IOSR Journal of Dental and Medical Sciences (IOSR-JDMS)
e-ISSN: 2279-0853, p-ISSN: 2279-0861.Volume 24, Issue 6 Ser.8 (June 2025), PP 24-31
www.iosrjournals.org

Evaluation Of Anchorage Loss in Fixed Orthodontic Technique with Chromosome Appliance and Transpalatal Arch in Maxilla-A Fem Study

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Abstract:
Background: *To evaluate the anchorage loss during fixed orthodontic treatment using different reinforcement methods, including transpalatal arch, chromosome appliance, and second molar banding, in comparison with conventional first molar anchorage. The analysis was performed using the finite element method.*
Materials and Methods:
A CBCT scan was used to create a 3D model of the maxilla and mandible. DICOM data were processed in MIMICS software, and STL files were reverse-engineered for modeling in Dassault Systèmes' 3D EXPERIENCE platform. Four models were developed: (1) first molar banding, (2) first and second molar banding, (3) TPA, and (4) chromosome appliance. All models included 0.022×0.028-inch MBT brackets, 0.019×0.025-inch stainless steel archwires, and retraction power arms.
Each model was meshed to generate nodes and elements, and material properties were applied to teeth, PDL, bone, and appliances. The superior maxillary border was restrained to simulate clinical stability. A 150-gram retraction force was applied from the power hook to the molar tube. Displacement of the first molar was measured in the sagittal plane using 3D-matic software, with the mesial CEJ as a reference point. Simulation was performed in ANSYS 2024 R2.
Results:
FEM analysis revealed that anchorage loss, measured as anterior displacement along the Y-axis, decreased with the addition of reinforcement. The greatest displacement occurred in the first molar-only model, while the chromosome appliance showed the least.
Conclusion:
The chromosome appliance provided the most effective anchorage control, followed by second molar banding and TPA. First molar-only anchorage showed the highest displacement, underscoring its limitations. These findings highlight the clinical importance of selecting appropriate anchorage strategies to minimize unwanted tooth movement and enhance treatment efficiency.
Key Word: *Anchorage loss, Finite Element Method (FEM), Chromosome appliance, Transpalatal arch (TPA), CBCT*

Date of Submission: 10-06-2025 Date of Acceptance: 23-06-2025

I. INTRODUCTION

Anchorage refers to the resistance provided by an anatomical unit to prevent unwanted tooth movement during orthodontic treatment. Every orthodontic appliance has active and resistance components; the resistance unit offers anchorage to enable desired tooth movement. According to Newton's third law, forces applied to teeth create equal and opposite reciprocal forces, which must be resisted to avoid unwanted tooth movement. Anatomical structures such as teeth, hard palate, alveolar bone, occipital bone, and neck muscles can help provide anchorage control. Anchorage loss is a biomechanical response that can reduce treatment effectiveness, especially in complex cases like severe crowding or bimaxillary protrusion. To enhance anchorage, adjunct appliances such as the Nance holding arch, transpalatal arch (TPA), chromosome appliance, and lingual arch are used. Stabilizing molars by engaging multiple teeth and applying differential moments also helps control unwanted movements.

Traditionally, anchorage concerns focus on mesial drift of posterior teeth, which compromises anterior retraction by causing unwanted forward movement of anchor teeth. While earlier studies emphasized anteroposterior changes, vertical and transverse effects must also be considered because they influence occlusion and mandibular rotation. Common methods to evaluate anchorage loss include dental casts and lateral cephalograms, but both have limitations. Finite element method (FEM) offers a non-invasive, accurate alternative by simulating biomechanical behavior and predicting tissue response under orthodontic forces. Although TPA and chromosome appliances are commonly used for maxillary anchorage reinforcement, their effectiveness in preventing anchorage loss individually is limited. This study aims to compare anchorage loss during fixed orthodontic treatment using TPA, chromosome appliance, and second molar banding versus conventional first molar anchorage through finite element analysis.

II. MATERIAL AND METHODS

This is a three-dimensional computer simulation study executed in the Department of Orthodontics, PSM Dental College, Thrissur and PG CAD lab of aeronautical and automobile engineering in MIT, Manipal. Ethical approval for the conduct of this study was granted by the Institutional Ethics Committee, PSM college of Dental Science and research.

