ORIGINAL RESEARCH

Displacement Pattern, Stress Distribution, and Archwire Play Dimensions during En-masse Retraction of Anterior Teeth using Sliding Mechanics: A FEM Study

Harvinder Singh[1], Mannu Khanna[2], Chanjyot Walia[3], Harjoy Khatria[4], Asiya Fatima[5], Navjot Kaur[6]

Abstract

Aims: This finite element study was undertaken to evaluate the pattern of stress distribution around the implant and anterior teeth during en-masse retraction in the premolar extraction case. Displacement of the teeth and play of wire in the bracket slot were also evaluated to determine the most favorable height of the power arm attached to the arch-wire.

Materials and methods: A three-dimensional (3D) finite element model of the maxilla was constructed using computed tomography (CT) scan. A total of 12 models were fabricated with different heights of power arms placed distal to the canine. A retraction force of 1.5 N was applied from the implant placed between the roots of the second premolar and first molar, and the response was predicted using Analysis of Systems (ANSYS) software.

Results: When power-arm height was near the center of resistance of the anterior segment, stability in the stress distribution around the implant site and anterior teeth was observed. Displacement of the teeth varied along the three planes of space with the change in power-arm height.

Conclusion: For en-masse retraction, power-arm height should be kept at a level of the center of resistance. Play in the bracket slot and the archwire show a negative role in the bodily movement of anterior teeth.

Clinical significance: For efficient en-masse retraction of anterior teeth, it is imperative to study the most effective site of application of force. Therefore, our study recommends certain key points to keep in mind during the attachment of the power arm and engaging wire in the bracket slot, which could benefit the orthodontist immensely.

Keywords: En-masse retraction, Finite element model, Height of power arm, Play, Temporary anchorage devices.

International Journal of Clinical Pediatric Dentistry (2022): 10.5005/jp-journals-10005-2463

Introduction

Bialveolar dental protrusion is the most prevalent anomaly in different ethnic groups in India. It is characterized by dentoalveolar flaring of both the maxillary and mandibular anterior teeth with lip protuberance and facial convexity.[1] Extraction spaces in such cases can be closed using sliding or loop mechanics.

As the use of pre-adjusted appliances has increased, various forms of sliding mechanics have replaced closing loop arches.[2] Sliding mechanics might have great benefits, such as minimal wire-bending time and adequate space for activations. However, friction occurs at the interface between the archwire and the bracket, which may lead to anchorage loss.[3] This difficulty can be overcome by using mini-screws as orthodontic anchorage appliances.[2]

Nowadays, temporary anchorage devices are the choice of anchorage control in clinical orthodontics due to benefits like absolute anchorage, small size, and ease of placement and removal. Additionally, time can be saved effectively by using microscrew implants in the treatment of bimaxillary protrusion with en-masse retraction of six anterior teeth.[4]

Sliding mechanics, with the combined use of power arms, has gradually been applied for obtaining controlled anterior tooth movements during space closure.[2]

The finite element method (FEM) was introduced into dentistry to allow accurate analysis of the biomechanical effects in various treatment modalities. For the evaluation of biomechanical components such as displacements, strains, and stresses which are induced in living structures from various external forces, it had been the choice of study for many engineers.[5]

[1]Department of Orthodontics & Dentofacial Orthopaedics, National Dental College and Hospital, Dera Bassi, Punjab, India

[2]Department of Orthodontics & Dentofacial Orthopaedics, Teerthanker Mahaveer Dental College & Research Centre, Teerthanker Mahaveer University, Moradabad, Uttar Pradesh, India

[3–5]Department of Orthodontics & Dentofacial Orthopaedics, Maharishi Markandeshwar College of Dental Sciences & Research, Maharishi Markandeshwar (Deemed to be University), Mullana, Ambala, Haryana, India

[6]Department of Oral & Maxillofacial Surgery, Rayat Bahra Dental College and Hospital, Mohali, Punjab, India

Corresponding Author: Harjoy Khatria,Department of Orthodontics & Dentofacial Orthopaedics, Maharishi Markandeshwar College of Dental Sciences & Research, Maharishi Markandeshwar (Deemed to be University), Mullana, Ambala, Haryana, India, Phone: + 9149736456, e-mail: dr.harjoy31oct@gmail.co

How to cite this article: Singh H, Khanna M, Walia C, *et al.* Displacement Pattern, Stress Distribution, and Archwire Play Dimensions during En-masse Retraction of Anterior Teeth using Sliding Mechanics: A FEM Study. Int J Clin Pediatr Dent 2022;15(6):739–744.

