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Stress Analysis of the Occlusal Force on the Mandibular First Premolar

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Abstract The occlusal force of the tooth leads to loss of tooth tissue owing to attrition and abrasion, and may cause abfraction and pathological change of the dentin. Thus, we developed finite element models, examined them by applying ordinary occlusal force, and analyzed the stress distribution. Specimens used were mandibular first premolars from 15 Korean males and 13 females and were made into finite element models from medical images that were obtained using a Micro-CT. We have found that the irregular feature of the tooth is not only useful to masticating and pronouncing as well known, but it is also suitable for protecting inner tissue by dispersing stress and delivering proper pressure to periodontal tissue to continue a physiological action. Also, image analysis could let us know the factor that is the cause of a disorder due to stress concentration in the cervical line. These results are expected to support the field of dental treatment planning, operating procedure and clinical trial, and the advance of technical expertise to develop implants and dentures.

Keywords: Mandibular First Premolar, Micro-CT, FEM, Occlusal Force, Dental Cervical Line

1. Introduction

Dental interlocking is a key factor for oral health and function of patients to have a physiological maxillomandibular relation and adequate contact to the antagonist tooth. It also has the full implications involved in oral functions such as mastication, articulation, and esthetic dentition. The occlusal force causes attrition and abrasion, and leads to dental tissue loss. This force also causes abfraction or secondary dentin formation (Sohn et al., 2005).

The irregular feature of the tooth is suitable for protecting inner tissue by dispersing stress and delivering proper pressure to periodontal tissue to continue a physiological action. The dispersion of the occlusal force is essential to occlusal therapy. Thus, we used the finite element model, applied typical occlusal force and then determined the internal stress distribution of the model.

2. Materials and Methods

2.1 Specimens

Specimens were mandibular first premolars from 15 Korean males and 13 females. Medical images of the cross sections were obtained using SkyScan1072 (Skyscan, Belgium). The spacing between cross sections of the specimen was set to 21.31 μm and then the specimen photo was taken. In case the tooth length was less than 20 mm, about 1000 cross sections were photographed for each tooth.

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2.2 Model Generation

The surface-model from CT-images were obtained using Vworks (Ver. 4.0, CyberMed) of 3D medical imaging software and built the mesh-model using Rapidform (2006, INUS Tech.) and HyperMesh (Ver. 7.0, Altair Eng.). As indicated in Fig. 1, the tooth model was created by dental tissue as the enamel, dentin, and pulp. Nastran (MSC) was used as a solving engine of 28 models of all specimens and ABAQUS (Ver. 6.4) was used for a comparison of a stress path between one selected model of 1st premolar and three models of posterior teeth.

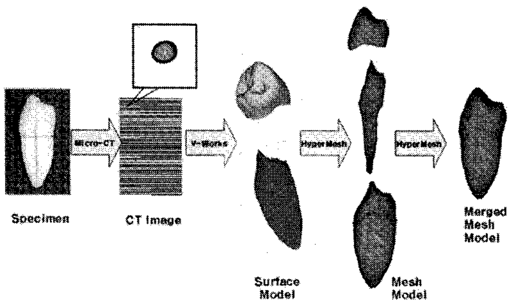


Fig. 1 Model generation from CT-image

2.3 Applying Conditions

Each model was meshed with tetra elements. To make up for the weak points of tetra mesh, the second order element type of C3D10 in ABAQUS was used and made sufficiently small. The characteristic length was about 0.29. Young's modulus of the enamel, dentin and pulp was 84.1 GPa, 18.6 GPa and 2 GPa, respectively. Properties of dental tissue (Lee, et al., 2002, Lin, et al., 1999) are shown in Table 1. The occlusion is acted around a functional cusp mainly in buccal triangular ridge. And a mandibular has movements in 45° inclined direction from the perpendicular. According to Worner (Horiuchi, et al., 2003), the occlusal force is 265 N for male and 235 N for female. Thus, loading conditions were applied to each

Table 1 Properties of dental tissue

	Young's modulus [GPa]	Poisson's Ratio
Enamel	84.1	0.20
Dentin	18.6	0.31
Pulp	02.0	0.45

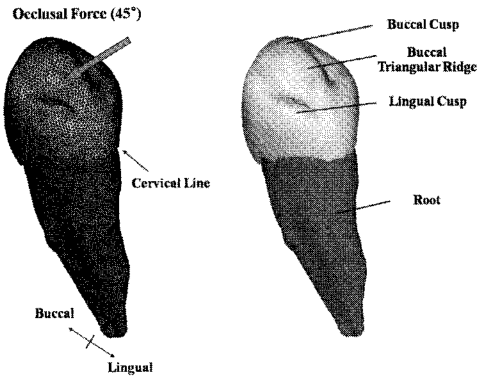


Fig. 2 Occlusal force direction

model as shown in Fig. 2. The loading and the direction is shown as Fig. 2. A alveolar bone, which has a role of holding teeth, exists around dental cervical line. Accordingly, a clinical dental root of each model was fixed.

