Mechanical analysis of magnetic attachment dentures with implant support using the three-dimensional finite element method

K. Nakamura, H. Kumano, W. Fujinami, R. Kanbara, T. Masuda, K. Shoji, Y. Nakamura, K. Nomura, S. Ozawa and J. Takebe

Department of Removable Prosthodontics, School of Dentistry, Aichi Gakuin University

Abstract:

The purpose of this study is to examine the mechanical effects of different implant placement positions on the design of removable partial dentures using a three-dimensional finite element method. A mandibular model missing #35, #36, #45, #46, and #47 was used as the basic model. A metal-based denture was designed with RPI clasps on #34 and #44 and magnetic attachment on #37 as an overdenture abutment. Three experimental models were constructed by placing one implant in the right free-end missing corresponding to #45, #46, and #47 respectively. The stress analysis results of the experimental models compared to the basic model were as follows. Stress decreases were observed around abutment tooth #44 in all models. The stress increased as the implant placement position moved to the distal side. Decreased displacements of the denture showed in all models. In particular, the minimal displacement showed on the #46 implant placement model. These results suggest that implant placement in free-end missing area reduces stresses on the abutment teeth and surrounding tissues, decreases denture movement, and provide the support function in removable partial denture design.

Introduction

In recent years, the safety and effectiveness of dental implant therapy have been well established. The use of implants as new support elements in partial denture design has been reported[1]. Such prosthodontic treatments allow for minimizing the number and length of implants, thereby reducing surgical invasiveness. However, many aspects of the mechanical behavior of implant support in relation to the viscoelastic properties of mucosa and periodontal ligament remain unclear.

Objective

This study aimed to examine the mechanical effects of different implant placement position in the distal free-end missing area in the design of partial dentures, where a magnetic attachment was applied to the mandibular posterior molar as an overdenture abutment, using three-dimensional finite element method.

Material and Methods

1. Analysis model

The mandibular model utilized in this study is shown in Fig 1. For its construction, a mandibular plaster model and a skull model, both provided by Nissin Co., Ltd., were used (Fig 2). The mandibular plaster model was scanned using a high-resolution 3D scanner (Dental Wings 7 Series, Dental Wings) to produce STL-format digital data. The skull model, on the other hand, was CT-scanned, and the obtained CT data were processed using three-dimensional modeling software (Mimics, Materialise) to generate STL data. This ensured accurate reconstruction of the mandibular and cranial structures.

Fig.1 : The mandibular model used in this study

Fig.2 : Mandibular plaster model and a skull model

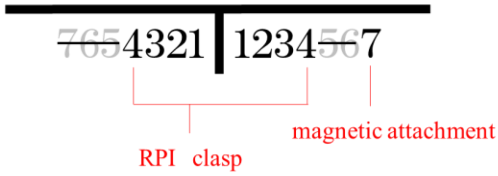
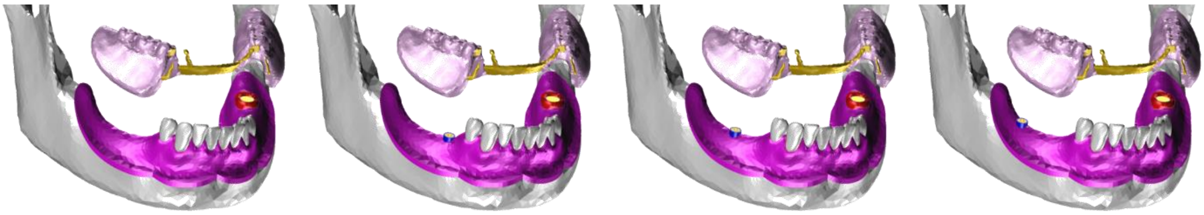


Fig.3 : The design of the removable partial denture

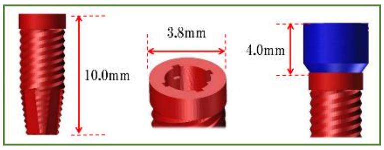
The mandibular denture model was designed to address edentulous regions in #35, #36, #45, #46, and #47. A magnetic attachment (GIGAUSS D1000) was applied to #37, serving as an overdenture abutment, while RPI clasps were incorporated on #34 and #44 as direct retainers to ensure secure denture placement. A magnetic attachment (GIGAUSS D1000) was modeled with precise dimensions to accurately replicate its diameter and width in the analysis model.

