11. The Effect of Abutment Tooth Connection with Extracoronal Attachment using the Three Dimensional Finite Element Method
- Part 2. The Construction of Finite Element Model from CT Data -

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Introduction

An extracoronal magnetic attachment retainer design for partial denture prosthetic applications has been developed. Restorative limitations of space and physiologic function requirements may complicate esthetic placement of attachments in a partial denture design. Our previous reports have presented the advantages of an extracoronal magnetic attachment design for extracoronal applications with vital teeth. The traditional retainer design requirements satisfying retention and resistance form and while providing an applications that is esthetic has shown good patient feedback[1-3].

In a distal extension partially edentulous treatment, a patient may refuse to wear bilateral denture for several reasons, including esthetic concerns and satisfactory hard and soft tissue adaptation and fit.

In applications of distal extension and cantilever, an extracoronal attachment has potential to cause overload. The optimal and proper use of any remaining teeth adjacent to the edentulous area for use as supporting abutments is of great concern. Any decision in the selection of abutment number or interconnected splinting of supporting abutment teeth is based on the best knowledge based upon comprehensive dental evaluation. However, there are clinical situations where minimal supporting information exists to appropriately render these decisions.

Finite Element Method (FEM) has been well applied in stress evaluations for prosthodontic dental studies. We have previously reported the use of two-dimensional models of prosthodontic treatment situations. This study utilized the application of three dimensional modeling to evaluate the applications and stress distribution patterns for extracoronal magnetic attachment retainers for partial dentures.

Objective

The aim of the present study was to fabricate three-dimensional finite element model from actual patient data. We investigated the effect of interconnected abutment number in case of unilateral use of extracoronal magnetic partial denture retainers using the FEM model.

Materials and Methods

1. Materials

A subject was selected from patients who were diagnosed and treated in the department of implant dentistry at our university hospital. The selected patient was given informed consent before the study. The CT data at diagnosis and the study model were used in the present study (Fig. 1).

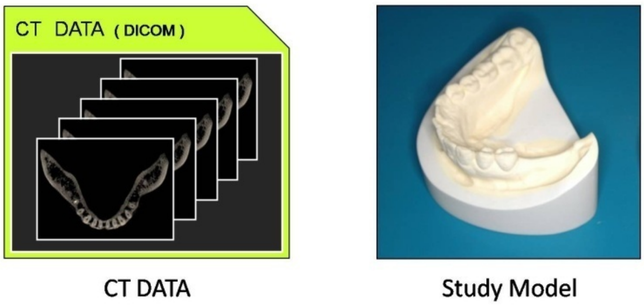


Fig . 1 Materials

The patient was a 42-year old woman who visited our implant department due to the left mastication disorder. At first visit, lower left first and second molars were missing, and no problem was found in the bone and periodontal tissue.

2. Methods

1) Geometry data formation

Table.1 shows the flow chart of the geometry data formation.

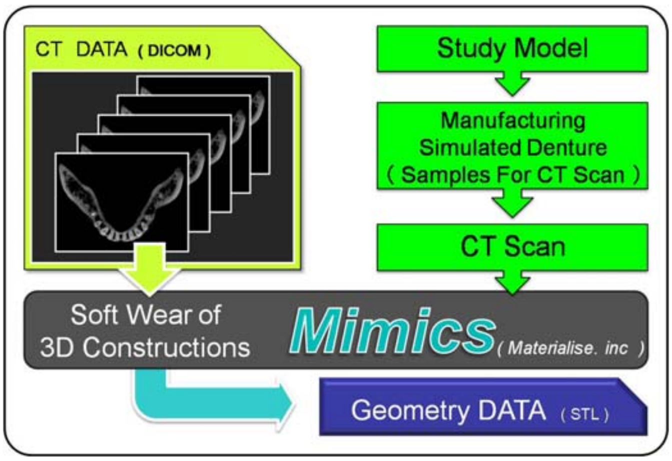


Table . 1 Flow Chart untill The Geometry DATA

(1) CT data process

The DICOM data obtained from CT was processed using three-dimensional image processing and editing software (Mimics, Materialise), and geometry was extracted from CT concentration value. Segmentation of the teeth, cortical and cancellous bones was performed. Constructed 3D geometry data was output as a STL format (Fig. 2).

