Stress Analysis of Implant Keepers with Different Retaining Methods

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Introduction

Restorative implant materials and technique have continued to evolve and improve. Implant overdentures with magnetic attachment are drawing attention due to their excellent retentive mechanism.

A keeper corresponding a magnetic assembly is secured to the implant to exert the function of an attachment.

In the screw-retaining method, a keeper is mechanically secured to an implant using a retaining screw. The benefit of this method is that a keeper can be removed by operators, and, therefore, suitable for the maintenance. However, since a keeper is mechanically fixed using a screw, safety should be considered in the long-term intraoral performance of this implant. There have been several reports on clinical problems such as a fracture of an abutment screw. It is extremely important to understand mechanical influence of keeper fixture methods on implants to investigate the optimal retaining method.

Objective

The purpose of the present study was to investigate mechanical influence of keeper retaining method with screws using the three-dimensional finite element method.

Analysis methods

1. Analysis model

Figure 1 shows the keeper retaining methods of 2 types of keepers.

The methods include “fixation structure A” in which a fixture and an abutment are fixed with abutment screw and keeper unit, and “fixation structure B” in which a fixture and an abutment are fixed with abutment screw, and a keeper is separately fixed with an abutment on top.

Finite element models of “fixation structure A” (Model A) and “fixation structure B” (Model B) were constructed using a general purpose finite element pre-post processor (Patran 2010, MSC software). These FEM models are shown in Fig. 2.

The detailed size of each model is shown in Figures 3 and 4. The screw structure followed the same standard, and the pitch of the screw was 2 mm.

The element type designation was three-dimensional tetrahedral primary element. A total nodal point and total element count of Model A were 36,931 and 211,512, respectively, and those of Model B were 38,759 and 222,615, respectively.

The cortical bone surrounding a fixture was constructed for the convenience of analysis.

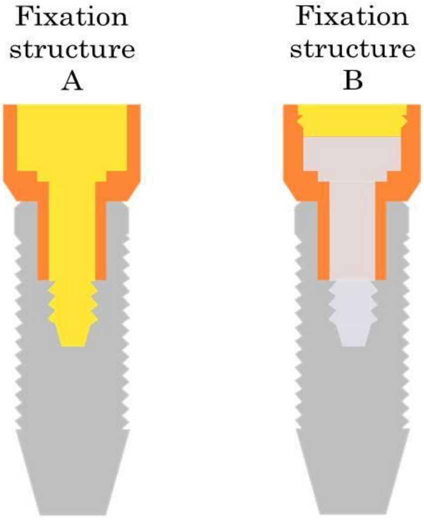


Fig. 1. The keeper retaining methods of 2 types of keepers.

