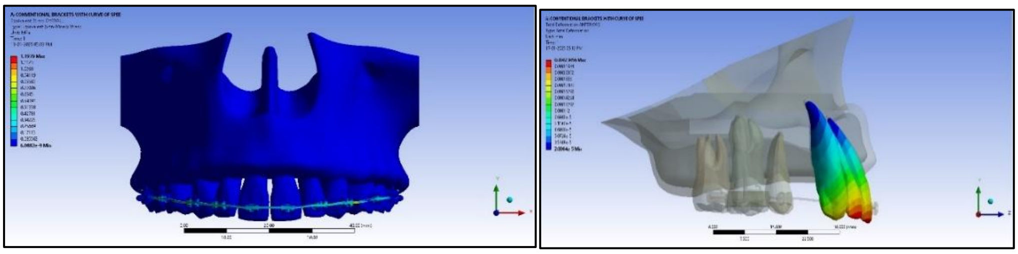


Figure 13 and 14: Depicting von Mises stress (MPa) and displacement (mm) for model 1

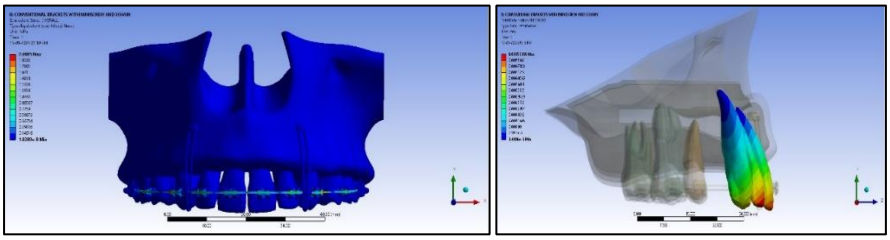


Figure 15 and 16: Depicting von Mises stress (MPa) and displacement (mm) for model 2

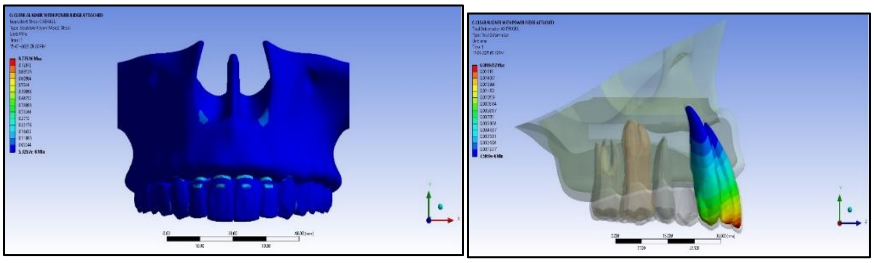


Figure 17 and 18: Depicting von Mises stress (MPa) and displacement (mm) for model 3

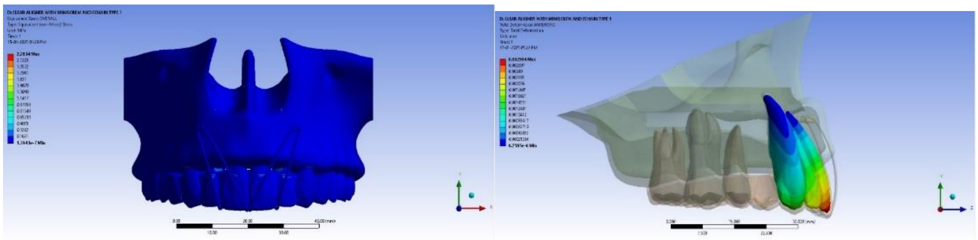


Figure 19 and 20: Depicting von Mises stress (MPa) and displacement (mm) for model 4