MODELING PROCEDURE:

1. Creating 3D Model of the Skull

A Cone Beam Computerized Tomographic (CBCT) image with the slice thickness of 300µm as acquired in DICOM (Digital Imaging Communications in Medicine) format of a patient's skull with skeletal class I malocclusion having full component of teeth. Prior to the CT scan, the patient's informed consent was taken. The MIMICS (Materialize Interactive Medical Image Control System) software, Materialise NV, Belgium, was used to extract the borders and outlines of the teeth and bone needed to construct the FEM from the CT images.

2. Modeling of Orthodontic System

The formats of images were processed and exported as STL files using reverse engineering technique in PG CAD lab of aeronautical and automobile engineering in MIT, Manipal. Stereo lithographic (STL) format was used for the models that were acquired from MIMICS.

Using Dassault Systèmes' 3D, the model was loaded into 3D Experience software in order to construct the surface and solid aspects of the geometric model. Individual surface models of the mandible and maxilla were generated. To create precise outlines, the models were smoothened and improved. A continuous surface model was created by healing and joining the discontinuous surfaces. Using the surface model, a solid version was constructed.

Three-Dimensional model was created for following components:

1. The maxilla with complete dentition, excluding the third molars.
2. The periodontal ligament with thickness of 0.25mm.
3. A standard conventional preadjusted edgewise brackets of 0.022 slot MBT prescription and buccal tubes.
4. Transpalatal arch and Chromosome appliance
5. 19×25 Stainless Steel archwire
6. Power arms

The bracket, archwire, retraction hook, transpalatal arch appliance and chromosome appliance was modeled using 3D EXPERIENCE software. The 0.022 x 0.028-inch MBT prescription brackets were secured to the crown, ensuring that the facial axis point aligned with the center of the bracket slot. The primary archwire was modeled based on the specifications of a 0.019 × 0.025-inch stainless steel archwire. To minimize deflection during the application of retraction force, the retraction hook was positioned between the lateral incisor and canine.

3. Meshing of the Orthodontic System

After importing the images, the software automatically performed meshing by assigning predefined material properties. During this process, the models were discretized into individual elements, ensuring no overlap occurred and that connections were established exclusively at designated points, referred to as nodes. The organization of these elements through nodal connections, along with the removal of redundant nodes, constitutes the meshing process. The total number of elements and nodes established in this study were mentioned. [Table 1]. The interface contact condition between arch wire and bracket was considered as bonded contact.

Maxilla	Nodes	Elements
Model 1	309086	156767
Model 2	327126	165104
Model 3	312772	157267
Model 4	350239	176967

Table 1: Nodes and Elements Count of Maxilla

4.Application of Material Properties & Boundary/Loading Conditions

Once meshing and contacts are defined the next process is to define boundary conditions. The model was restrained at the superior border of the maxilla in order to avoid any motion against the loads imposed on the dentoalveolar structures

The properties of the materials used in this study were depicted in Young's modulus and Poisson's ratio[14,15].[Table 3]

	Young's Modulus	Poisson's ratio
Teeth	1.96×104	0.31
PDL	0.667	0.45
Stainless steel[2]	190,000	0.31
Cancellous bone	1.37×103	0.30

Table 2: Material Properties of Various Components used in This Study

5. Static Structural Analysis of Orthodontic System

In Maxilla, four different models were constructed. (Figure 5,6,7,8, Table 3):

Model 1: Comprises of maxilla with all the teeth bonded with 0.022 slot MBT prescription brackets and banding done on first molar. A stainless steel archwire measuring 0.019 × 0.025 inches was utilized, with retraction hooks positioned between the lateral incisors and canines. An e-chain was extended from hooks to buccal tube for retraction.

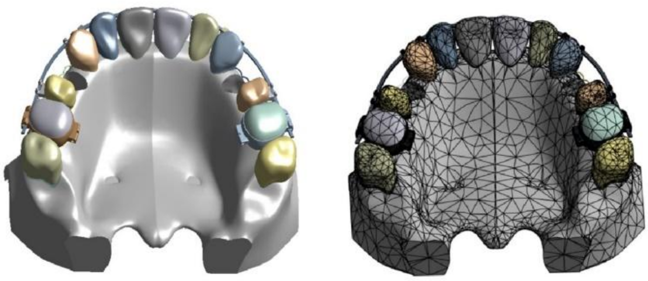


Figure 5: FEM Model with anchorage from first molar

Model 2: It resembles Model 1, but banding on second molar is included in addition to it.

