A three-dimensional finite element analysis of a tilted molar as a fixed partial denture abutment

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Purpose: To evaluate the stress distributions around the tilted molar abutment of a fixed partial denture (FPD) using finite element analysis.
Materials and Methods: Three-dimensional finite element models of tilted mandibular molar before and after the restoration of a 3-unit FPD as the abutment were constructed by the combination of the computed tomographic (CT) scanning technology and Ansys software. A vertical load was applied to the central fossa of the second molar. The stress distributions were calculated and compared between these models.
Results: The results showed that the introduction of a FPD decreased the stresses on the mesial area of the root and the adjacent area to the apex of the tilted molar and increased the stress surrounding the second premolar which is the other abutment of the FPD.
Conclusion: It is concluded that the placement of the FPD modified the stress distribution around the roots of the tilted molar abutment and favored the tilted molar. **(Int Chin J Dent 2007; 7: 23-26.)**
Key Words: fixed partial denture, three-dimensional finite element analysis, tilted abutment.

Introduction

It is frequently found in the clinical practice that the teeth adjacent to the lost teeth tend to tilt if the edentulous space has not been restored in time which may attribute to the influence of mesial components of occlusal force.[1] It is always a dilemma to choose this kind of tilted molar as the fixed partial denture (FPD) abutment or not. Although in early days, Tylman[2] has insisted that it was inappropriate to choose those teeth tilted over 24 degrees as FPD abutments, a number of scholars have made researches about this issue in order to investigate the further applications of such teeth.[3,4] The introduction of FPD may modify the stress distribution around the tilted molar abutment because the FPD can share and conduct the occlusal force on the tilted molar to the other abutments. The CT-based three-dimensional (3D) finite element analysis (FEA) is an accepted theoretical technique used in the investigation of biomechanical problems. It has been proven to be a precise method for evaluating dental restorations and it offers many advantages over other methods. FEA modeling not only can simulate complex geometric shapes and material properties, but also can simulate various boundary conditions, which are difficult to replicate in experiments.[5] Therefore, this study compared the stress distribution of dental supporting structures of a tilted mandibular molar as an abutment before and after the restoration of three-unit FPD (mandibular second premolar to second molar) using software of 3D FEA, by this means, in order to ascertain further how the placement of a fixed prosthesis modified these stresses and their distribution.

Materials and Methods

Construction of 3D FEA models

The CT scan section images of a donor were obtained on a PQ6000 CT machine (Picker International Inc., Cleveland, OH, USA) to provide the data of finite element models. The donor was a male adult with complete dentition and healthy occlusion. The obtained 38 CT photos which related to the needed teeth were converted into the BMP files and imported into the software of Amira (Mercury computer systems Inc., Chelmsford, MA, USA). Then the computer model of the exterior rough surface meshing of the second premolar, first and second mandibular molars was procured from Amira Software and exported as IGES files. The model was assigned an orthogonal XYZ coordinate system. UG NX4 Software (UGS Inc., Plano, TX, USA) was utilized to construct the inner structures and tilting angle and finally compose the final solid mesh of FPD. The models of FPD with and without the surrounding bones were shown in the Fig. 1. In this study, one unrestored model with tilted first molar of 30°and second premolar and one model of 3-unit FPD with the second premolar and tilted molar as abutments were created. And the type of the pontic in the model is the modified ridge-lap design which is commonly used in the clinical practice. The tilting angle was ascertained according to the axis of the midline of dentition. ANSYS (ANSYS Inc., Canonsburg, PA, USA) finite element solver software was used to mesh, compute and analyze the stresses in each model. The untreated model consisted of 465,300 elements and 80,505 nodes. And the restored model consisted of 603,120 elements and 107,185 nodes.

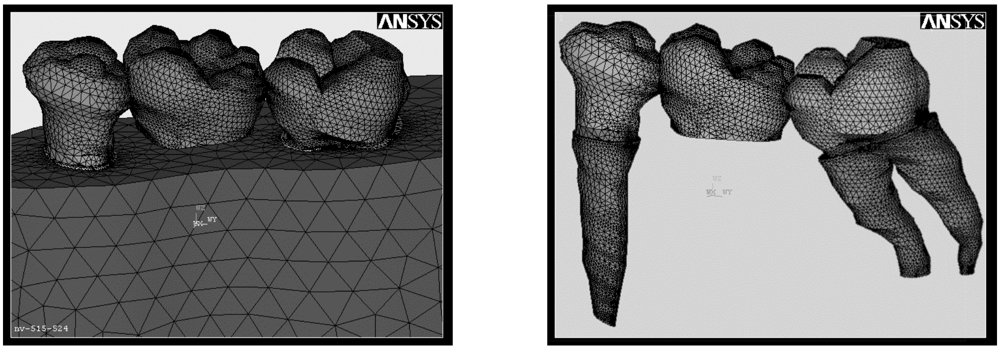

Fig. 1. Model of FPD having titled molar abutment with and without the surrounding bones.

Material properties and load type

Poisson ratio and the modulus of elasticity of materials are listed in Table 1 which are adopted from the literature.[6-8] The following assumptions were made in order to simplify the calculations. The material of the FPD, the tooth dentine, and the luting cement after setting were assumed to be homogeneous, linearly elastic, and isotropic. The anisotropy of the FPD and the dentin was not taken into account. The lateral and distal planes and the bottom were assumed to be fixed; no translation or rotation was allowed in any direction.

Table 1. Mechanical parameters of the related materials.

