ขนาดของแรงในการดันเข้าของฟันหน้าบนหกซี่ด้วยหลักยึดหมุดฝังในกระดูก วิเคราะห์โดยวิธีไฟไนต์เอลิเมนต์

Magnitude of Force for Intrusion of Six Maxillary Anterior Teeth Using Mini-screw Anchorage: A Finite Element Study

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บทคัดย่อ

วัตถุประสงค์: เพื่อประเมินขนาดของแรงสูงสุดที่ไม่ทำให้ความดันในเอ็นยึดปริทันต์เกินความดันในเส้นเลือดฝอย (0.0047 เมกะปาสคาล) ในการดันเข้าของฟันหน้าบนหกซี่ ด้วยกลไก 2 ชนิดโดยใช้หลักยึดหมุดฝังในกระดูก วิเคราะห์โดยวิธีไฟไนต์เอลิเมนต์

วิธีการ: สร้างแบบจำลองไฟไนต์เอลิเมนต์ของฟันหน้าบนหกซี่ พร้อมทั้งเอ็นยึดปริทันต์ และกระดูกเบ้าฟัน กลไกแบบที่ 1 ใช้หลักยึดหมุดฝังในกระดูก 1 ตัว ฝังที่ระหว่างรากฟันตัดซี่กลางบน ให้แรงที่ลวดเส้นหลักบริเวณระหว่าง

Abstract

Objectives: To evaluate the greatest magnitude of force that did not create the pressure in the periodontal ligament (PDL) exceeding the capillary hydrostatic pressure (0.0047 MPa) for the intrusion of six maxillary anterior teeth using two patterns of mini-screw anchorage, analyzed by the finite element method.

Methods: A finite element (FE) model of six maxillary anterior teeth with PDL and alveolar

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ฟันตัดซี่กลางบน กลไกแบบที่ 2 ใช้หลักยึดหมุดฝังในกระดูก 2 ตัว ฝังที่ระหว่างรากฟันตัดซี่ข้างบนและฟันเขี้ยวบน ให้แรง 2 ข้าง ซ้ายและขวา ในแนวเฉียงที่ลวดเส้นหลักบริเวณฟันตัดซี่กลางบนและฟันตัดซี่ข้างบน ทำการวิเคราะห์ความดันในเอ็นยึดปริทันต์

ผลการศึกษา: ขนาดของแรงสูงสุดในการดันเข้าของฟันหน้าบนหกซี่ โดยไม่ทำให้ความดันในเอ็นยึดปริทันต์เกินความดันในเส้นเลือดฝอย (0.0047 เมกะปาสคาล) ในกลไกแบบที่ 1 คือ 16 กรัม และในกลไกแบบที่ 2 แรงรวมคือ 47 กรัม หรือ 23.5 กรัมต่อข้าง ขนาดของแรงสูงสุดในการดันเข้าของฟันหน้าบนหกซี่ ด้วยกลไกแบบที่ 2 (47 กรัม) มากกว่าในกลไกแบบที่ 1 (16 กรัม) บริเวณที่มีความดันสูงสุดในกลไกแบบที่ 1 อยู่ที่ปลายรากฟันด้านเพดานของเอ็นยึดปริทันต์ของฟันตัดซี่กลางบนด้านขวา ขณะที่บริเวณที่มีความดันสูงสุดในกลไกแบบที่ 2 อยู่ที่ปลายรากฟันด้านเพดานของเอ็นยึดปริทันต์ของฟันตัดซี่ข้างบนด้านขวา

สรุปผล: ปริมาณแรงสูงสุดในการดันเข้าของฟันหน้าบนหกซี่ โดยกลไกแบบที่ 1 ที่ไม่ทำให้ความดันในเอ็นยึดปริทันต์เกินความดันในเส้นเลือดฝอยมีปริมาณแรงเท่ากับ 16 กรัม ส่วนกลไกแบบที่ 2 มีปริมาณแรงรวมเท่ากับ 47กรัม หรือเท่ากับ 23.5 กรัมต่อข้าง

คำสำคัญ: หลักยึดหมุดฝังในกระดูก การดันเข้าของฟันหน้าบน วิธีไฟไนต์เอลิเมนต์

bone was constructed. In anchorage pattern 1, one mini-screw was placed between the central incisors with force applied to the arch wire between the central incisors towards the mini-screw. In anchorage pattern 2, used two mini-screws were placed between the lateral incisors and canines, left and right with force applied to the arch wire between the central and lateral incisors in an oblique direction towards the mini-screws. The pressure in PDL was analyzed.