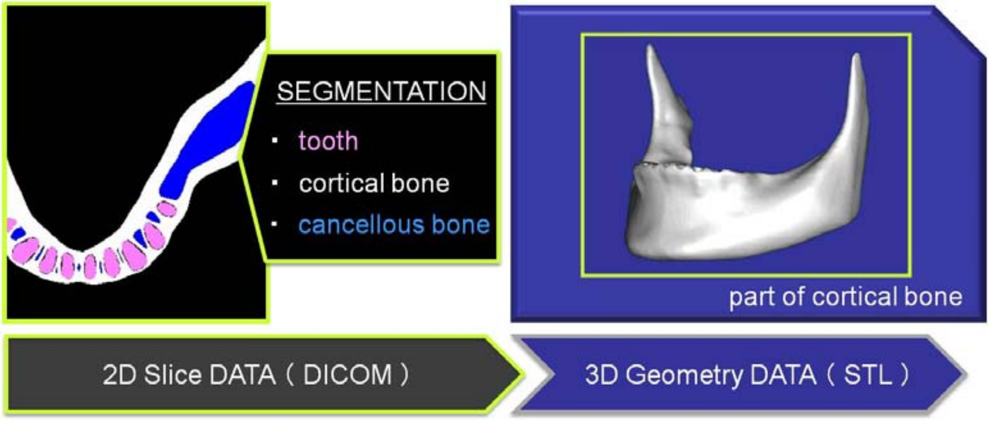


Fig . 2 Managements of CT DATA

(2) Fabrication of a sample for CT scan

A sample for CT scan was fabricated to reproduce complex geometry such as extracoronal attachment and denture. The following is a fabrication process:

① Fabrication of a copy model

A copy model of the study model made at diagnosis was fabricated, and used as a work model (Fig. 3).

Simulate fabrication of a denture and crowns were performed on this work model representing an oral cavity.

Fig . 3 A copy of Study Model

② Simulate preparation of abutments and fabrication of resin crowns

Simulate preparation of abutments was performed on the work model (Fig. 4-a), followed by the build-up of resin crowns (Fig. 4-b). Scanning resin (Yamahachi Dental MFG, Co.) was used to fabricate a sample. This radiopaque quick cure resin is suitable for reading the geometry since radiopaque contrast agent is homogenously dispersed.

a . preparation

b . resin crown

Fig . 4 Simulate Preparation

③ Placement of an attachment

The EC keeper tray plastic pattern was duplicated with scanning resin, and was placed on the distal part of the second premolar following the conventional method. Milling was performed on the lingual surface of the second premolar, and the male part for an interlock was created between the lingual surface of the second premolar and the crown of the first premolar (Fig. 5).

Fig . 5 Complete of Part of Male

④ Build-up of a metal frame

A removable metal frame that fits into the placed attachment was fabricated (Fig. 6).

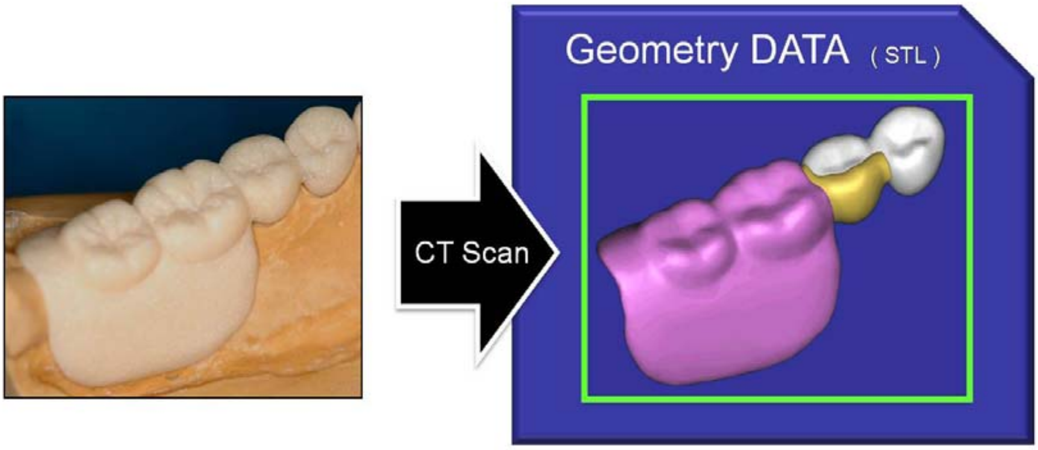
Fig . 6 Part of Metal Flame

⑤ CT scan and three-dimensional construction

A sample was scanned with Micro-focus X-ray CT (Shimazu Corp.) in Tiff format. The data was then processed using three-dimensional image processing and editing software (Mimics, Materialise), and geometry was extracted (Fig. 7-a).

