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Effect of Archwires on Simultaneous Intrusion and Retraction in Orthodontic Tooth Movement in Maxilla and Mandible During Extraction Space Closure with Miniscrew Sliding Mechanics by Finite Element Method

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KEYWORDS

Archwire, Extraction Space Closure, Finite Element Analysis, Orthodontics, Stress

ABSTRACT:

Introduction: Finite element method (FEM) can anticipate visualization of tissue responses through observation of areas of stress created from applied orthodontic mechanics. The present study with the help of FEM elucidated how and why the archwire size affects long-term tooth movement in miniscrew sliding mechanics.

Materials and Method: Digitalized maxillary and mandibular model with first premolar extraction spaces bilaterally with all other permanent teeth present were included. Retraction forces of 150 g and intrusion forces of 60 g were applied on maxillary and mandibular anterior teeth; using nickel-titanium (NiTi) closed coil springs by means of mini-implants and retraction hook. Geometry of 3D finite element model of maxilla and mandible was constructed from a CBCT scan image of the skull and GEOMAGIC modelling software was used to convert geometric models into finite element models. The study included three simulation models for both maxilla and mandible using three different archwire dimensions: (a) 0.021 x 0.025" SS (b) 0.019 x 0.025" SS (c) 0.016 x 0.022" SS.

Results: On force application, model 1, 2 and 3 of maxilla showed tipping and torque of 1.3° & 0.19°, 1.6° & 0.22° and 2.7° & 0.37° respectively. The model 1, 2 and 3 of mandible showed tipping and torque of 0.42° & 0.077°, 0.53° & 0.082° and 0.96° & 0.110°. The intrusion & extrusion shown by model 1, 2 and 3 of maxilla was 4.96 E-03mm & 4.44 E-03mm, 5.38 E-03mm & 5.53 E-03mm and 7.51 E-03mm & 9.72 E-03mm respectively. The intrusion & extrusion shown by model 1, 2 and 3 of mandible was 1.46E-03mm & 42.61E-03mm, 1.57E-03mm & 4.17E-03mm and 1.92E-03mm & 5.46E-03mm respectively.

Conclusion: The decrease in arch wire size result in increase in tipping angle, torque angle, intrusion and retraction.

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Introduction

Correction of different types of malocclusions often requires tooth extraction, molar distalization, expansion of dental arches, interproximal reduction resulting in dental space gain. It is a challenging task to deal with space closure. Appropriate knowledge of biomechanics coupled with new materials and techniques have made space closure attainable using simplified mechanics. Biomechanics allows determining anchorage and treatment options, to presume prognosis using varying options, and to understand the effect of specific adjustments on outcome of care. Factors determining space closure include biomechanical forces applied to the teeth, variation in force and moment magnitude, moment-to-force ratio (M/F), force-to-deflection rate, and anchor unit.[1] Sliding mechanics and closing loop mechanics are two basic biomechanical strategies that can be utilised for space closure.[1] Sliding mechanics is standard method employed to close extraction spaces owing to its simplicity but it has compromised effects due to friction.[2,3] In modern orthodontics, successful of orthodontic treatment relies on the anchorage protocol planned for each specific case. Anchorage can be obtained using dental implants,[4] miniplates,[5] miniscrews,[6] and microscrews[7,8]. Miniscrew implants offers easy placement and removal in the intra-arch alveolar bone without discernible damage to tooth roots.[8] The finite element method (FEM) is a non-invasive and accurate engineering resource applied to calculate the stress and deformation of complex structures. It provides detailed data on the physiological reactions possible to occur in tissues, applying the FEM can anticipate the visualization of these tissue responses through the observation of areas of stress created from applied orthodontic mechanics.[9] Previously very few studies have evaluated has focused on the effect of arch wire force, arch wire size or modified archwire, on tipping, torquing, intrusion and retraction.[10,11] Thus, the present study with the help of FEM elucidated how and why the archwire size affects long-term tooth movement in miniscrew sliding mechanics.