Results: The greatest magnitude of force for the intrusion of six maxillary anterior teeth, that did not create the pressure in PDL exceeding the capillary hydrostatic pressure (0.0047 MPa) in anchorage pattern 1 was 16 g, and in anchorage pattern 2 was 47 g in total, or 23.5 g per each side. The greatest magnitude of force for the intrusion of the six maxillary anterior teeth in anchorage pattern 2 (47 g) was greater than that in anchorage pattern 1 (16 g). The greatest pressure area in anchorage pattern 1 was at the apex of the palatal side of PDL of the right central incisor, while the greatest pressure area in anchorage pattern 2 was at the apex of the palatal side of PDL of the right lateral incisor.

Conclusions: The greatest magnitude of force for the intrusion of the six maxillary anterior teeth that did not create the pressure in the periodontal ligament (PDL) exceeding the capillary hydrostatic pressure in anchorage pattern 1 was 16 g. In anchorage pattern 2, the greatest magnitude of force was 47 g in total or 23.5 g per each side.

Keywords: mini-screw, intrusion of maxillary anterior teeth, finite element method

Introduction

A temporary anchorage device, like a mini-screw, helps orthodontist in many mechanics of tooth movement. It has advantages of good anchorage control, ease of use and do not require patient co-operation.(1) Mini-screw anchorage also allows for more precise control of force level, helping to prevent the incidence of root resorption. Since root resorption is strongly related to force level and stress distribution in the periodontal ligament (PDL), intrusive tooth movement is the most common cause of root resorption.(2-5)

Tooth movement is related to the pressure-tension theory.(5) The optimal force is the force leading to a change in tissue pressure that approximated the capillary blood pressure. The optimal force will move teeth fast without adverse effects such as root resorption and severe pain. Force below the optimal level cause no reaction in the periodontal ligament whereas excessive force magnitude produces pressure in PDL over the capillary hydrostatic pressure and creates undermining resorption that delays tooth movement. The present literatures accepted the capillary hydrostatic pressure of 0.0020-0.0047 MPa.(6,7) Dorow and Sander(6) and Hohmann, *et al.*(7) concluded that the pressure greater than the capillary hydrostatic pressure was the best indication of an area prone to root resorption. Many studies recommended varieties of force magnitude for the intrusion of anterior teeth.(2,8,9)Therefore, the clinicians use different magnitude of force for intrusion of two to six maxillary anterior teeth with mini-screw anchorage, and no conclusive evidence on which to establish the most appropriate range.

The finite element method (FEM) is a simulation program which predicts how an object react to different stimuli based on its properties.(10) It is an accurate technique for analyzing structural stress. In orthodontics, the FEM provides orthodontists with quantitative data that can facilitate the understanding of physiological reactions happening within the dento-alveolar complex.

The purposes of this study were to evaluate the greatest magnitude of force that did not create the pressure exceeding the capillary hydrostatic pressure (0.0047 MPa) for intrusion of the six maxillary anterior teeth using two patterns of mini-screw anchorage, and to compare the result of them, analyzed by the FEM.

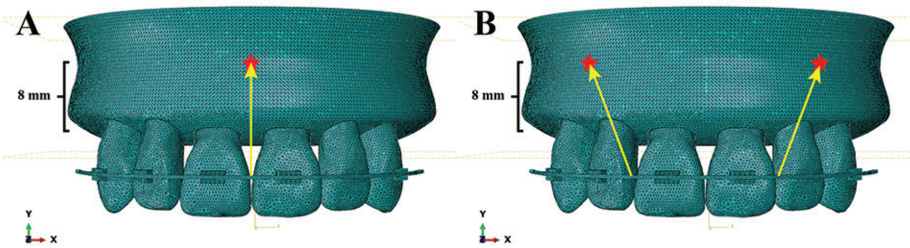
Materials and methods

A finite element (FE) model of six maxillary anterior teeth, including central and lateral incisors and canines, was generated from the scanned commercial maxillary model (Model-i21FE-400C; Nissin Dental Products, Kyoto, Japan). The other compartments were constructed using SolidWorks software (Dassault Systèmes Americas, Waltham, Mass., USA). The periodontal ligament (PDL) was 0.2-mm linear thickness as described in previous study.(11,12) The maxillary bone consisted of cancellous bone and 1.0-mm thickness cortical bone. The brackets and main arch wire were stainless steel. The bracket slot dimensions were 0.0022x0.0028-in and the brackets attached to the center of the crown of each tooth. The main arch wire dimensions were 0.0017x0.0025-in. It was assumed that no play between the brackets and main arch wire. A mini-screw was not created in the model but its position was set 8 mm apical to the cemento-enamel junction (CEJ) of the central incisors as recommended for mini-screw placement from the study of Choi, *et al.*(13) (Figure 1)

The FE model was imported to the Abaqus software (Dassault Systèmes Americas) for discretization into several small elements. After discretization, the model consisted of 3,312,844 elements and

792,987 nodes. All nodes had six degrees of freedom. All contacts were tie contact. The teeth had no contact and no friction between them

In this model the x-axis represented the mesio-distal, the y-axis the occluso-gingival, and the z-axis the labio-palatal aspects (Figure 2). The boundary conditions were assigned at the periphery nodes of top and back of the model. All materials were assigned as solid elements, isoparametric and homogeneous linear elastic properties (Table 1) except the PDL was assigned as non-linear properties (Table 2).