Materials	Elastic modulus (MPa)	Poisson's ratio (-)	Reference
Dentin	1.35×10^4	0.30	5 Shimizu et al., 2005
Cortical bone	1.45×10^4	0.30	6 Aydin and Tekkaya, 1992
Trabecular bone	2.15×10^2	0.30	6 Aydin and Tekkaya, 1992
Cementum	1.38×10^4	0.30	7 Yang et al., 1996
Alloy	8.46×10^4	0.40	6 Aydin and Tekkaya, 1992

This study set a bite force of 225 N on the central fossa of second molar, which is about the maximum normal functional bite force of Chinese people.[9] The bite force was distributed uniformly on the points of the crown of the second mandibular molar in contact in occlusion perpendicular to the surface. Loading forces on the models were static. Analyses of the stress distributions formed on the root and adjacent alveolar bone were undertaken.

Results

The maximum Von mises stress, tensile stress and compressive stress values in the supporting tissues were listed in the Table 2. Von mises stress is a scalar function of the components of the stress and can express the equal effective stress in the finite element analysis model. And the Von mises stress values in the different areas were shown in the Fig. 2. From the stress patterns of the unrestored models, it is found that the Von mises stress was concentrated in the top area of mesial alveolar bone and areas around the apex of mesial and lateral roots. And the highest stress value was observed in the top area of mesial alveolar bone. The compressive stresses located mainly in the mesial area of roots with the maximum value appearing in the top area of the mesial alveolar bone. However, the tensile stresses were concentrated in the lateral areas and the maximum value appeared in the top area of lateral part. There is a rather small stress distribution with a range of -0.03-0.10 MPa in the supporting tissues around the second premolar because of the absence of the load on it. For the restored model by a FPD, although the stress distribution of the tilted molar is similar with that of the unrestored one, the stress values decreased for all the areas such as top areas of alveolar ridge, apex area and furcation area. And for the second premolar, the stresses increased which concentrated in the apex area as compressive stress and the cervix area as tensile stress. From the detailed values in the Table 2, all the three kinds of maximum stress values for the restored model were lower than those of unrestored one. And as it is shown in the Fig. 2, the maximum values of Von mises stress appeared in the top area of the mesial alveolar ridge before and after the restoration. And for other areas, the minimum values appeared in the top area of lateral alveolar ridge. However, for all the areas, the Von mises stress values decreased after the introduction of FPD.

Table 2. Maximum stress values before and after the restoration in MPa.

Models	Before	After
Tensile stress	5.86	2.56
Compressive stress	-12.08	-9.22
Von mises stress	14.02	9.45

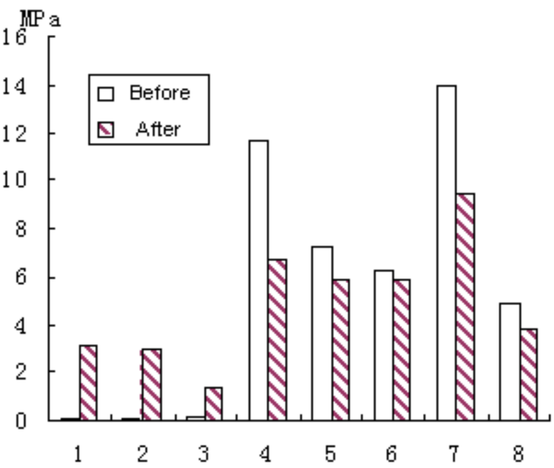

Fig. 2.
Von mises stress values in the different areas before and after the restoration: 1, top area of mesial alveolar ridge of second premolar; 2, top area of lateral alveolar ridge of second premolar; 3, apex area of second premolar; 4, mesial apex area of second molar; 5, lateral apex area of second molar; 6, furcation area of second molar; 7, top area of mesial

Discussion

A mandibular molar that tilts mesially into the edentulous space is a common problem in clinical practice of fixed prosthodontics. When the separate molar endures the occlusal force itself, the mesial component of the force can not be conducted to the subjacent teeth and finally counteract in the midline and therefore, that will induce an unusual strain in the supporting tissues and may lead to the aggressive mesial bone absorption.[10] Then the dentist must consider this situation and decide the proper treatment. This study adopted the CT-based 3D FEA method to investigate the stress distribution of the FPD with the tilted molar as abutment. This method has better geometric similarity than the 2D FEA and it is also more convenient and simpler than the conventional methods.

The results proved the hypothesis that the introduction of the FPD can modify the stress distribution around the tilted molar abutment. The data showed that the stress values of tilted molar decreased and the stress of premolar increased after the restoration. That indicated that the occlusal force was conducted by the FPD to the second premolar. This improved the stress distribution of tilted molar by the supporting of the two abutment teeth after the introduction of fixed prosthesis. And this conducted force can be further shared by the other teeth. Before the restoration, the stress is highest in the mesial area of the supporting tissues and that will hurt the alveolar tissues and may lead to the bone resorption. The introduction of FPD can make the stress distribution more stable and protect the periodontal tissue which was consistent with the 2D and photoelastic results reported by some researches.[2,3,11] The restoration can modify the stress distribution but it can not change the pattern of stress distribution. After the restoration, there is also stress concentration in the mesial area of tilted molar. However, there are still some limitations in the study. The further study will be carried out for the models with larger tilting angles because the tilting angle was set as 30 degrees in this study. Besides, experimental mechanical method such as photoelastic study should be done to complement and prove the results of finite element analysis.

Here we present a study of CT-based 3D FEA to investigate the stress distribution of a FPD using a tilted molar as abutment and compare the stress distribution and values before and after the restoration. It can be concluded that the restoration of FPD can improve the stress distribution of tilted molar and the occlusal force can be shared by the other abutment. The stress distribution has become more stable and that will help to prevent the trauma of periodontal tissue and the possible bone absorption after the restoration of FPD. Then the further study is also needed to investigate the change of stresses for the molar abutments with different tilting angles in order to help the decision of clinical treatment.

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