Source of support: Nil

Conflict of interest: None

Although its development can be traced back to work by Alexander Hrennikoff (1941) and Richard Courant (1942), this method offers accurate replication of the tooth and the structures which surround the tooth and its complicated geometry. It permits detailed analysis of various force applications on structures such as teeth, bones, and joints.[6]

A number of studies have been done to explain the effect of bracket slot and archwire dimensions on anterior tooth movement during space closure in sliding mechanics. These include bracket and archwire material,[5,7] irregularities in tooth morphology,[6] errors in bracket placement[6] and bevelling of archwires.[8–10] Tanne K et al.[11] suggested that there should be an exact description of slot geometry and standardization in SI units[12,13] and are among the many authors who have described the variability of slot and archwire manufacturing dimensions.[2,11,14–18] In spite of these studies, very few compare the stress distribution and amount of play between bracket slot and archwire dimension.

Therefore, the purpose of this study was to evaluate the displacement of anterior teeth and the stress distribution around the implant site and anterior teeth to be retracted by using the varying height of the power arm and to see the dimension of play between the bracket slot and archwire during retraction.

Materials and Methods

The FEM provides quantitative data to the operator that can extend the understanding of the physiological reactions that occur in the system.

A 3D geometrical model of the maxilla was generated using a CT scan of a dry human skull. The Microsoft Windows Bitmap Format of two-dimensional images of CT scan was entered into Materialize Interactive Medical Image Control System Software that changes them to 3D surface models. The geometric model of the maxilla was generated from Rapidform software. Geometric models of brackets and implants were constructed by reverse-engineering technique. Titanium implants of 1.5 × 9 mm dimensions and stainless steel MBT prescription brackets with slot size 0.022 inch were used for the construction of models.

The results would be the same for both sides of the maxilla. Therefore, only one side of the maxilla was studied, and the boundary condition would not change. A model of a half-maxilla was constructed. The 3D models of the bracket were assembled at the center of the clinical crown of the teeth. Nodes were merged at the borders to create connectivity between the two models (Fig. 1).

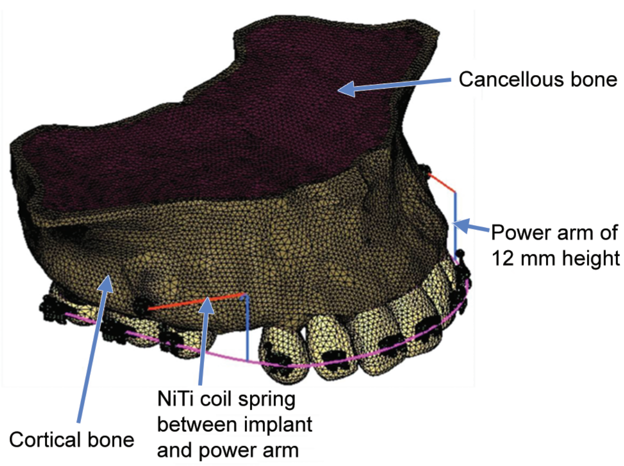


Fig. 1: Geometric model of maxilla with force applied from implant to power arm

The first premolar was removed from the model to retract the anterior teeth in a posterior direction. The 3D image of the implant was imported into the model of the maxilla and assembled between the roots of the second premolar and first molar. The stainless steel archwire of 0.019 × 0.025 inch dimensions with a power arm just distal to the canine was fabricated on the model. The height of the power arm was varied from 1 to 12 mm, with a 1 mm difference from the level of the bracket slot, thereby creating twelve models. A total of 12 finite element models were generated using HyperMesh Software version 13.0.

Material parameters, including Young's modulus and Poisson's ratio, were assigned to finite element model[9] to simulate their behavior.

After the preparation of models, a load of 1.5 N in an anteroposterior direction was applied on each model from the implant to the power arm (Fig. 1). ANSYS software version 12.1 was used to predict the response of the loads applied. The responses were in the form of Von Mises stress interpreted by various colors.