Materials and Method

Ethical Statement

This study was reviewed and approved by the Institutional Ethical Committee of Sri Aurbindo College of Dentistry, Indore, India.

Methodology

The study included digitalized maxillary and mandibular model with first premolar extraction spaces bilaterally with all other permanent teeth present.Model comprising of deciduous or mixed dentition or full permanent dentition were excluded from the study.The retraction forces of 150 g and intrusion forces of 60 g were applied on maxillary and mandibular anterior teeth, using nickel-titanium (NiTi) closed coil springs by means of mini-implants and retraction hook. The geometry of 3D finite element model of the maxilla and mandible with their periodontal structures, i.e., PDL, alveolar bone was constructed from a CBCT scan image of the skull. These images were processed and stereo lithographic (STL) model of each tooth was constructed using 3D image processing and editing software- 3D-Doctor 60 (Able Software Corp., Lexington, Massachusetts, USA). Brackets (PEA MBT 0.022”), archwire of different sizes, 4 titanium mini-implants (1.3 mm×11 mm, 1.3x8 mm) in maxilla and mandible both, NiTi closed coil springs, and retraction hooks (4 mm) were virtually modelled using reverse engineering technique. With the help of GEOMAGIC modelling software, the geometric models were converted into finite element models. With the help of GEOMAGIC modelling software, the geometric models were converted into finite element models. All materials employed for the finite element model study were isotropic, homogenous, and linearly elastic. The steps of construction of FEM model have been depicted in figure 1. The steps of formation of maxillary and mandibular models have been depicted in figure 2 and 3 respectively. Element qualities like Warpage, Aspect Ratio, tet Collapse were checked & required modification were done in the model to improve the element quality. The models were locked in all degrees of freedom to restrict the displacement. Angle Measurement: two nodes: one on root tip and other on crown tip marked the long axis of the tooth. The position of these two nodes, before and after force application helped in determining the tipping and torquing angle. The study included three simulation models for maxilla and three for mandible using three different archwire dimensions: MAXILLA a. Model $1_{(Maxilla)}$ - 0.021 x 0.025” SS b. Model $2_{(Maxilla)}$ - 0.019 x 0.025” SS c. Model $3_{(Maxilla)}$ - 0.016 x 0.022” SS MANDIBLE a. Model $1_{(Mandible)}$ - 0.021 x 0.025” SS b.

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Model 2(Mandible) - 0.019 x 0.025" SS c. Model 3(Mandible) - 0.016 x 0.022" SS.

Results

The amount of intrusion, retraction, tipping and torquing angle as obtained by maxillary simulation model and mandibular simulation model has been described in table 1, figure 4 and table 2, figure 5 respectively. The maxillary simulation models showed that with decrease in the size of the wire there was an increase in the torque angle, tipping angle, intrusion and retraction.

Table 1. Description of intrusion, retraction, torque angle and tipping angle of simulation models of maxilla

Simulation model	Arch-wire dimension	Displacement (mm) x1000		Tipping Angle (°)	Torque Angle (°)
		Z axis (Intrusion)	Y axis (Retraction)		
Model 1 (Maxilla)	0.021 x 0.025" SS	4.96	4.44	1.3	0.190
Model 2 (Maxilla)	0.019 x 0.025" SS	5.38	5.53	1.6	0.220
Model 3 (Maxilla)	0.016 x 0.022" SS	7.51	9.72	2.7	0.370

Table 2. Description of intrusion, retraction, torque angle and tipping angle of simulation models of mandible

Simulation model	Arch-wire dimension	Displacement (mm) x1000		Tipping Angle (°)	Torque Angle (°)
		Z axis (Intrusion)	Y axis (Retraction)		
Model 1 (Mandible)	0.021 x 0.025" SS	1.46E-03mm	42.61E-03mm	0.42°	0.077°
Model 2 (Mandible)	0.019 x 0.025" SS	1.57E-03mm	4.17E-03mm	0.53°	0.082°
Model 3 (Mandible)	0.016 x 0.022" SS	1.92E-03m	5.46E-03mm	0.96°	0.110°