รูปที่ 1 *แบบจำลองไฟไนต์เอลิเมนต์ที่สร้างตาข่ายแล้ว แสดงตำแหน่งของหลักยึดหมุดฝังในกระดูก (รูปดาวสีแดง) และทิศทางของแรง (ลูกศรสีเหลือง)*

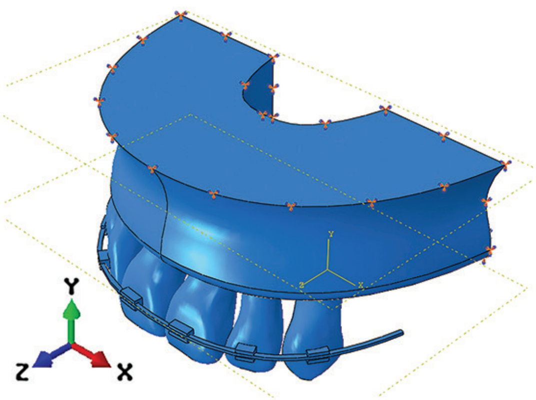
A) หลักยึดแบบที่ 1 ใช้หลักยึดหมุดฝังในกระดูก 1 ตัว ปักระหว่างฟันตัดซี่กลาง และให้แรงจากหลักยึดหมุดฝังในกระดูกไปยังลวดเส้นหลักระหว่างฟันตัดซี่กลาง

B) หลักยึดแบบที่ 2 ใช้หลักยึดหมุดฝังในกระดูก 2 ตัว ปักระหว่างฟันตัดซี่ข้างและฟันเขี้ยว ให้แรงจากหลักยึดหมุดฝังในกระดูกไปยังลวดเส้นหลักระหว่างฟันตัดซี่กลางและฟันตัดซี่ข้าง

Figure 1 *Meshed FE models with mini-screw placement (red stars) and force direction (yellow arrows).*

A) Anchorage pattern 1: one mini-screw between the central incisors and a force applied from the main arch wire between the central incisors to the mini-screw.

B) Anchorage pattern 2: two mini-screw between the lateral incisors and canines and forces applied from the main arch wire between the central and lateral incisors to the mini-screw.



รูปที่ 2 *ระนาบอ้างอิงต่าง ๆ x คือด้านซ้าย, -x คือด้านขวา, y คือด้านบน, -y คือด้านล่าง, z คือด้านใกล้ริมฝีปาก, -z คือด้านใกล้เพดาน ลูกศรสีส้มแสดงเงื่อนไขขอบเขตทางด้านบนและด้านหลังของแบบจำลองไฟไนต์เอลิเมนต์*

Figure 2 *Reference planes: x, left; -x, right; y, superior; -y, inferior; z, labial; -z, palatal directions. Orange arrows show the boundary conditions at the top and back of the FE model.*

In anchorage pattern 1, one mini-screw was placed between the central incisors, 8 mm above the CEJ. A force was applied to the main arch wire between the central incisors. (Figure 1) The force direction was upward and backward towards the mini-screw location, along the contour of the teeth and gingiva, at about 80° to the occlusal plane as measured from the commercial maxillary model. The magnitude of force of 10, 15, 16, 17, 18, 19, 20, 25, 30, 35, 40, 45, 50, 60, 70 g was applied. Those forces were divided between the vertical (y-axes) and labio-palatal (z-axes) force vector. (Figure 3)

ตารางที่ 1 *คุณสมบัติของเนื้อฟัน กระดูกทึบ กระดูกโปร่ง และเหล็กกล้าไร้สนิม*[14]

Table 1 *Material properties of tooth, cortical and cancellous bone and stainless steel*[14]

Material	Young's modulus (MPa)	Poisson's ratio
Dentin	19613.3	0.15
Cortical bone	13700	0.26
Cancellous bone	1370	0.3
Stainless steel	200000	0.3

ตารางที่ 2 *คุณสมบัติของเอ็นยึดปริทันต์ ค่าสัมประสิทธิ์ลำดับที่สามของสมการอ็อกเด็น**[15]

