

STRESS DISTRIBUTION OF PERIODONTAL LIGAMENT  
IN MANDIBULAR SECOND MOLAR WITH DIFFERENT  
DISTAL ALVEOLAR BONE LOSSES

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**Abstract**

To explore the effect of occlusal adjustment in mandibular second molar with different distal alveolar bone losses on the stress distribution of periodontal ligament, a left mandibular second molar was modelled using finite element analysis based on X-ray CBCT scanned images with different distal alveolar bone losses and different occlusal effects. The equivalent stress of periodontal ligament was analyzed to study the biomechanical properties of periodontal ligament in mandibular second molars with different occlusal areas and different distal alveolar bone losses. Results demonstrate that periodontal tissue plays an important role in supporting teeth, and the residual periodontal tissue is suggested to be retained as much as possible in clinical treatment.

**Key words:** mandibular second molar, alveolar bone loss, periodontal ligament, occlusal adjustment, finite element analysis

**Introduction.** The mandibular second molar is one of the most important teeth to achieve oral chewing function, and is located in the innermost part of the oral cavity except for the third molar. If the third molar does not erupt or is pulled out after eruption, the distal adjacent surface of the mandibular second

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molar will be lost. Such situation often occurs in clinic, so the mandibular second molar is often located at the free end of the dentition; that determines the occlusal force characteristics of mandibular second molar are different from the other two adjacent teeth. Meanwhile, the mandibular second molar is one of the most frequently carious teeth, especially in the part of distal adjacent surface, which may be related to the mandibular second molar located close to the root of the tongue and the floor of the mouth, difficult to clean and the existence of impacted third molars [1,2]. Related studies have indicated that the incidence of mandibular second molar in distal caries is caused by the mandibular impacted third molar in the range of 7–63% [3,4]. But as the symptoms of early caries in mandibular second molar are not obvious, it is easy to be ignored by patients. When the patient visits hospital after discovering the symptoms, the caries of the distal adjacent surface of the mandibular second molars are usually serious, even pulp necrosis and apical inflammation have occurred. So the clinical symptoms of the mandibular second molar are closely related to the third molars [5,6].

The eruption time of the third molar is relatively late, usually between 16 and 25 years old, and the alveolar bone generally cannot provide enough eruption space for the third molar, which could result in abnormal eruption symptoms of the third molar, such as ectopic eruption and impaction [7]. The abnormal eruption may cause dental caries, periodontitis, pulpitis, severe pain, and other oral diseases, so the third molar with abnormal eruption is often treated with extraction or preventive extraction [8]. At the same time, because of the abnormal eruption of the third molar, the distal alveolar bone of the second molar is usually reduced, which is often irrecoverable. As a result, the occlusal relationship of the second molar will change relatively due to the distal alveolar bone reduction, showing the supporting condition of the second molar changed, after the extraction of the third molar. Occlusal relationship mainly refers to the contact relationship of occlusal surface, and abnormal occlusal relationship will lead to abnormal stress distribution in periodontal tissue, causing temporomandibular joint disorders (TMD), such as maxillofacial pain and masticatory activity disorder. However, the stress distribution suffered by the teeth can be changed by adjusting the occlusion to improve the occlusal relationship. Therefore, it is necessary to study the stress of periodontal tissue of mandibular second molars under bite force after alveolar bone loss, and analyze the stress distribution characteristics of periodontal tissue under different distal alveolar bone losses and bite forces, in order to obtain the adjustment basis and provide guidance for clinical treatment.

**Materials and methods. Geometric modelling.** The dental model was provided by the Department of Stomatology, the First Affiliated Hospital of Henan University of Science and Technology. An 25-year-old male patient's left mandibular third molar was in middle impaction with the second molar, and the tooth needed to be extracted because of swelling and pain. The volunteer, whose left and right sides of the face were symmetrical, the neuromuscular function of the

masticatory system was normal, the upper and lower dentition was intact, and the shape of the second molar was good without caries, repair and excessive wear, fully understood the purpose of the experiment and agreed the relevant data to be collected and analyzed. The left mandibular second molar and alveolar bone were scanned with a CBCT scanner, and the sequential sliced images were exported in Dicom standard format. The patient understood the study purpose and methods used in the study and agreed to participate in the study. All methods were carried out in accordance with relevant guidelines and regulations, and all experimental protocols were approved by the Ethics Committee of the First Affiliated Hospital of Henan University of Science and Technology.