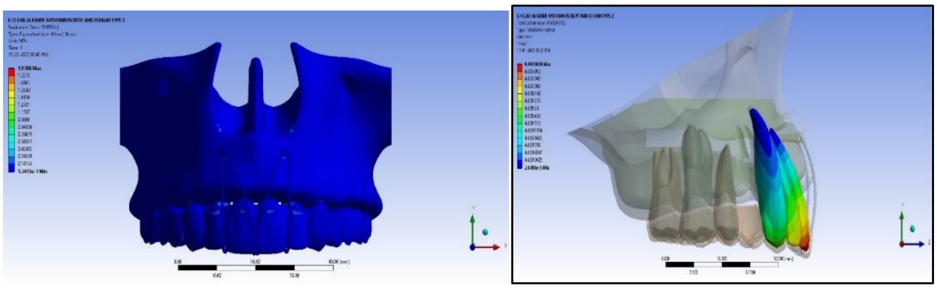
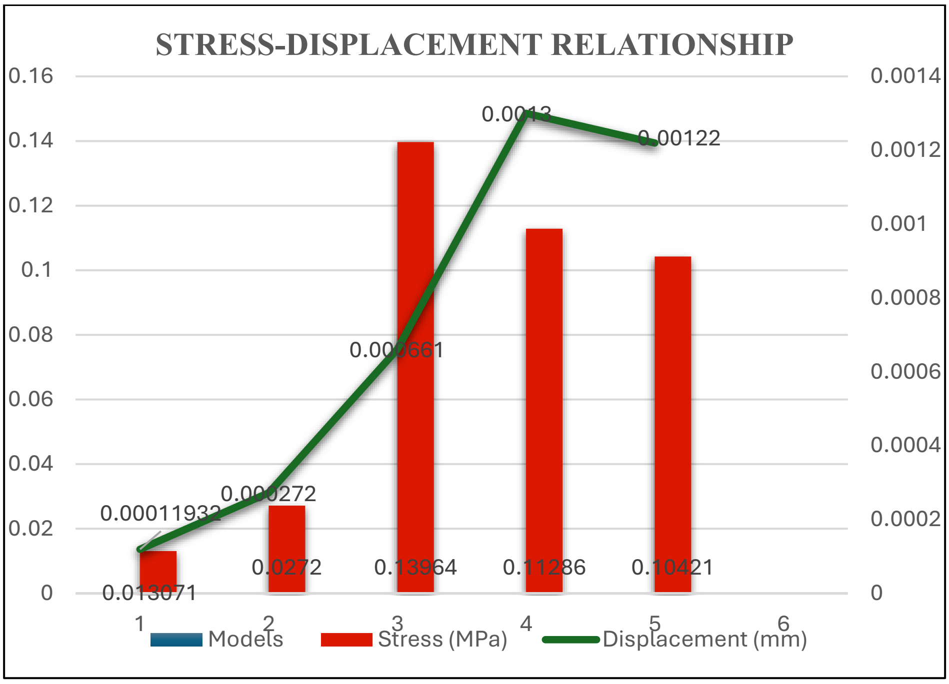


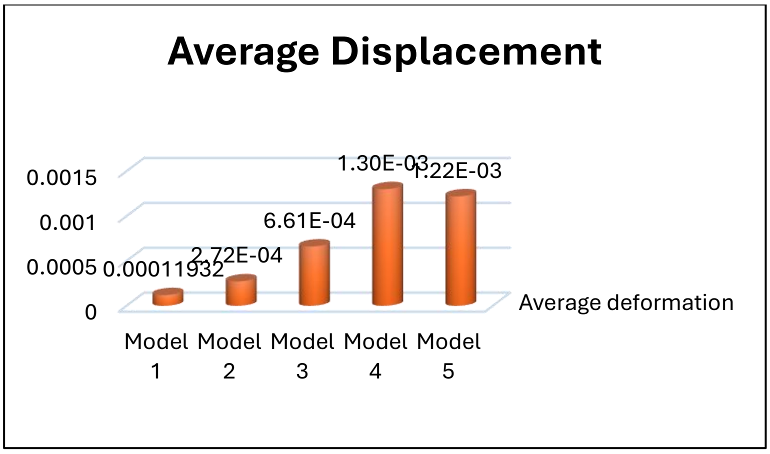
Figure 21 and 22: Depicting von Mises stress (MPa) and displacement (mm) for model 5

The relationship between stress and displacement was compared for all 5 models is depicted in Graph 1.



Graph 1: Showing stress-displacement relationship across 5 models

The average displacement recorded in (mm) in maxillary anterior teeth for 5 models are shown in Graph 2.



Graph 2: Showing average displacement in maxillary anterior teeth across 5 models

4. CONCLUSION

The comparative effectiveness of clear aligners versus fixed appliance therapy—particularly when assessed using FEA—has not been extensively investigated. Therefore, this study aimed to compare and evaluate the potential advantages of clear aligners and fixed orthodontic appliances, both with and without mini-implants, in achieving upper anterior teeth torque movement and intrusion, using FEA as the analytical framework.

A recent study revealed by Rajan et al7 found that the Invisalign appliance expressed 41.9% of the planned torque change in maxillary central incisors in patients in which at least 10° of lingual root torque was planned, underscoring the limitations of clear aligners in effectively expressing torque changes in maxillary anterior teeth. Therefore, it is challenging to control torquing movement in clinical studies. The observed underexpressed torque in previous studies underscores the necessity for further investigation into more effective torque control strategies for the upper anterior teeth and intrusion. Power ridges are a form of mechanical reinforcement that increase the torque movement of clear aligners, overcoming some limitations of the aligner material.8

