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Assessing Mid- Palatal Mini Implant Assisted Intrusion And Distalization Of The Whole Maxillary Arch With High Pull Palatal Gear: A 3-Dimensional Finite Element Analysis

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Abstract:
Objective *This study investigated the impact of the anterior and posterior high pull palatal gear (HPPG) technique on maxillary whole dentition using three-dimensional finite element model(3D-FEM) analysis.*
Materials and Methods*: A three-dimensional finite element model was generated using the original cone beam computed tomography (CT) data of a patient with normal occlusion. Two distinct loading methods were utilized based on mini- screw position: method 1, Anterior HPPG where the mid palatal mini- implant positioned distal to the third rugae and method 2, Posterior HPPG where the mid palatal mini- implant located at the interproximal level of the second premolar and first molar. A force of 200 gram was exerted from the lingual buttons attached on the palatal aspects of both maxillary lateral incisors to the mini-implant site.*
Results*: In both models, the whole maxillary teeth showed intrusive movement with the anterior teeth exhibiting the highest degree of intrusion than posterior teeth. But in the case of posterior HPPG, there was an increase in intrusion for posterior teeth, while the amount of intrusion for anterior teeth decreased compared to Anterior HPPG. Distinct retraction was noticed for all teeth. For both HPPG technique, the highest stress value was observed at the palatal aspect of the lateral incisor crown. Posterior HPPG results in more pronounced anterior teeth retraction and crown angulation change to the palatal plane than anterior HPPG.*
Conclusion: *Positioning mid- palatal mini- implants in anterior or posterior locations allows for targeted intrusion and retraction of maxillary teeth depending on the individual treatment goals.*
Key Word: *Mini- implant, Maxillary arch, Intrusion, Distalization, High Pull Palatal Gear*

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I. Introduction

Malocclusions can be skeletal or dental and may occur in the vertical, sagittal, or transverse planes. Vertical malocclusions include deep bite, open bite, and vertical maxillary excess, with a gummy smile being a manifestation of vertical maxillary excess. Patients with a vertical growth pattern generally show a downward and backward rotation of the mandible, leading to an increased lower anterior facial height, often accompanied by a gummy smile and a convex facial profile. Whole maxillary arch intrusion is the optimal treatment strategy for issues in the vertical plane. En masse distalization or retraction of the teeth is the recommended treatment for dental protrusion.

During the growth period, high-pull headgear treatment alters maxillary development by either restricting its forward expansion or guiding it towards a posterior direction.[1] When attached to a splint, it restricts the downward growth of the maxilla.[2,3] Dental effects such as vertical eruption control and upper molar distalization can still be observed after growth cessation.

In adult patients with vertical maxillary excess and extreme high mandibular plane angle cases, orthognathic surgeries such as Le Fort I osteotomy and superior impaction can lead to autorotation of the mandible and a reduction in lower anterior facial height.[4] The emergence of temporary anchorage devices has made tooth intrusion and distalization easier, resulting in mild to moderate skeletal effects.

The "high-pull palatal gear" (HPPG) technique employs a single mid-palatal mini- screw to accomplish whole maxillary dentition intrusion and distalization on a rigid archwire.[5] It leads to the successful counterclockwise rotation of the upper occlusal plane, which in turn promotes the forward rotation of the mandible in hyperdivergent patients. The HPPG technique generates force vectors similar to those of high-pull headgear.[5]

The aim of this study was to evaluate the impact of the anterior high pull palatal gear technique and posterior high-pull palatal gear technique on the maxillary whole dentition by assessing intrusion, distalization, and stress response using three-dimensional finite element model (3D-FEM) analysis.

II. Material And Methods

Generating of 3D geometric model

The Computed Tomography scan data of the skull was processed in MIMICS Research 19.0 software. From the acquired DICOM images, the region of interest—the maxilla in this study—was segmented and converted into STL format.