The Dicom data was imported into the 3D image conversion software, Mimics (ver. 16.0, Materialise Ltd, Belgium), which converted the sliced images acquired from CT into a numerical 3D model. The software also provided means for threshold division, smoothing the surface, repairing the surface, and so on. Then the numerical 3D model was imported into Geomagic (ver. 12.0, Geomagic Ltd, U.S.A.) and SolidWorks (ver. 2014, Dassault Ltd, U.S.A.) to complete 3D solid modelling with enamel, dentin, dental pulp, periodontal ligament, cortical bone and cancellous bone, as shown in Fig. 1a. At last, the different distal alveolar bone losses models with 0 loss, 20% loss, 40% loss, 70% loss, 100% loss (the distal root was completely exposed with 100% loss), were created by SolidWorks, as shown in Fig. 1b.

**Finite element modelling.** All the assemblies saved in XT format were imported into an FEA software, ABAQUS (ver. 6.14, Dassault Ltd, USA), and the analysis type, material attributes, relationships between part instances, mesh types, load type, boundary condition were defined respectively in ABAQUS. A static analysis was used for the job with the mesh type of tetrahedron four node elements and tie constraint between different components. According to the basic assumptions of elasticity, all the material properties were assumed to be

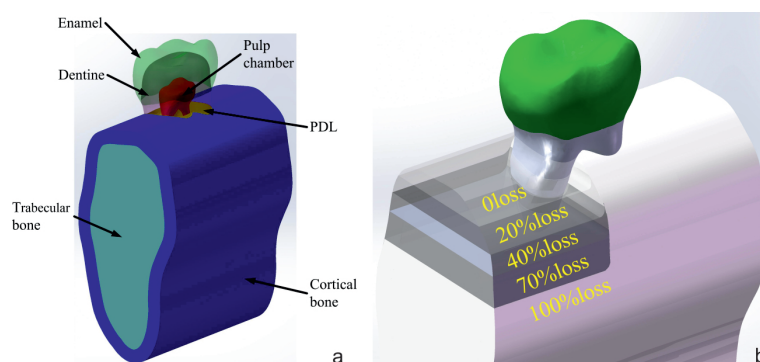


Fig. 1. Three dimensional model of second molar and periodontal tissue. (a) tooth structure; (b) distal alveolar bone losses

isotropic, homogeneous, and linear-elastic. Material properties [9–11] used in this study for FE analysis are as follows: (Young's modulus (E/MPa)/Poisson's ratio ( $\nu$ )): Enamel (8.41e4/0.33); Dentin (1.86e4/0.31); Dental pulp (2.00e0/0.30); Periodontal ligament (0.68e0/0.49); Cortical bone (1.37e4/0.30); Cancellous bone (1.37e3/0.30).

The boundary conditions of all models were set to be fixed at both ends of the alveolar bone. In order to simulate different occlusal adjustment effects [12], the areas loading with area A, area B, area C were divided, as shown in Fig. 2a. Each loading area was divided into five equal parts approximately in which five loading effects with 1/5 loading, 2/5 loading, 3/5 loading, 4/5 loading, 5/5 loading can be provided. The loading directions of A/C area loading vertical to the occlusal surface and A/B/C area loading vertical to the alveolar ridge top surface were applied to the occlusal area [13] with the pressure of 5 MPa, as shown in Fig. 2b and Fig. 2c. A total of 50 FE models were established for analysis.

The equivalent stress (Von Mises Stress) of periodontal ligament was selected as the analysis parameter, which mainly investigates the comprehensive stress of materials in various directions, reflects the comprehensive stress situation of materials at a certain point and the position of stress concentration.

