博 士 論 文

Mechanical effect of an implant under denture base
in implant-supported distal free-end removable partial dentures
（インプラントに支持を求めた遊離端部分床義歯における インプラントの力学的効果）

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Introduction

Removable partial dentures (RPDs) are generally used for recovery of oral function of partially edentulous patients. However, RPDs occasionally cause many problems such as insufficient recovery of function, overload of abutment teeth, and resorption of residual ridge [1,2].

Recently, dental implants (hereinafter abbreviated simply as “implants”) are widely used and recommended as one of the best options than RPDs for partial edentulism, due to their masticatory function and satisfaction of patients [3]. However, they demand amount / quality of bone and are accompanied with surgical invasion [4].

On the other hand, implant assisted RPDs (IARPDs) are clinically used and reported as a better option of prosthodontic treatment for higher satisfaction of patients [5,6]. Furthermore, applicability of shorter implants can decrease surgical invasion and expand indication [7,8]. However, their mechanical advantage is not clear [9-19].

The aim of this study was therefore to investigate the influence of an implant under the saddle of distal extended removable partial dentures on stress sharing among abutment teeth and residual ridge, using finite element (FE) models based on CT images.

Materials and methods

FE models

This study used CT data of a patient with defect of mandibular right molars in the Department of Removable Prosthodontics, Hokkaido University Hospital. Outline of bone and teeth were extracted from the CT images encoded in Digital Imaging and Communications in Medicine (DICOM) format according to the CT value by computer-aided design (CAD) software [Materialise Mimics Medical 21.0 (Materialise, Leuven, Belgium)]. FE model of the right half of the mandible, teeth, implant, and a denture was constructed and analyzed as a bilateral distal free-end removable partial denture (Fig. 1).

The outline of PDL and mucosa was constructed with a Computer Added Design (CAD) software (Materialise 3-matics Medical 12.0, Materiarise, Leuven, Belgium) from the surface of teeth and alveolar residual bone, respectively. Metal frameworks of RPD and IARPDs was designed with denture frame CAD software (DIGISTELL, C4W/DIGILEA, France) (fig. 2). The Co-Cr framework had a set of a cingulum rest, an I-bar clasp, and a distal proximal plate on each abutment tooth (Fig. 3).

Cylindrical dental implant made by titanium, with 3.5mm in diameter and 8.5mm in width was placed under denture saddle. Their location was region of first premolar, second premolar or first molar (IARPD4, IARPD5 and IARPD6, respectively). In addition, a model without an implant (RPD) was constructed as a control. These CAD data were outputted as Standard Triangulated Language (STL) files.

The CAD data were imported into FEA pre-post processor software (Marc. Mentat2010, MSC USA) and converted into FE models (Fig. 4). Material properties indicated Table 1. This study was approved by the Institutional Review Board of Hokkaido University Hospital for Clinical Research (016-0152).

Condition of contact

Condition of contact at the interfaces of mucosa-denture base, denture base- implant, and retainer-abutment tooth was considered in the analysis. Friction at these interfaces without the retainer-tooth interface were neglected, according to the lubricate effect of saliva. The coefficient of friction at the retainers was determined as μ=0.05 [20-22].

Boundary conditions

In IARPD models (IARPD4, IARPD5 and IARPD6), we decided amount of relief between the top of the implant and the denture base so that they are in contact with each other under 100N of vertical load on L6 (Table 2) [24,25].

The displacement was restricted at each node on the top of condyle and the stop of masseter muscle for all direction, and at all nodes in cross section of the midline of mandible for lateral direction (Fig. 5).

Vertical load of 200N was applied on one of the loading points located on the point corresponding to first premolar (L4), second premolar (L5), and first molar tooth (L6) and second molar tooth (L7). (Fig. 6).

Evaluation of the analysis

We evaluated each model with the relative vertical displacement of denture base at its distal end and apex of abutment tooth (canine) with reference to the nearest node on the surface of bone. We also evaluated the distribution of equivalent stress in alveolar ridge.

Results

Equivalent stress in alveolar mucosa (Fig. 7-10).

In all models, the stress was largest under the L7 load, compared with the other load conditions. IARPD6 showed most effective reduction of stress by placing an implant compared with RPD.

Likewise, the amount of the displacement of denture base was the largest under L7 load (Fig.11). As the position of an implant was more distally located, the displacement decreased proportionally.

Equivalent stress in PDL (Fig. 12-15).

The RPD model showed a decrease of the stress in PDL under L7 load compared to the L4, L5, and L6 loads. However, the IARPD models showed the most decrease under L6 load. Compared with RPD, most of all IARPD models shows reduction of stress in PDL, except for IARPD5 under L7 load.

Fig. 16 showed vertical displacement at the apex of canine. In the RPD model, the vertical displacement of canine became smaller as the loading point located distally. On the other hand, in all of the IARPD models, the canine displaced upward under L7 load.

Discussion

In the free-end denture, the masticatory efficiency decreases because the denture sinks and the stress on the abutment tooth increases accordingly [29-32]. Therefore, clinical application by IARPD has been proposed [5,6].

