# CHAPTER 5

# Discussion

## 5.1 Materials and Methods

In FEM studies, the reliability of the results depends on the accuracy of the model. This study had some limitations. In this study, a commercial maxillary model, representing a population average with the optimal occlusion, was used to generate the FE model. The teeth were created tooth by tooth, then the left and right teeth were not the mirror-imaged to each other. There was some small difference in the anatomy of the root and the PDL for the left and right teeth. So, each left and right tooth had slightly different results.

The PDL and cortical bone were created with uniform thickness. In reality, however, the PDL and the cortical bone are not of uniform thickness.(13, 53, 60) Friction between teeth is also another factor relating to the magnitude of force applied for tooth intrusion. However, this study applied no friction between any teeth. The first premolar was not created in the FE model, which was another limitation. Additionally, intrusion of maxillary anterior teeth usually does in deep overbite cases. However, in this study, the intrusion was done in the model with optimal occlusion.



An elasticity of materials is governed by Young's modulus and Poisson's Ratio. All materials, except the PDL, were assigned with linear elastic properties descripted from the previous study.(59) The PDL, as a key of tooth movement, was concluded in previous studies(39, 50, 53, 63, 64) to have a non-linear property. The Ogden models, as a world-wide accepted hyper-elastic model, was used in this study from the capable of accurately representing the elastic response of the biological soft tissues and the recommendation of the experience finite element study engineer.

Proffit et al. [21] recommended that an intrusive force should be kept light. They suggested the force of 10-20 g per tooth, the values depend in part on the size of the tooth; smaller values appropriate for incisors, higher values for multi-rooted posterior teeth. Therefore, this study applied the net force of 60 g per six single-rooted anterior teeth to the FE model. The oblique force then was divided between 3-axes that like the clinical application and easy to simulate this pattern in clinical use in the further study.

The model also did not include the creation of a mini-screw. We assigned the placement of the mini-screw by the direction of force. The anchorage designs used were those recommended by Nanda and Tosun[14], with the vertical level of 8 mm above the CEJ of the central incisors, as recommended placement in a previous study[13]. We measured the angles from the force application point to the mini-screw in three axes (x, y, and z axes) for the divided force input to the Abaqus software from the commercial maxillary model. Those angles depended on the arch forms and the bony and gingival contours of individual persons. In clinical applications, the direction of force varied depending on each person. Clinical results would probably differ from those of this study.

Naturally, there are other forces constantly acting over the maxillary teeth: mastication forces and tongue, lip, and cheek pressures.[61, 65] However, the amount and direction of these forces are undefined, and their effects on orthodontic tooth movement remain unclear.[61] For these reasons, they were not considered in this study.

**5.2 The pattern of the von Mises stress distribution in the PDL**



In anchorage design 1, the von Mises stress was more concentrated on the central incisors than on the lateral incisors or canines, whereas in anchorage design 2, the stress was concentrated equally on both the central and lateral incisors. There was less stress on the canines than on the central and lateral incisors in both anchorage designs. From the results of this study, the distribution of stress was greater on the teeth that were closer to the force application points. The greatest stress possible in anchorage design 1 ($+1.184 \times 10^{-2}$ MPa) was greater than the greatest stress in anchorage design 2 ($+1.775 \times 10^{-3}$ MPa) due to the division of force. Since the net forces in both anchorage designs were equal, the stress of 60-g force in anchorage design 1 was focused on a single point of force application, whereas in anchorage design 2, the force was divided between $F_L$ and

$F_R$. Therefore, in anchorage design 2, which had more points of force application, the stress was equally distributed in the four incisors. The teeth in anchorage design 2 had less stress than that in anchorage design 1 and the stress distribution was better, too. In addition to the points concluded above, the apices of the incisors received great stress in both anchorage designs, a finding which was consistent with the findings of previous studies[66, 67], which stated that the area around the apices of the incisors was the most prone to resorption, especially the lateral incisors[68-70]. The great stress areas were coincided with the direction of tooth movement, like in the central incisors in anchorage design 1 that were proclined, so the apices of the palatal side of the PDL were the great stress area.

