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Finite Element Analysis on Loosen Teeth using Fibrous Periodontal Splint Restoration

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Abstract: Objective To investigate the effect of fibre periodontal splint restoration on mandibular anterior teeth displacement and periodontal membrane stress. **Methods** Micro-CT scanning technology, combined with Mimics, Geomagic studio and SolidWorks were used to establish 3D dental models of mandibles with teeth and the models fibre periodontal splint restoration; the models of mandibular anterior loosen teeth was constructed under 30 degree oblique 25N loading on the labial and lingual sides respectively. Then, under different angles force with or without the splint, the analysis on dental mechanical state are given. **Results** It was determined that the sum of the maximal displacement of the loosen tooth model at the lingual and labial sides was 1 mm, which represented the degree I loosen model. After splint repair on the model, the maximal displacement of loosen tooth decreased 47.7%, 85.1% and 85.8% at 0 degree, 15 degree and 30 degree forces respectively, and the maximum stress of periodontal membrane decreased by 22.3%, 61.2% and 74.9%. **Conclusion** Fixation of loosen teeth through fibre periodontal splints can reduce the maximum stress of periodontal membrane and the maximal displacement of the teeth, thus ensuring the stability of loosen tooth.

1. Introduction

Periodontal disease is a tissue disease caused by many factors. Dental plaque, periodontal inflammation, traumatic occlusion and other factors usually cause periodontal support tissue damage and alveolar bone absorption, which greatly affect the bearing of the teeth ability [1]. In addition, the alveolar bone absorption makes periodontal tissue around the loosen teeth reduce. Even if normal bite occurs, it will also lead to tooth movement and occlusion dislocation. With the development of the disease, the degree of the teeth mobility gradually increases, eventually leading to shedding or removal [2]. The tooth mobility refers to the degree of activity of natural teeth under external force, which is to evaluate the status of dental support, the development of treatment options and prognostic indicators [3].

In clinical, to achieve the purpose of dental stability, loosen teeth are treated by combining periodontal treatment and occlusal correction [4-5]. Using the fibre periodontal splint (FPS) to fix the loosen teeth can achieve the target that redistribute the force when the patient chews food [6], mobilized the potential reserve of periodontal tissue and improved the bite force, so it is benefit to restore the loosen teeth [7].

In recent years, many oral scholars have made a lot of pathological researches on alveolar bone resorption. However, there is little research on the displacement and the stress of periodontal membrane in the repaired single loosen teeth and healthy tooth connected with FPS. In this paper, we used the three-dimensional finite element method to model the periodontal tissue and the FPS in the human mandible. From the biomechanical point of view, we investigated the effect of fibre periodontal splint repaired loosen tooth on mandibular anterior teeth displacement and periodontal membrane stress under different angles force.

2. Materials and Methods

In this study, selecting patients with I degree loosen tooth (You1) while other teeth were healthy and normal. The establishment of three-dimensional finite element models include: a total of six teeth from the left canine to the right canine, mandible model, and the periodontal membrane. The structure of these models were mainly derived from tomography (Micro-CT) acquisition of computer software. Then using Mimics software to establish models of the mandibles with teeth, whose surface were smoothed and optimized by Geomagic studio software. In addition, the model of the periodontal membrane was founded by applying a positive offset of 0.25 mm based on the middle-lower part surface model the tooth. Finally, all the models processed above were imported into SolidWorks and transformed into solid models (Fig. 1), and the FPS model was designed based on the shape of tooth surface. In this paper, the splint size is 2.5 * 80mm, while the actual length is based on the physician's use.

All solid models were imported into the finite element analysis software and divided into quadratic tetrahedral units (Fig. 2). Then setting the rotation of the X-axis, Y-axis and Z-axis of the bottom surface of the alveolar bone were completely restrained; and the bonding constraint was applied between the tooth and the periodontal membrane between the periodontal membrane and the alveolar bone, as well as between the tooth and the FPS. In addition, the angle between the oblique lingual side and tooth axis was set as 0 degrees, 15 degrees and 30 degrees, and the load force was 25N. In the simulation process, the teeth, periodontal membrane, alveolar bone and FPS were all isotropic elastic materials. Referencing to the previous scholars' research results, material parameters are shown in Table 1 [8-10].