There are several reports concerned with the mechanical behavior of the abutment teeth and implants of IARPDs under occlusal load [11,14]. Moreover, FE models generated from computed Tomography (CT) images becomes common recently. However, there are only a few reports on stress analysis with precise FE models of IARPDs based on CT images, because of the complexity of shapes, material properties, and boundary conditions including contact analysis [12,15,16,18]

In this study, FE analysis was performed with rough elements for the implant and bone to reduce analysis time within the limit by the hardware used since the purpose of this study is to investigate the burden of the abutment tooth and mucosa. Therefore, the occlusal pressure burden of the implant and the surrounding bone could not be evaluated in this study. In order to evaluate the distribution of stress in implants and surrounding bones under IARPDs, it is necessary to construct models with preciseshape of the implant and surrounding bone including the thread.

The amount of relief was determined so that the top of the implant would be in contact with denture base under occlusal force during mastication of about 100N. Since the displacement of the mucosa is much larger than that of the implant, the behavior of the denture base under occlusal force smaller than 100N was basically the same as that of conventional RPDs [24,25]. Therefore, if the relief was small, the implant would contact under smaller occlusal force and support most of occlusal force like one of a fixed prosthesis. On the contrary, too much relief would result in the same behavior of denture base as conventional RPDs unless a stronger occlusal force is applied.

With respect to the location of an implant, more distally location was favorable because of effective reduction of stress in mucosa and PDL of abutment teeth. However, more distally located load than the implant lifted abutment teeth. This displacement was due to the lever effect with a fulcrum of implant. However, in IARPD4 model, this effect was negligible because of the smallest movement of denture base around the implant, which was near the rest of the retainer on canine.

Matsudate described that there were cases where lifting to the abutment tooth occurs in the model study on unilateral free-end cases [14].

The results of this study also correspond with the report by Ohyama et al [17]. They described that the implant under denture base reduced displacement of abutment teeth under load located mesially, because it suppressed the displacement of denture base in unilateral free-end IARPDs.

On the other hand, from this study, it seemed to be better to locate an implant in the second molar area because it was speculated that the displacement of denture base and abutment teeth can be suppressed more effectively than IARPD6. However, it was impossible to place an implant there in the case used this study because of insufficient bone height from mandibular canal. Although shorter implant would be applicable, its effect on IARPDs should be investigated in the future.

Conclusion

Within the limitations of this study, the area corresponding to the first molar was recommended for the location of an implant under denture base of bilateral distal free-end IARPDs. The implant located in the area corresponding to second premolar can cause non-physiological extrusion force on abutment teeth by the load on the artificial second molar.

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Table 1. Material properties [23, 26-28]

		Elastic modulus（MPa）	Poison’s ratio
Bone (coronal bone)		13700	0.30
Mucosa		0.5	0.45
Tooth	Enamel	80000	0.30
	Dentin	17600	0.25
Co-Cr alloy		211000	0.3
Denture (Acrylic resin)		2200	0.31
Titanium		110000	0.33
PDL		2.3	0.49