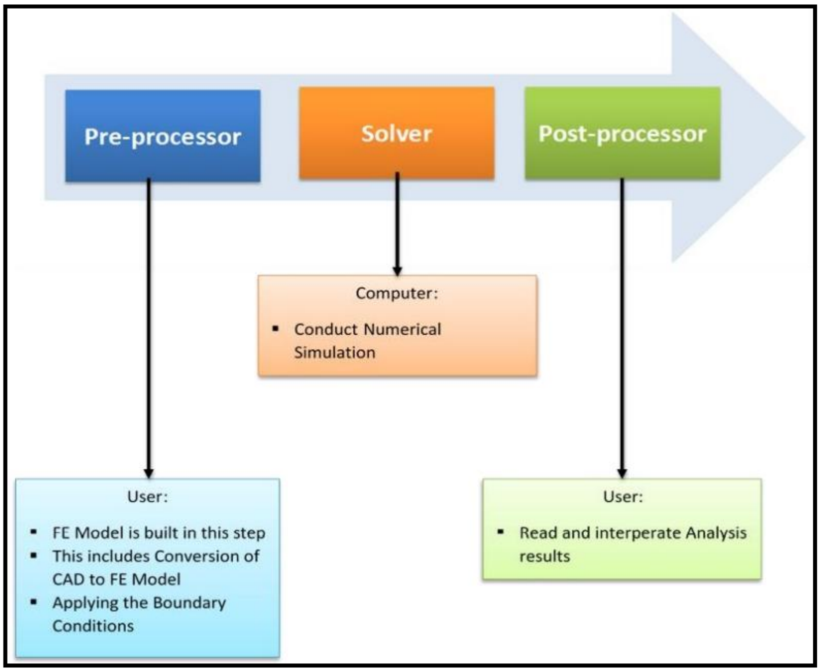

Figure 1. The steps of construction of FEM model

Figure 2.1 Brackets and Archwire.

Figure 2.2 Bracket, Archwire and Teeth.

Figure 2.3 Bracket, Archwire, Teeth and Periodontal ligament.

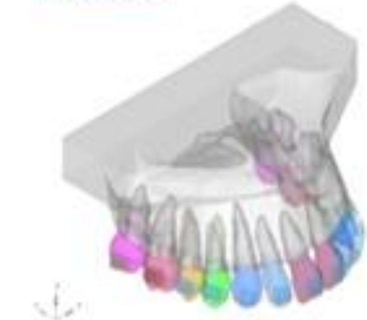

Figure 2.4 Bracket, Archwire, Teeth, Periodontal ligament and Jaw bone.

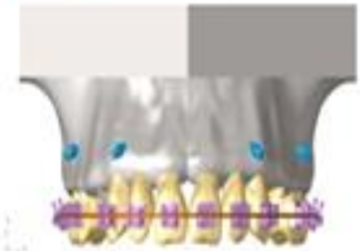

Figure 2.5 Bracket, Archwire, Teeth, Periodontal ligament and Jaw bone with Titanium mini-implants.