Results

Stress Distribution around Implant Site

Cancellous bone: for all values of load studied, when a load of 1.5 N was applied at the implant, the maximum stress was seen around the implant site at 12 mm height of the power arm (Table 1).

Cortical bone: when a load of 1.5 N was applied to the implant, the maximum stress level observed in cortical bone was at the distal, mesial, and basal portions of the implant at 12 mm height of the power arm (Table 1).

The stress values increased with an increase in the height of the power arm.

Stress Distribution around Anterior Teeth

Stress distribution around anterior teeth was reduced in the case of cancellous bone when compared to cortical bone (Table 2).

Displacement of Anterior Teeth

In this study, displacement of anterior teeth was studied in all three planes of space.

Table 1: Stress Distribution around implant site in cortical and cancellous bone

Power-arm height	*Stress Distribution (Mpa) (cortical bone)*	*Stress Distribution (Mpa) (cancellous bone)*
1 mm	0.67	0.086
2 mm	1.486	0.176
3 mm	7.639	0.337
4 mm	13.906	0.691
5 mm	17.673	0.875
6 mm	20.18	0.995
7 mm	21.712	1.087
8 mm	22.557	1.225
9 mm	22.998	1.342
10 mm	22.969	1.241
11 mm	23.547	1.316
12 mm	24.159	1.378

Table 2: Stress distribution around anterior teeth in cortical and cancellous bone

	Cortical bone (Mpa)			*Cancellous bone (Mpa)*		
Power-arm height	*Central incisor*	*Lateral incisor*	*Canine*	*Central incisor*	*Lateral incisor*	*Canine*
1 mm	1.331	1.331	3.313	0.731	0.409	0.489
2 mm	1.486	1.486	5.149	0.772	0.432	0.346
3 mm	1.295	1.295	5.101	0.746	0.419	0.337
4 mm	2.001	2.001	5.972	0.885	0.304	0.304
5 mm	2.546	2.546	5.067	0.752	0.384	0.264
6 mm	2.904	2.904	5.784	0.855	0.295	0.295
7 mm	3.123	3.123	3.123	0.781	0.324	0.324
8 mm	3.243	3.243	3.243	0.879	0.360	0.187
9 mm	3.296	3.296	3.296	0.204	0.204	0.204
10 mm	3.300	3.300	3.300	0.218	0.218	0.218
11 mm	3.383	3.383	3.383	0.230	0.230	0.230
12 mm	3.470	3.470	3.470	0.240	0.240	0.240

Displacement along the x-axis: there was no movement of the central incisor and lateral incisor at all levels of the power arm at which retraction force is applied.

In the case of canine, when the power-arm height was 1–5 mm, the crown of the tooth moved buccally by 0.001 mm, and when power-arm height was further increased up to 12 mm, no movement was seen.

Displacement along the Y-axis: along the Y-axis in the case of central incisor at the height of 1–8 mm, there is a trend of palatal root tipping and palatal crown tipping at a rate of 0.003–0.005 mm, respectively. When the height of the power arm was increased to 9–12 mm, the lingual root tipped by 0.002 mm, and the crown tip moved lingually by 0.004 mm. The same pattern was seen for lateral incisors.

In the case of canine, when the power-arm height was 1 mm, the crown moved distally by 0.005 mm, and the root moved distally by 0.002 mm. When power-arm height was increased from 2 to 4 mm, the distal movement of the crown increased by 0.006 mm. Further increase in power arm from 5 to 7 mm causes crown movement by 0.005 mm. When the power-arm height was increased to 12 mm, the crown movement decreased by 0.004 mm. Movement of the root of the canine remains constant at 0.002 mm, irrespective of power-arm height.

Displacement along the z-axis: in this study, central and lateral incisors showed extrusion of crowns by 0.001 mm at a power-arm height of 1 mm. They extruded by 0.002 mm with each 1 mm increase in the height of the power arm. In the case of canine, when power-arm height was 1–9 mm, there was an extrusion of 0.001 mm observed at the crown. When power-arm height was 2–8 mm and 10–12 mm, there was an extrusion of 0.002 mm.

Dimension of Play between Bracket and Wire

When an archwire is twisted by a bending moment of the power arm, two opposite corners of the arch-wire contact the opposite surfaces of the bracket slot.

