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Effects of Braces' Mini-Screw and Lever Arm Position on Tooth Movement

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Abstract

An optimum position of mini-screw and height of lever arm in en-masse maxillary anterior teeth retraction of 2 premolar extractions for orthodontic purposes were determined in this work. Both experimental investigation by using a typodont model and finite element analysis were carried out. Four combinations of miniscrew and lever arm at various heights representing different force directions, namely, 3-3, 5-5, 7-7 and 9-9 mm related to the archwire, were examined. Then, rotation of teeth was evaluated with regard to the difference between incisor edge movement and cervical line movement. The typodont experimental results showed that occurred rotation was small when the position of the mini-screw and lever arm became higher. It was also found that these higher positions led to larger bodily movement. However, the high miniscrew and lever arm position likely caused a root resorption, which should be considered in orthodontic treatment as well. In case of FE simulations, model geometries, force magnitudes and directions were defined similar to those in the experiments. It was observed that calculated bodily movement somewhat deviated from the experimental results. Nevertheless, tendency of the calculated teeth movements fairly agreed with those in other previous works. The FE analysis showed that the position 9-9 mm from bracket provided the lowest teeth rotation. Therefore, this position was supposed to be used as the center of rotation.

Keywords: Mini-Screw / Bodily Movement / Center of Rotation / Intrusion / Typodont Model

1. Introduction

Teeth play an important role in human body. The human teeth are not only responsible for a good look and self-confidence, but also for a person's speech and digestion mechanism. Teeth with different types work together to break down various kinds of food during digestion [1]. A protrusion or proclination is one of the tooth malocclusion, This problem has effects on physical appearance, jaw function, tooth decay and gums disease [2]. A patient's proclination could be solved by various types of braces such as traditional braces, ceramic braces, lingual braces and invisalign [3]. Another available technique is called miniscrew implant, or a temporary anchorage device. Small screws mostly made of titanium alloy are placed into alveolar bone, in which osseointegration contributes to a firm anchoring. In order to pull the anterior teeth, two Newton force from springs acting between miniscrews and lever arms are applied [4-6]. The advantages of mini-screw implant include high rate of movement, less rotation and high bodily movement [7, 8]. In practice, position and direction of the forces could be adjusted by varying the miniscrew position and lever arm height [9, 10].

In this work, rotation and bodily movement of 6 anterior teeth were investigated. Effects of mini-screw positions and lever arms height, namely, 3-3, 5-5, 7-7 and 9-9 mm related to the archwire that led to varying force directions were studied. Through experiments using a typodont model and finite element (FE) simulations, bodily teeth movement could be qualitatively determined and resulted optimum force directions were discussed. It was found that trend of bodily movement and rotation in dependence on the mini-screw and lever arm position could be acceptably predicted.

2. Experiment

Due to the ethics, experiments in this work could not be done with patients. Thus, the 12D-400C Typodont model was employed and two sets of samples were used in the experiments. A two Newton force [4] was applied by means of springs, which were attached between mini-screws and lever arms. Forces induced by different heights of lever arm and positions of mini-screws exhibited different force directions.

2.1 Typodont Model

The typodont model is a model of teeth, which is made of wax as gums and plastic as teeth. Firstly, to prepare the teeth model was by cleaning, and etching with phosphoric acid 37%. Secondly, attach the bracket to teeth model by applying light cure adhesive primer, and paste. The dental curing light was radiated in order for curing of the adhesive primer and adhesive paste. An archwire was placed in bracket slots to obtain tentative teeth alignment. Then, gum was cast by using wax material on the basis of the aligned teeth.

Finally, teeth, lever arm, mini-screw and spring were assembled on the wax gum, as shown in Fig. 1. Each tooth in the Typodont model was designated by a number, as given in Fig. 1.

Fig. 1 Typodont model

2.2 Experimental Procedure

During the experiment, the spring force was measured by a tension gauge, as shown in Fig. 2. To increase the rate of teeth movement, the typodont model was placed into a 50°C bath for 1 hour after each tension condition. Four conditions of mini-screw position and lever arms height were investigated, which include 3-3, 5-5, 7-7 and 9-9 mm positions. The first and the second number represent the distance from archwire to lever arm and archwire to mini-screw, respectively. Fig. 3 illustrates the method used for measuring bodily movement and rotation, in which the green line was defined as the reference position. The resulted bodily movement was then calculated from the difference between the length of the blue perpendicular line from incisor edge and cervical line before and after applying force. By measuring the length between incisor edge and cervical line, teeth projection could be observed. The differences between teeth projection length before and after the experiment lead to teeth rotation.