Conversion of three-dimensional geometric model into finite model

For FEM analysis the reconstructed 3D geometric model was imported to the 3D-FEM analysis software (ANSYS 2023 R2). The fundamental 3D-FEM model was constructed using a mesh of tetrahedral elements including the teeth, periodontal membrane, bone, arch wire, lingual button and mini-implant (Figure 1). The PDL thickness was maintained at a constant 0.25 mm, and the Young's modulus along with Poisson's ratio for the structures and components used in the study are presented in Table I. 0.018 slot brackets and a 0.017×0.025-inch stainless steel arch wire was placed on the surface of the teeth. The mini-implant size was 1.5* 8 mm. A total of 165553 nodes and 87180 elements were used for the model 1 and 191355 nodes and 102309 elements were used for model 2. In model 1 or the anterior HPPG, the mid palatal mini-implant was positioned to be distal to the third rugae at T-zone (Figure 2). In model 2 or the posterior HPPG, the mid palatal mini- implant was located between second premolar and first molar (Figure 3). The entire dentition was interpreted as single unit and system was considered rigid. In both models a force of 200 gm was applied from the lingual buttons attached on the lateral incisors to the mini- implant. The horizontal and vertical displacement at root apex and cusp tips of the teeth and the Von Mises stress along the tooth surface were assessed.

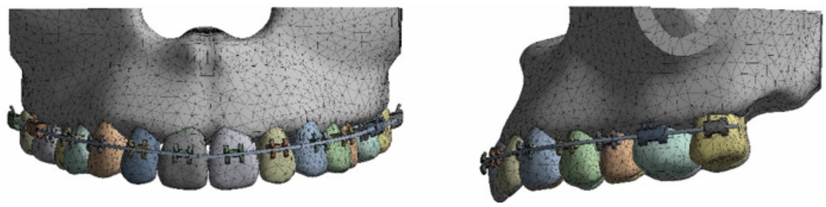

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Figure 1. 3D FEM Mesh model. A) Frontal view B) Lateral view

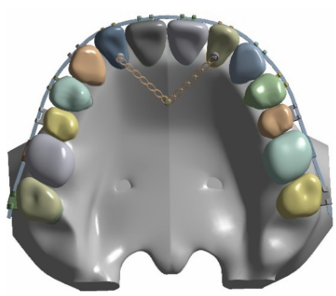


Figure 2. Model 1- Anterior HPPG- Mid palatal mini-implant is positioned distal to the third rugae at T-zone.

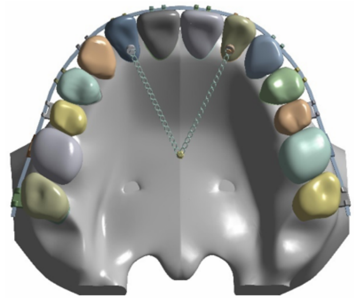


Figure 3. Model 2- Posterior HPPG- Mid palatal mini-implant is located between second premolar and first molar

Defining the boundary conditions

After the model fabrication was completed, boundary conditions were assigned to all peripheral nodes of the bone, with 0 degree of movement in all direction.

Interpretation of results

In the baseline coordinate system, tooth movement was interpreted based on node displacement: shifts along the y-axis corresponded to horizontal displacement of anterior and posterior teeth, while shifts along the z-axis reflected intrusive movement in the vertical plane. Following the application of the boundary conditions, the results were analyzed. The horizontal and vertical displacement at root apex and cusp tips of the teeth and the von Mises stress along the tooth surface were assessed.

III. Result

Vertical and horizontal displacements on crown cusp tips and root apices of each tooth of the simulation models are shown in Table I-VIII. In both types of HPPG, the whole maxillary teeth showed intrusive movement with the anterior teeth exhibiting the highest degree of intrusion.

Table I. Anterior HPPG: Displacement on the root apices [left]

		Displacement	
		Vertical	Horizontal
Central incisor		7.657e-006 mm	6.8889e-006 mm
Lateral incisor		7.3776e-006 mm	7.2635e-006 mm
Canine		5.4213e-006 mm	8.9845e-006 mm
First premolar		4.5163e-006 mm	8.923e-006 mm
Second premolar		2.9436e-006 mm	8.0489e-006 mm
First molar	Mesial	1.8245e-006 mm	7.4236e-006 mm
	Distal	1.4149e-006 mm	7.2472e-006 mm
	Palatal	1.9159e-006 mm	7.3343e-006 mm
Second molar	Mesial	1.1262e-006 mm	6.8766e-006 mm
	Distal	1.1294e-006 mm	6.9194e-006 mm
	Palatal	1.4287e-006 mm	7.0002e-006 mm