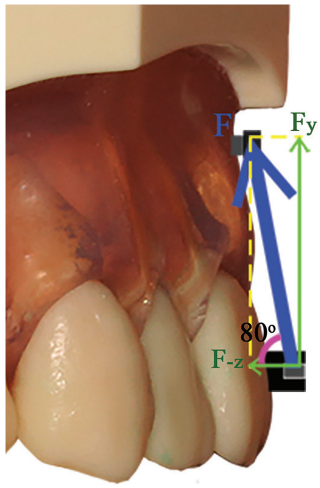
Table 2 *Material properties of the PDL. The coefficients of the third order Ogden model**[15]

i	μ_i	α_i	D_i
1	-24.4237016	1.99994222	4.87164332
2	15.8966494	3.99994113	0.00000000
3	8.56953079	-2.00005453	0.00000000

* The equation of the Ogden models:

$$W = \sum_{i=1}^{N} \frac{2\mu_i}{a_i^2}\left(\bar{\lambda}_1^{\alpha_i} + \bar{\lambda}_2^{\alpha_i} + \bar{\lambda}_3^{\alpha_i} - 3\right) + \sum_{i=1}^{N} \frac{1}{D_i}(J-1)^{2i}$$

W is strain energy function. λ_1, λ_2 and λ_3 are the principle stretches. J is elastic volume ratio. μi is related to the initial shear modulus of the material. a_i and D_i are the parameters of material.

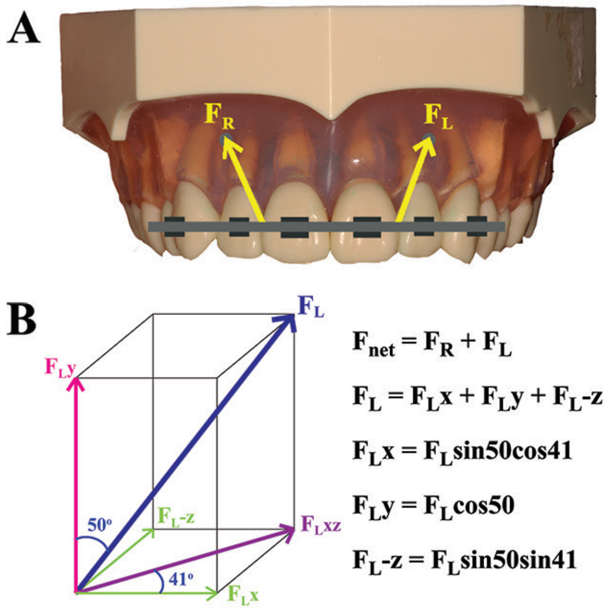


รูปที่ 3 *แรงในกลไกที่ 1 ที่ลวดระหว่างฟันตัดซี่กลาง แรงเป็นแนวเฉียงไปตามรูปร่างของฟันและเหงือก ทำมุม 80 องศากับระนาบบดเคี้ยว แรงถูกแตกออกในแนวแกน y และ -z และนำไปใส่ค่าในโปรแกรมอบาคัส*

Figure 3 *The force in anchorage pattern 1 was applied to the arch wire between the central incisors. The force was oblique along the contour of the teeth and gingiva, about 80o to the occlusal plane. The force was divided between the y and -z -axis and input to the Abaqus program.*

In anchorage pattern 2, two mini-screws were placed between the lateral incisors and canines, left and right. The magnitude of force of 10, 15, 20, 25, 30, 35, 40, 45, 46, 47, 48, 49, 50, 60, 70 g was applied. Those net force was divided by two and applied to the arch wire between the lateral incisor and canine on each side in an oblique direction towards the mini-screw locations. (Figure 1B) For example, the 50-g force in total was divided by two, then 25-g force was applied to the arch wire per each side. The left force (F_L) and right force (F_R) were divided among the x, y and z-axes. F_L and F_R were equal in magnitude, but F_R-x was in the opposite direction to F_Lx. (Figure 4)

The Abaqus software (Dassault Systèmes Americas) was used to analyze the pressure for the intrusion of the six maxillary anterior teeth.



รูปที่ 4 *แรงในกลไกแบบที่ 2 ให้ที่ลวดระหว่างฟันตัดซี่กลางและฟันตัดซี่ข้าง ด้านซ้ายและขวา*
A) แรงรวมถูกแบ่งออกเป็น 2 แรง F_R และ F_L
B) แตกแรง F_L ตามมุมที่หาจากแบบจำลองฟัน F_R มีค่าเท่ากับ F_L ยกเว้น F_R-x จะมีทิศทางตรงกันข้ามกับ F_Lx

Figure 4 *The forces in anchorage pattern 2 were applied to the arch wire between the central and lateral incisors, left and right.*
A) The net force was divided by two, F_R and F_L.
B) Division of F_L by the angle measured from the commercial maxillary model. F_R was equal to F_L, but F_R-x was in the opposite direction to the F_Lx.