The horizontal and vertical dimension of play, when 0.019- × 0.025-inch stainless steel wire was used in a 0.022-inch slot bracket, was 0.003 inch, although the vertical dimension of play was equally divided into two halves that are 0.0015 inches above and below the arch-wire. The height of the power arm had no effect on the play of the wire.

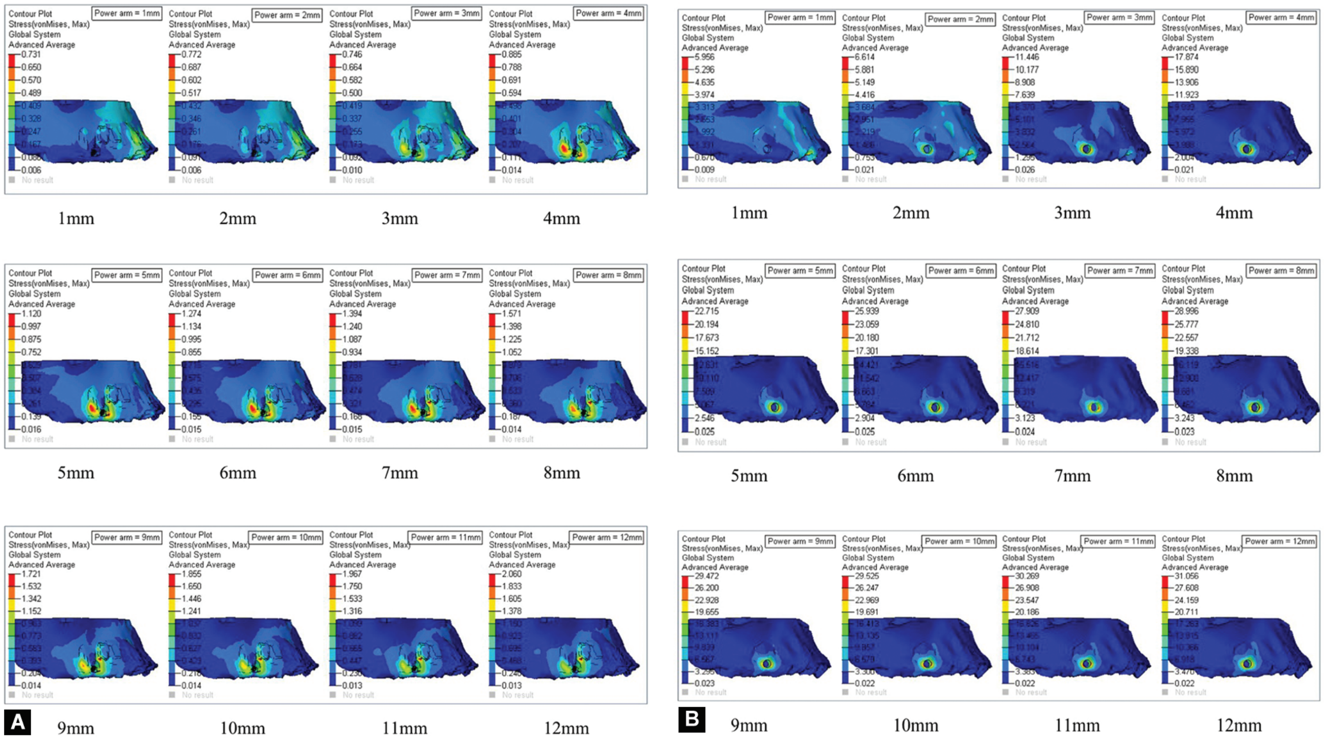
Discussion

The pattern of stress distribution in the cortical bone around the implant was different for all the heights of the power arm when subjected to 1.5 N of retraction force. Maximum stresses were concentrated just distal and mesial to implant in the direction of the load applied. As shown in Figure 2, when retraction force was applied on the power arm at 1 mm height, the magnitude of the maximum stress value was found to be 0.67 Mpa. As the height of the power arm was increased up to 12 mm from the bracket slot level, maximum stress also increased around the implant site in cortical bone. Since cortical bone has a higher modulus of elasticity and it is stronger and more resistant to deformation, it will bear more load than cancellous bone in clinical situations.