Table 2. Relief amount of between implant and denture on 100N vertical load

	IARPD4	IARPD5	IARPD6
Relief amount (mm)	0.06122	0.09335	0.12698

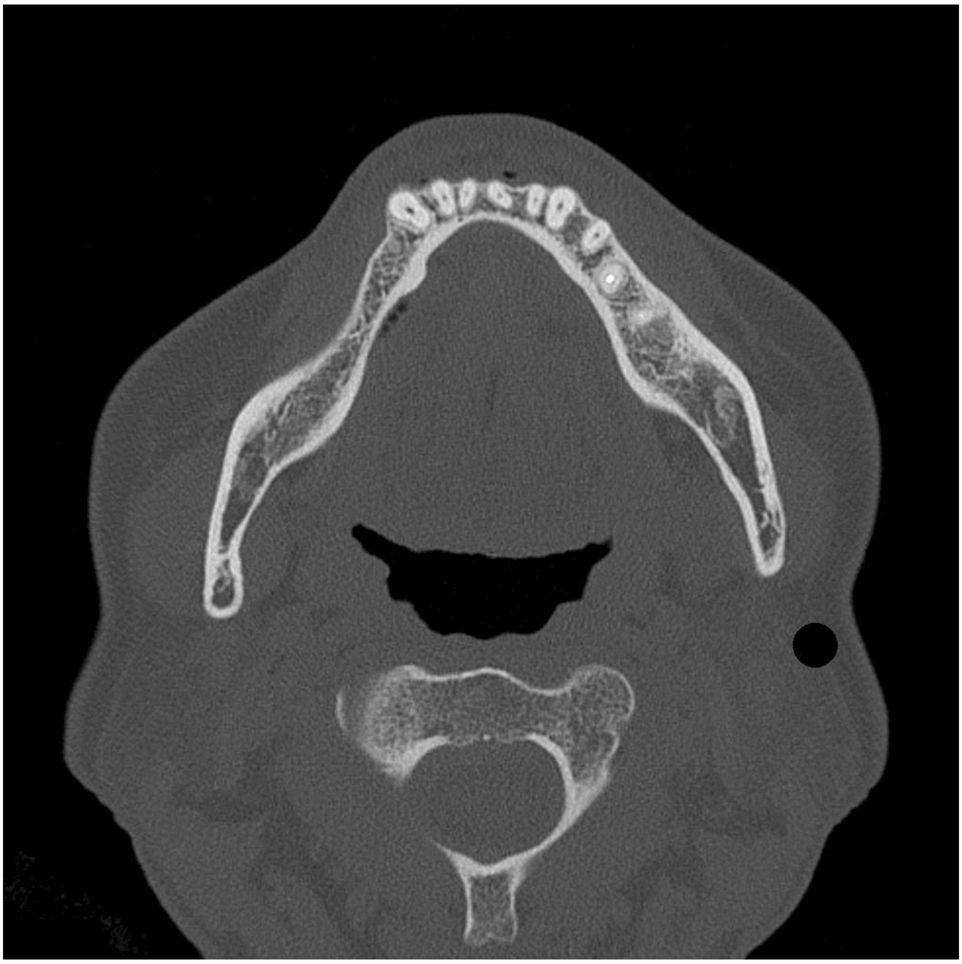


Fig. 1 CT date (DICOM) of mandibula bone

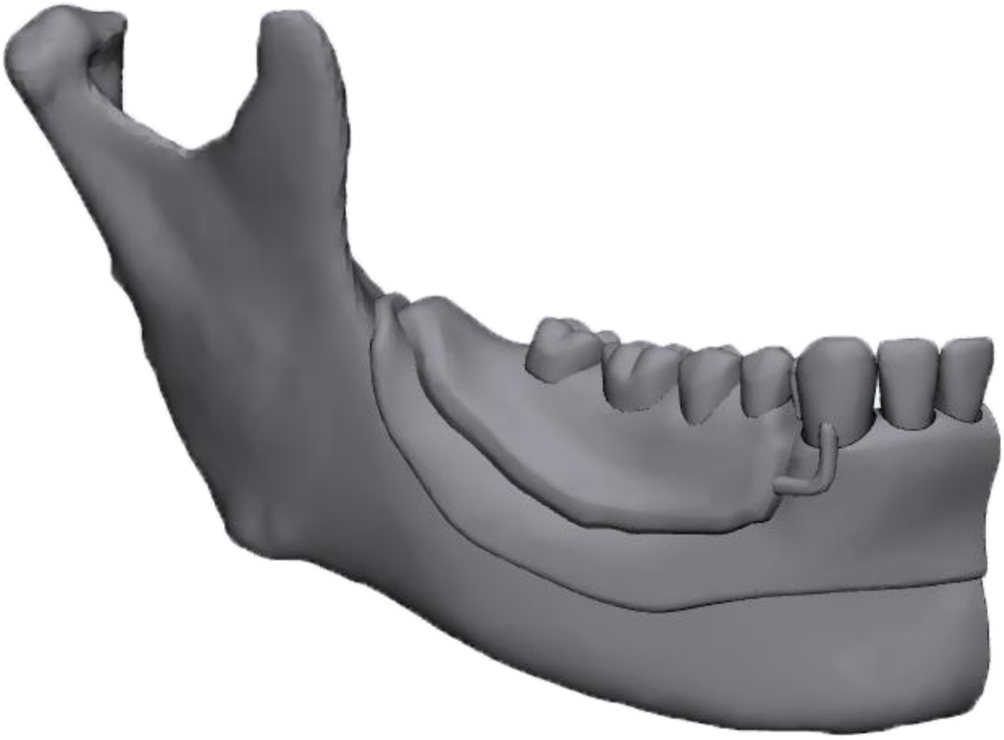


Fig. 2 CAD model (STL format)

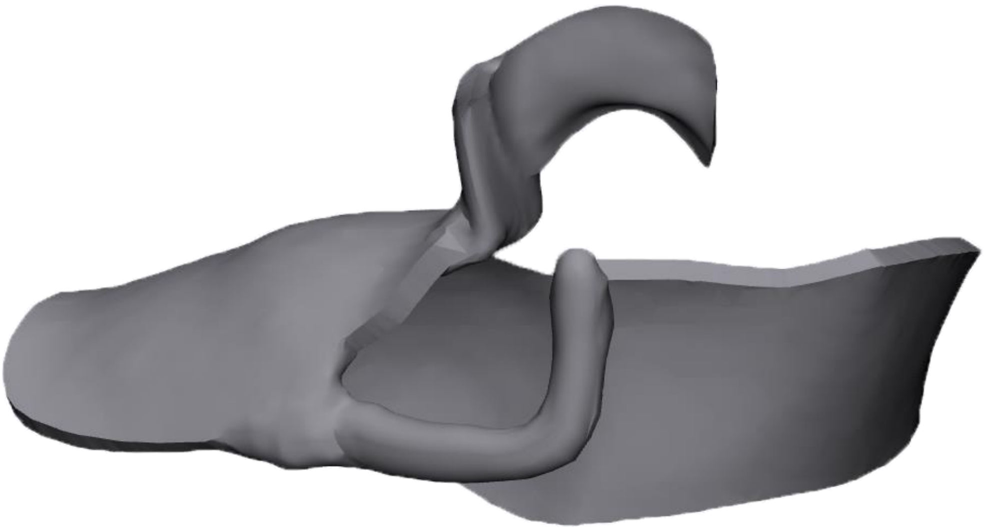


Fig. 3. Denture Metal frame was designed with denture frame CAD software (DIGISTELL, C4W/DIGILEA, France) and imported with CAD software (3-matics 12.0). The Co-Cr framework had a set of a cingulum rest, an I-bar clasp, and a distal proximal plate on each abutment tooth.