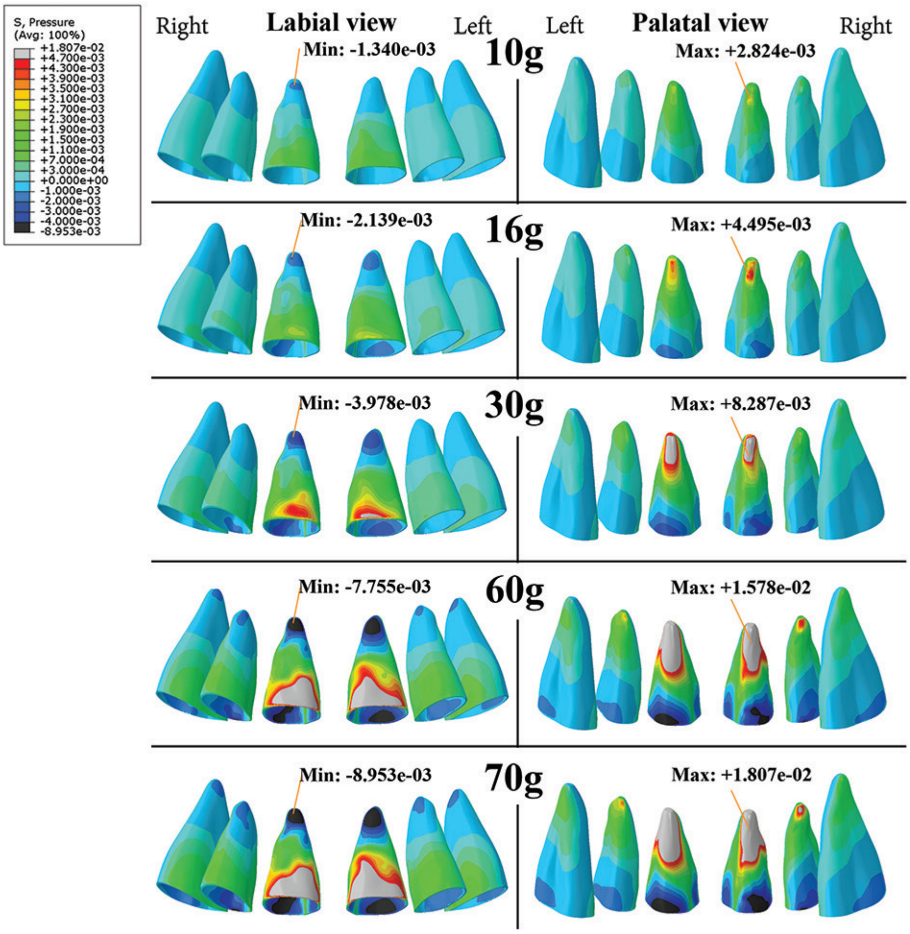
Results

In anchorage pattern 1 (one mini-screw anchorage), the palatal side of the PDL had more pressure than the labial side. On the labial side, the pressure was greater at the cervix and decrease toward the apex. On the palatal side, the pressure was greater at the apex and decreased towards the cervix. The greatest pressure point was at the apex of the palatal side of the PDL of the right central incisor. The greatest tension point, the least pressure point or the negative pressure value, was at the apex of the labial side of the PDL of the same tooth. (Figure 5) The force of 10, 15 and 16 g did not create any area with the pressure greater than 0.0047 MPa (the grey-colored area). The force of 17 g and greater created the grey area at the apex of the palatal side of the PDL of the right central incisor (Figure 6). Therefore, in anchorage pattern 1, the greatest magnitude of force that did not produce the pressure in the PDL exceeding the capillary blood pressure (0.0047 MPa) for the intrusion of the six maxillary anterior teeth was 16 g. When the force increased, the pressure was increased at the apex of the palatal side of the PDL of the right and left central incisors, the cervix of the labial side of the PDL of the same teeth, and the apex of the palatal side of the PDL of the right lateral incisor. The grey area was larger when the force increased.

While the grey area of compression was larger with greater force, the blue and black area of tension was larger with the greater force. The tension areas were at the apex of the labial side and the cervix of the palatal side of the PDL.