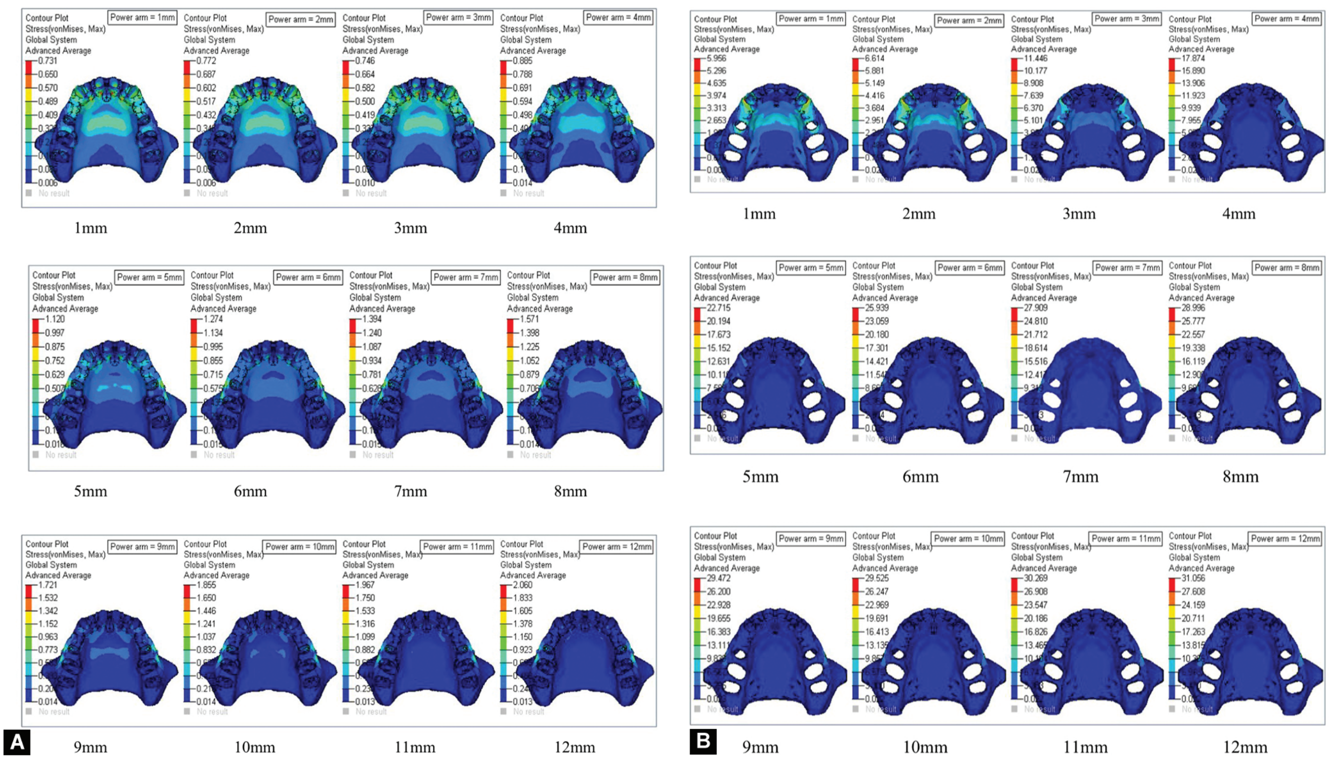
In this study, the maximum Von Mises stress in the cancellous bone around the mini-implant was 1.378 Mpa when the level of force was 12 mm from the bracket slot, as shown in Figure 2. The stress value gradually decreased when the power-arm height was decreased from 12 to 1 mm at the interval of 1 mm. The cancellous bone of the maxilla was exposed to very little stress during the retraction of the anterior teeth.

In the cortical bone, stress distribution around the central incisor and lateral incisor gradually increased with an increase in the height of the power arm. According to Figure 3 at 1 mm, the stress distribution around the central and lateral incisor was 1.331 Mpa which gradually increased to 3.47 Mpa when the power-arm height was increased to 12 mm. The high values of stress are seen around the canine due to the fact that the root of the canine is surrounded mostly by the cortical bone. Most of the torsional forces are produced on the arch-wire due to the retraction forces on the power arm. This distortion of the wire takes place just distal to the canine, where the power arm is attached to the arch-wire. These torsional forces are transferred to the canines, which are shown as stress around the root of the tooth on the cortical bone. Minimal torsional forces are transferred to the central and lateral incisors, which show less stress distribution as compared to the canine.