Both the mandibular model and the mandibular denture model were subsequently imported into finite element analysis software (Patran 2023.1 64-bit, MSC Software) to construct a unified analysis model. The analysis model created by the aforementioned method was used as the basic model in this study. This analysis model, representing the structural and functional characteristics of the mandible and denture system, served as the foundation for the study's finite element simulations.



Basic Model　Implant at #45 Model　Implant at #46 Model　Implant at #47 Model

Fig.4 : Analysis items



2. Analysis Items

The analysis items are shown in Fig 4. Three implant-supported models were created by placing a single implant at the sites corresponding to #45, #46, and #47 in the distal free-end missing area of the basic model. Each model had a healing abutment (4.0 mm in height) attached to the implant, which was designated as a support area under the denture base. Mechanical properties of the analysis models are shown in Table 1[2,3]. Nonlinear material properties for the periodontal ligament and residual ridge mucosa were incorporated using a material constant conversion program (Table 2)[4].

Table1 : Mechanical property values

	Young's Modulus(Mpa)	Poisson's Ratio
Mandibular bone	11,760	0.250
Enamel	41,400	0.350
Dentin	18,600	0.350
Resin	2,450	0.300
Co-Cr	200,000	0.300
Gold Alloy	142,000	0.390
Titanium	104,100	0.340
Ti-6Al-4V	113,800	0.340

Table2 : Material constant conversion program

	Young's Modulus(Mpa)	Poisson's Ratio
Periodontal Ligament	0.020	0.200
	0.085	0.300
	1.500	0.350
	2.500	0.400
	4.000	0.490
Residual Ridge Mucosa	0.150	0.300
	0.700	0.350
	3.000	0.350
	3.900	0.350
	4.600	0.450
	11.000	0.470
	16.500	0.490

3.Analysis Conditions

Loading conditions are shown in Fig 5. Loads were applied at six positions on the denture occlusal surface corresponding to #35, #36, #37, #45, #46, and #47.

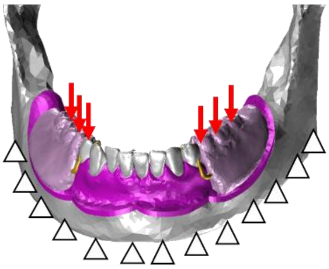


Fig.5 : Load conditions

The total load was set to 300 N, with 50 N per site. The inferior border of the mandibular model was completely constrained in the X, Y, and Z directions. Coulomb friction (friction coefficient μ = 0.09)[5)] was applied to the contact areas between the denture and mucosa. Von Mises stress and denture displacement were used as evaluation criteria.

The analysis evaluations were based on Von Mises equivalent stress and the displacement of the denture.

Analysis Results

1. Stress distribution in the alveolar bone

Fig 6 shows the stress distribution in the alveolar bone of each abutment tooth. Stress reductions were observed at #44 in models with implants placed at #45 and #46 at compared with the basic model. When implant placement moved distally, the stress increased at distal alveolar bone at #44. In contrast, no significant differences were observed at #34 on the left side or at #37 with the magnetic attachment.

