Research Article

A New Appliance for Improving the Miniscrew Stability

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The aim of this study is to present a new appliance called stability leg designed as an additional anchorage providing device for increasing primary stability of orthodontic miniscrew. For this purpose, two finite element models (FEMs) with two different cortical layer thicknesses of 1 mm and 2 mm are considered. In order to achieve the stability analysis, these two main models, namely, Model I and Model II, are divided into subgroups according to stability leg lengths. Two types of forces are considered. (1) First force is a constant force of 1 N which is applied to all two models. (2) Second force is defined in the range of 1–4 N. Each of 1, 2.5, and 4 N of the second force is applied with a position angle ranging from 34° to 44°. Results show that stability of a miniscrew with 5 mm leg increases primary stability of the miniscrew.

1. Introduction

The anchorage is one of the most important subjects of orthodontics [1]. Mainly, it can be classified as extraoral and intraoral. Extraoral anchorage can be provided with extraoral appliances. Actually, aesthetic is probably major difficulty about extraoral appliances. Internal anchorage can be divided into two groups as intramaxillary and intermaxillary. Dental implant researches mainly focus on dimensions and design of miniscrew or patient related factors such as bone quality and insertion area. Until now, different appliances, mechanics, elastics, wire bends, and so forth, have been designed. Result of a successful orthodontic treatment can be obtained by providing effective anchorage control [2–8].

Temporary anchorage devices (TADs) as miniscrews are used in modern orthodontic treatment mechanics. In spite of their stability problems, miniscrews can provide enough anchorage [9, 10]. Once they lost their stability, it is difficult to reinsert them into the same location and this situation causes an ineffective solution. Particularly, different studies have been presented to improve the stability of the miniscrews focusing on the shape/size of miniscrews, quality of alveolar bone, or insertion site of the implant [11–13].

General purpose finite element code has been used at different studies of the orthodontic treatment mechanics [14].

It is a proper way to compute the stability of orthodontic miniscrews. For the computational analysis, a finite element model represents the human jaws approximately. Cortical layer thickness of the model is chosen between 1 and 2 mm in many finite element studies [15]. Generally, it is obvious for such studies that maximum load range is between 1 and 2 N [16]. Also, critical clinical angle range is assumed to be from 34° to 44° for the force application. This range is chosen in order to simulate intermaxillary Class II and Class III elastic usage. These conditions of loading and position are very important for a miniscrew stability which is controlled under both of intermaxillary and intramaxillary force load conditions [17–20]. Therefore, it is clearly seen that stability loss is major disadvantage of miniscrews.

In this study, a new appliance which is called *stability leg* is proposed as an additional anchorage creating device for increasing primary stability of miniscrew.

2. Materials and Method

In order to predict the fields of stress and displacement of a miniscrew stability, two different finite element models (FEMs) with two different cortical layer thicknesses are considered by using a general purpose finite element code ANSYS [21]. Each of the two FEMs is in 10 mm × 10 mm ×

FIGURE 1: (a) FEM for miniscrew stability. (b) Force positions for the stability analysis.

FIGURE 2: Representation of leg length and applied forces with a position angle ranging from 34° to 44°.

10 mm volume. While first FEM, namely, Model I, possesses a cortical layer of 1 mm in thickness, second FEM as Model II does a cortical layer of 2 mm in thickness, because the miniscrew's primer stability strongly depends on cortical bone strength [14]. Mechanical properties of the cortical layer are as follows: Young's Modulus = 13.7 GPa, Poisson's ratio = 0.3, and density = 1.8 g/cm³. Additionally, mechanical properties of the trabecular layer are as follows: Young's Modulus = 0.3 GPa, Poisson's ratio = 0.3, and density = 0.8 g/cm³. Miniscrew with 1.6 mm in width and 8 mm in length is Grade IV titanium alloy (Young's Modulus = 110 GPa, Poisson's ratio = 0.3, and density: 4.5 g/cm³) which is used for the FEMs including inserting the 8 mm screw along the bone. Both a higher order three-dimensional 20-node solid element (SOLID 186) and a three-dimensional 10-node tetrahedral structural solid element (SOLID 187) are used for the FEMs. In the analyses, while Model I includes 191024 elements, Model II possesses 315249 elements. The general representation of the FEMs is given in Figure 1(a).

In this analysis, a constant force (first force, F_1) of 1 N is applied to all two models. And second force (1, 2.5, or 4 N as F_2) is applied to the models with respect to the critical

clinical angle ranging from 34° to 44°. The critical value of the second force is 4 N, because, clinically, when the second force level exceeds 1 N, dimensions of miniscrew become a significant factor for the primer stability of miniscrew [22]. All loading cases are applied to the tip of the screw through x -direction (see Figure 1(b)). Consequently, numerical analysis on stability of a miniscrew is completed at different boundary conditions. Actually, there are two critical regions in the analysis: (i) force contact region (FCR) and (ii) surface contact region (SCR).

Each of the two FEMs is divided into three subgroups: *screw with 0 mm leg* (without a leg), *screw with 5 mm leg*, and *screw with 10 mm leg* presented in Figure 2. For all subgroups, stress distribution and tip displacement of the miniscrew are computed by taking FCR and SCR into account.