Figure 2. The steps of formation of maxillary model

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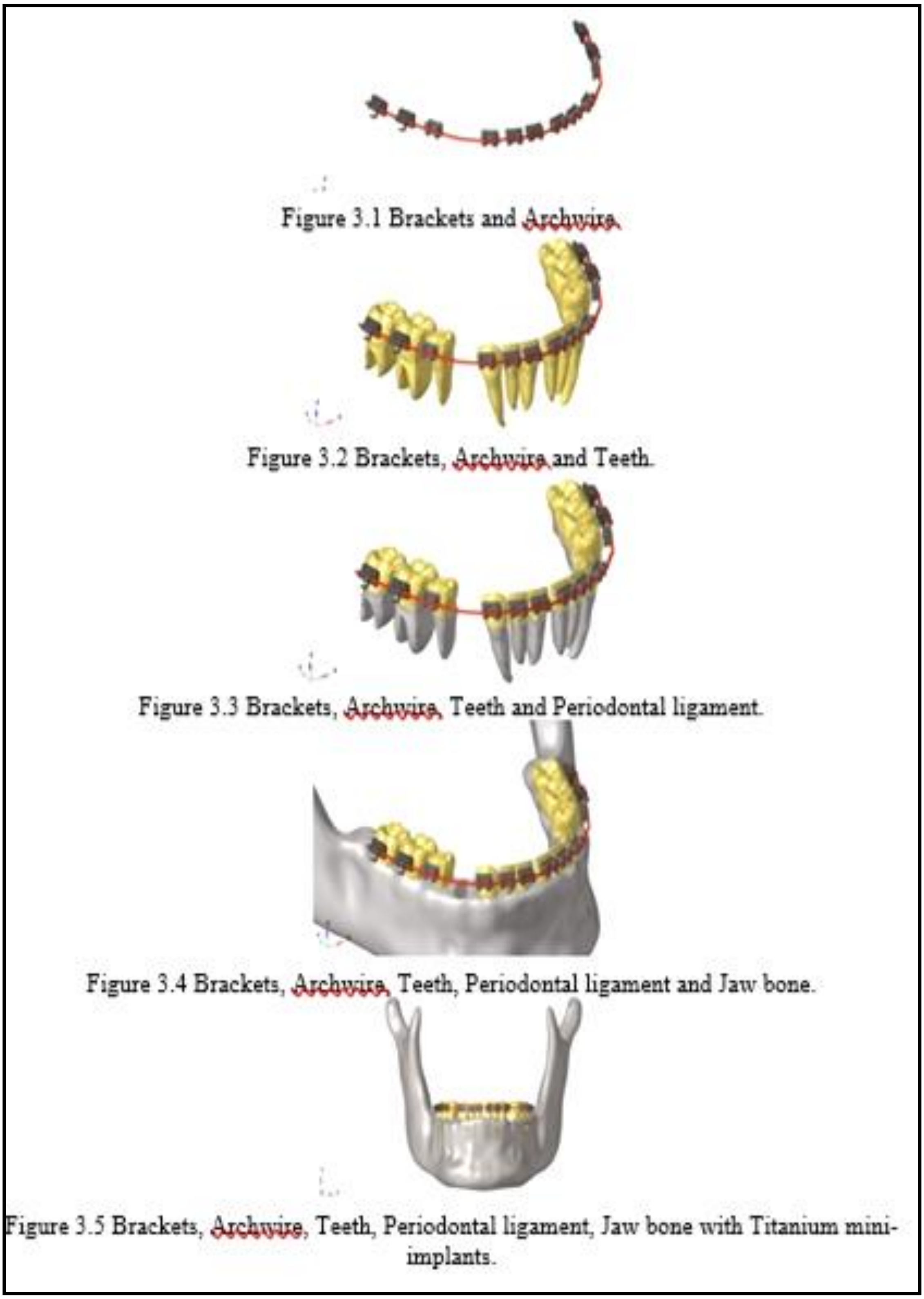
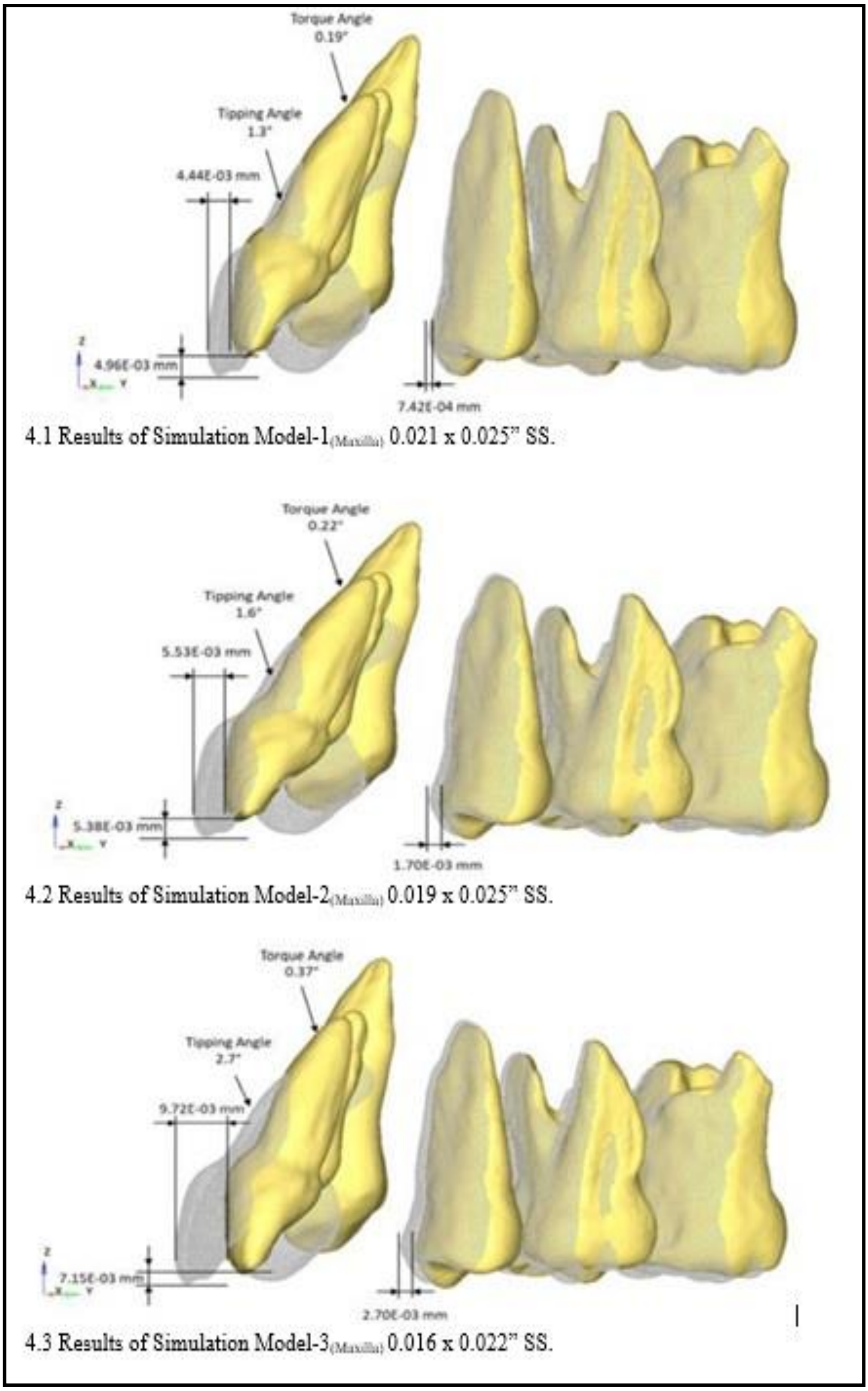