Fig. 2 Two Newton force measurement using tension gauge

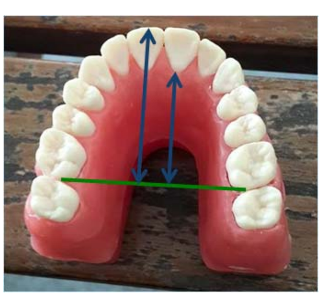


Fig. 3 Teeth movement measurement

3. Simulation

For FE simulation, teeth model was scanned by a GOM 3-D scanner. The brackets, mini-screws, lever arms, archwire, gums, and PDL were all afterwards generated in SolidWorks. The FEM simulations were performed under static condition and linear elastic properties in ABAQUS. To accurately describe deformation of gum material, viscoelastic properties should be defined in the simulation [11]. However, in this work, calculation time was reduced by omitting the viscoelastic properties. Additionally, it was aimed to obtain qualitative results for understanding effects of position of mini-screw and lever arm on the bodily movement and rotation.

3.1 FE Model

Each part model (teeth, gum, bracket wire, mini-screw) was assembled together, as seen in Fig. 4. Mechanical properties given for the material of these parts were taken from literatures, which are summarized in Table 1 [4,11]. The brackets were defined as a stainless steel, while the lever arms and archwire were defined as rigid body.

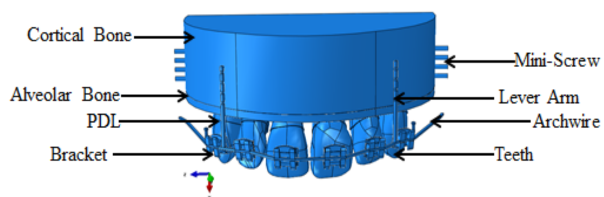


Fig. 4 FE model of the typodont model

Table 1 Mechanical properties used in simulation

	Poisson's Ratio	Young's Modulus (MPa)
Teeth	0.15	19,613
PDL*	0.49	0.6668
Cortical Bone	0.31	13,700
Mini-screw	0.31	114,000
Stainless Steel	0.30	200,000
Wax**	0.36	260
Plastic Teeth	0.35	7700

*PDL is the periodontal ligament.
**Wax properties were obtained from experimental results.

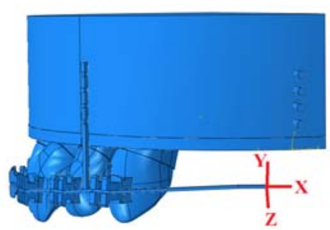
The tetrahedral 3-D mesh was assigned for the model, in which the total number of used elements was 515,702. Note that the convergence study of mesh size was not done in this work. However, employed mesh sizes were smaller than those shown in some published works [10]. The mesh size of 1 mm was used for the cortical bone and alveolar bone, whereas teeth, archwire, and lever arms had the mesh size of 0.5 mm. The smaller mesh size of 0.2 mm was defined for the PDL, brackets, and mini-screws.

3.2 Boundary Conditions

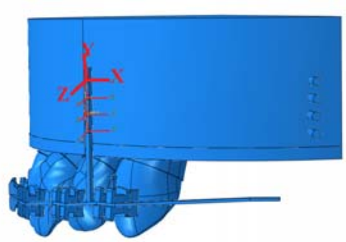
The boundary conditions given in the simulations were in accordance with those in the experiments. The contact conditions between each part of the FE teeth model were defined, as provided in Table 2. As seen, all gums surfaces, except for the contact surface to the PDL, were fixed in place. Both sides of archwire ends could be only move in the bracket slot direction or in the positive local x-axis, as depicted in Fig. 5a. Other local coordinate were introduced on the lever arm for assigning tension force in 3-3, 5-5, 7-7 and 9-9 mm directions related to the archwire, as shown in Fig. 5b. Note that mini-screws were placed in the model in order to set the local coordinate of lever arm. Therefore, their mechanical properties should not have an influence on the results.