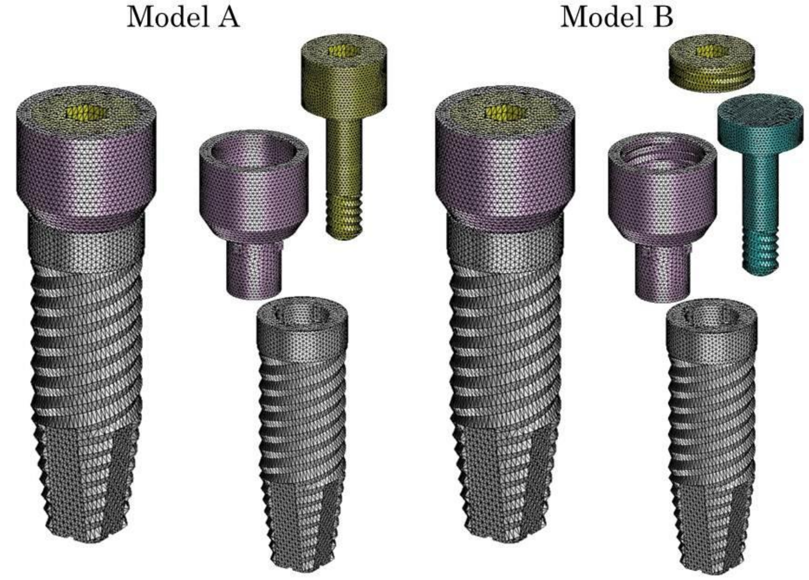


Fig. 2. Finite element models

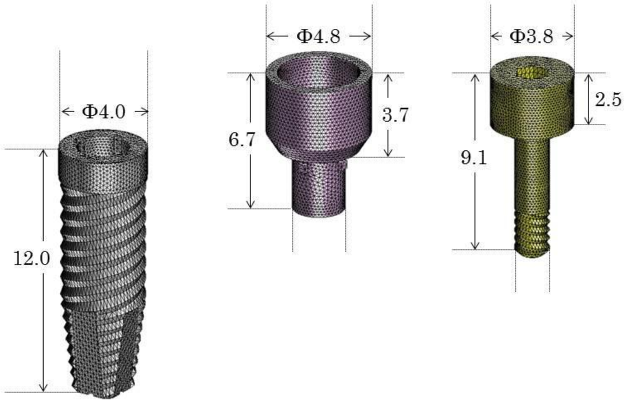


Fig. 3. The detailed size（Model A）

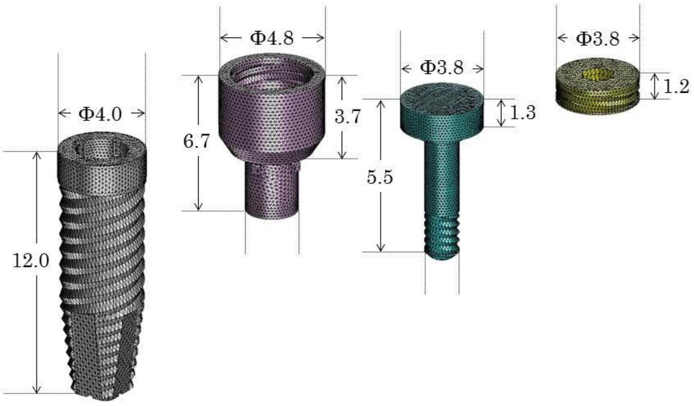


Fig. 4. The detailed size（Model B）

2. Analysis condition

An elastic stress analysis was performed using a general purpose finite element program (Marc 2010, MSC software). A workstation DELL PRECISION T 7400 (DELL) was used throughout the study.

1) Boundary condition

A complete constraint was applied to the inferior and lateral surfaces of the cortical bone in the X, Y, and Z directions (Fig. 5).

Two loading conditions (LC 1 and 2) were applied. A 800 N load was applied to the upper surface of a keeper in the vertical direction of the implant long axis in LC 1. A 800 N load was applied to the upper surface of a keeper in the 45 °direction of the implant body long axis in LC 2.

A contact condition was applied between each structure except for a fixture and the cortical bone.

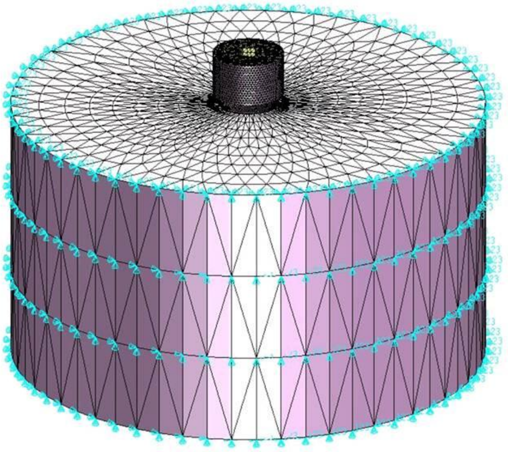
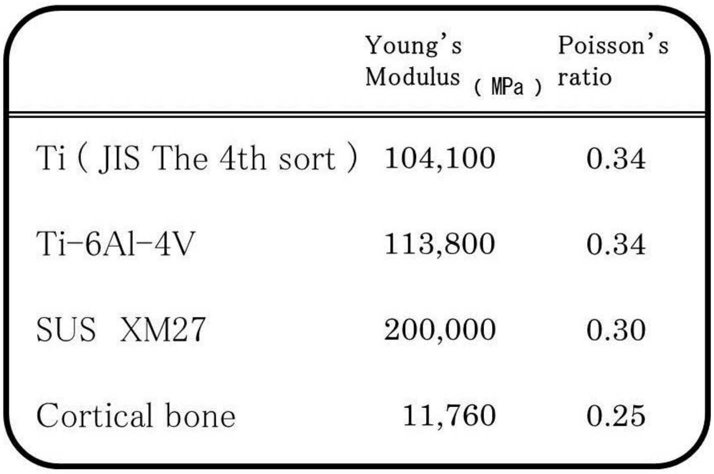


Fig. 5. Fix condition

2) Mechanical properties

Table 1 shows material constants used in the present study. Soft magnetic stainless steel SUSXM 27 was used as a keeper material of a magnetic attachment, and the abutment screw of Model B was made of Ti-6AL-4V. Material constants of a fixture and abutment were set according to the previous references.