⑥ Build-up of a denture base

A denture base part was built-up on the metal frame part, and its morphology was modified (Fig. 7-b).



a . Part of Removable Denture b . 3D Constructions (MIMICS)

Fig . 7 Complete of Sample and 3D Constructions

2) Finite element Modeling

All geometry data was imported into Patran (MSC Software Corp.) The cervical margin of the crown obtained from CT data and the cervical margin of the fabricated crown were adjusted to coincide in good balance in the three-dimensional space based on the occlusal plane and panoramic radiography (Fig. 8).

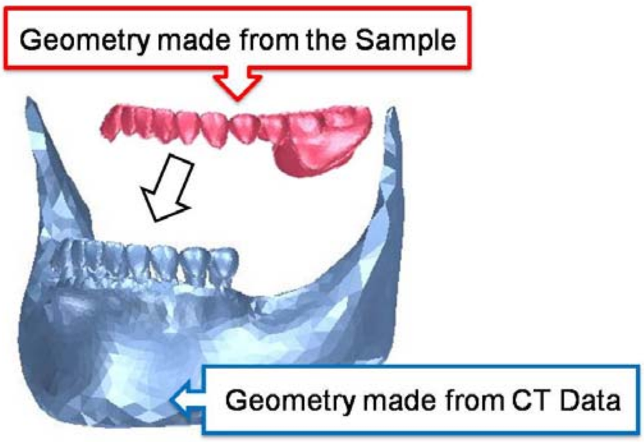


Fig . 8 FEM Modeling

3) Analysis

Mechanical property value was input into the constructed finite element model. The boundary condition was applied, followed by the calculation of an analysis solver (Marc2005r3, MSC Software).

(1) Analysis model

Fig. 9 shows an overall view of the FEM model. Four models with #4-5, 3-4-5, 2-3-4-5, and 1-2-3-4-5 interconnected abutments were constructed. Element and nodal point numbers are shown in Table.2.