Table II. Anterior HPPG: Displacement on the root apices [right]

		Displacement	
		Vertical	Horizontal
Central incisor		7.6971e-006 mm	6.8286e-006 mm
Lateral incisor		7.4621e-006 mm	7.1094e-006 mm
Canine		5.5231e-006 mm	8.7939e-006 mm
First premolar		4.8086e-006 mm	8.7978e-006 mm
Second premolar		2.9796e-006 mm	7.8909e-006 mm
First molar	Mesial	1.9641e-006 mm	7.0908e-006 mm
	Distal	1.5468e-006 mm	6.902e-006 mm
	Palatal	1.9548e-006 mm	7.0029e-006 mm
Second molar	Mesial	1.1881e-006 mm	6.4572e-006 mm
	Distal	1.1739e-006 mm	6.4702e-006 mm
	Palatal	1.4218e-006 mm	6.5528e-006 mm

Table III. Anterior HPPG: Displacement on the crown cusp tip or incisal edge[left]

		Displacement	
		Vertical	Horizontal
Central Incisor		8.671e-006 mm	3.819e-006 mm
Lateral Incisor		7.6453e-006 mm	5.441e-006 mm
Canine		5.8774e-006 mm	5.8589e-006 mm
First Premolar	Buccal	3.5154e-006 mm	5.7697e-006 mm
	Lingual	3.8554e-006 mm	6.1035e-006 mm
Second Premolar	Buccal	2.4363e-006 mm	5.974e-006 mm
	Lingual	2.5827e-006 mm	6.4449e-006 mm
First Molar	Mesiobuccal	1.7236e-006 mm	6.3167e-006 mm
	Distobuccal	1.2386e-006 mm	6.3956e-006 mm
	Mesiolingual	1.7827e-006 mm	6.5585e-006 mm
Second Molar	Mesiobuccal	9.733e-007 mm	6.4917e-006 mm
	Distobuccal	8.239e-007 mm	6.5592e-006 mm
	Mesiolingual	1.3083e-006 mm	6.7172e-006 mm

Table IV. Anterior HPPG: Displacement on the crown cusp tip or incisal edge[right]

		Displacement	
		Vertical	Horizontal
Central Incisor		8.7315e-006 mm	3.8216e-006 mm
Lateral Incisor		7.8466e-006 mm	5.4231e-006 mm
Canine		6.1244e-006 mm	6.0927e-006 mm
First Premolar	Buccal	3.7241e-006 mm	5.8354e-006 mm
	Lingual	3.9798e-006 mm	6.12e-006 mm
Second Premolar	Buccal	2.5854e-006 mm	5.9374e-006 mm
	Lingual	2.802e-006 mm	6.2985e-006 mm
First Molar	Mesiobuccal	1.8567e-006 mm	6.166e-006 mm
	Distobuccal	1.341e-006 mm	6.177e-006 mm
	Mesiolingual	1.8157e-006 mm	6.3476e-006 mm
Second Molar	Mesiobuccal	1.0685e-006 mm	6.2365e-006 mm
	Distobuccal	9.0208e-007 mm	6.2355e-006 mm
	Mesiolingual	1.3118e-006 mm	6.4139e-006 mm

Table V. Posterior HPPG: Displacement on the root apices [left]

		Displacement	
		Vertical	Horizontal
Central Incisor		5.516e-006 mm	1.125e-005 mm
Lateral Incisor		5.5954e-006 mm	1.1718e-005 mm
Canine		4.5675e-006 mm	1.197e-005 mm
First Premolar		3.7317e-006 mm	1.3106e-005 mm
Second Premolar		2.7869e-006 mm	1.1752e-005 mm
First Molar	Mesial	2.7161e-006 mm	1.0797e-005 mm
	Distal	2.9479e-006 mm	1.0787e-005 mm
	Palatal	2.6595e-006 mm	1.065e-005 mm
Second Molar	Mesial	3.2516e-006 mm	1.0099e-005 mm
	Distal	3.4417e-006 mm	9.9299e-006 mm
	Palatal	3.2019e-006 mm	1.0003e-005 mm