As the height of the power arm increased, the total stress distribution decreased around the canine and increased on the lateral and central incisors. At the level of the center of resistance, the force becomes stabilized as compared with the shorter power-arm



Figs 2A and B: Stress distribution around implant site in (A) cancellous and (B) cortical bone



Figs 3A and B: Stress distribution around anterior teeth in (A) cancellous and (B) cortical bone height hence, relatively less variability in stress distribution around the cortical bone. The same pattern is applied to the cancellous bone around the anterior teeth.

In the case of cancellous bone, stress distribution around the central incisor was high at the power-arm height of 1 mm, as shown in Figure 3A. Stress distribution was highest when the power-arm height was 4 mm, that is, 0.0885 Mpa, 0.879 Mpa at the power-arm height of 8 mm decreased to 0.204 at the height of 9 mm. According to Felicita, lingual root tipping was seen when the point of force application was occlusal to the mini-implant. If the mini-implant placement is at the level of the center of resistance, no moment is generated. When the point of force application is apical to the center of resistance, a counterclockwise moment is generated with extrusive and retraction components of force. The retraction force has to overcome the labial flaring of the teeth to allow them to be retracted.[19]

Stress distribution around the lateral incisor and canine remains stable at all the heights of the power arm as compared to the central incisor. Maximum stress distribution was found around the central incisors. Bucco-palatal width of the maxilla decreases from the central incisor to the canine. The root of the central incisor is surrounded mainly by the cancellous bone. As the quantity of cancellous bone decreases from the area around central incisors to the canine, the stress distribution also decreases, as shown in Figure 3. Maximum stress is found around the central incisor, then the lateral incisor and the least stress is seen around the canines.

The different retraction force levels produced displacement in the anterior teeth to various levels. The displacement was recorded for that particular time at which the load was applied. Hence, they were instantaneous displacements.

In this study, the displacement of anterior teeth was studied in all three different planes of space.

Displacement along the x-axis (transverse plane): no movement was seen for central and lateral incisors. For canines, positive values should show lingual movement, and negative showed buccal movements. In the case of canine, the crown moved buccally when power-arm height was 1, 2, 3, and 4 mm with no movement when it was further increased up to 12 mm.

According to Bohara et al.[20] and Zhang et al.,[21] the difference in the tipping direction of the incisor and canine was due to the transverse moment produced by the force of retraction. The outward force moment crossed via hook to reach the archwire, and opposing archwire deformation was produced at the location of the lateral incisor and canine. Torque was produced due to the deformation of the wire and made its crown tipped buccally.

Displacement along the y-axis (sagittal plane): for central and lateral incisors, positive values showed lingual movement, and negative showed buccal movement. For canines, positive values showed distal movement, and negative showed mesial movement. In the case of the central incisor and lateral incisor, at the height of 1–8 mm, there is a trend of the palatal crown and root tipping. When the height of the power arm was increased to 9–12 mm, the lingual root tipped 0.002 mm, and the crown tipped 0.004 mm. Thus, more crown movement was seen as compared to the root movement. In the case of canine, when the power-arm height was 1 and 4–11 mm, the crown moved distally by 0.005 mm. At 2–4 mm, the distal movement increased to 0.006 mm and reduced to 0.004 at 12 mm. Movement of the root of the canine remains constant irrespective of power-arm height. These findings suggest the controlled lingual tipping movement of anterior maxillary teeth during the application of retraction forces from implants.

This is in slight contrast to the study done by Zhang et al.,[21] where the crown and root of the lateral incisor showed equal displacement, indicating bodily movement in a lingual direction. The crown of the central incisor and canine were also tipped lingually. This difference can be attributed to the fact that placement of the power arm on the archwire. Zhang et al.[21] placed the power arm placed mesial to the canine, whereas, in this study, the power arm was placed distal to the canine.

This study is in accordance with the findings of Ashekar et al.[22] who reported that when the implant was placed at the height of 6 mm and the power-arm height was 8 mm, tipping and extrusion of anterior teeth were seen. This is in further concordance with Upadhyay et al.,[1] who concluded that controlled tipping movement and partly translation movement was seen during retraction with implants because the forces were applied near the center of resistance of anterior teeth of the maxilla.