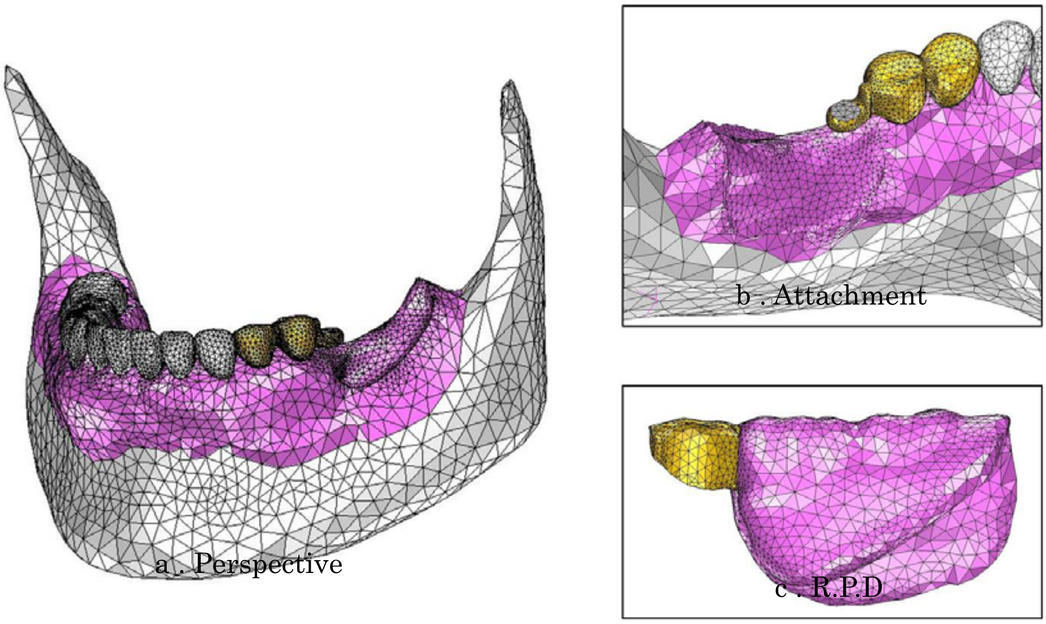


Fig . 9 FEM Model

Model	elements	nodes
45 interconnected	117,943	27,030
345 interconnected	118,085	27,038
2345 interconnected	118,104	27,030
12345 interconnected	118,329	27,043

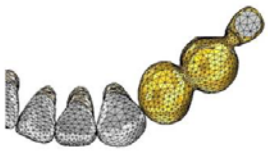
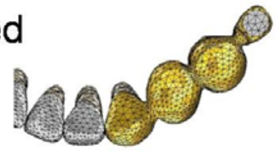
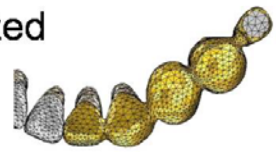
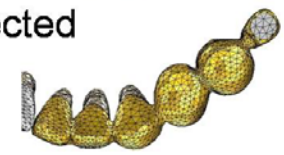





Table . 2 Number of Elements and Nodes

(2) Analysis condition

Contact conditions were introduced between a denture and the mucosa, and an abutment and attachment. Friction type was Coulomb friction, and the friction coefficient μ was set at 0.01. Analysis type was linear elastic stress analysis, and three-dimensional tetrahedron and pentahedron element were employed. DELL PRECISION 470 (DELL) was used for the analysis.

Mechanical Properties

	Young's Modulus (MPa)	Poisson's Ratio
periodontal ligament	1 . 00	0 . 45
oral mucosa	0 . 10	0 . 45
cortical bone	11,760	0 . 25
cancellous bone	1,470	0 . 30
tooth	11,760	0 . 35
metal	94,080	0 . 30
denture	2,450	0 . 30

Table . 3 Components and Mechanical Properties

① Components and mechanical properties

Table. 3 shows components and mechanical properties of the model. Same mechanical property value was applied for a crown, attachment, and metal frame. For the periodontal membrane and mucosa, a preliminary experiment was performed so that the vertical displacement of teeth against the applied load is close to the known value.

② Constraining and loading conditions

Lower bilateral coronoid processes was a complete constraint. A total of 10 N of vertical loads to the occlusal plane was applied on the occlusal surface of denture teeth (Fig. 10).

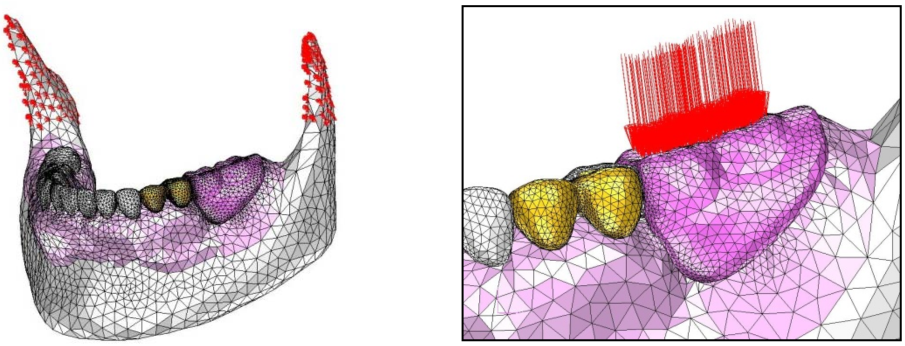


Fig . 10 Fix and Load Conditions

Results

1 . Distributions

Stress distribution pattern demonstrated con Mises equivalent stress distribution.

1) Abutment

Abutments from the tooth #1 to 4 were extracted from the analysis model. Figures.11a-d show the stress distribution of each model. All models showed stress concentration in the crown margin of the most posterior abutment. However, stress distribution was observed extensively in the #4-5 interconnected model when focusing on the root of the most posterior tooth #5. The models include the tooth #3 as an abutment demonstrated little change in the stress distribution although slight stress relaxation was observed.