Figure 3. The steps of formation of mandibular model



4.1 Results of Simulation Model-1$_{(Maxilla)}$ 0.021 x 0.025" SS.

4.2 Results of Simulation Model-2$_{(Maxilla)}$ 0.019 x 0.025" SS.

4.3 Results of Simulation Model-3$_{(Maxilla)}$ 0.016 x 0.022" SS.

Figure 4. Results of simulation model 1, 2 and 3 of maxilla

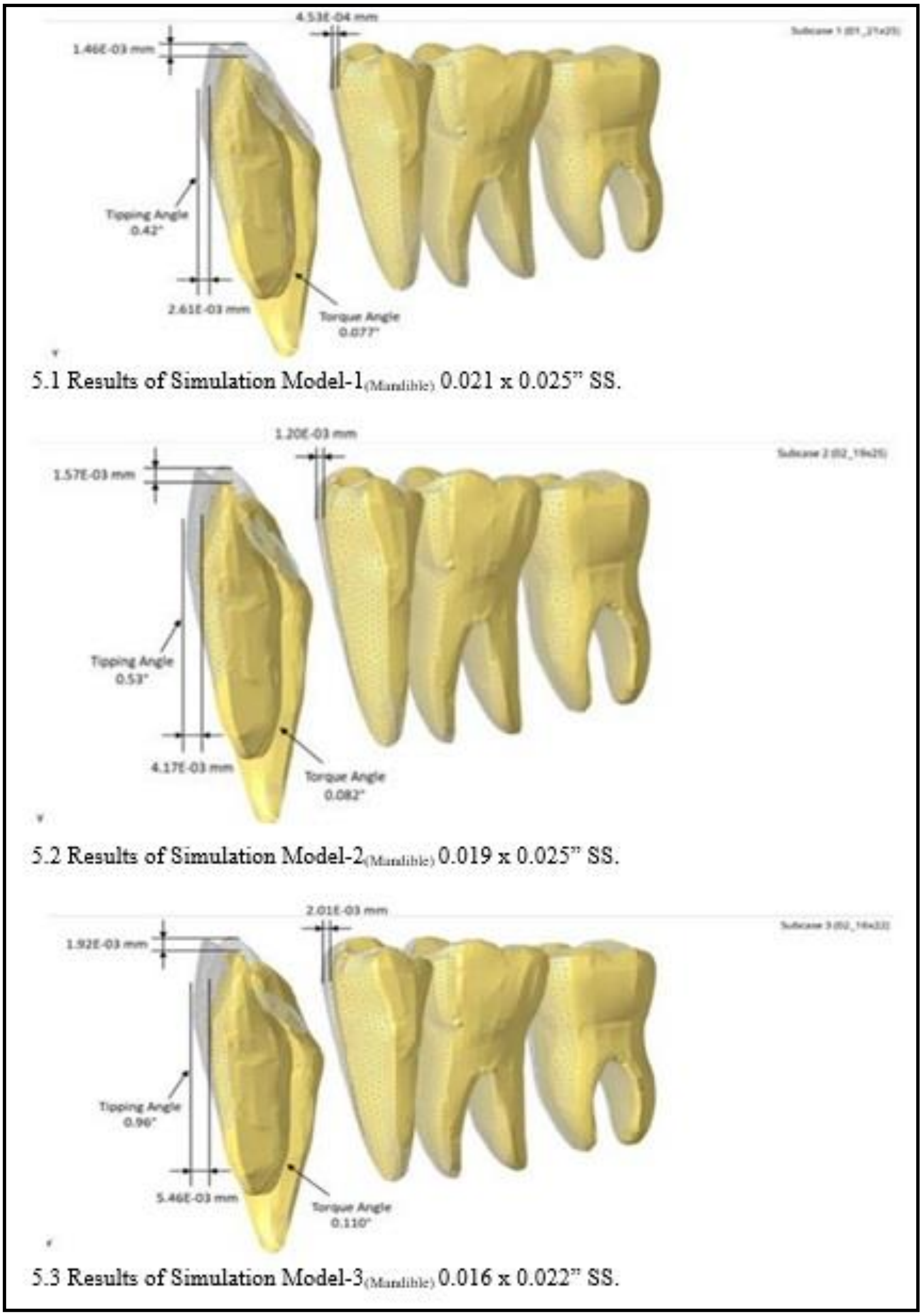


Figure 5. Results of simulation model 1, 2 and 3 of mandible

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Discussion

In the present study an effort had been made to evaluate the effect of the size of the arch-wire on the movement of tooth in intrusion and retraction while performing extraction space closure using FEM method. The evaluation of tooth movement was done by using finite element method. The reason of utilizing finite element method was based on the fact that FEM is a powerful tool for analyzing the biomechanical effects of various treatment modalities and is an approximation method to represent both the deformation and the 3D stress distribution in bodies that are exposed to stress. It precisely sketches the displacement of the body before and after the application of the load. FEM has applicability to solids of irregular geometry that contain heterogeneous material properties. It is therefore suited to evaluate the structural behaviour of teeth.[12] In the present study, the closure of extraction space was attempted using miniscrew. Mini-screw allows treatment to proceed easily and successfully with practically no anchorage loss, resistance to unwanted tooth movement and requiring minimal patient cooperation.[13,14] Present study employed sliding mechanics to achieve the movement of tooth using mini-screws. Sliding mechanics helps in transferring retraction forces to any height level on the retraction hook and as bracket slides along the archwire the movement the tooth in a pre-determined direction can be achieved easily.[15,16] In the present study, three simulation models were created for maxilla and mandible using stainless steel wires of the following dimensions: 0.021 x 0.025" SS, 0.019 x 0.025" SS and 0.016 x 0.022" SS. It was demonstrated that with the decrease in the size of the arch-wire there was an increase in the torque angle, tipping angle, intrusion and retraction. The tipping angle for Model $1_{(Maxilla)}$ was 1.3° whereas it was 2.7° in Model $3_{(Maxilla)}$. [Table-1] Similarly in mandible, the tipping angle in Model $1_{(Mandible)}$ was 0.42° whereas it was 0.96° in Model $3_{(Mandible)}$. [Table-2] *Kawamura J et al.