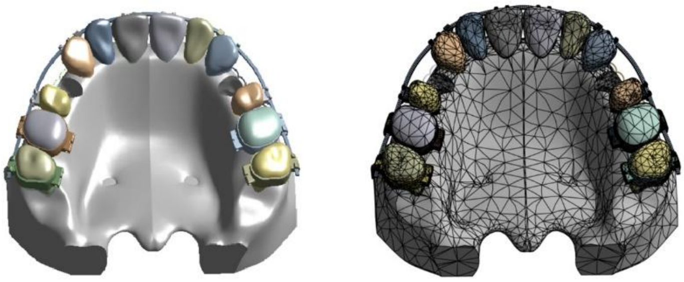


Figure 6: FEM Model with anchorage from first and second molar

Model 3: It resembles Model 1, but it also incorporates a TPA of 0.036-inch (0.9 mm) round stainless steel that extends bilaterally from one first molar to the other.

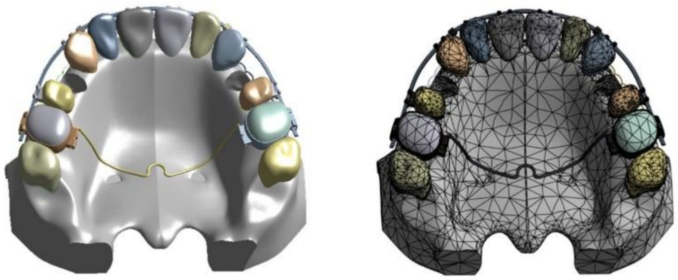


Figure 7: FEM Model with anchorage from Transpalatal arch appliance

Model 4: It resembles Model 2, but it also incorporates a Chromosome appliance of 0.036-inch (0.9 mm) round stainless steel.

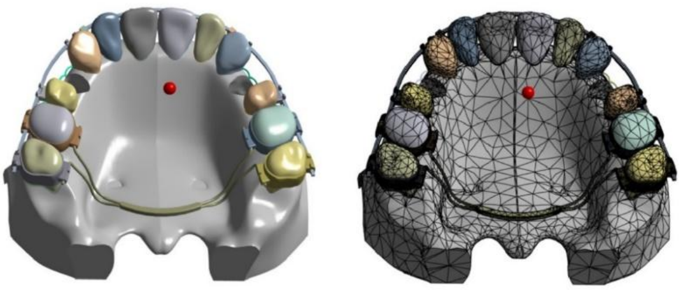


Figure 8: FEM Model with anchorage from Chromosome appliance

6.Force application and result analysis in Orthodontic System

The landmark used for the assessment of displacement was the mesial surface of first molar at the cementoenamel junction which was analyzed by FEM simulated models using 3D-matic software. A standard coordinate system was established with the x-axis corresponding to the transverse direction, the y-axis to the sagittal direction, and the z-axis to the vertical direction.

A force of 150 grams was applied between the power-arm and hook of molar tube in all four models. Anchorage loss was assessed by means of displacement of maxillary first molar teeth in anteroposterior plane in all models. Once the loads were defined, programs were run using ANSYS 2024 R2 software and the findings have been tabulated. The results obtained from the simulation were examined to support clinical validation