Firstly, on the reference of some teeth mobility tests, we reduced the elastic modulus of the alveolar bone model that peripheral loosen teeth about 0.5mm, then apply the loading of 25N in inclined 30 degree to determined that the sum of the maximal displacement of the loosen tooth model at the lingual and labial sides was 1 mm. Then, under 0 degree, 15 degree and 30 degree oblique 25N loading, the effects of loads in different directions on loosen tooth were evaluated. Finally, adding FPS in the anterior teeth the effects on model at the same loading conditions were determined.

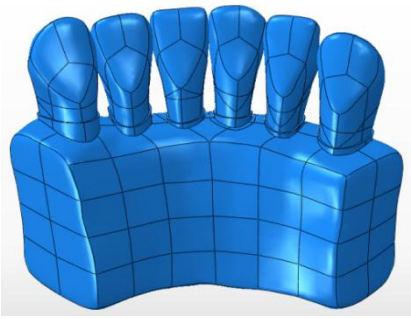

Figure 1. 3D solid model of mandibles with teeth with curved surface.

Figure 2. Finite element model mandibles with teeth after FPS repair.

Table 1. Material parameters in finite element model of teeth.

Material	Elastic Modulus（MPa）	Poisson's ratio
Enamel	41 410	0.30
Dentin	18 600	0.32
Periodontal Membrane	50	0.45
Alveolar Bone	13 800	0.3
Fibre Periodontal Splint	28 000	0.3

3. Results

The sum of the tooth displacements on the lingual and labial sides meets I degree loosen conditions. So we can make sure the model is I degree mobile model. The loosen teeth displacement nephogram are shown in Figure 2.

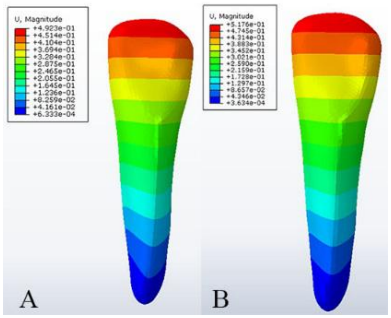

Figure 3: The loosen teeth displacement nephogram under the labial and lingual loading.
Figure 3A: Under labial side loading.
Figure 3B: Under lingual side loading.

The maximal displacement of teeth and the maximum von Mises stress of periodontal membrane are shown in Figure 3 and Figure 4 under different angles applied force with or without the splint. The range of maximal displacement and maximum von Mises stress were reduced under same angle load before and after FPS repair. For example, under the vertical load before FPS repair, the maximum von Mises stress ranged from 0.36 to 2.7 MPa and the maximal displacement of the teeth ranged from 0.0032 to 0.017 mm. After FPS repair, maximum von Mises stress ranged from 0.40 to 2.1 MPa, and maximal displacement ranged 0.0030 to 0.0091mm.

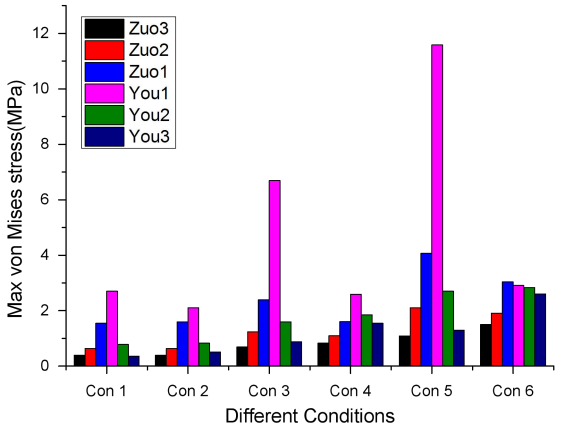

Figure 4. Max von Mises stress of periodontal membrane under different conditions.

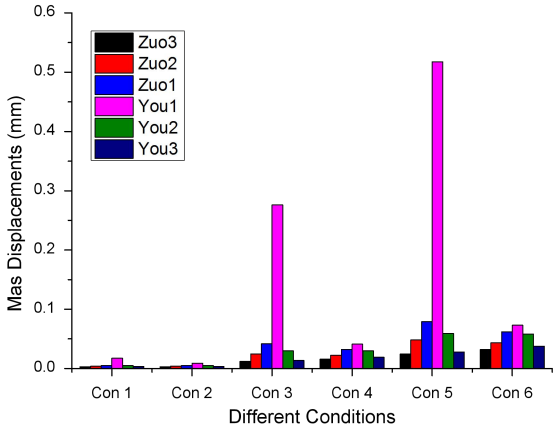

Figure 5. Max displacement of teeth under different conditions.