Table VI. Posterior HPPG: Displacement on the root apices [right]

			Displacement	
			Vertical	Horizontal
Central Incisor			5.436e-006 mm	1.1157e-005 mm
Lateral Incisor			5.4055e-006 mm	1.1472e-005 mm
Canine			4.1848e-006 mm	1.1737e-005 mm
First Premolar			3.7721e-006 mm	1.1707e-005 mm
Second Premolar			2.963e-006 mm	1.0674e-005 mm
First Molar	Mesial		2.765e-006 mm	9.551e-006 mm
	Distal		2.9755e-006 mm	9.4277e-006 mm
	Palatal		2.8129e-006 mm	9.5766e-006 mm
Second Molar	Mesial		3.3034e-006 mm	8.7283e-006 mm
	Distal		3.5085e-006 mm	8.5837e-006 mm
	Palatal		3.32e-006 mm	8.7874e-006 mm

Table VII. Posterior HPPG: Displacement on the crown cusp tip or incisal edge[left]

		Displacement	
		Vertical	Horizontal
Central Incisor		4.4052e-006 mm	1.4354e-005 mm
Lateral Incisor		4.3109e-006 mm	1.3982e-005 mm
Canine		4.183e-006 mm	1.2373e-005 mm
First Premolar	Buccal	3.3103e-006 mm	1.114e-005 mm
	Lingual	3.429e-006 mm	1.1877e-005 mm
Second Premolar	Buccal	2.8668e-006 mm	1.1243e-005 mm
	Lingual	2.7525e-006 mm	1.1738e-005 mm
First Molar	Mesiobuccal	2.8092e-006 mm	1.1432e-005 mm
	Distobuccal	3.0587e-006 mm	1.1364e-005 mm
	Mesiolingual	2.8414e-006 mm	1.1639e-005 mm
Second Molar	Mesiobuccal	3.3359e-006 mm	1.1415e-005 mm
	Distobuccal	3.8979e-006 mm	1.1226e-005 mm
	Mesiolingual	3.4689e-006 mm	1.1495e-005 mm

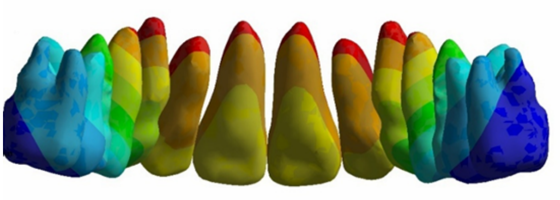
Table VIII. Posterior HPPG: Displacement on the crown cusp tip or incisal edge[right]

		Displacement	
		Vertical	Horizontal
Central Incisor		4.3449e-006 mm	1.4252e-005 mm
Lateral Incisor		4.1143e-006 mm	1.3744e-005 mm
Canine		3.8876e-006 mm	1.1834e-005 mm
First Premolar	Buccal	3.3033e-006 mm	1.0458e-005 mm
	Lingual	3.4968e-006 mm	1.1187e-005 mm
Second Premolar	Buccal	2.9482e-006 mm	1.0122e-005 mm
	Lingual	2.9666e-006 mm	1.068e-005 mm
First Molar	Mesiobuccal	2.8667e-006 mm	1.0086e-005 mm
	Distobuccal	3.084e-006 mm	9.8934e-006 mm
	Mesiolingual	2.9815e-006 mm	1.0379e-005 mm
Second Molar	Mesiobuccal	3.3506e-006 mm	9.8514e-006 mm
	Distobuccal	3.9379e-006 mm	9.6016e-006 mm
	Mesiolingual	3.5808e-006 mm	1.0083e-005 mm

Vertical Displacement: - (+) upward, (-) downward

Horizontal Displacement: - (+) backward (-) forward
Anterior HPPG: Nodes (165553) Elements (87180)
Posterior HPPG: Nodes (191355) Elements (102309)

Anterior HPPG showed the maximum value of intrusive displacement at the incisal edges of the central incisors followed by lateral incisors and canines with a decrease of displacement value distributed from the anterior to the posterior directions. Mesio lingual cusps of molars showed more intrusion than buccal cusps. For the evaluation of horizontal displacement palatal cusps of posteriors picturised the highest backward displacement than other teeth. When comparing horizontal displacements at root apices, canine root apex exhibited more backward displacement than others (Figure 4).