III.RESULT

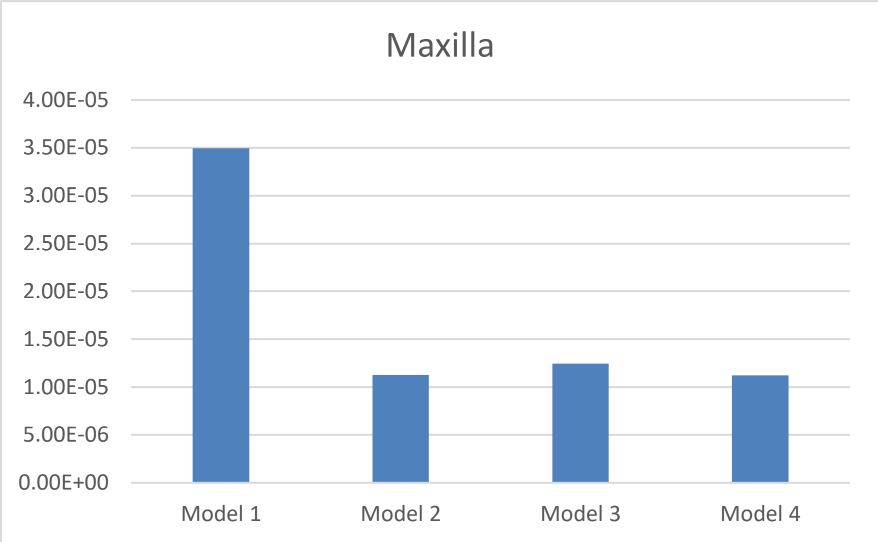
The study was conducted to evaluate the differences between anchorage loss during fixed orthodontic technique while using different anchorage preparation methods like TPA, chromosome appliance and banding of second molar in maxilla to conventional fixed orthodontic technique using finite element method. In the present study, FEM interpretation was done for Y axis. Y axis signifies displacement in anteroposterior plane, [a positive value (+Y) indicates posterior displacement and a negative value (-Y) indicates anterior displacement], The extent of displacement was determined using a series of color bands.

When a force of 150 grams is applied between the power-arm and hook of molar tube, initial displacement of the teeth mainly occurred in the anterior segment. The force was also expressed in the posterior segment, resulting in mild mesial movement of the molars. Anchorage loss was assessed by means of mesial displacement of maxillary first molar teeth in anteroposterior plane in all models. The cementoenamel junction at mesial surface of first molar were used as landmark for the assessment of displacement was measured.

Displacement of first molar in anteroposterior plane

In the maxillary model, with increasing anchorage component, there was a descending trend in the displacement (Y-axis). The least anterior displacement of molar was seen in chromosome appliance anchorage model (1.122900E-05 mm) and maximum was noticed in first molar anchorage model (3.495000E-05 mm). The data did not demonstrate any considerable variation in the displacement of the molar in first and second molar anchorage model and transpalatal arch anchorage model.

The displacement of maxillary first molar in anterior direction was maximum in first molar anchorage model (3.495000E-05 mm), followed by transpalatal arch anchorage model (1.245200E-05 mm), first and second molar anchorage Model (1.125600E-05 mm) and least in Chromosome appliance anchorage model (1.122900E-05 mm). Table 4, Figure 9,10,11,12 and graph 1 depict the displacement in Y axis.



Graph 1: Displacement of Maxillary first molar teeth in Anteroposterior Plane – Y Axis

	Minimum [mm]	Maximum [mm]	Average [mm]
Model 1	5.787900E-07	4.773500E-05	3.495000E-05
Model 2	4.212900E-07	4.035900E-05	1.125600E-05
Model 3	3.494700E-07	4.773300E-05	1.245200E-05
Model 4	4.028800E-07	4.034500E-05	1.122900E-05

Table 4: Displacement of Maxillary first molar teeth in Anteroposterior Plane – Y Axis

Figure 9: Displacement of Maxillary first molar teeth (Anteroposterior Plane – Y Axis) in Model 1

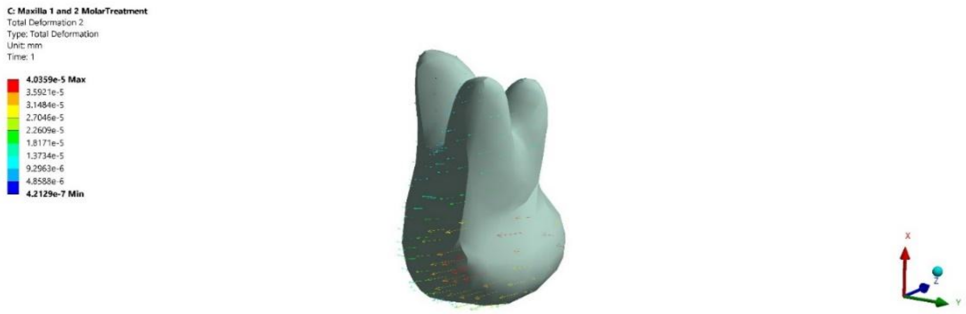


Figure 10: Displacement of Maxillary first molar teeth (Anteroposterior Plane – Y Axis) in Model 2