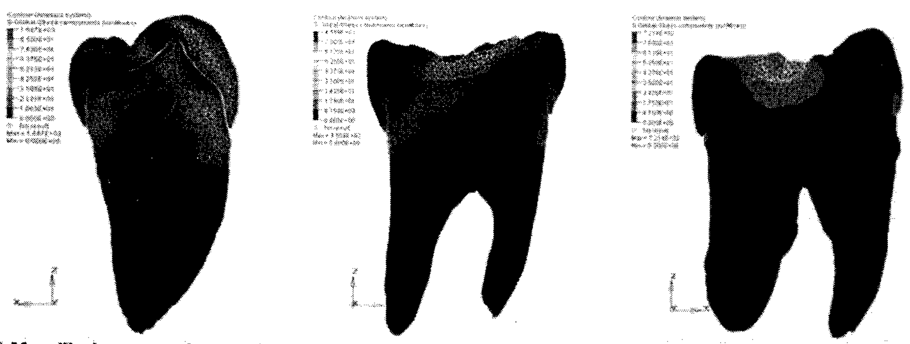
3. Results

Fig. 3 shows the internal stress distribution of the mandibular first premolar by the occlusal force. This force loaded on the buccal cusp was dispersed mainly along the enamel, and then the stress of it was concentrated on the CEJ (cement-enamel junction). Throughout the paper, all stress presented is the von Mises stress by combining all three dimensional stress components. The compressive stress acted on the buccal CEJ, and this was larger than the tensile stress on the lingual CEJ. It is noticed from the following figure that the stress on the buccal cusp of the enamel was transferred mainly away from the DEJ (dentin-enamel junction) because of the cone shape and an adequate inclination of dentin of the crown. It was also not transferred to pulp.

Fig. 3 Internal stress distribution of mandibular first premolar

As shown in Fig. 4, other types of mandibular teeth have some different paths from the mandibular first premolar. A color of Fig. 4 means same stress level in each of posterior teeth. The stress of cervical line was higher than other parts except a loading area. The stress path of mandibular second premolar developed between the loading area and the cervical line as in the mandibular first premolar. The path was shown on one side in the mandibular first molar and near a loading area in the mandibular second molar. Thus, It could be inferred that molars were less affected by bending of the repetitive occlusal force.

Fig. 5 illustrates the average of the stress values at the dental cervical line. These values were averages from 15 male and 13 female tooth models (Lee et al., 2006). These graphs were measured along the center line of the cross



(a) Mandibular second premolar (b) Mandibular first molar (c) Mandibular second molar

Fig. 4 Internal stress distribution of three posterior teeth

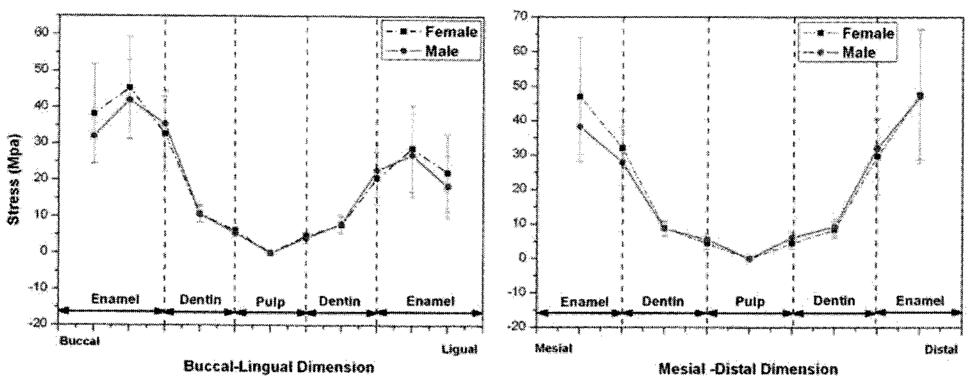


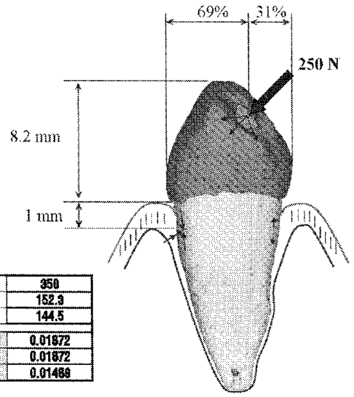
Fig. 5 Stress distribution at cross section of the case occluded on buccal triangular ridge

section at the cervical line in the respect of buccal-lingual dimension and mesial-distal dimension. The occlusal force decreased rapidly through dentin of the crown, and scarcely affected the pulp.

4. Discussion

An occlusion is divided into two types of contacts, a one-point contact and three-point contact. Fig. 6 represents the consequence of the occlusal force for the case occluded on the buccal triangular ridge in the direction of 45°. The oblique occlusal force has the demerit that partial dentin withstands a rapid stress change. Fig. 7 demonstrates the three-point contact and the resultant force acts on teeth in the vertical direction.