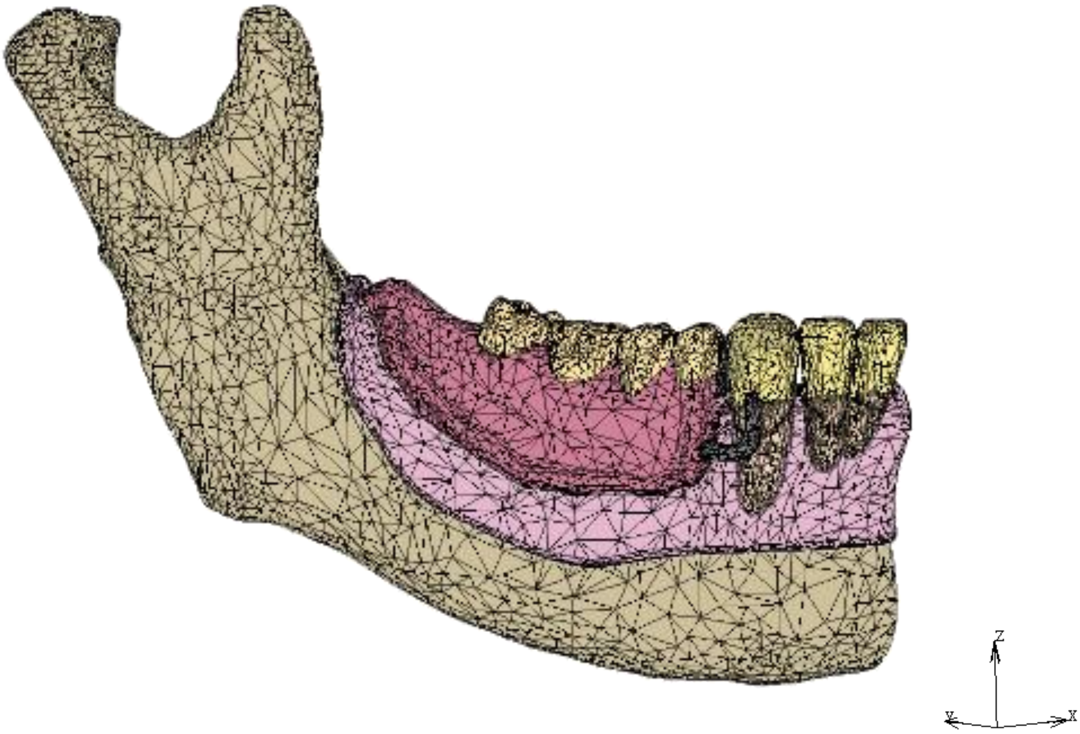


Fig. 4 Bilateral distal free-end removable partial denture FE model. Material properties are displayed in table 1. [15-18]. All materials were assumed to be isotropic and elastic.