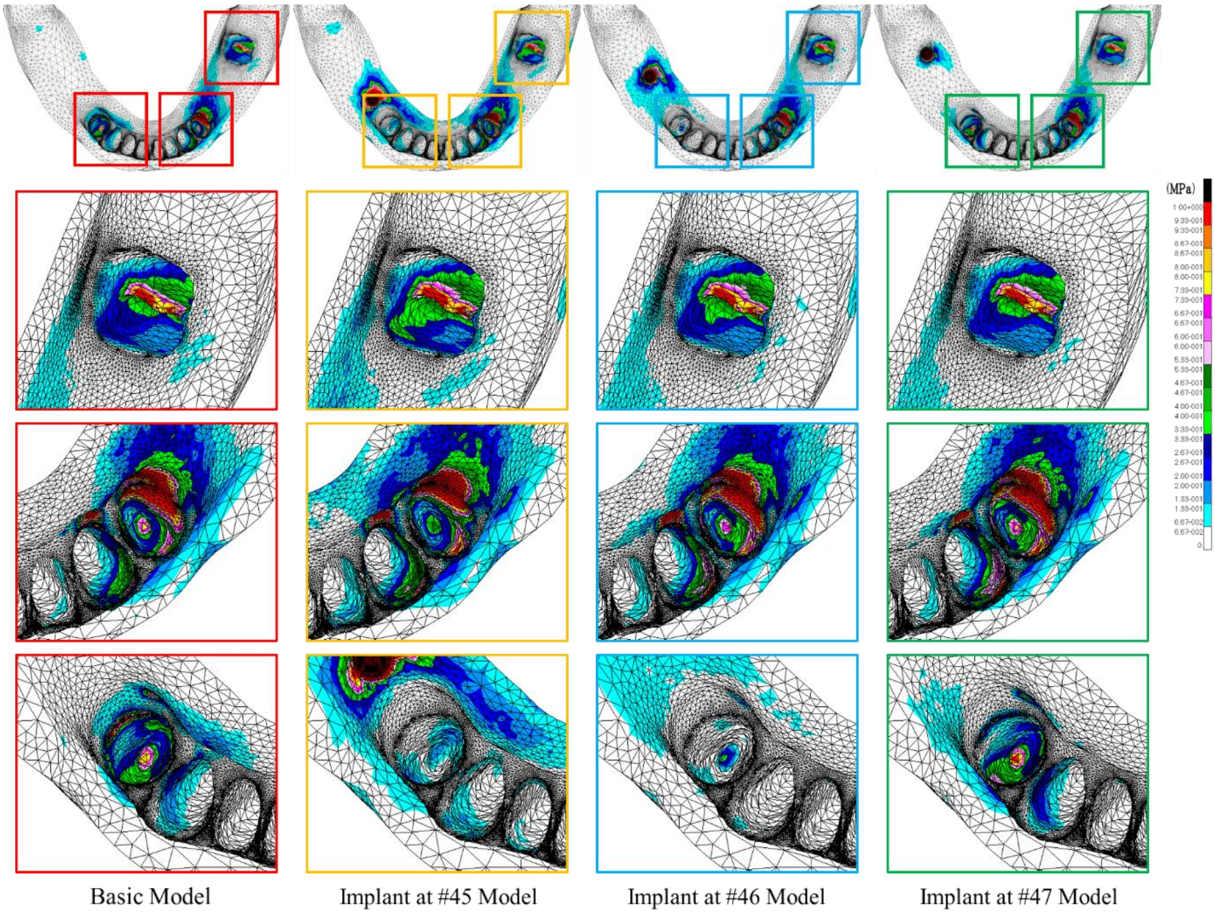


Fig.6 : Stress distribution in the alveolar bone

2. Stress distribution in the alveolar ridge mucosa

Fig 7 shows the stress distribution in the alveolar ridge mucosa. On the right side, stress reduction was observed in the implant-supported models compared to the basic model, confirming a reduction of the mucosal support area of the denture. Among the implant-supported models, the model with the implant placed at #46 showed the most stress reduction.

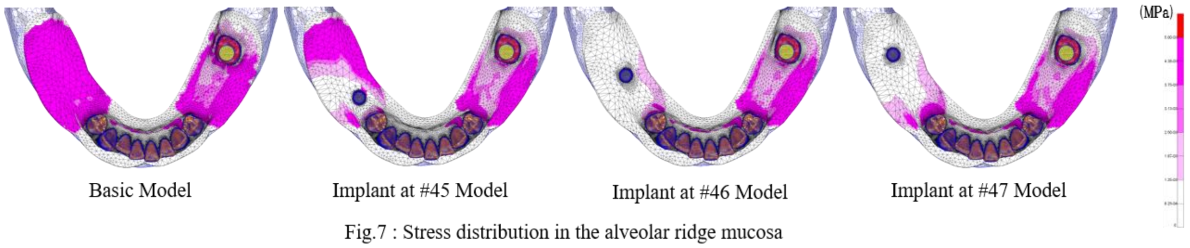


Fig.7 : Stress distribution in the alveolar ridge mucosa

3. Displacement of denture base

Fig 8 shows the displacement of the denture base. No significant differences in displacement were observed at #35, #36, and #37 between the basic and implant-supported models. However, at #45, #46, and #47, displacement was reduced in the implant-supported models compared to the basic model. The denture base displacement was decreased when those were close to the implant placement site. The smallest displacement was observed in the model with the implant at #46.