### 5.3 The displacement of the six maxillary anterior teeth

The anterior teeth are usually tipped labially when they are intruded. In this study, the von Mises stress distribution and displacement of the teeth suggest that the teeth would be proclined if anchorage design 1 were to be used in the clinical setting. However, in anchorage design 2, the lateral incisors and canines were slightly proclined, but the central incisors were intruded along the long axis. Other FEM studies concerning the intrusion of maxillary incisors also reported the proclination of the incisors[66, 67]. Saga et al.[67] reported a strong tendency towards proclination of the maxillary central incisors when the point of force application was more anterior. However, their study included only the four maxillary incisors and only a vertical force was applied. Park et al.[15] reported that equal stress distribution and pure intrusion of the six mandibular anterior teeth occurred when mini-screws were placed distal to the canines and the force applications were between the central and lateral incisors. The results had shown that an oblique force, such as that used in anchorage design 2, consists of the combined forces of the distal and the intrusive vertical force vectors, leading to pure intrusion of the anterior teeth.

The direction of tooth movement is related to the location of the center of resistance (CRe) and the direction of the applied force[71]. The CRe of a single-rooted tooth with normal periodontium was at the midpoint of the embedded portion of the root. When the teeth are laced together into a group, the group is said to have a group CRe. The CRe of the group of six maxillary anterior teeth in the vertical direction is 12.2[72], 13.5[73] and

14.5[74] mm apical to the incisal edges of the central incisors or 15 mm from the occlusal plane[75]. In the labio-palatal direction, the CRe of the group of six maxillary anterior teeth is 14 mm posterior to the incisal edges of the central incisors[74] or on a line 3 mm behind the distal surface of the canines[76].

In this study, in anchorage design 1, the direction of force was labial to the group CRe, so all teeth were proclined. The point of force application was medial to the tooth CRe; therefore, the four incisors tipped mesially when they were intruded. The canines were also tipped mesially with the roots were slightly extruded and the crowns were slightly intruded. Because the canines were the farthest teeth form the force application point, when the incisors were intruded, there were the reciprocal force that slightly extruded the canines.  In anchorage design 2, the direction of forces was oblique and close to the group CRe. The oblique forces, were divided by two, left and right, and were divided again among 3-axes. The forces in y-axis, $F_R$y and $F_L$y, were an intrusive force, while the forces in x-axis, $F_R$-x and $F_L$x, were in the opposite direction, so the forces in x-axis were clearing each other and had no effect to the teeth. The forces in z-axis were the horizontal force that moved the teeth in the palatal direction and resisted the proclination of the teeth, so the teeth in anchorage design 2 were intruded along their long axes. The FE results, shown by the von Mises stress distribusion and the displacement of the teeth, was consistent with the tooth movement prediction derived from the CRe concept. Teeth in anchorage design 1 moved a greater distance than the teeth in anchorage design 2 due to the difference in the direction of applied force and the stress distribution in the two patterns. In anchorage design 1, the stress distribution was concentrated in the central incisors, which were closest to the force application point. Thus, the central incisors in anchorage design 1 moved the greatest distance. Anchorage design 2, however, had two force application points, which is why the stress was distributed among the four teeth, central and lateral incisors. Because the stress was distributed to the four incisors, the incisors then moved a similar distance. Therefore, the central incisors in anchorage design 2 moved a shorter distance than those in anchorage design 1, whereas the lateral incisors and canines in anchorage design 2 moved a slightly greater distance than those in anchorage design 1. These results show that the force application point affected the stress distribution on each tooth. Teeth that were closer to the force application point had greater stress than those that were further from the force application point.

### 5.4 The clinical applications

From this study, anchorage design 2 moved the teeth close to pure intrusion, and the stress distribution was rather equal in the four incisors. In cases that the teeth are well aligned and would need inclination control, anchorage design 2 is recommended. In anchorage design 1, the stress distribution was concentrated in the central incisors much greater than the lateral incisors or canines, and the teeth were intruded with proclination. In cases that the teeth are already proclined, this design should be avoided.

Intrusion is strongly related to the root resorption. The previous studies[68-70] reported that the incisal roots are the most prone to root resorption. Therefore, the intrusion of the anterior teeth should be done with caution and the optimal force magnitude should be studied further.

Further study is needed to determine the effect of treatment time on the movement of teeth, because, in clinical settings over long periods of time, the movement of teeth would probably differ from that in this study, since only the initial movement was studied, because this study was a static FEM study. Other improvements in research methods such as model construction with CBCT and clinical trial would be studied in the next researches to report more accuracy results in the future.