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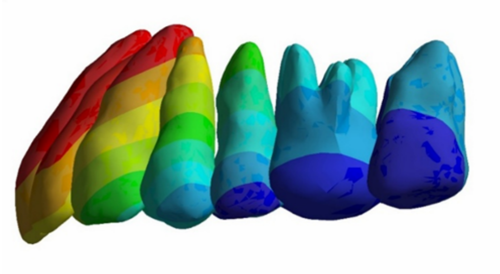

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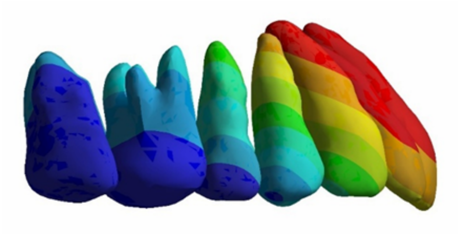

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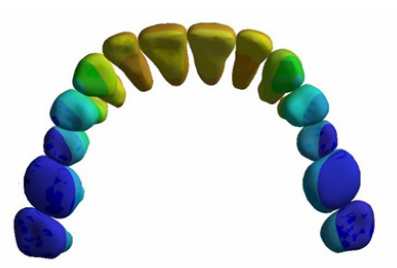

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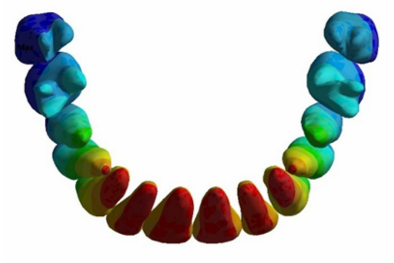

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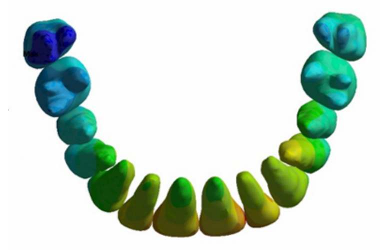
Figure 4. Displacement of teeth- Anterior HPPG. A- Labial view. B- Palatal view. C- Sagittal view(external) right side. D- Sagittal view(external) left side. E- Occlusal view (crown side). F- Coronal view (root side).

In posterior HPPG, the maximum intrusive displacement on the central incisor, then lateral incisor and canine as similar to anterior HPPG but there was an increase in intrusion for posterior teeth, while the amount of intrusion for anterior teeth decreased compared to Anterior HPPG. Backward displacement of whole teeth increased considerably in posterior HPPG with anterior teeth showing greater retraction and increased crown angulation change to the palatal plane. (Figure 5).



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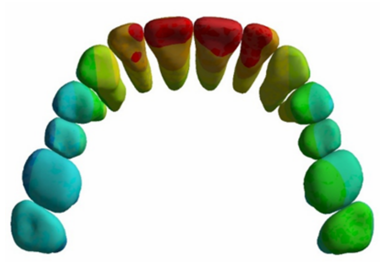

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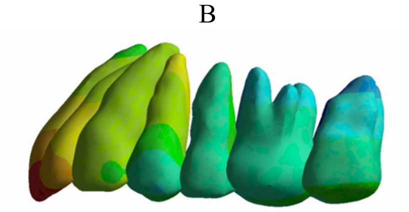

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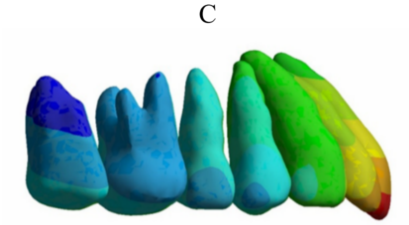

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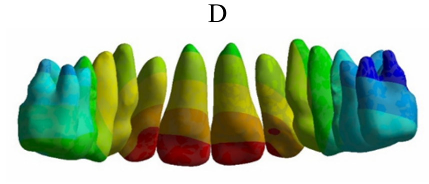