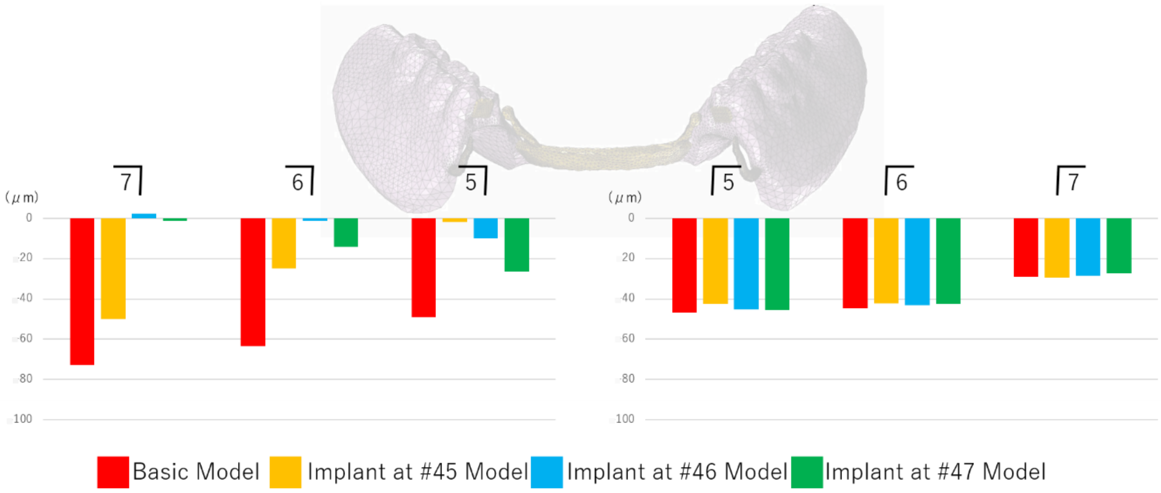


Fig.8 : A mount of displacement of the denture base

Discussion and Conclusion

The results of this study demonstrated the following mechanical effects of implant support in the design of partial dentures:

1. In the abutment tooth #44, stress reduction was observed in the models with implants placed at #45 and #46, and stress on the abutment tooth increased as the implant placement position moved distally.
2. Stress distribution in the alveolar mucosa showed the most significant reduction in the model with the implant placed at #46.
3. The minimal amount of denture base displacement was observed in the model with the implant placed

at #46.

The results of this study suggest that the mechanical effects of implant support include the reduction of stress on the alveolar mucosa and the decrease of denture movement. Furthermore, the differences in implant placement positions are significant, and the findings indicate that the most effective implant placement position is at the first molar (#46).

References

1. C. Okubo: Designs and viewpoints of RPD using implant support, The Journal of the Japan Prosthodontic Society 2020;12(1):23-28.
2. A. Ando, Y. Nakamura, R. Kanbara, Y. Ohno, Y. Tanaka: Effect of Abutment Tooth Connection ofanExtracoronal Magnetic Attachment on the Stress Distribution in their Periodontal Tissues analyzed by the Three Dimensional Element Method, J J Mag Dent 2009；18（1）：32-41.
3. Cheng H.， Xu M., Zhang H., Wu W., Zheng M. and Li X.: Cyclic fatigue properties of cobalt-chromium alloy clasp for partial removable dental prostheses. J Prostet Dent 2010；104（6）:389-395.
4. R. Kanbara, Y. Nakamura, KT. Ochiai, T. Kawai, Y. Tanaka: Three-dimensional finite element stress analysis: The technique and methodology of non-linear property simulation and soft tissue loading behavior for different partial denture designs. Dent Mater J 2012；31:297-308.
5. Y. Sato, Y. Abe, Y. Yuasa, Y. Akagawa: Effect of friction coefficient on akers claspretention. J Prostet Dent 1997 ; 78 (1) : 22-27.