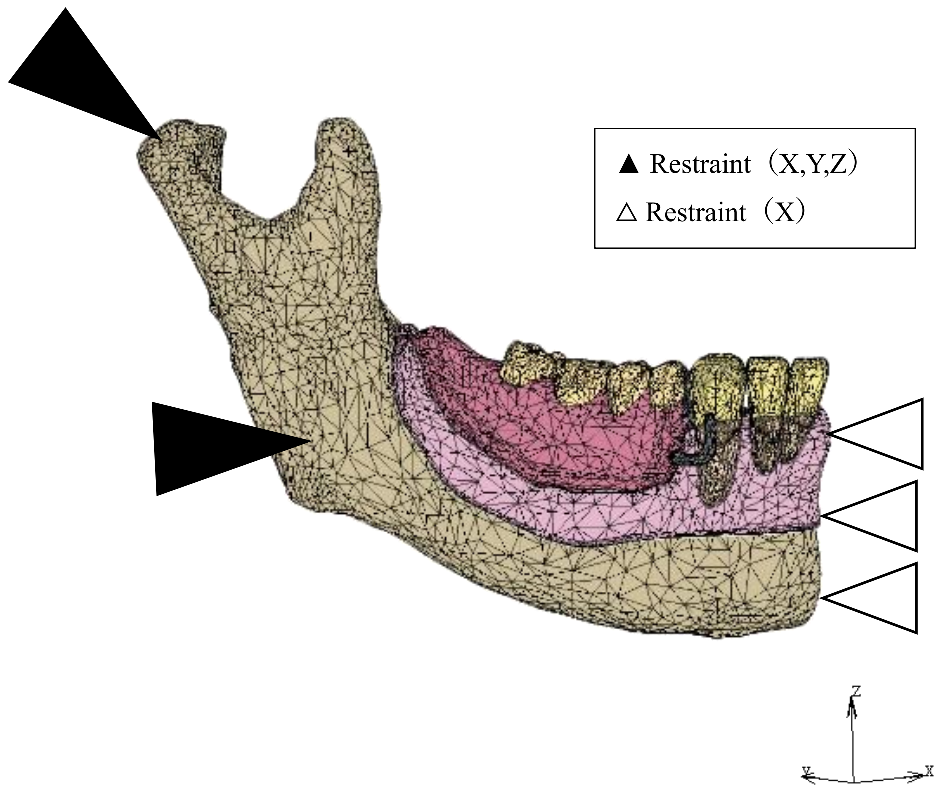


Fig. 5 Boundary condition

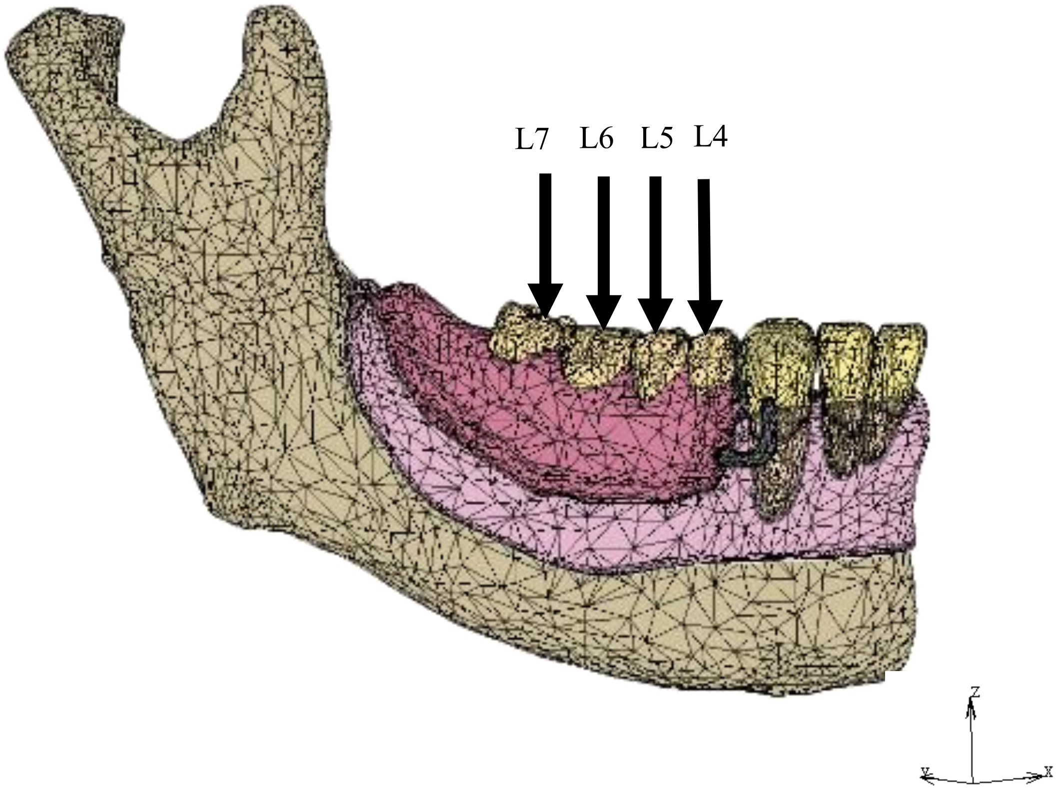


Fig. 6 Load point

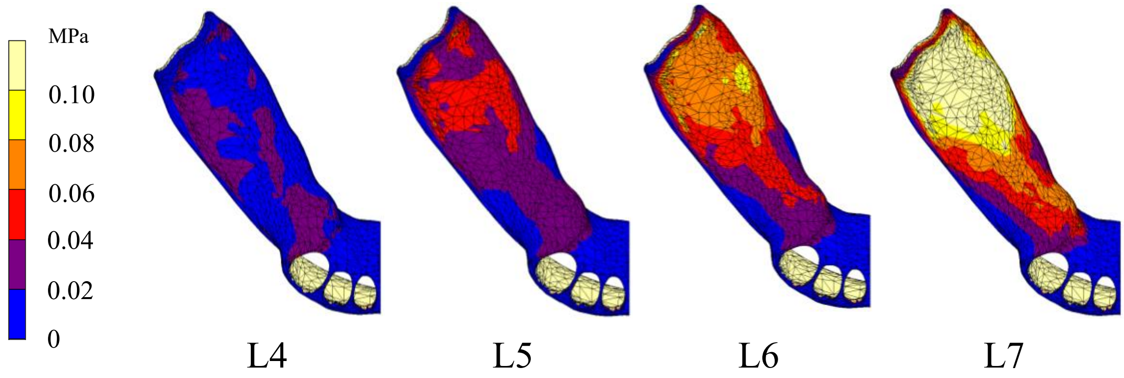


Fig. 7 Equivalent stress of mucosa area (RPD)