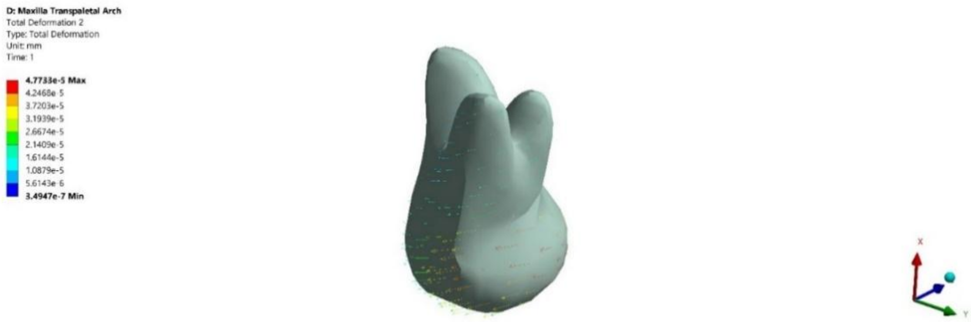


Figure 11: Displacement of Maxillary first molar teeth (Anteroposterior Plane – Y Axis) in Model 3

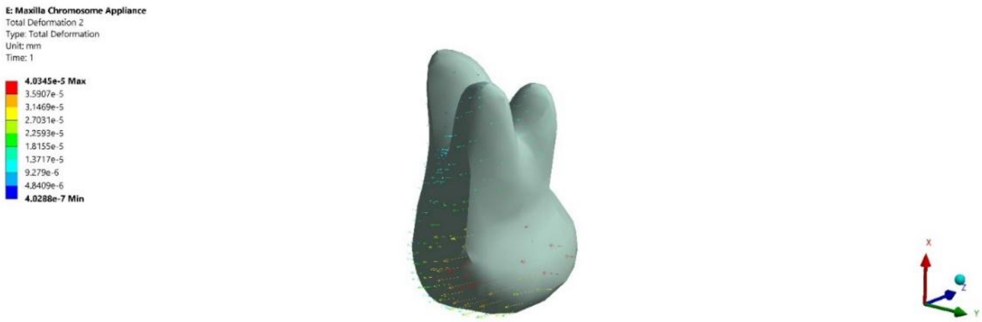


Figure 12: Displacement of Maxillary first molar teeth (Anteroposterior Plane – Y Axis) in Model 4

IV. DISCUSSION

Anchorage control remains one of the most critical challenges in contemporary orthodontics. In planning and executing fixed orthodontic treatments, it is imperative to understand and manage the side effects of force application, particularly the phenomenon of anchorage loss.

Dental casts and lateral cephalogram superimpositions are the primary methods used to assess anchorage loss. However, cephalometric superimposition has an inherent limitation caused by the bilateral structural overlap. Conversely, although dental casts are valuable diagnostic tools, their application is limited to evaluating anchorage loss within the maxillary arch.[19]To overcome these limitations, anchorage loss was evaluated using the finite element approach. Finite Element Method (FEM) as a tool provides insights into the stress distribution and tooth movement, and has been validated as an effective means for simulating orthodontic forces. FEM functions by discretizing intricate structures into simpler elements, enabling the assignment of material properties for the purpose of analyzing mechanical or anatomical responses.

The transpalatal arch and chromosome appliance are among the most commonly used adjuncts in clinical orthodontics for anchorage reinforcement. On the contrary, when used individually, these appliances often fall short in providing adequate anchorage to fully prevent anchorage loss. Therefore, it is important to evaluate their effectiveness in maintaining anchorage stability. The present study was aimed to compare the anchorage loss during a conventional fixed orthodontic technique with alternative fixed techniques that incorporate supplementary anchorage aids. Specifically, the study compared the effects of different anchorage preparation methods like the transpalatal arch, the chromosome appliance and the banding of the second molar in maxilla to the first molar banding system using a finite element method analysis.