Table 2 Boundary conditions between each part

Master	Slave	Boundary Condition
Archwire	Bracket	Tie
Bracket	Teeth	Tie
Teeth	PDL	Tie
PDL	Cortical Bone	Tie
PDL	Alveolar Bone	Tie
Cortical Bone	Alveolar Bone	Tie



(a)



(b)

Fig. 5 (a) Archwire direction and (b) force direction

4. Result and Discussion

In this work, only the movement and rotation of the right side teeth were evaluated. Moreover, considering the configuration of typodont model, a symmetry condition could be assumed. Thus, for a further work, a symmetry plane can be introduced in the FE model instead of the full model. Note that from the center, R5, R6, and R7 represented the first, second and third tooth from left to right, respectively.

4.1 Experimental Results

From the experiments, it was found that the bodily movement became higher as the height of miniscrew and lever arm from the archwire increased, as shown in Fig. 6. Moreover, higher position of miniscrew and lever arm generally led to less teeth rotation, as illustrated in Fig. 7. Thus, it could be stated that the higher position of miniscrew and height of lever arm provides better results for orthodontic treatment. However, such higher positions obviously caused intrusion of teeth, in which some teeth moved upward and cause root resorption, as depicted in Fig. 8. The effect on this teeth intrusion must also be considered during the treatment.

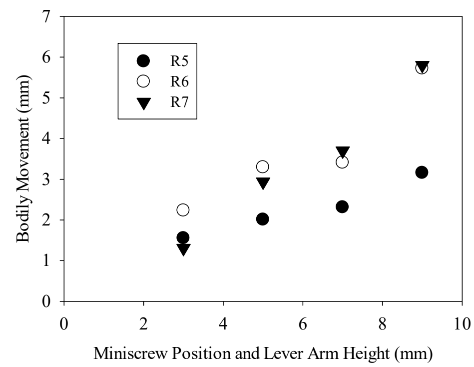


Fig. 6 Bodily movement of teeth determined from the experiments

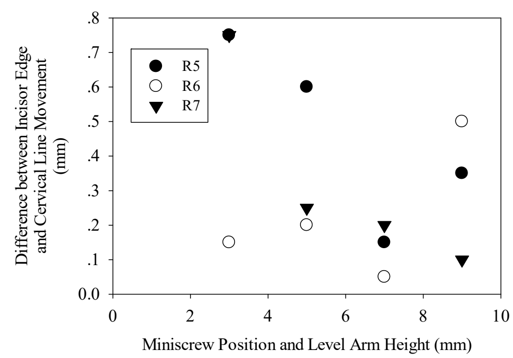


Fig. 7 Rotation of teeth determined from the experiments

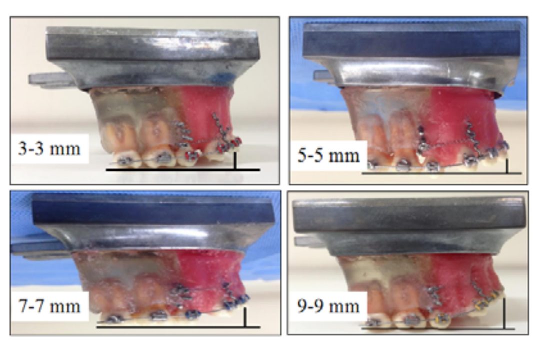


Fig. 8 Teeth intrusion

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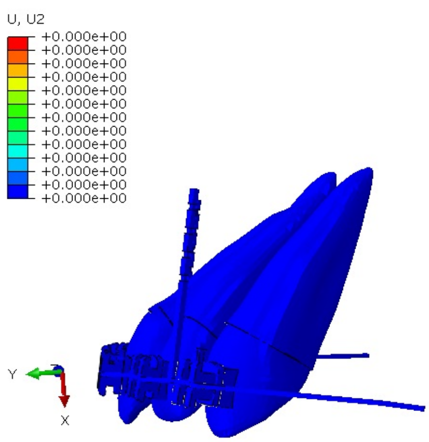
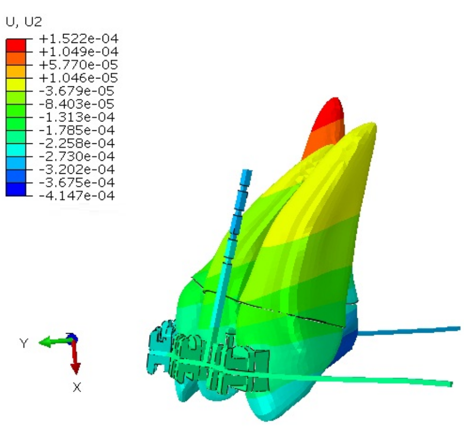
4.2 FE Results