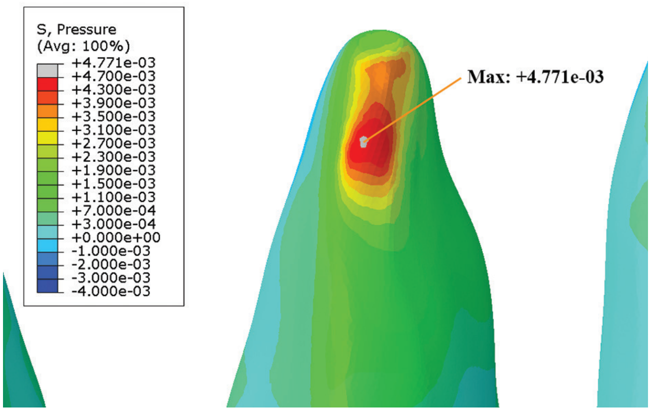
The distribution of pressure was greater on the central incisors than the lateral incisors or canines, respectively.

In anchorage pattern 2 (two mini-screw anchorage), the palatal side of the PDL had slightly greater pressure than the labial side. On the labial side, the pressure distribution was rather equal with slightly greater at the cervix. On the palatal side, the pressure was greater at the apex and decreased toward the cervix. The greatest pressure point was at the apex of the palatal side of the PDL of the right lateral incisor. The greatest tension point, the least pressure point or the negative pressure value, was at the cervix of the palatal side of the PDL of central incisors. (Figure 7) The net force of 10, 15, 20, 25, 30, 35, 40, 45, 46 and 47 g did not create any area with the pressure greater than 0.0047 MPa (the grey-colored area). The



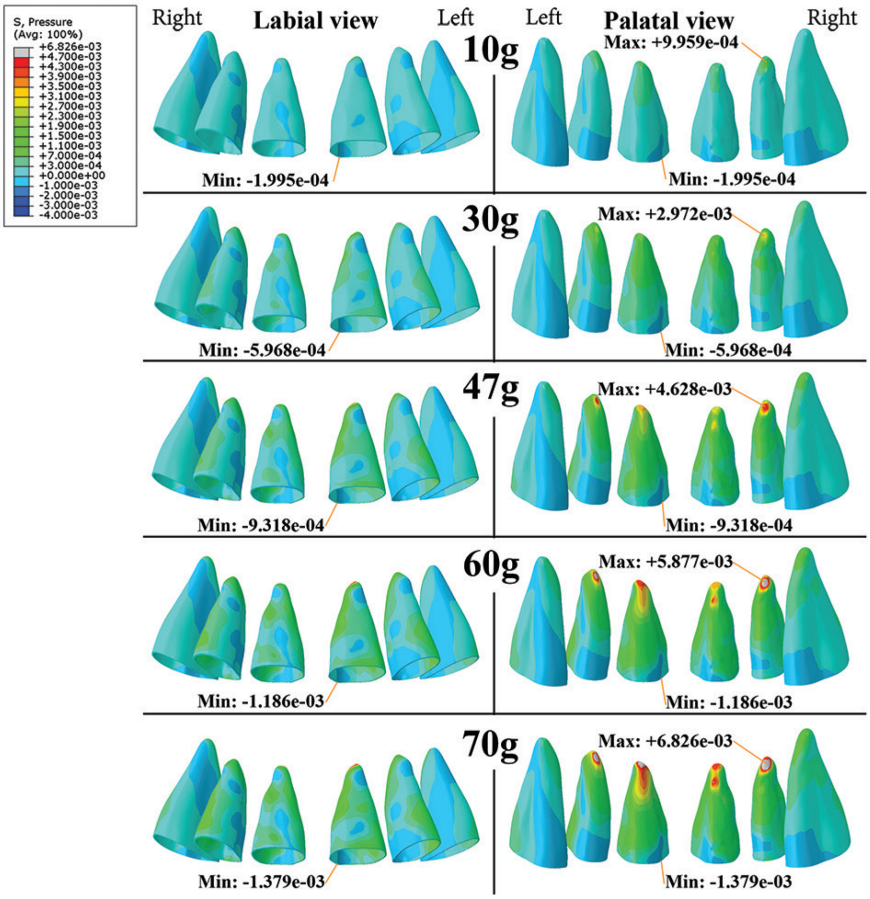
รูปที่ 5 *ความดันในเอ็นยึดปริทันต์ในกลไกแบบที่ 1 เมื่อให้แรง 10, 16, 30, 60 และ 70 กรัม บริเวณที่เป็นสีเทาแสดงค่าความดันที่สูงกว่าความดันในเส้นเลือดฝอยคือ 0.0047 เมกะปาสคาล*