Displacement along the z-axis (vertical plane): Positive values showed intrusion, and negative showed extrusive movement. In this study, the anterior teeth showed extrusion of crowns with an increase in power-arm height.

The extrusion can be explained by a force vector that was below the center of resistance of maxillary anterior teeth. Retraction forces with mini screw anchorage produced rotation of the entire arch around the center of rotation near the premolar root, which may result in maxillary anterior teeth. The intrusion of the central incisor was shown in the studies done by Sung et al.[23] and Zhang et al.[21] Such difference in movement may be due to the level of height of retraction force and the extent of the lingual crown tipping of the teeth.

Play, also called deviation angle, was defined as a rotation movement of the rectangular arch-wire from its passive position to a position where two opposite edges of the arch-wire contact two opposite walls of the bracket slot. According to Tominaga et al., a smaller play between the bracket and the arch-wire contributes to a more efficient torque application.[9] In this study, the horizontal dimension of play in a 0.022-inch slot system is 0.003 inches, and the vertical dimension of play is 0.0015 inches above and below the arch-wire when no force was applied. No difference was seen in the play in the arch-wire and the bracket slot on any of the anterior teeth on changing power-arm height. Therefore, it becomes difficult to prescribe an optimal power-arm length for achieving the desired type of anterior teeth movement if there is large arch-wire/bracket clearance.

Conclusion

The purpose of this study was to evaluate the stress distribution around anterior teeth and implant sites in sliding mechanics. The study concluded that:

- Lingual crown tipping and extrusion of the central and lateral incisors were observed.
- In the case of canines, the buccal crown movement was seen, which gradually reduced to zero with an increase in power-arm height. Moreover, distal crown movement and extrusion were also observed.
- As the power-arm height increased, the stress distribution around the implant in cortical bone and cancellous bone also increased.
- Stress distribution around the central incisor in the cancellous bone was found to be maximum which eventually decreased and became equal to the lateral incisor and canine after the power-arm height reached the center of resistance.

- Stress distribution around canine in cortical bone was found to be maximum which eventually decreased and became equal to lateral incisor and central incisor after the power-arm height reached the center of resistance.
- There was no effect of power-arm height on the play of wire in the bracket slot.

The drawback of the study was that a clinical environment similar to the patient's teeth and alveolar bone could not be created in the computer-constructed models.

Clinical Significance

The study throws light on the most preferred site of force application for efficient tooth movement. Therefore, archwire bracket play should be minimal to avoid friction between the archwire and bracket slot. Moreover, the position of the power arm should be at the level of the center of resistance to produce effective bodily movement of teeth to close extraction spaces.