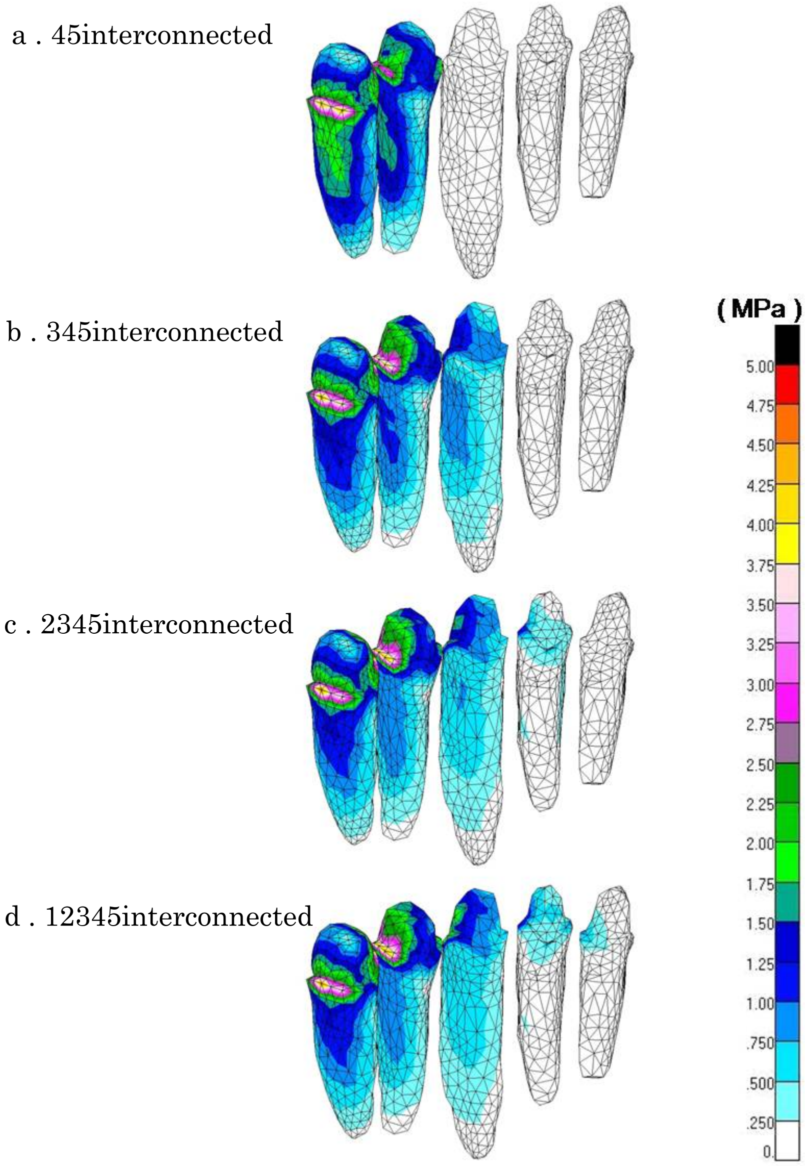


Fig . 11 Stress Distributions of Abutment Tooth

2) Cortical bone

Figures 12 a-d show stress distributions of the cortical bone. The data of the cortical bone was extracted from the model. In the 4-5 interconnected model, stress concentration was observed throughout the compact bone around abutment teeth. As the number of abumtment teeth increased, stress distribution was shifted towards the mesial area.