**Results. A/C loading.** The stress distribution of periodontal ligament under A/C loading is shown in Fig. 3a. (1) The stress of periodontal ligament increased gradually with the increase of loading area, and the loading area was closely related to the change of periodontal ligament stress. (2) The periodontal ligament stress increased first and then decreased with the increase of alveolar bone loss. (3) When the loading area was more than 3/5 loading, the periodontal ligament stress reached the maximum value in about 40% loss of the alveolar bone. (4) When the loading area was 1/5 loading or 2/5 loading, the change of periodontal ligament stress was small from 0 loss to 100% loss of the alveolar bone. (5) The decreasing rate of stress increased when the alveolar bone loss exceeded 70% with the increase of loading area, and when the alveolar bone loss reached 100% (the distal root completely exposed), the stress value was similar to that of 0 loss.

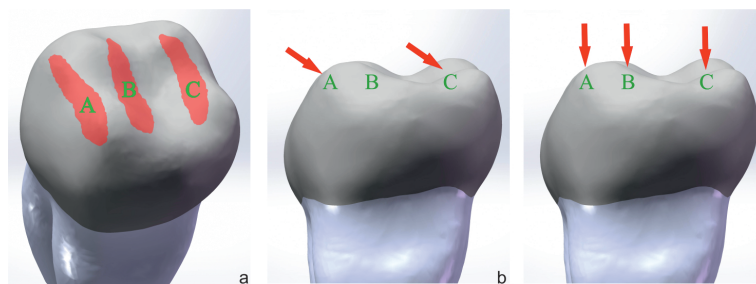


Fig. 2. Occlusal area and loading direction. (a) occlusal area; (b) A/C loading; (c) A/B/C loading

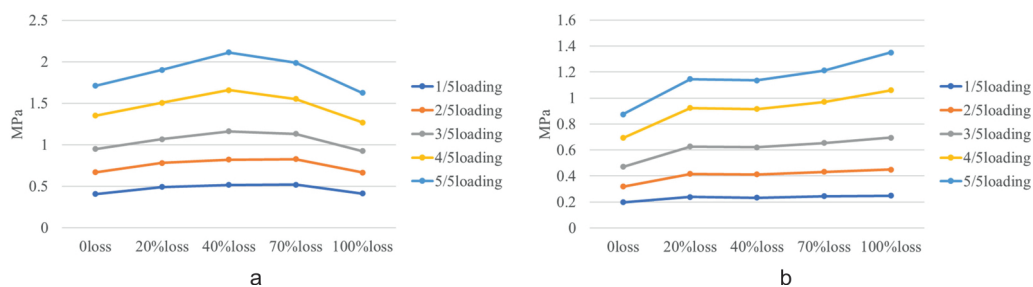


Fig. 3. Stress distribution of periodontal ligament (a. under A/C loading; b. under A/B/C loading)

According to the simulation data, the supporting effect of periodontal tissue on the teeth changed with the alveolar bone loss, which mainly performed the change of stress value and the change of stress concentration area. Before 40% alveolar bone loss, the periodontal ligament stress mainly showed the change of stress value, and the maximum stress value increased with the increase of the alveolar bone loss. After 40% alveolar bone loss, the periodontal ligament stress mainly showed the change of stress concentration area, the stress concentration area increased while the maximum stress value decreased with the increase of the alveolar bone loss. The results showed that the supporting effect of periodontal tissue on the tooth was obvious before 40% alveolar bone loss, which supporting area was similar to that of 0 loss. But the supporting effect of periodontal tissue gradually changed after 40% alveolar bone loss, the effective supporting area became larger (the stress concentration area became larger), indicating that the tooth might be loosened or there was a trend of loosening. When the alveolar bone loss was 100%, the stress concentration area of the periodontal ligament near the root tip expanded significantly, and the probability of loosening was the largest at this time.