Table. 1. Mechanical Properties



	Young's Modulus (MPa)	Poisson's ratio
Ti (JIS The 4th sort)	104,100	0.34
Ti-6Al-4V	113,800	0.34
SUS XM27	200,000	0.30
Cortical bone	11,760	0.25

Analysis results

1. Stress distribution

Stress evaluation of LC1 and 2 was performed using Von-Mises stress. The evaluation was conducted for the surface and longitudinal plane of an abutment screw.

Stress evaluation of LC2 was performed using principal stress. The evaluation was conducted for the surface of an abutment screw.

1)Von-Mises stress

Figure 6 shows the overview of LC1. Although there was no significant mechanical difference in an abutment screw between Models A and B, a minor stress relaxation was observed in Model B.

Figure 7 shows the overview of LC2. A larger stress concentration in the neck and center parts of an abutment screw was observed in Model A compared with Model B.

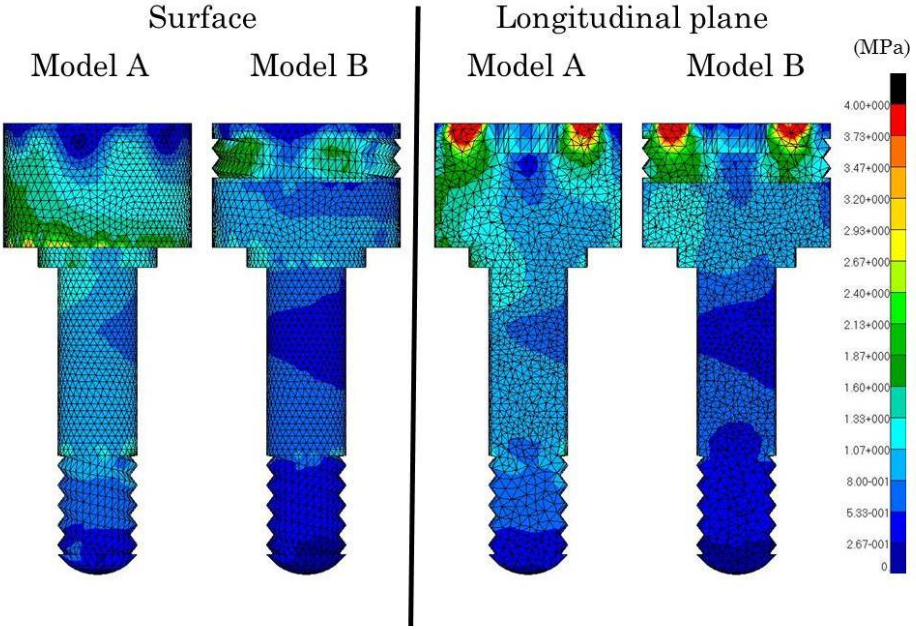


Fig. 6.　Von-Mises stress (LC1)

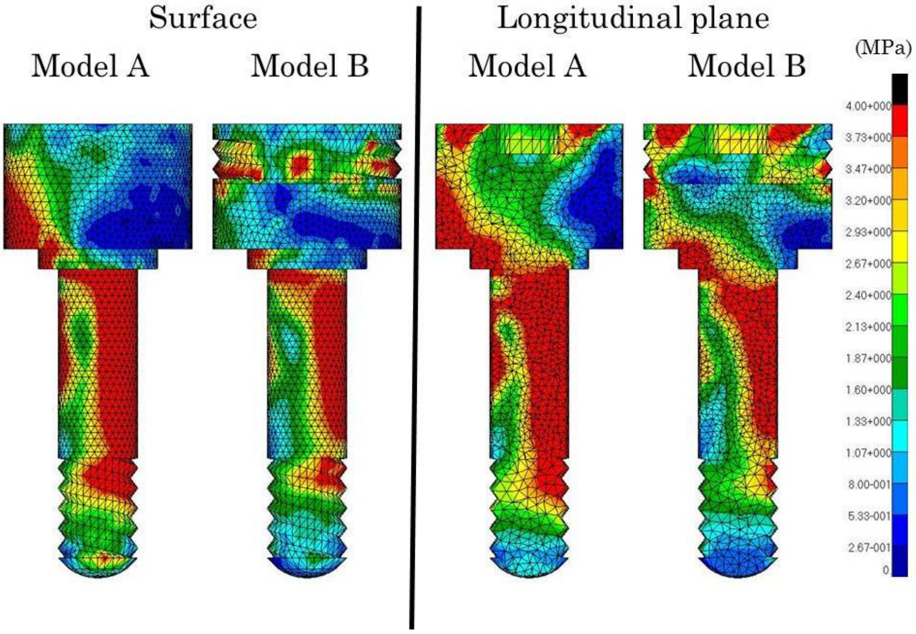


Fig. 7.　Von-Mises stress (LC2)

2)Principle stress

Figure 8 shows the minimum principle stress distribution chart. The higher compressive stress concentration was observed in the corner and neck parts of an upper abutment screw in Model A compared with Model B.