a . 45interconnected

b . 345interconnected

c . 2345interconnected

d . 12345interconnected

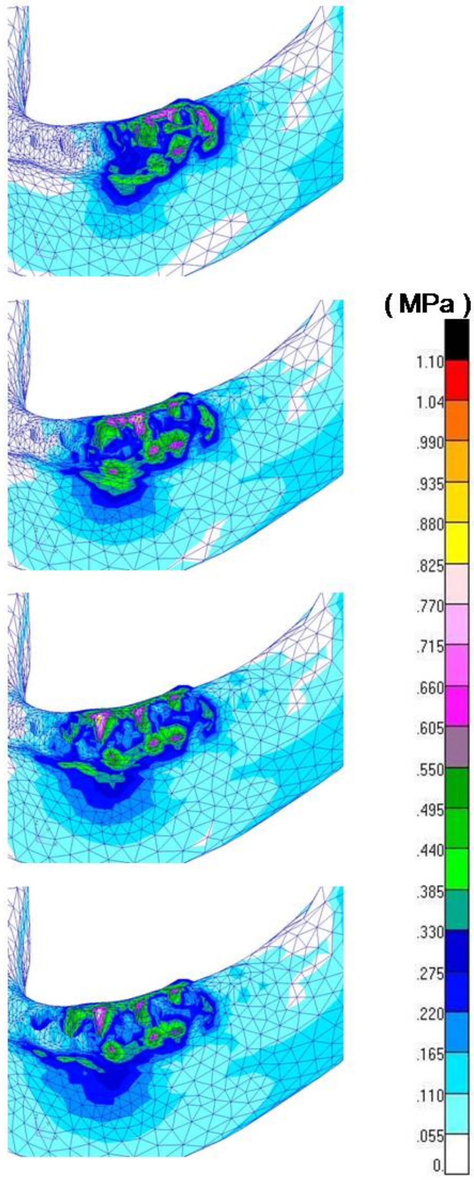


Fig . 12 Stress Distributions of Cortical Bone

2 . Displacement

1) Abutment

Figure. 13 shows the distal displacement of abutments. Measuring points were cusp tips of the most posterior abutments. The results showed a decrease in the displacement as the number of interconnected abutment increased, especially in the models including the tooth #3 as an abutment. The 3-4-5 interconnected model demonstrated a decrease by 50% compared with the 4-5 model.

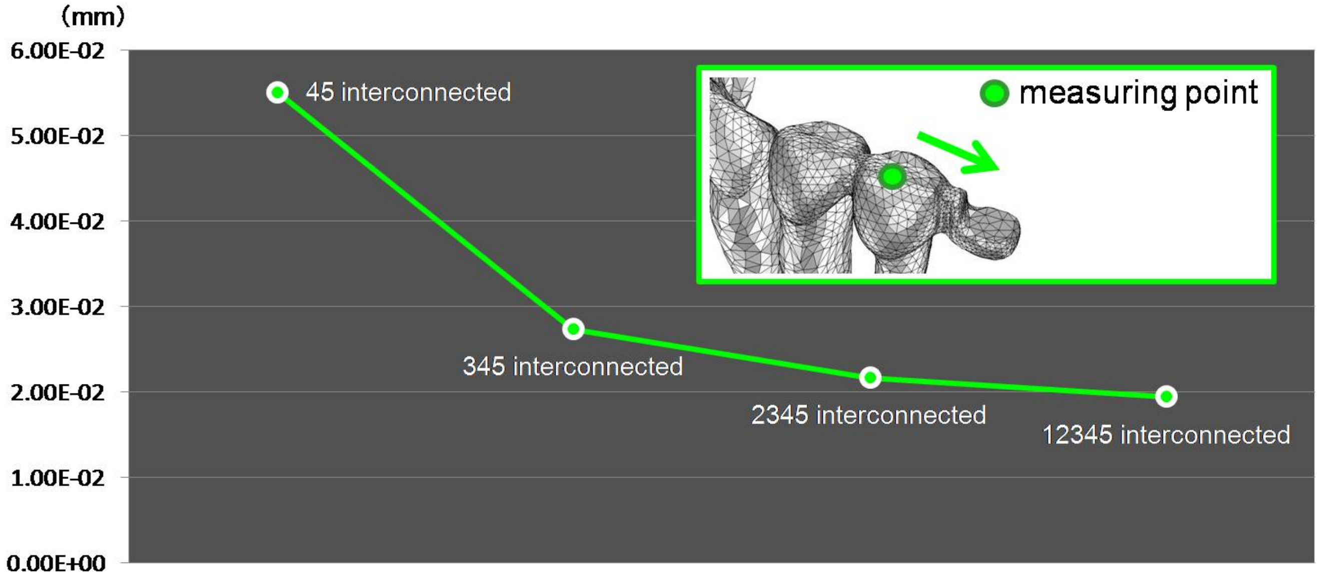


Fig . 13 Displacement of abutment

2) Denture

Figure. 14 shows the vertical displacement of a denture. The measuring point was posterior margin of a denture. The vertical displacement decreased as the number of interconnected abutment increased, especially in the models including the tooth #3 as an abutment. The 3-4-5 model interconnected model demonstrated a decrease by 35% compared with the 4-5 model.