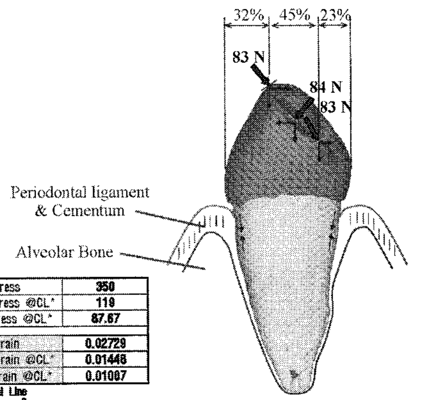
As shown in Fig. 5, the stress value was less than 50 MPa at the cervical line. The level of the stress was not enough to lead to fracture of a tooth. However the repetitive loading gives occasion to secondary dentin. Fig. 8 shows the compression stress under the buccal and lingual cervical line. In the cross section images at cervical line, the buccal-lingual dimension had less affection and the mesial-distal dimension had tension and compression stress each. The stress region of the Fig. 8(a) case of the following figure inclines to one side more than that of the Fig. 8(b) case from the center line. Also, the Fig. 8(a) case has a wider area and respectively higher stress than Fig. 8(b). Thus, its stress did not spread into the crown and concentrated on the cervical line. Therefore, the three-point contact was more stable for the



Max Stress	350
Comp Max Stress @CL*	152.3
Tens Max Stress @CL*	144.5
Max Strain	0.01872
Comp Max Strain @CL*	0.01872
Tens Max Strain @CL*	0.01489

*CL is a Cervical Line
**Unit: MPa, N, mm^2

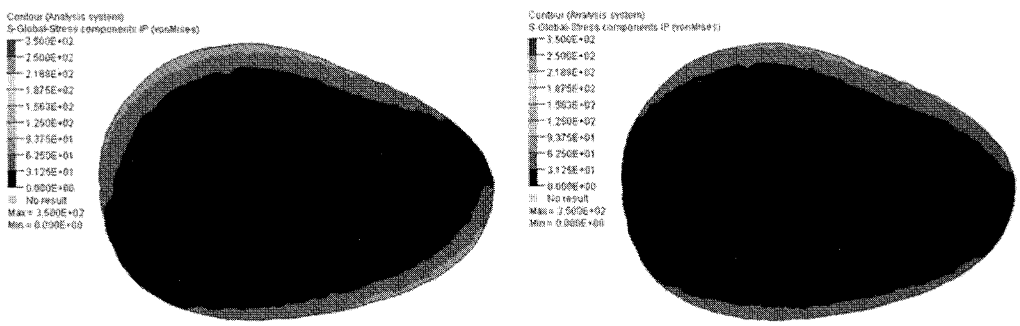
Fig. 6 Effects of occlusal force for a one-point contact



Max Stress	350
Comp Max Stress @CL*	119
Tens Max Stress @CL*	87.67
Max Strain	0.02729
Comp Max Strain @CL*	0.01448
Tens Max Strain @CL*	0.01087

*CL is a Cervical Line
**Unit: MPa, N, mm^2

Fig. 7 Effects of occlusal force for a three-point contact



(a) Case of Figure 6. (b) Case of Figure 7.

Fig. 8 Stress distribution at cross section of cervical line influence of the stress on the cervical line as indicated in Fig. 8.

5. Conclusion

This paper studied the consequence of the occlusal force on mandibular first premolars. The results indicate that the irregular feature of the tooth is a suitable structure for dispersing the occlusal force and the degree of the stress concentration on the cervical line is according to the stress transfer path. As well, dentin lasts the stress and pulp are not affected by it at the cross section of the cervical line.

The three-point contact was found more stable for the influence of the stress on the cervical line. Therefore, it is recommended that dental clinicians should treat a false occlusion such that the three-point contact may occur than the one-point contact.

This study is expected to support the field of dental treatment planning, operating procedure and clinical trial as well as the advance of technical expertise to develop implants and dentures.

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References

Horiuchi, H., Kasahara, Y., Morimoto, T., Suzuki, T., Shinkai, T. and Matsuo, R. (2003) *Oral Physiology,* Gomoonsa, pp. 129-152

Lee, H. E., Lin, C. L., Wang, C. H., Cheng, C. H. and Chang, C. H. (2002) Stresses at the Cervical Lesion of Maxillary Premolara Finite Element Investigation, *Journal of Dentistry*, Vol. 30, pp. 283-290

Lee, H. J. and Chun, K. J. (2006) A Study on the Internal Structure of the Mandibular First Premolar Using the Finite Element Analysis, *KSPE Conference,* I, pp. 171-172

Lin, C. L., Chang, C. H., Cheng, C. S., Wang, C. H. and Lee, H. E. (1999) Automatic Finite Element Mesh Generation for Maxillary Second Premolar, *Computer Methods and Programs in Biomedicine,* Vol. 59, pp. 187-195

Sohn, H. O., Song, S. S. and Lee, T. J. (2005) *Occlusion and Occlusal Surface Formation,* JiSung Publisher