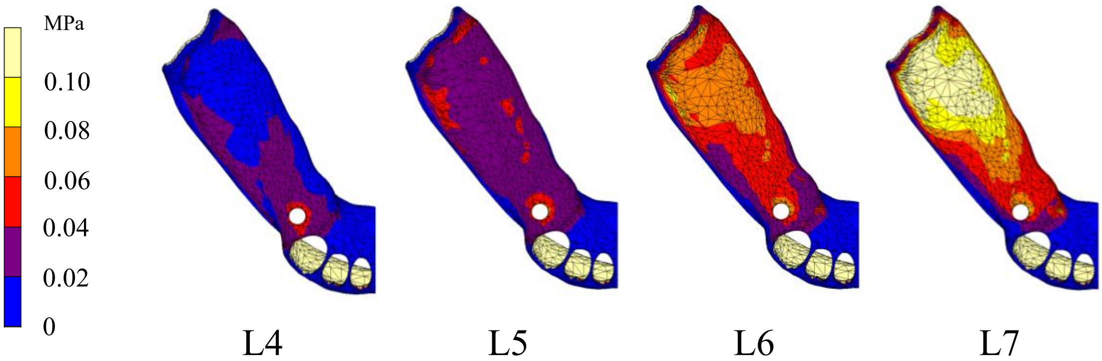


Fig. 8 Equivalent stress of mucosa area (IARPD4)

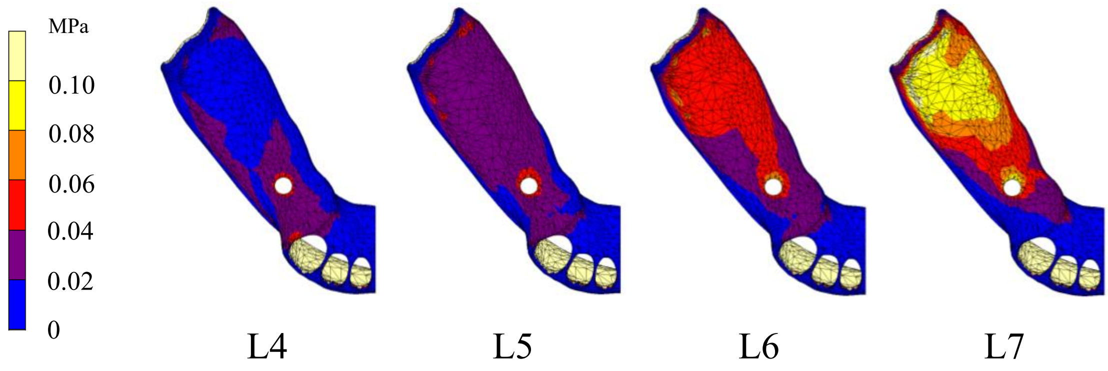


Fig. 9 Equivalent stress mucosa area (IARPD5)

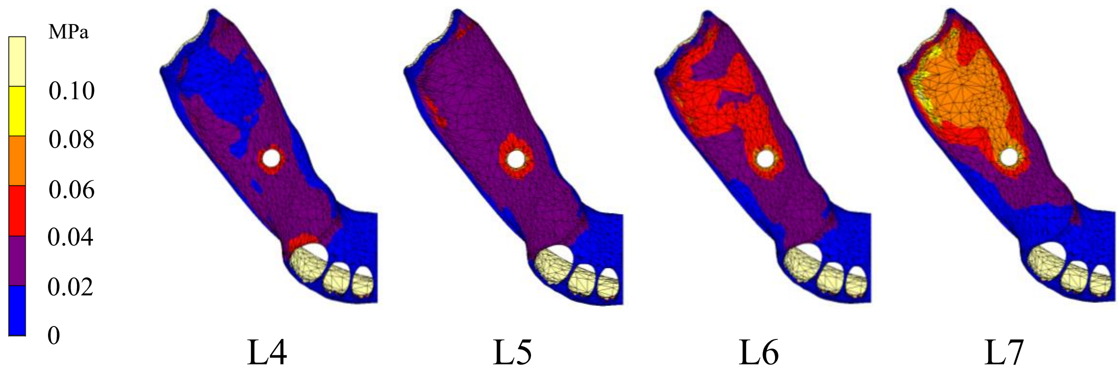


Fig. 10 Equivalent stress of mucosa area (IARPD6)