3. Results and Discussion

Due to the clinical importance, results of stress and displacement distributions of FCR and SCR are given in x - and z -direction. On one hand, results of FCR for Model I and Model II under constant position angle of 34° are given in Figures

FIGURE 3: Variation of stress at x -direction for FCR of Model I under the position angle of 34° .

FIGURE 4: Variation of stress at x -direction for FCR of Model II under the position angle of 34° .

3–6. Figures 3 and 4 say that while Model I shows a concave stress distribution, Model II does a convex one. That means that increasing applied force increases stress gradient quickly.

Similarly, Figures 5 and 6 give that (a) displacement field at x -direction of a miniscrew with 5 mm leg is more useful than the others, (b) while Model I has a linear translation behavior and Model II still possesses a convex behavior. Corresponding to Figures 4 and 6, one can conclude that, over the applied force of 1.25 N, stability of the miniscrew is questionable for Model II. However, Figures 3 and 5 clarify that the miniscrew with 5 mm leg of Model I is more suitable for the stability up to the load of 1.25 N.

On the other hand, results of SCR of Model I and Model II under the angle of 34° are given in Figures 7 and 8. These two figures introduce that stress field at the horizontal direction x of a miniscrew with 10 mm leg is in convex behavior for both Model I and Model II. However, stress field of the other two types (0 mm leg and 5 mm leg) varies linearly. In the stability point of view, a miniscrew with 5 mm leg is preferred for both

FIGURE 5: Variation of displacement at x -direction for FCR of Model I under the position angle of 34° .

FIGURE 6: Variation of displacement at x -direction for FCR of Model II under the position angle of 34° .

models because of decreasing stress field around the contact region.

Finally, in order to figure the difference among the three screw types out, variation of position angle under the maximum force of 4 N in z -direction is also considered and results of FCR for Model I and Model II are presented in Figures 9–12.

Figure 9 shows that, due to the cortical bone thickness, a miniscrew with 10 mm leg does not improve its stability. However, a miniscrew with 5 mm leg is still suitable for the clinical applications according to the screw tip displacement of Model I given in Figure 11.

Figures 10 and 12 conclude that all types of stability leg display similar stability behavior for Model II and the lowest similarity is provided from 10 mm stability leg. This result can be seen due to the moment effect of the force system.

Besides, Table 1 is given as three-dimensional mean stress levels of the models with their standard deviations in the range of position angle 34 – 44° . Values of the mean stresses

FIGURE 7: Variation of stress at x-direction for SCR of Model I under the position angle of 34° .

FIGURE 8: Variation of stress at x-direction for SCR of Model II under the position angle of 34° .

indicate that a miniscrew with 5 mm leg is superior to the other two configurations in all directions.

4. Conclusion

In order to determine which stability leg of the miniscrew is more suitable for stress or displacement field, finite element analysis is very powerful tool due to the geometrical, material, and loading difficulties of biomechanical investigations. This study concludes that (i) clinical application of stability leg is useful for not only increasing primary stability of miniscrews, but also decreasing the failure rate of miniscrews, (ii) a miniscrew with 5 mm leg is superior to the other two configurations, (iii) the results of the proposed FEMs are significantly acceptable for the sake of experimental/clinical conditions, and (iv) this type of investigation is an open area and more studies on this issue are needed, that is, new solid miniscrew with a leg design to improve the clinical studies or new porous miniscrew design with a leg to improve the biocompatibility.

FIGURE 9: Variation of stress at z-direction for FCR of Model I under 4 N.

FIGURE 10: Variation of stress at z-direction for FCR of Model II under 4 N.

FIGURE 11: Variation of displacement at z-direction for FCR of Model I under 4 N.

TABLE 1: Mean stress levels of the models in the range of position angle 34–44°.

Model/ σ (MPa)	σ_x (0 mm)	σ_x (5 mm)	σ_x (10 mm)	σ_y (0 mm)	σ_y (5 mm)	σ_y (10 mm)	σ_z (0 mm)	σ_z (5 mm)	σ_z (10 mm)
FCR (Model I)	10.66 ± 0.17	8.27 ± 0.67	7.75 ± 0.94	6.75 ± 0.05	7.66 ± 0.03	6.74 ± 0.05	16.27 ± 0.33	18.55 ± 0.47	16.03 ± 0.57
0.57FCR (Model II)	10.6 ± 0.21	8.67 ± 0.71	8.78 ± 0.54	7.71 ± 0.05	7.8 ± 0.08	7.58 ± 0.05	17.09 ± 0.23	17.32 ± 0.26	18.12 ± 0.55
0.55SCR (Model I)	4.46 ± 0.36	4.13 ± 0.21	4.87 ± 1.16	3.72 ± 0.16	4.29 ± 0.65	3.85 ± 0.58	9.64 ± 0.5	9.45 ± 0.32	11.77 ± 0.23
0.23SCR (Model II)	3.49 ± 1.02	3.82 ± 0.37	4.67 ± 0.05	2.78 ± 0.26	3.17 ± 0.22	3.33 ± 0.41	9.89 ± 0.25	10.39 ± 0.24	12.07 ± 0.77

FIGURE 12: Variation of displacement at z-direction for FCR of Model II under 4 N.

Competing Interests

The authors declare that they have no competing interests.

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