**A/B/C loading.** The stress distribution of periodontal ligament under A/B/C loading is shown in Fig. 3b. (1) The stress of periodontal ligament gradually increased with the increase of loading area, and the loading area was also closely related to the change of periodontal ligament stress under A/B/C loading. (2) The maximum stress value of periodontal ligament gradually increased with the increase of alveolar bone loss, which indicated that periodontal tissue had obvious supporting effect on the tooth, and residual periodontal tissue could reduce the periodontal ligament stress. (3) When the loading area was 1/5 loading or 2/5 loading, the change of stress value was small from 0 loss to 100% loss of the alveolar bone. (4) The stress of periodontal ligament increased rapidly before 20% loss and after more than 40% loss of the alveolar bone, but the periodontal ligament stress was relatively stable between 20% loss and 40% loss of the alveolar bone, which indicated that there existed a certain stable range of alveolar bone loss to make the change of periodontal ligament stress value relatively constant and this stable range increased with the decrease of loading area.

According to the simulation data, the periodontal ligament stress under A/B/C loading was less than that under A/C loading, and the effective supporting area of periodontal ligament under A/B/C loading was larger (the stress concentration area larger). Because of the existence of the stress stable range, it can be used in the treatment of occlusal adjustment to retain residual alveolar bone as far as possible.

**Discussion.** The mechanical characteristics about the supporting of alveolar bone on teeth have always been a hot topic in oral biomechanics, including the change of fracture strength after alveolar bone height change, the selection of repair materials, and the stress characteristics of periodontal tissue, and so on. But due to the small shape of tooth tissue, complex internal structure, irregular external surface, and the direct study of oral problems involving many problems such as ethics, difficult sampling, long natural research cycle, and so on, it is difficult to study oral biomechanics in vivo. However the finite element method can be used to analyze this complex structure effectively and efficiently. Since THRESHER [14] first applied the finite element method to the field of stomatology in 1973, the use of finite element method to study oral biomechanics has been recognized by more and more scholars [15,16]. At present, the research on alveolar bone loss mostly focusses on the mechanical properties of teeth after both sides height change of the alveolar bone, but few scholars explore the mechanical properties of teeth after unilateral height change of the alveolar bone. In this study, the distal alveolar bone reduction of the second molar after third molar extraction was taken as the research object, and the influence of occlusal adjustment on periodontal ligament stress was discussed in order to obtain the biomechanical relationship between alveolar bone loss and occlusion to reduce the incidence of periodontal tissue diseases caused by mechanical factors.

The considerations of periodontal tissue affected by occlusal force include not only occlusal state (occlusal force, occlusal area, occlusal direction), but also the inherent characteristics of teeth (mesial-distal angle, buccal-lingual angle, occlusal surface angle, external height of teeth, and so on). In this study, the influence of buccal-lingual angle on periodontal tissue is the main factor. The mechanical model of teeth under bite force was established to be simplified as a two-dimensional cantilever structure, as shown in Fig. 4.

The couple distance under different occlusal directions can be expressed as follows:

$$(1) \quad M_1 = F_1 \times \cos \beta \times \left( \frac{H}{\sin \alpha} - a \times \cos \beta \right), \quad \frac{\pi}{4} < \alpha < \frac{\pi}{2},$$

$$(2) \quad M_2 = F_2 \times \cos \alpha \times \left( \frac{H}{\sin \alpha} - a \times \cos \beta \right), \quad 0 < \beta < \frac{\pi}{2},$$

$$(3) \quad F = P \times S,$$

where couple distance  $M$  can be used to characterize the effect of teeth on peri-