Zou3, Zou2, Zou1, You1, You2, You3 represent: Left canine, Left lateral incisors, Left central incisors, Right central incisors, Right lateral incisors, Right canine.

Con 1 through 6 represent: 0 degree without FPS (Con 1), 0 degree with FPS(Con 2), 15 degree without FPS (Con 3), 15 degree with FPS (Con 4), 30 degree without FPS (Con 5), 30 degree with FPS (Con 1).

Under 15 degree oblique load of force, with or without FPS, the nephogram of teeth displacement

are shown in Figure 6 and Figure 7. The distribution area of the maximal displacement of teeth shifted from the uniform state to the oblique direction of the near middle.

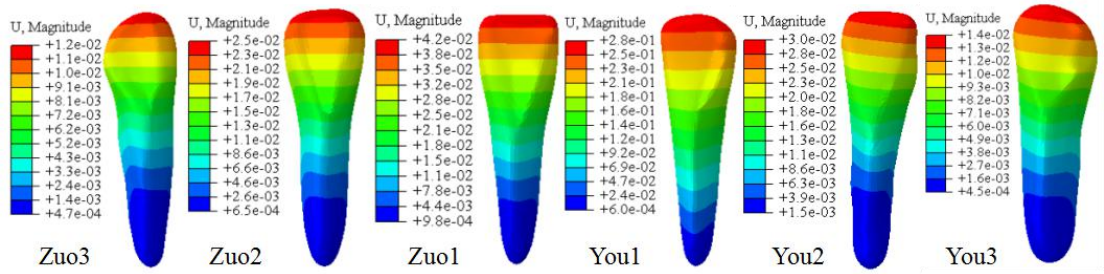

Figure 6. Teeth displacement nephogram under 15 degree oblique load before FPS repair.

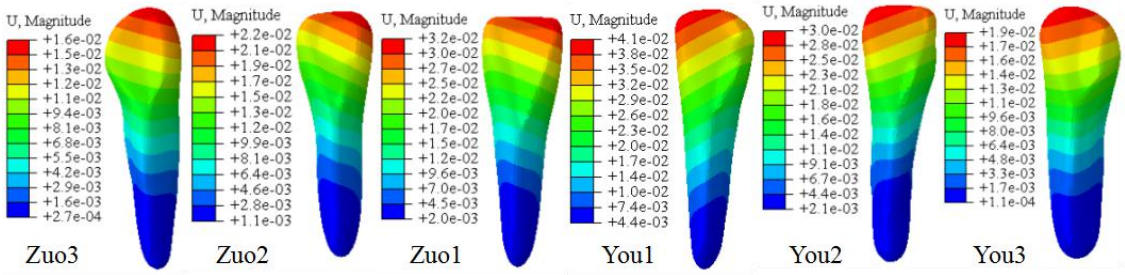

Figure 7. Teeth displacement nephogram under 15 degree oblique load after FPS repair.

4. Conclusion

In this paper, through the finite element simulation of mandibles with teeth and the models FPS restoration, the law of tooth displacement and periodontal membrane stress under different angles force was suggested. No matter there is a FPS or not, the maximum stress of periodontal membrane and maximal displacement of the teeth are increased with loading angle increase. Under same angle load with FPS repair, maximal displacement and maximum stress of loosen tooth decreased significantly. The displacement nephogram of each tooth was obviously changed under 15 degree oblique load after repairing with splint. The analysis showed the FPS restoration played the role of bridge, and healthy teeth shared the displacement of loosen tooth. Therefore, the use of FPS will transfer occlusal force of the loosen tooth to other healthy teeth. It can reduce the maximal displacement of loosen teeth and the maximum stress of periodontal membrane. These can ease the injury of the teeth chewing force on the loosen tooth, which improves the efficiency of periodontal tissue repair and provides the possibility of recovering the chewing ability of the teeth as soon as possible.

Acknowledgments

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