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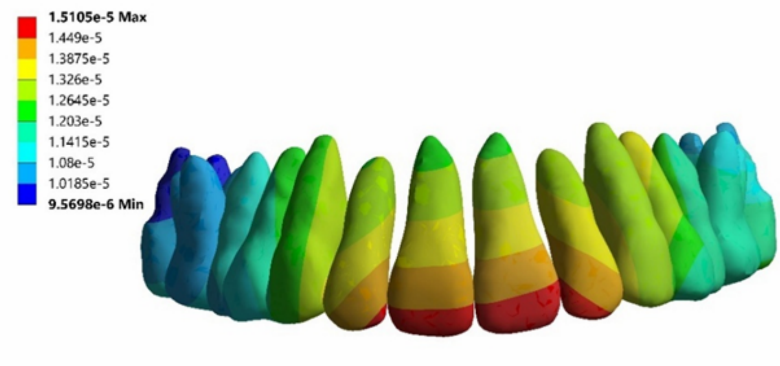

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Figure 5. Displacement of teeth- Posterior HPPG. A- Labial view. B- Palatal view. C- Sagittal view(external) right side. D- Sagittal view(external) left side. E- Occlusal view (crown side). F- Coronal view (root side).

For assessing stress distribution on maxillary whole dentition, both anterior and posterior HPPG showed the highest stress concentration on the palatal aspect of the lateral incisor crown, where the force was applied (Figure 6 and 7).

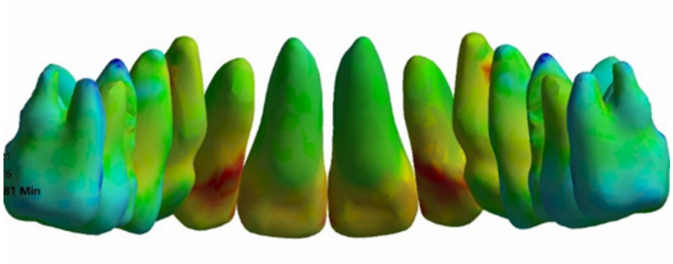

Figure 6. Von Mises stress distribution. Anterior HPPG. Palatal view.

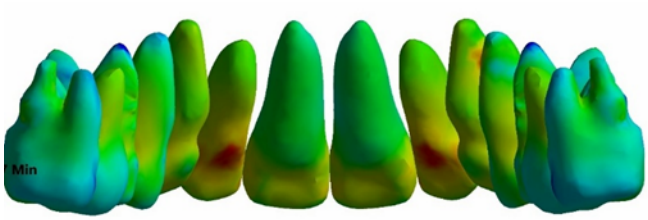

Figure 7. Von Mises stress distribution. Posterior HPPG. Palatal view.

IV. Discussion

Whole maxillary arch intrusion and distalization is a treatment method for skeletal class II hyperdivergent patients with a gummy smile.[6] Intrusion and retraction of the entire maxillary teeth in orthodontics presents significant challenges because of the indeterminate mechanical requirements, difficulties in securing adequate anchorage, possible side effects and potential anatomical constraints. Intrusion can be done simultaneously with the levelling or space-closing procedure.[7] Simultaneous intrusion and retraction using a segmented approach, such as a three-piece intrusion arch, results in relative intrusion of the anterior teeth along with extrusion of the posterior teeth.[8] These posterior teeth extrusion is undesirable in skeletal Class II hyperdivergent patients, as it can exacerbate the condition. Temporary anchorage devices enable absolute anchorage from various sites for intrusion and retraction with minimal side effects. The boundaries of tooth movement have been expanded by TADs.[9]

Skeletal anchorage for the intrusion of the entire maxillary teeth can lead to mandibular counterclockwise rotation, better chin projection, a more attractive soft-tissue profile, and enhanced lip-incisor and occlusal relationships.[9] To balance the force in intrusion mechanics using mini-implants on the buccal or palatal alveolar bone, multiple mini-implants or additional accessory appliances are required.[10] However, with HPPG technique just one mid- palatal mini-implant is enough to support the intrusion and distalization of the entire maxillary teeth on rigid archwire. [5] This enhances patient compliance and provides a financial benefit to the patient.