* (2019) [15] reported inverse relationship between archwire size and tipping angle. Lesser archwire size greater play of the archwire-bracket slot, as well as the elastic deformation of the archwire, resulting in greater lingual tipping of the incisors. When increasing the archwire size, bending stiffness of the archwire increases[15] and with the increase in the diameter of the wire, the free space in the slot decreases and the amount of tip required to achieve the critical contact angle decreases and thus it results in lesser tipping of the tooth.[17] According to *Jun YaTominaga et al.* (2014) an effective torque application to the anterior teeth becomes clinically difficult in sliding mechanics when the archwire/bracket play is large.[18] In the present study with the decrease in the size of the arch-wire there was an increase in the torque angle. The torque angle for Model $1_{(Maxilla)}$ was 0.190° whereas it was 0.37° in Model $3_{(Maxilla)}$. [Table-1] Similarly in mandible, the torque angle for Model $1_{(Mandible)}$ was 0.077° whereas it was 0.110° in Model $3_{(Mandible)}$. [Table-2] This can be explained by the fact that the decrease in archwire size allowed for more archwire/bracket play and thus posed difficulty in torque expression which was manifested as increase in torque angle. In the current study we observed that when we used archwire of the smaller size the intrusion increases which was contrary to the result obtained by *Hamdan and Rock* in 2016.[19] Present study showed that the amount of retraction was also increased with decrease in archwire size. The increase in play decreased the friction archwire and bracket slot and thus made retraction easier.[20] Our research also found that there is slight distalisation of both maxillary and mandibular posteriors during anterior retraction using mini-screw implants which increases with decrease in size of archwire which is similar to that found by *Kawamura and Tamya* in 2019. [15] This posterior distalisation is due to slight counter clockwise rotation of posterior teeth. [15] It is advantageous over conventional sliding mechanics in which there is mesialisation of anchor teeth to some extent, thus leading to anchor loss.

Conclusion

Based on the observations, it was concluded that there exists an inverse relation between archwire size and tipping angle, torquing angle, intrusion and extrusion of teeth. Amongst the three archwire sizes included in the study, archwire of dimension 0.021" X 0.025" is most appropriate for bodily movement and lingual crown tipping of anterior teeth.

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