Figure 5 *The pressure on the PDL, in anchorage pattern 1, when the force of 10, 16, 30, 60 and 70 g was applied. The grey-colored areas represented the pressure exceeded the capillary hydrostatic pressure of 0.0047 MPa.*



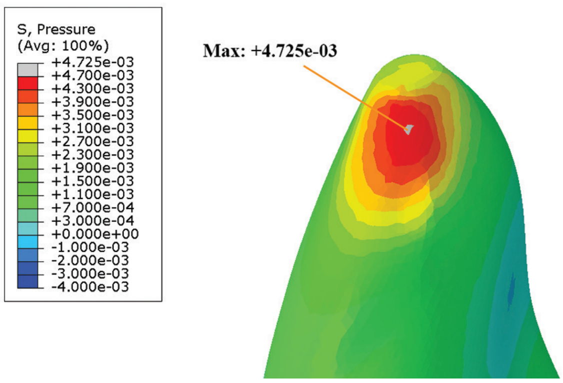
รูปที่ 6 *ในกลไกแบบที่ 1 แรง 17 กรัม ทำให้เกิดความดันที่สูงกว่า 0.0047 เมกะปาสคาล ที่ปลายรากด้านเพดานของเอ็นยึดปริทันต์ของฟันตัดซี่กลางด้านขวา (ภาพขยาย)*

Figure 6 *In anchorage pattern 1, the force of 17 g created the pressure greater than 0.0047 MPa at the apex of the palatal side of the PDL of the right central incisor (Magnified viewport).*



รูปที่ 7 *ความดันในเอ็นยึดปริทันต์ในกลไกแบบที่ 2 เมื่อให้แรงรวม 10, 30, 47, 60 และ 70 กรัม บริเวณที่เป็นสีเทาแสดงค่าความดันที่สูงกว่าความดันในเส้นเลือดฝอยคือ 0.0047 เมกะปาสคาล*

Figure 7 *The pressure on the PDL, in anchorage pattern 2, when the net force of 10, 30, 47, 60 and 70 g was applied. The grey-colored areas represented the pressure exceeded the capillary hydrostatic pressure of 0.0047 MPa.*



รูปที่ 8 *ในกลไกแบบที่ 2 แรงรวม 48 กรัม หรือ แรง 24 กรัมต่อข้าง ทำให้เกิดความดันที่สูงกว่า 0.0047 เมกะปาสคาล ที่ปลายรากด้านเพดานของเอ็นยึดปริทันต์ของฟันตัดซี่ข้างด้านขวา (ภาพขยาย)*

Figure 8 *In anchorage pattern 2, the net force of 48 g, or 24 g per each side, created the pressure greater than 0.0047 MPa at the apex of the palatal side of the PDL of the right lateral incisor (Magnified viewport).*

net force of 48g, or 24 g per each side, and greater created the grey area at the apex of the palatal side of the PDL of the right lateral incisor (Figure 8). Therefore, in anchorage pattern 2, the greatest magnitude of force that did not produce the pressure in the PDL exceeding the capillary blood pressure (0.0047 MPa) for the intrusion of the six maxillary anterior teeth was 47 g in total, or 23.5 g per each side. When the force increased, the pressure was increased at the apex of the palatal side of the PDL of the central and lateral incisors. The grey area was larger when the force increased.

While the grey area of compression was larger with greater force, the blue area of tension was larger with the greater force. The tension areas were at the apex of the labial side and the cervix of the palatal side of the PDL.

The distribution of pressure was rather equal on the central incisors and the lateral incisors and greater than on the canines.

Discussion

An intrusive tooth movement caused root resorption more than other types of tooth movement[3], according to a small pressure area at the root apex.[2] The magnitude of force for the intrusion is crucial. Proffit, *et al.*[2] suggested that the light force was required for an intrusion. They recommended a force of 10-20 g per tooth for an intrusion. Burstone[8] reported that if the magnitude of force was too great, the rate of intrusion was not increased, but the rate of root resorption increased. He suggested 25 g of force for intrusion of a central incisor, 50 g of force for central and lateral incisors and 100 g of force if a canine was added to the group. Gianelly and Goldman[9] used the range of 15 to 50 g of force to intrude small teeth. In this study, the greatest force that did not produce the pressure in the PDL exceeded the capillary blood pressure is 16 g for intrusion of six maxillary anterior teeth in anchorage pattern 1, and 47 g in total, or 23.5 g per each side, in anchorage pattern 2. The magnitude of force was different because of the uncertain distribution of force on the roots of teeth. The tooth close to the force-applied point had greater pressure than the tooth far away. The greatest pressure area was on the central incisors in anchorage pattern 1 and on the lateral incisor and central incisors on anchorage pattern 2. The canines had the least pressure on both anchorage pattern. According to the uncertain distribution, the force applied to the group of teeth could not divide to each tooth to be the definite value recommended for one tooth.