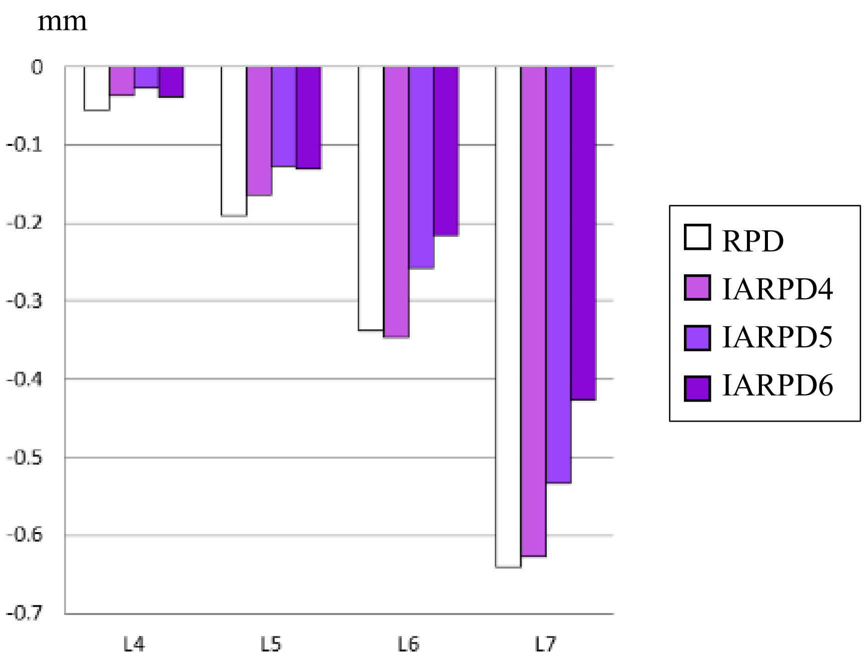


Fig. 11 Displacement of denture

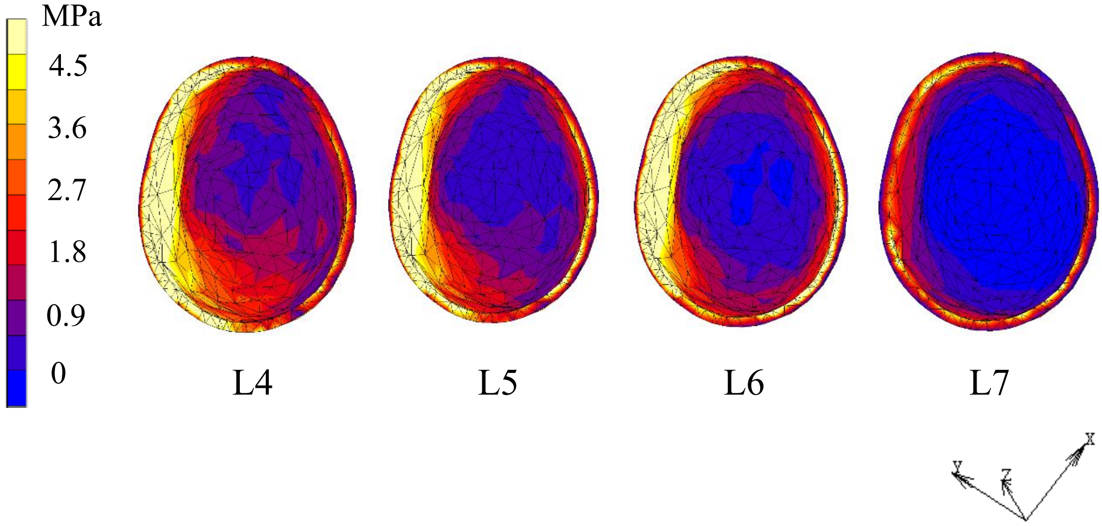


Fig. 12 Equivalent stress of canine PDL (RPD)

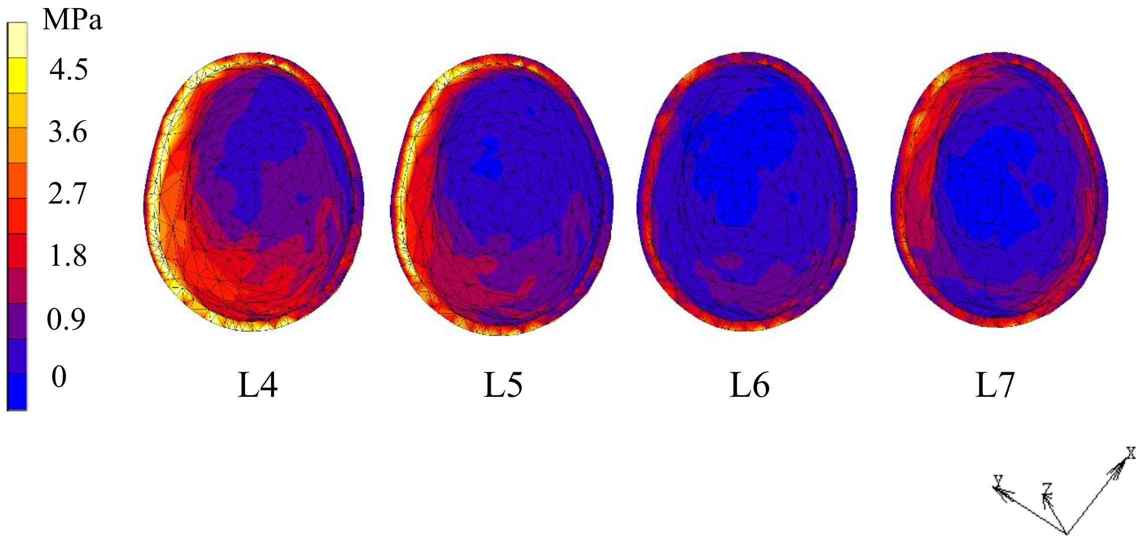


Fig. 13 Equivalent stress of canine PDL (IARPD4)