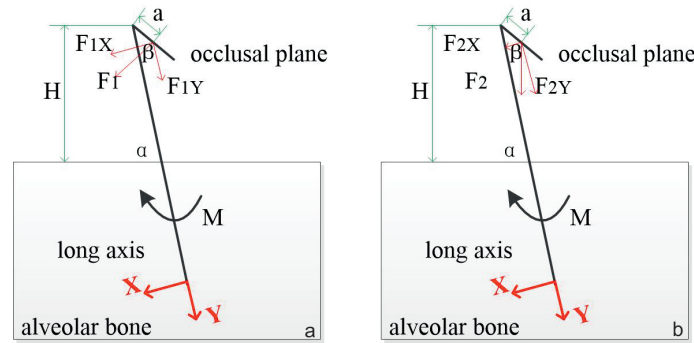


Fig. 4. Mechanical model of teeth under bite force.  
(a) A/C loading; (b) A/B/C loading

odontal tissue during occlusion.  $M_1$  is the couple distance under A/C loading;  $M_2$  is the couple distance under A/B/C loading;  $F_1$  is A/C loading force;  $F_2$  is A/B/C loading force;  $H$  is the height from the incisal edge of the incisor to the upper alveolar ridge;  $\alpha$  is the intersection angle between the long axis of the incisor and the labial side of the upper alveolar ridge;  $\beta$  is the intersection angle between the long axis of the incisor and occlusal surface;  $a$  is the distance from the incisal edge to the application point;  $P$  is the loading load;  $S$  is the loading area.

As the value of  $a \times \cos \beta$  is relatively small, it can be ignored, and after simplification, the following equations are obtained:

$$(4) \quad M_1 = P \times S_1 \times H \times \frac{\cos \beta}{\sin \alpha},$$

$$(5) \quad M_2 = P \times S_2 \times H \times \frac{\cos \alpha}{\sin \alpha} = P \times S_2 \times H \times \cot \alpha.$$

In this study,  $P$ ,  $\alpha$ ,  $\beta$  are constant. When  $H$  is constant,  $M$  increases with the increase of  $S$ , which indicates that when the alveolar bone defect is fixed, the larger the occlusal area, the greater impact on periodontal tissue. This is consistent with the simulation results. In clinical treatment, we can reduce the occlusal area to improve the stress of periodontal tissue.

Our study shows that when the height of alveolar bone changes, the supporting structure of teeth will change, and the original balanced occlusal relationship will also change. At this time, it is not suitable to wait for the way of physiological wear to establish a stable occlusion, but it is better to simulate the process of natural occlusion, and adjust the occlusion appropriately to establish a stable occlusal relationship as soon as possible. Occlusal adjustment is a common treatment technique in oral clinics, but the clinicians need to consider carefully how to adjust occlusion for it is an irrecoverable treatment method to remove certain hard tissue of teeth by manual method. Besides, the occlusal surface shape of posterior teeth has little influence on the appearance of teeth, so the design of

occlusal contact relationship is mainly based on functional needs. The reasonable distribution and transmission of occlusal force is the key to the design of occlusal surface morphology. The simulation results showed the second molar with distal alveolar bone loss might properly preserve distal cusp occlusal area, and carrying on partial occlusal adjustment according to the condition of alveolar bone loss might lead to occlusal force conduction being beneficial to physiological health, ensuring the normal exercise of occlusal function when the distal root is not completely exposed. When the distal root is completely exposed, our findings indicate that the distal cusp occlusal area could be removed to avoid the second molar loosening and fracture during normal chewing. It should be noted that although the smaller occlusal area, the smaller stress on the periodontal ligament (the smaller impact on periodontal ligament), but at the same time the smaller function of the mandibular second molar. Therefore, we should not only ensure the reasonable biomechanical load of periodontal ligament, but also try to retain the function of teeth in determining the clinical plan.

**Conclusion.** After extraction of the third molar, the distal alveolar bone loss of the second molar is a common clinical phenomenon. But there are some disputes about whether the second molar should be occluded to improve the occlusal relationship and the amount of occlusal adjustment. The results of finite element analysis show that active adjustment therapy should be carried out after the third molar extraction to improve the occlusal relationship, and the selection of occlusal adjustment amount is closely related to the residual height of alveolar bone. The alveolar bone plays an important role in supporting the teeth, and the remaining alveolar bone should be retained as far as possible when determining the treatment plan.

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