Calculated node displacement in y-direction of the FE teeth model before and after applying force was presented in Fig. 9. Fig. 10 and Fig. 11 show the incisor edge movement and cervical line movement of teeth obtained from FE simulations, respectively. It was qualitatively found that the bodily movement of the teeth tended to be lower as the position of miniscrew and height of lever arm became higher. It could be seen that the teeth movement determined from experiments and simulations were in contrast. In some published works, FE simulation results also showed that calculated bodily movement decreased by increased height of lever arm [12]. Thus, this could be due to the simple experimental setup and assumption of linear elastic property in the simulation and must be further studied. Nevertheless, Fig. 12 shows that the position 9-9 mm from bracket provided the lowest teeth rotation that was in accordance with the experimental results. For the orthodontic treatment, this position can be supposed to be the center of rotation.



(a)



(b)

Fig. 9 Calculated node displacement in y-direction of the teeth (a) before and (b) after applying force

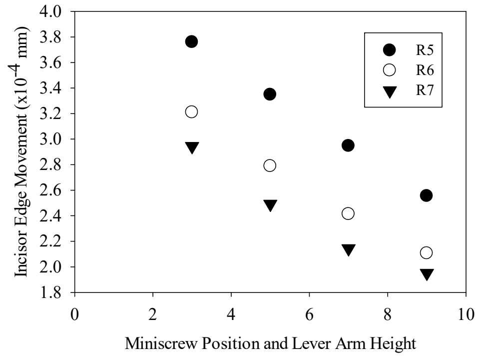


Fig. 10 Incisor edge movement of teeth calculated by FE simulations

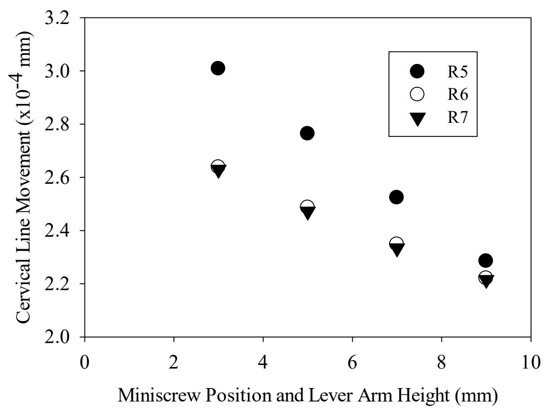


Fig. 11 Cervical Line Movement of Teeth Calculated by FE Simulations

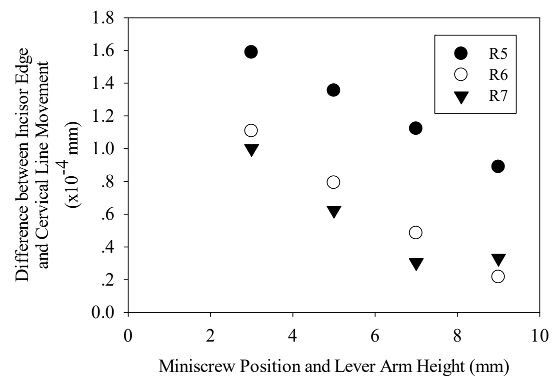


Fig. 12 Rotation of teeth calculated by FE simulations

5. Conclusion

Effect of position of miniscrew and lever arm on the movement and rotation of anterior teeth was investigated in this work. Tension force and four conditions of miniscrew position and lever arm height, which represented varying force directions, were applied. The experiment results from the typodont model showed that less rotation and more body movement occurred by using higher position of miniscrew and lever arm related to the archwire. The experiment also presented that the 9-9 position likely seemed to be the most optimum position. However, teeth intrusion was observed under such higher position condition. From FE simulations, it was also qualitatively found that lower positions caused high rotation. Therefore, the 9-9 mm position from the archwire can be defined as the center of rotation. The teeth movements calculated by FE simulations were somewhat different from those of the experiments. This could be due to the simplification of the experiment and neglecting viscoelastic properties in the simulations.

6. Acknowledgement

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