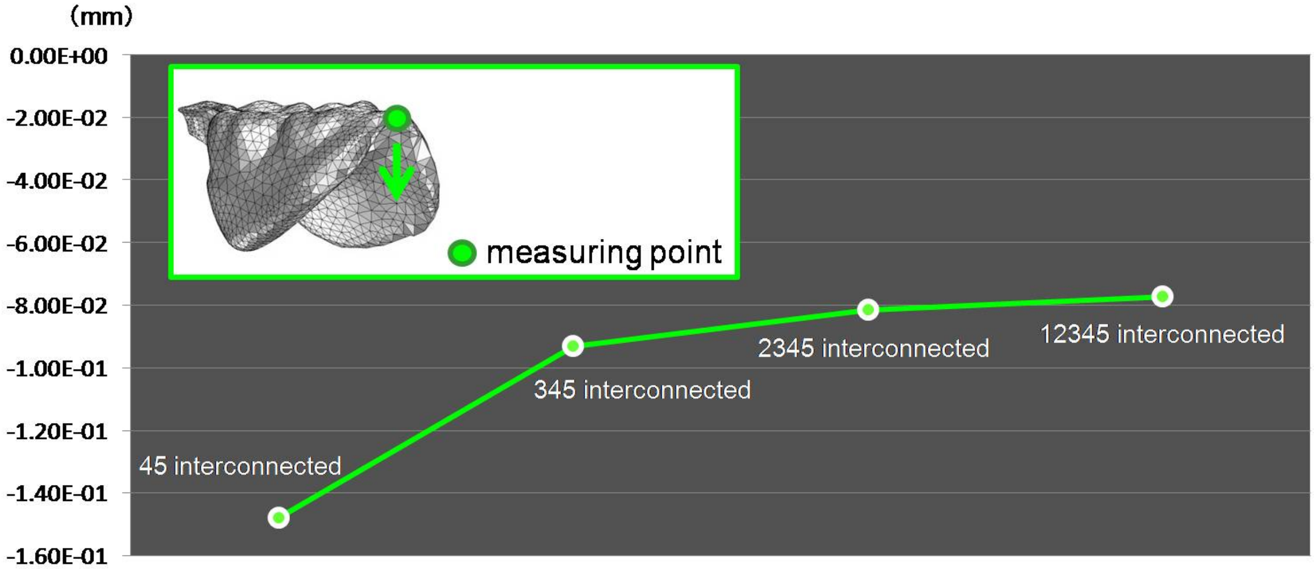


Fig . 14 Displacement of Denture

Discussion

1. Modeling

We have been investigating the influence of the number of interconnected abutment on the stress distribution in the tissue around the denture in order to provide theoretical evidence for the decision-making of the number of interconnected abutment. In previous studies, we performed the analysis using a simple designed model due to the difficulty in constructing a complex designed model. However, the analysis results could not be used as clinical evidence due to the simplicity of the model although analysis results were consistent. The model construction method that we used in the present study was non-invasive, and allowed to construct finite element models with accurate size and structure by fabricating simulated restorations. Each patient has a different oral cavity construction. We believe that Finite Element Method has a great potential for providing theoretical evidence for the optimal denture design in the clinical settings by using this method to easily fabricate the patient's model.

2. Analysis results

The distal displacement of the most posterior abutment and vertical displacement of a denture significantly decreased by interconnecting three abutments between the second premolar and canine. No significant decrease was observed by increasing the number of interconnected abutment more than three. These results are presumably due to an increase of the number of interconnected abutment, and long canine root.

Conclusion

In the present study, more accurate analysis model was constructed by using actual patient's data and a study model.

In the unilateral application of extracoronal attachment, the stress on abutments was mitigated and the vertical displacement of a denture decreased by increasing the number of interconnected abutment.

A significant stress relaxation was observed by including the canine as an abutment. No significant change was observed by increasing the number of interconnected abutment more than three.

Reference

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