In contrast, mini-implants offer an advantage of immediate force application, clear biomechanics and diversity of implantation site and direction of force. Additionally, enables precise control over the axial inclination of maxillary anterior teeth, resulting in improved functional stability and clinical outcomes.9 Inadequate torque control with clear aligner alone can result in decreased labio-lingual inclination, which can cause deepening of the overbite, extrusion of teeth, loss of anchorage and can induce “the roller coaster effects.” This can lead to unsatisfactory smile aesthetic results after the completion of orthodontic treatment.5

In the present study, model 1, designed with fixed appliance with a curve of Spee on 0.019x0.025 SS wire, exhibited the least von Mises stress value for the overall anterior teeth across the models, measured at 0.013071 MPa, with minimal displacement recorded at 0.00011932 mm. While the model 2 incorporating fixed appliances with mini-implants placed distal to the lateral incisors, exhibited the second-lowest von Mises stress value at 0.0272 MPa, along with minimal displacement at 0.000272 mm, indicating comparatively low stress and displacement values following model 1.

Conversely, model 3, featuring clear aligners with power ridges positioned on the labio-gingival and palato-incisal surface—exhibited the highest von Mises stress across all the models, measured at 0.13964 MPa, while presenting an intermediate displacement value of 0.000661 mm. Model 4, which combined clear aligners with power ridge on the labio-gingival surface and mini-implants placed distal to the lateral incisors, recorded the second-highest von Mises stress at 0.11286 MPa and experienced the highest displacement among the models, measured at 0.00130 mm. These findings also suggest that this model showed displacement values for the central incisors, lateral incisors, and canines, all higher than in the other models. In model 5, which utilized clear aligners with power ridge on the labio-gingival region and mini-implants placed distal to the central incisors, demonstrated a von Mises stress value of 0.10421 MPa, the third highest among the models, with the second-highest overall displacement of the upper anterior teeth measured at 0.00122 mm.

The current study focused on the comparison of torque movement between fixed appliance and clear aligners with and without mini-implant using FEM analysis. The stress and displacement were calculated with the 3D geometric models with a uniform force of 7.9Nmm with 100g of elastic forces each directed bilaterally towards mini-implants. To assess differences in force application levels associated with the power ridge height of 0.7 mm, consistent with the findings of Cheng et al.6 After FEM simulation was performed, the results showed that model 3 (clear aligner with double power ridges) demonstrated highest von Mises stress values (0.13964 MPa) with intermediate displacement measured at 6.61E-04 mm among different models. Conversely, model 4 (clear aligner with mini-implants located at distal to the lateral incisors) exhibited the highest displacement measured at 1.30E-03 mm among all the models with the second-highest von Mises stress measured at 0.11286

MPa, suggesting efficient torque movement during intrusion of the upper anterior teeth with mini-implants. These findings further highlighted that the addition of power ridges on both the labial and palatal surfaces and auxiliaries like mini-implants to clear aligners improved torque control in the upper anterior teeth compared to fixed appliances.

The result of the present study is in accordance with the findings of the FEM study by Cheng et al2 which demonstrated that clear aligners designed with proper thickness and power ridges achieved better control of torque in upper anterior teeth and reduced the bowing effect. However, maintaining posterior anchorage remains challenging. Our results revealed that clear aligner showed improved torque control with additional torque compensation was incorporated through power ridges in the upper anterior teeth during intrusion. In contrast to the single power ridge on the labio-gingival surface used in previous studies, our study utilized double power ridges— horizontal rectangular attachments fabricated on both labio-gingival and palato-incisal surfaces. Therefore, using double power ridge for torque movement showed controlled moment-to-force (M/F) ratios, resulted in more precise torque movements compared to single power ridge design.

According to Liu et al10 CAT resulted in lingual tipping and extrusion of incisors during anterior retraction. Incisor intrusion and palatal root torque was achieved with anterior mini-screws and elastics. Linguoincisal elastics were superior to labial elastics suggesting less occurrence of buccal open bite. Similar results were confirmed in the present study when clear aligner along with mini-screws showed better torquing movement during intrusion of upper incisors. However, in this study two mini-implants were used at two distinct locations at same heights instead of single mini-implant. The elastics applied in both the models 4 and 5 were from linguoincisal region which demonstrated uniform distribution of forces along with power ridges on the labial surfaces. The results indicated better torque control and highest displacement values in model 4 than in model 5 when intrusive forces were applied.

Simon et al11 investigated the moments generated by series of Invisalign aligners on three tooth movements: incisor torque, premolar derotation, and molar distalization. Incisor torque movements supported by power ridges and attachments resulted in enhanced torque control, with improved moments compared to conventional designs. Both the studies emphasized the need for design enhancements for proper torque, particularly in correction of gummy smile where intrusion is necessary. A study by Sandhya et al12 indicated that finite models using thermoplastic aligners with power ridges showed greater root movement than those without auxiliaries. Similar results were obtained in our study highlighted the efficiency of torque movement with the use of auxiliaries in CAT.