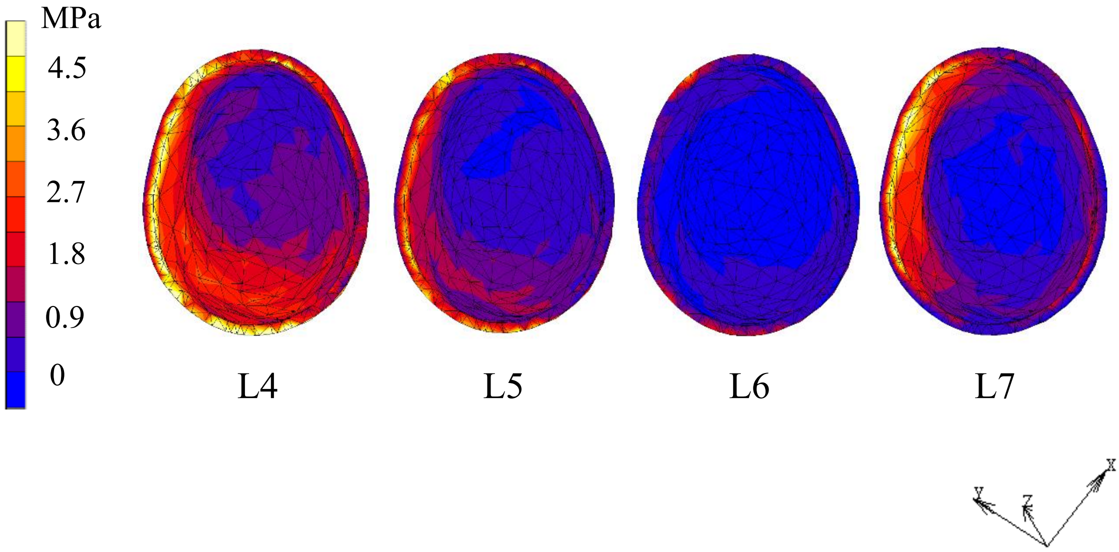
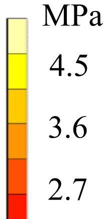


Fig. 14 Equivalent stress of canine PDL (IARPD5)



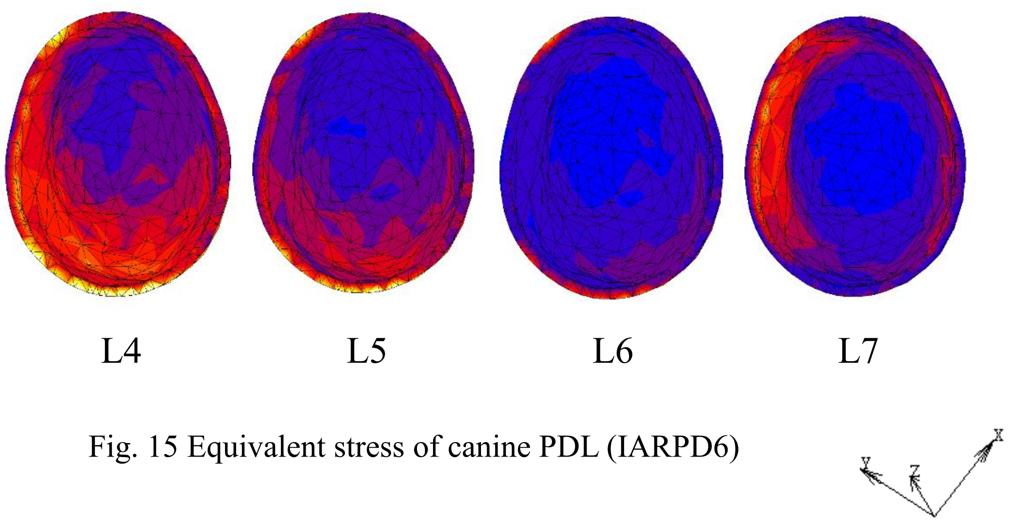


Fig. 15 Equivalent stress of canine PDL (IARPD6)

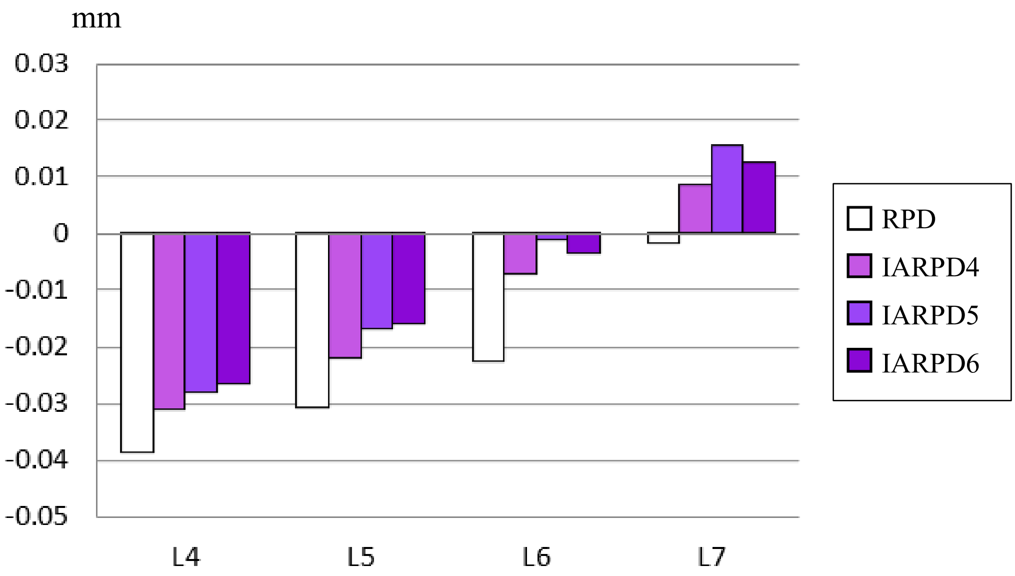


Fig. 16 Displacement of canine apex area