The results of the study indicate that the chromosome appliance offered the greatest anchorage control followed by second molar banding, TPA, and the least control observed when using first molar banding alone. Several authors have emphasized the critical role of reinforcing molar anchorage with auxiliary devices, particularly in extraction cases requiring significant retraction of the anterior teeth. Using finite element method (FEM) analysis, Kojima and Fukui observed decreased mesial movement of the molars when second molars were included in the anchorage system [4].

Several studies have examined the effectiveness of the Transpalatal Arch in anchorage control, with varying conclusions. Finite element analysis by Bobak et al.[12] revealed that while the TPA had no significant effect on molar tipping, it was effective in limiting molar rotation and exhibited minimal influence on periodontal stress, altering stress magnitudes by less than 1%. Similarly, Zablocki et al. [3]. conducted a cephalometric study which found that the TPA did not significantly control the mesial movement of maxillary first molars during extraction-based treatment. Kojima and Fukui [4] also concluded that the TPA was ineffective in preventing molar tipping and preserving anchorage against mesial displacement, although it did provide some control over molar rotations. They attributed this limitation to the appliance's inability to resist forces applied perpendicular to the anchorage unit. Taken together, these results indicate that while the TPA may offer some benefits in controlling rotation and transverse movement, its effectiveness in sagittal anchorage control remains limited. The present study found that TPA appliance provide moderate control over the mesial migration of maxillary first molars relative to the standard first molar anchorage system. However, its anchorage performance was still not as strong as that of the second molar banded appliance.

Chromosome arch appliance is constructed from round stainless-steel wire arranged in an "X" shape and is cemented to all four upper molars. It is a rigid, multi-component design, distributing force more evenly across the arch, thereby offering contributing to its superior anchorage control. The Chromosome arch appliance provided effective control of the anchor teeth in the sagittal plane, owing to its unique design. This is made possible by incorporating more teeth into the anchorage unit, which increases the root surface area. Unlike the Transpalatal arch, which uses two molars as the anchorage unit, the Chromosome appliance employs four molars as a single anchorage unit.

Banding the second molar appears to provide a larger surface area and a more stable posterior anchorage unit. Some authors previously emphasized that increasing the number of teeth in the anchorage unit enhances resistance to undesired movements. The broader distribution of force across the larger area of the periodontal ligaments likely results in a more physiological force, thereby reducing the risk of anchorage loss. SM Londhe et al.[20] also noted that anchorage loss is minimized when the second molar is involved in the treatment process. Compared to conventional banding of the first molars, this system experienced the greatest anchorage loss, highlighting that first molars alone are insufficient for reliable anchorage. This finding is well-supported by Proffit et al, who recommend anchorage reinforcement whenever significant retraction is planned [7].

Clinically, these findings indicate that when maximum anchorage is required in maxillary arch, the chromosome appliance may be the preferred choice. These insights can guide clinicians in selecting cost-effective and biomechanically sound anchorage reinforcement strategies without immediately resorting to skeletal anchorage.

While FEM provides a controlled method to study force systems and tooth movement, it cannot fully replicate the biological complexity of the oral environment. A major limitation is its static nature, which excludes the time-dependent behavior of bone remodeling and periodontal ligament response. As Tanne et al. noted, dynamic modeling may reveal different stress patterns over time. The models also did not account for soft tissue resistance or muscular forces during functions like chewing, which can affect tooth movement. Additionally, assumptions regarding material properties and boundary conditions may reduce accuracy. Using average mechanical values overlooks variations in bone density, enamel, and dentin across individuals. These factors can significantly impact simulation results, limiting direct clinical applicability.

V. CONCLUSION

The study led to several key conclusions. The transpalatal arch showed moderate effectiveness in limiting the mesial movement of maxillary first molars, offering an improvement over conventional anchorage using first molar banding alone. The chromosome arch appliance demonstrated superior anchorage control compared to the transpalatal arch, making it more effective in resisting unwanted tooth movement. Additionally, incorporating the second molars into the anchorage unit significantly improved overall stability. Among all methods evaluated, the conventional approach relying solely on first molars resulted in the greatest degree of anchorage loss, underlining its limitations in providing adequate resistance during space closure. Clinically, the chromosome arch appliance appears to be the most effective strategy for achieving maximum anchorage in the maxillary arch.

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