Figure 9 shows the maximum principle stress distribution chart. The higher tensile stress concentration was observed in the neck part in Model A compared with Model B.

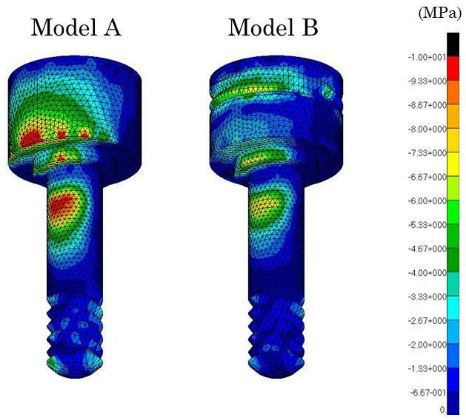


Fig. 8. The minimum principle stress

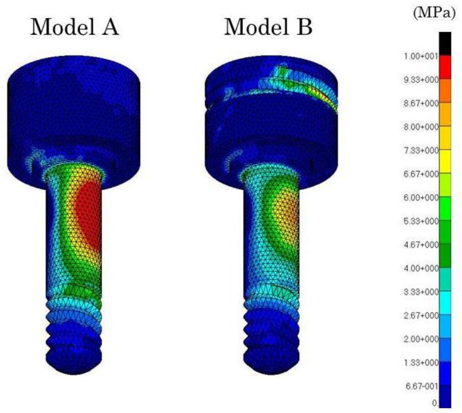


Fig. 9. The maximum principle stress

2. Stress values (maximum and minimum principle stress)

Figure 10 shows the minimum and maximum principle stress values of LC2. The measurement point excludes the point adjacent to the loading point. Minimum and maximum principle stress values were higher in Model A compared with Model B.

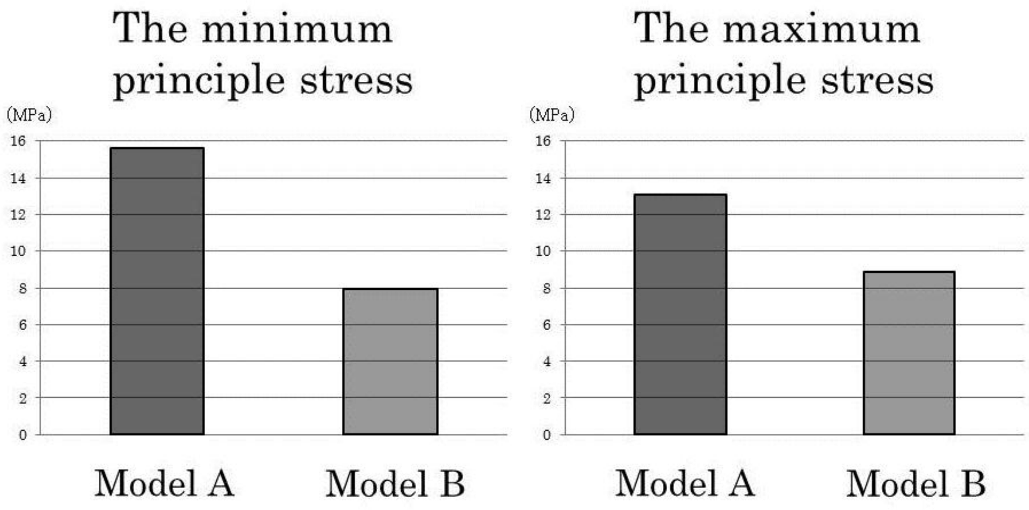


Fig. 10. The minimum and maximum principle stress values

Discussion

1. Stress distribution

The main purpose of the present study was to investigate the mechanical influence of the difference in the fixation method of a magnetic implant keeper on a load. The inner structures of two analysis models were faithfully constructed according to the size shown in Fig. 2.

Compared to “fixation structure A” in which a fixture and an abutment are directly fixed with abutment screw and keeper unit, “fixation structure B” is physical fixation of an abutment screw and a keeper using screw structure. Therefore, an appropriate setting is necessary regarding the interfacial positional relationship. An abutment screw and a keeper of “fixation structure B” were constructed on the model in the contacted position without space to evaluate the influence of the difference in the two fixation methods of a magnetic implant keeper on a load.