Whole maxillary arch intrusion and distalization can be achieved using three or four buccal interradicular mini- implants (two IZC implants and one or two anterior interradicular implants). However, these implants can interfere with dental roots, increasing the risk of implant failure and treatment delays.[11] Using such a high number of mini- implants creates an indeterminate system, making it difficult to predict forces and moments accurately. In contrast, a single mid-palatal mini- implant for full arch intrusion and distalization generates a single force vector, making the system more determinate.

The "T-Zone", the area located just behind the palatal rugae, is considered more suitable for palatal mini-implant insertion due to its increased bone volume.[12] The dense cortical bone found in the median and paramedian regions of the palate provides ample bone quality and quantity to support mini- implants. This anatomical zone boasts advantages including the absence of significant structures like nerves, blood vessels, or roots that might impede the precise placement of mini- implants.[13] Moreover, the presence of keratinized tissues covering the palatal bones, coupled with minimal potential for soft tissue irritations, makes palatal regions highly suitable for the insertion of mini- implants.[14]

To maintain control and prevent torque loss, light force should be applied during whole arch intrusion and distalization on a stiff archwire, ensuring the teeth move steadily within the alveolar bone.[5] Active self-ligating brackets exhibit superior torque expression compared to passive self-ligating and conventional brackets.[15] High-torque active self-ligating brackets are recommended to prevent torque loss, especially when force is applied from the palatal side of the anterior teeth, or by incorporating torque into the archwire. For cases with initially straight incisors, 10° of buccal crown torque can be added to the archwire to control buccolingual inclination.[5]

In skeletal Class II cases, the maxilla tends to grow more vertically than in the sagittal direction, causing downward and backward rotation of the mandible and resulting in a hyperdivergent condition with reduced chin prominence. Maxillary whole-arch intrusion using HPPG induces counterclockwise rotation of the maxillary occlusal plane[16]. A combination of the HPPG technique with mandibular buccal shelf or interradicular mini- screws can correct the pitch of the occlusal plane, leading to autorotation of the mandible in hyperdivergent Class II patients.[16]

3D-FEM analysis provides a reliable method for assessing biomechanical aspects, including stress distribution and deformation, in structures with intricate geometries under defined condition.[17] It allows for the anticipation of tissue responses to applied orthodontic force. This study evaluated the effect of the anterior and posterior HPPG on the intrusion and distalization of the maxillary whole teeth. The model for this study was derived from an adult male patient with normal occlusion to ensure a high degree of similarity with the maxillary dentition. 0.018 slot brackets and a 0.017×0.025-inch stainless steel arch wire was placed on the labial surface of the teeth. All the teeth in the arch engaged by a rigid stainless steel archwire, the entire assembly was treated as a single system. The mini-implant size was 1.5* 8 mm. All interfaces were demonstrated as fully bonded surfaces to distinctly indicate the biomechanical effects of a mid-palatal mini- implant for the intrusion and distalization of the entire maxillary dentition.

In both techniques, maximum Von Mises stress values were observed on the palatal aspects of the maxillary lateral incisors where the force was applied from the mini- implant. In both models, all the teeth demonstrated intrusion and distalization, with greater intrusion observed in the anterior teeth compared to the posterior teeth. Additionally, a counterclockwise rotation of the maxillary occlusal plane was noted in both techniques. However, in the anterior HPPG, a greater vertical component of the applied force was delivered to the anterior teeth compared to the posterior HPPG. Conversely, the posterior HPPG showed greater backward displacement and angulation change of the anterior teeth due to more pronounced horizontal force vectors.

The findings of this study confirm the feasibility of achieving simultaneous intrusion and distalization of the entire maxillary dentition using a single mid-palatal mini- implant.

V. Conclusion

A single mid-palatal mini- implant is effective for the intrusion and distalization of the entire maxillary arch. When placed in the anterior position of the midpalate, there is greater intrusion of the maxillary anterior teeth, whereas placement in the posterior midpalate results in increased intrusion of the posterior teeth and significant retraction and greater crown angulation changes to the palatal plane.

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