Another study by Xia et al13 conducted a thorough comparison between clear aligners and fixed appliances for orthodontic retraction and intrusion of maxillary incisors. Their research revealed that fixed appliances provided superior control over the torque applied to anterior teeth, which is crucial for achieving optimal alignment and aesthetics. This contrasts with the results of our study, where model 1 and model 2 demonstrated low overall stress-displacement values, underscoring its inadequacy in maintaining precise axial inclination during intrusion. Additionally, in the present study, the fixed appliance model with and without mini-implant model 1 and model 2 demonstrated the lowest values for stress and displacement, reflecting loss of torque control, anchorage, functional stability, and smile aesthetics. In contrast, model 4, which included a clear aligner with labio-gingival attachment and mini-implants placed distal to the lateral incisors, exhibited the highest levels of displacement, despite the presence of additional anchorage.

LIMITATIONS: The limitations of the present study stated the fact that, while FEM offers a reliable, non-invasive, and highly precise method for controlling study variables, its outcomes may not exactly correspond to those of in vitro or clinical studies owing to differences in the oral environment and inherent anatomical constraints. Consequently, the results obtained through finite element analysis (FEA) simulations require clinical validation to substantiate their applicability in the context of clear aligner therapy with mini-implants.

5. CONCLUSION:

Overall, the clear aligners with auxiliaries like (power ridges and mini-implants) demonstrated more effective torque control than fixed appliances, offering a balance between force application and flexibility for controlled torque movement

REFERENCES

[1] Rauch ED. Torque and its application to orthodontics. Am J Orthod. 1959;45(11):817-830.

[2] Cheng Y, Gao, J, Fang S, Wang W, Ma Y, Jin Z. Torque movement of the upper anterior teeth using a clear aligner in cases of extraction: a finite element study. Prog Orthod. 2022;23(1):26.

[3] Brezniak N, Wasserstein A, Protter N. Clear aligner biomechanical limitations: anchorage and couple (torque) development. Angle Orthod. 2023;93(5):615-616.

[4] Li N, Lei X, Cao Y, Liu L, Zhang Y, Ning Q et al. The effect of increasing the gaps between the front teeth on torque and intrusion control of the incisors for anterior retraction with clear aligners: a prospective study. BMC Oral Health. 2024;24(1):115.

[5] Meng X, Wang C, Xu W, Wang R, Zheng L, Wang C et al. Effects of different designs of orthodontic clear

aligners on the maxillary central incisors in the tooth extraction cases: a biomechanical study. BMC Oral Health. 2023;23(1):416.

[6] Vela-Hernández A, Gutiérrez-Zubeldia L, López-García R, García-Sanz V, Paredes-Gallardo V, Gandía-Franco JL et al. One versus two anterior miniscrews for correcting upper incisor overbite and angulation: a retrospective comparative study. Prog Orthod. 2020;21(1):34.

[7] Rajan N, Weir T, Meade MJ. Efficacy of planned moderate to severe torque changes in maxillary central incisors with the Invisalign appliance: a retrospective investigation. Am J Orthod Dentofacial Orthop. 2024;166(4):375-383.

[8] Liaw J, Huang G, Tsai FF, Wang SH, Liao W. Torque control of maxillary anterior teeth with the double J retractor and palatal miniscrews during en masse retraction: a case report. Angle Orthod. 2022;92(4):562-572.

[9] Xiao T, Su JY, Lei J, Zhang X, Yu J, Nie XP et al. Effectiveness of different intrusion modes of maxillary anterior teeth with mini-implants in clear aligner treatment: a three-dimensional finite element analysis. BMC Oral Health. 2024;24(1):758.

[10] Liu L, Zhan Q, Zhou J, Kuang Q, Yan X, Zhang X et al. Effectiveness of an anterior mini-screw in achieving incisor intrusion and palatal root torque for anterior retraction with clear aligners: a finite element study. Angle Orthod 2021;91(6):794-803.

[11] Simon M, Keilig L, Schwarze J, Jung BA, Bourauel C. Forces and moments generated by removable thermoplastic aligners: incisor torque, premolar derotation, and molar distalization. Am J Orthod Dentofacial Orthop. 2014;145(6):728-736.

[12] Sandhya V, Arun AV, Reddy VP, Mahendra S, Chandrashekar BS, Aravind. Biomechanical effects of torquing on upper central incisor with thermoplastic aligner: a comparative three-dimensional finite element study with and without auxillaries. J Indian Orthod Soc. 2022;56(1):49-56.

[13] Xia Q, Wang W, Wang C, Feng G, Wang C, Song J et al. Comparative assessment of orthodontic clear aligner versus fixed appliance for anterior retraction: a finite element study. BMC Oral Health. 2024;24(1):80.