References

1. Upadhyay M, Yadav S, Nagaraj K, et al. Treatment effects of mini-implants for en-masse retraction of anterior teeth in bialveolar dental protrusion patients: a randomized controlled trial. Am J Orthod Dentofacial Orthop 2008;134(1):18–29. DOI: 10.1016/j.ajodo.2007.03.025
2. Sia S, Koga Y, Yoshida N. Determining the center of resistance of maxillary anterior teeth subjected to retraction forces in sliding mechanics. An in vivo study. Angle Orthod 2007;77(6):999–1003. DOI: 10.2319/112206-478
3. Huang Y, Wang XX, Zhang J, et al. Root shortening in patients treated with two-step and en masse space closure procedures with sliding mechanics. Angle Orthod 2010;80(3):492–497. DOI: 10.2319/082409-479.1
4. Park HS, Kwon TG. Sliding mechanics with microscrew implant anchorage. Angle Orthod 2004;74(5):703–710. DOI: 10.1043/0003-3219(2004)074<0703:SMWMIA>2.0.CO;2
5. Herrera A, Ibarz E, Cegoñino J. Applications of finite element simulation in orthopedic and trauma surgery. World J Orthop 2012;3(4):25–34. DOI: 10.5312/wjo.v3.i4.25
6. Konda P, Tarannum SA. Basic principles of finite element method and its applications in orthodontics. JPBMS 2012;16(11):1–4.
7. Ammar HH, Ngan P, Crout RJ, et al. Three-dimensional modeling and finite element analysis in treatment planning for orthodontic tooth movement. Am J Orthod Dentofacial Orthop 2011;139(1):e59–e71. DOI: 10.1016/j.ajodo.2010.09.020
8. Chaudhry A, Sidhu MS, Chaudhary G, et al. Evaluation of stress changes in the mandible with a fixed functional appliance: a finite element study. Am J Orthod Dentofacial Orthop 2015;147(2):226–234. DOI: 10.1016/j.ajodo.2014.09.020
9. Tominaga JY, Ozaki H, Chiang PC, et al. Effect of bracket slot and archwire dimensions on anterior tooth movement during space closure in sliding mechanics: a 3-dimensional finite element study. Am J Orthod Dentofacial Orthop 2014;146(2):166–174. DOI: 10.1016/j.ajodo.2014.04.016
10. Miyakawa O, Shiokawa N, Matsuura T, et al. A new method for finite element simulation of orthodontic appliance-teeth-periodontium-alveolus system. J Biomech 1985;18(4):277–284. DOI: 10.1016/0021-9290(85)90845-0
11. Tanne K, Sakuda M, Burstone CJ. Three-dimensional finite element analysis for stress in the periodontal tissue by orthodontic forces. Am J Orthod Dentofacial Orthop 1987;92(6):499–505. DOI: 10.1016/0889-5406(87)90232-0
12. McGuinness NJ, Wilson AN, Jones ML, et al. A stress analysis of the periodontal ligament under various orthodontic loadings. Eur J Orthod 1991;13(3):231–242. DOI: 10.1093/ejo/13.3.231
13. McGuinness N, Wilson AN, Jones M, et al. Stresses induced by edgewise appliances in the periodontal ligament–a finite element study. Angle Orthod 1992;62(1):15–22. DOI: 10.1043/0003-3219(1992)062<0015:SIBEAI>2.0.CO;2
14. Isaacson RJ, Lindauer SJ, Davidovitch M. On tooth movement. Angle Orthod 1993;63(4):305–309. DOI: 10.1043/0003-3219(1993)063<0305:OTM>2.0.CO;2
15. Puente MI, Galban L, Cobo JM. Initial stress differences between tipping and torque movements. A three-dimensional finite element analysis. Eur J Orthod 1996;18(4):329–339. DOI: 10.1093/ejo/18.4.329
16. Vasquez M, Calao E, Becerra F, et al. Initial stress differences between sliding and sectional mechanics with an endosseous implant as anchorage: a 3-dimensional finite element analysis. Angle Orthod 2001;71(4):247–256. DOI: 10.1043/0003-3219(2001)071<0247:ISDBSA>2.0.CO;2
17. Knox J, Kralj B, Hubsch P, et al. An evaluation of the quality of orthodontic attachment offered by single- and double-mesh bracket bases using the finite element method of stress analysis. Angle Orthod 2001;71(2):149–155. DOI: 10.1043/0003-3219(2001)071<0149:AEOTQO>2.0.CO;2
18. Rudolph DJ, Willes PMG, Sameshima GT. A finite element model of apical force distribution from orthodontic tooth movement. Angle Orthod 2001;71:127–131. DOI: 10.1043/0003-3219(2001)071<0127:AFEMOA>2.0.CO;2
19. Felicita AS. Quantification of intrusive/retraction force and moment generated during en-masse retraction of maxillary anterior teeth using mini-implants: a conceptual approach. Dental Press J Orthod 2017;22(5):47–55. DOI: 10.1590/2177-6709.22.5.047-055.oar
20. Bohara P, Kumar M, Sharma H, et al. Stress distribution and displacement of maxillary anterior teeth during en-masse intrusion and retraction: a FEM study. J Indian Orthod Soc 2017;51(3):152–159. DOI: 10.4103/jios.jios_199_16
21. Zhang DQ, Su JH, Xu LY, et al. 3D finite element study of en masse retraction of maxillary anterior teeth in two typical force directions. Chin J Dent 2008;11(2):101–107.
22. Ashekar SS, Deshpande RS, Shetty P, et al. Evaluation of optimal implant positions and height of retraction hook for intrusive and bodily movement of anterior teeth in sliding mechanics: a FEM study. J Indian Orthod Soc 2013;47(8):479–482. DOI: 10.5005/jp-journals-10021-1208
23. Sung SJ, Jang GW, Chun YS, et al. Effective en-masse retraction design with orthodontic mini-implant anchorage: a finite element analysis. Am J Orthod Dentofacial Orthop 2010;137(5):648–657. DOI: 10.1016/j.ajodo.2008.06.036