It is considered that the analysis model constructed in the present study can accurately evaluate the difference in keeper fixation structure.

2. Analysis condition

Boundary condition significantly affects the analysis results. The appropriate boundary condition for the present study was carefully investigated. The cortical bone was constructed around the implant body, and a complete constraint was applied around the cortical bone.

The functional force applied to the implant overdenture includes component force in different directions. Therefore, a load was applied perpendicular and 45°to the keeper adsorption face to efficiently transfer stress to an abutment screw. A load larger than estimated occlusal force was applied.

A contact element that can reproduce the contact condition between objects was applied on the interface of fixture, abutment, abutment screw and keeper.

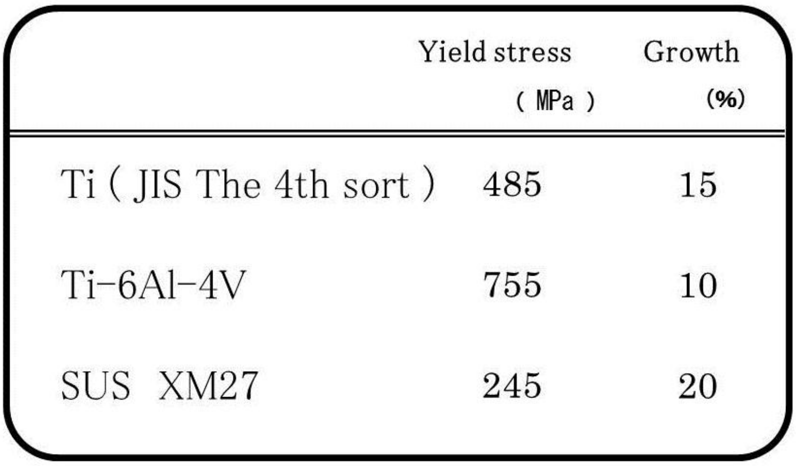
We focused on the difference in materials of soft magnetic stainless steel (SUSXM27) used as a keeper material of magnetic attachment and titanium material (Ti-6AL-4V) used as an abutment screw material to set mechanical property value of each analysis model component. Experimental data of these materials are shown in Table 2. The mechanical influence between materials needs to be considered when these materials are used for the implant inner structure. SUSXM27 was used for a keeper and abutment screw unit in Model A, whereas SUSXM27 was used for a keeper, and Ti-6AL-4V was used for an abutment screw in Model B.

3. Analysis result

Figure 6-10 shows obtained results. A significant difference was observed in stress distribution of two keeper fixation structures during a load application in 45°compared with a load application in the vertical direction. A load was applied in the long axis direction of the implant body during a load application in the vertical direction. Since a substantial load was placed on the inner abutment, there was little influence of the difference in fixation structures and materials on abutment screws for each model. In contrast, a tilted load was applied in the long axis direction of the implant body during a load application in 45°direction. A substantial load was placed on the mutual inner screw structure of an abutment and a fixture, and bending stress was placed against an abutment screw located in the center. Therefore, there was a significant influence of the difference in fixation structures and materials on abutment screws for each model.

For stress evaluation during a load application in 45°direction, Stress evaluation of was performed using principle stress that evaluates compressive and tensile stress, and Von-Mises stress that indicates various stress as scalar. A significant influence of the difference in fixation structures and materials was observed between Model A and Model B regarding the principle stress evaluation (Fig. 8 – 10). Regarding abutment screw materials (Tables 1 and 2), SUSXM27 has lower yield stress compared with Ti-6Al-4V, and principle stress has a significant influence during fracture and deformation of objects. These results suggest that Model B has a higher safety against fracture and deformation compared with Model B considering the repetitive stress application in the mouth.

Table. 2. Experimental data



	Yield stress (MPa)	Growth (%)
Ti (JIS The 4th sort)	485	15
Ti-6Al-4V	755	10
SUS XM27	245	20

Conclusions

The mechanical evaluation was performed regarding the keeper fixation using the screw retaining method. Mechanical evaluation was conducted using three-dimensional finite element method, and the following conclusions were drawn.

1. A significant stress relaxation was observed regarding compression and tensile stress during load application in 45°direction by separating an abutment and keeper.
2. For abutment screw materials, a higher mechanical safety was suggested in Ti-6Al-4V compared with soft magnetic stainless steel (SUSXM27).

References

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