Root resorption is one of the side effects of an orthodontic treatment.[16-18] Generally, the root resorption relates to the duration of treatment, magnitude of force, distance of tooth movement, and shape and size of the root. Intrusion is the riskiest type of tooth movement that cause root resorption. Han, *et al.*[3] found that root resorption from intrusive force significantly increased in percentage of resorbed root area. Harris, *et al.*[19] found that the volume of root resorption craters after intrusion was directly proportional to the magnitude of intrusive force.

The area of the root that prone to resorption is related to the distribution of force. From this study, the greatest pressure area was at the apex of the root of central incisors on anchorage pattern 1 and at the apex of the root of lateral incisors in anchorage pattern 2. When the force increased, the pressure on those areas was greater than the capillary blood pressure. This result was consistent to the previous report of Yu, *et al.*[20] that the root resorption was largest in the lateral incisors, followed by the central incisors, and then the canines. Salehi, *et al.*[21] studied in the FEM concluded that the apical region of lateral incisor was the most susceptible region to root resorption, too. Although the force distribution in anchorage pattern 2 was better than in anchorage pattern 1, the force concentrated at the apex of the root of lateral incisors. The lateral incisor is the smallest anterior maxillary teeth and has a highest incidence of root resorption.(20,21) The intrusion of the maxillary anterior teeth should be done with caution.

From previous study(22), the stress distribution pattern was correlated to the force distribution pattern in each anchorage pattern. The displacement of the six maxillary anterior teeth in anchorage pattern 1 was proclined and rotated with intrusion. In anchorage pattern 2, the central incisors were intruded along the long axes, and the lateral incisors and canines were slightly proclined and rotated with intrusion. For the magnitude of force, anchorage pattern 2 also applied greater force without exceeded the capillary blood pressure than anchorage pattern 1. The teeth were intruded better in anchorage pattern 2 than anchorage pattern 1 in all aspects: the stress distribution pattern, the magnitude of force and the displacement of the teeth.

In FEM studies, the reliability of the results depends on the accuracy of the model. In this study, the commercial maxillary model, representing the population average with the optimal occlusion, was used to generate the FE model. The PDL was 0.2-mm uniform thickness that described in the previous study.(11,12) However, Tom and Eberhardt(23) suggested that incorporation of the hourglass shape of the PDL was warranted. The cortical bone thickness also has the different in any area(13,24), but in this study, the cortical bone was constructed to be uniform thickness of 1.0 mm average depending on the difficulty of the model setting.

Friction between the teeth is another factor related to the magnitude of force needed for the intrusion. However, we assigned no friction between any tooth. The first premolars were not constructed in the model. These were some limitations.

Mini-screw were not constructed in the FE model. The placement of the mini-screws was assigned at 8 mm above the CEJ as it was recommended.(13) The force vectors were divided among the x, y and z-axes by the angles calculated from the commercial maxillary model. In clinic, the site of the mini-screw placement was different in persons.

The properties of all material except PDL were assigned as a homogenous linear behavior. The PDL plays a major role in orthodontic tooth movement, and the previous studies suggested hyper-elastic non-linear behavior of the PDL.(23,25,26) This report also studied the non-linear behavior of the PDL that the closest natural PDL properties were set, the results would be more precise.

Naturally, there are other forces constantly acting over the maxillary teeth such as mastication forces and tongue, lip, and cheek pressures.(11,27) However, the amount and direction of these forces are undefined, and their effects on orthodontic tooth movement remain unclear.(11) For these reasons, they were not considered in this study.

This study was a static FE study, that only the initial movement was demonstrated. In clinic, tooth movement occurs over long periods of time. Further studies such as a dynamic FE study and clinical trial are needed for more understanding and more accuracy results in the future.

Conclusions

This study does highlight the provide usefulness information and precision of the 3-D FEM technique in mapping structural stress in orthodontic simulations.

The greatest magnitude of force that did not produce the pressure in the PDL exceeded the capillary blood pressure (0.0047 MPa) for one mini-screw anchorage pattern was 16 g. The greatest magnitude of force in two-mini-screw anchorage pattern was 47 g in total, or 23.5 g per each side.

The force in two-mini-screw anchorage pattern was distributed widely over the six anterior teeth, whereas the force in the one-mini-screw anchorage pattern was concentrated only in the two central incisors.

The greatest force area was at the apex of the root of central incisors in one-mini-screw anchorage pattern, and at the apex of the root of lateral incisors in two-mini-screw anchorage pattern.

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Conflict of interest

None to declare.

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