Effects of Splinting on Displacement of Maxillary Canines as Abutments of Removable Partial Dentures: a Finite Element Analysis

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Clinical significance
This finite element study analyzed the displacement of maxillary canines as abutments for distal-extension removable partial dentures. Splinting of abutments was recommended in cases of reduced periodontal support or large and/or laterally directed occlusal force. Splinting six anterior teeth was recommended if these unfavorable conditions coincided with one another.

Abstract
Purpose: The purpose of this study was to investigate the relationship between the number of splinted teeth and the effect of splinting on the movement of canines as abutments for maxillary distal-extension removable partial dentures.

Methods: A three-dimensional finite element method was used for the analysis. Abutments with normal bone height and with bone height lowered by 3 mm were prepared. The numbers of splinted teeth were two, three and six units. A load of 50 N or 200 N was applied in the vertical, buccal-oblique and lingual-oblique directions at the node corresponding to the buccolingual center of the mesial marginal ridge of the left first molar. Different material properties of the mucosa and periodontal ligament were used depending on the amount of loading. The ligament was defined as an orthotropic material.

Results: The results showed that horizontal displacement of the canine in the “two-unit splint” model was approximately one-third to one-half of that in the single abutment model. There was little difference in the horizontal displacement between the two-unit splint and “three-unit splint” models. In the “six-unit splint” model, the displacement was reduced to approximately half of that of the two-unit splint model. In all of the splinted models, the vertical displacement was reduced to approximately half of that of the single abutment model.

Conclusion: In the cases of reduced periodontal support or large and/or laterally directed occlusal force, abutments should be splinted. In cases of a coincidence of these unfavorable conditions, splinting six anterior teeth was recommended.

Key words: splinting, maxillary canine, abutment tooth, removable partial denture, finite element analysis

Introduction
On the teeth used for abutment of distal-extension removable partial dentures (RPDs), there is a risk of overloading because they share the occlusal stress on the artificial teeth in addition to that on themselves. Teeth are highly resistant against axial stress, but not as resistant against lateral stress.\(^1\) Furthermore, the anterior teeth as abutments of maxillary RPDs may have a greater risk because of the application of occlusal force obliquely to the tooth axis. One effective method to protect abutment teeth from harmful occlusal force and to enhance the resistance of them is to splint them to adjacent teeth with fixed prostheses.\(^2\) It has been reported that splinting abutments enhances their resistance, causes a shift in the center of rotation and reduces the horizontal force transmitted.\(^3\)

However, splinting with fixed prostheses usually worsens oral hygiene, and makes the removal of plaque difficult. It is desirable to minimize the extent of splinting because diligent home care by patients is essential where splinting is utilized.\(^4,5\)

Although some studies reported\(^6\) on the effect
of splinting first or second premolars as the abutments of mandibular RPDs, there are only a few reports on maxillary RPDs and canines as abutments. In addition, the most efficient number of splinted abutments has not been clarified, because there is no report evaluating it quantitatively.

The purpose of this study was to investigate the relationship between the number of splinted teeth and the effects of splinting on the movement of canines as abutments for maxillary bilateral distal-extension removable partial dentures using three-dimensional finite element analysis.

Materials and methods

Finite element (FE) models

The 3-D FE models (Fig. 1 and 2) consisted of a Kennedy class I RPD, mucosa, maxillary canines as abutment teeth with the periodontal ligament (PDL) and cortical bone. Maxillary central and lateral incisors were added according to demand. The RPD framework included a palatal plate, cingulum rests, buccal retentive clasp arms, and proximal plates of cobalt-chromium alloy. The shape of the alveolar ridge was based on a commercially available model (G2-402F, Nissin Dental Products Inc., Kyoto, Japan). The thickness of each part of the mucosa and the palatal plate are shown in Figure 3. The elements of alveolar bone were omitted because most of the deformation of the edentulous area was considered to occur in mucosa due to a far smaller Young's modulus.

The dimensions and morphology of teeth were based on a commercially available model (C12AT1A, Nissin Dental Products Inc., Kyoto, Japan) and literature. Since it was considered to be occasionally difficult to prepare a cingulum rest seat with a sufficient depth on natural canines of Japanese with relatively thin enamel, the abutments were assumed to be restored. However, the crowns were made of cast gold alloy for simplification of the models.

The PDL was 0.33-mm thick at cervical margins, 0.25-mm thick at mid-root, and 0.28-mm thick at the apex. The cortical bone around the PDL was given a uniform thickness of 1.0 mm.

The models were comprised of eight-noded-hexahedral elements except for six-noded-penta-hedral elements at the cusp of each tooth. Details of the FE meshes used for each model depended
on the number of abutments as described below and presented in Table 1.

**Conditions of abutments**  
Two levels of cortical bone of abutments were prepared, the anatomical level in a “normal” model, and one lowered by 3 mm in a “reduced” model. Although they were expected to have some correlation with the height of the adjacent alveolar ridge, the shape of the alveolar residual ridge was not modified in order to clarify the effect of the conditions of abutments. The inclination of abutments was based anatomically, that is labially at an angle of 77.35 degrees and mesially at an angle of 94.55 degrees to the occlusal plane (Fig. 4).  

The number of splinted teeth was as follows: in the “two-unit splint” model, the canine and lateral incisor were splinted on each side (Fig. 5-b); in the “three-unit splint” model, the canine, lateral incisor and central incisor were splinted on each side (Fig. 5-c); and in the “six-unit splint” model, all six anterior teeth were splinted (Fig. 5-d). The adjacent teeth were connected with a few springs with the same Young’s modulus as the gold alloy around their proximal contact.

**Material properties**  
The PDL was defined as an orthotropic material with a principal axis parallel to its principal fibers (Table 2), and the other components were assumed to be isotropic and homogeneous (Table 3). Appropriate material properties of the PDL and mucosa were used depending on the amount of load (Table 4).  

**Loading and boundary conditions**  
A single load was applied to the node corresponding to the buccolingual center of the mesial marginal ridge of the left first molar. Three loading directions, vertically to the occlusal plane (load-V), a 45-degree oblique angle buccally (load-B) and a 45-degree oblique angle lingually (load-L), were employed (Fig. 6). The amount of load was 200 N in the “normal” model and 50 N and 200 N in the “reduced” model.

The nodes corresponding to the surface of alveolar bone and those on the external surface of cortical bone within 2 mm of the alveolar bone crest were constrained in all directions.

The contact conditions at the clasp/abutment and denture base/mucosa interface were simulated by using the ‘contact option’ of MSC.Marc.

**Table 1** Details of the FE meshes.  
<table>
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<th>reduced Nodes</th>
<th>reduced Elements</th>
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**Fig. 4** Conditions of abutments: left, normal cortical bone height; right, cortical bone height lowered by 3 mm.

**Fig. 5** The three-dimensional finite element models. a: single abutments, b: two-unit splint, c: three-unit splint, d: six-unit splint.

7.3 (MSC Software Corp., Santa Ana, CA). The friction at their interfaces was neglected.

**Evaluation of the results**  
To evaluate the displacement of the cusp apex of the left canine, a coordinate transformation was performed so that each axis indicated the tooth axis, buccolingual axis, and the axis perpendicular to the others.
Results

Displacement of abutments under 50 N loading in the reduced periodontal support models (Fig. 7)

Under load-B and load-L, the horizontal displacement of the abutment in the two-unit splint model was approximately one-third of that in the single abutment model. Although there was only a little difference in the horizontal displacement between the two-unit splint and the three-unit splint models, the six-unit splint model reduced the displacement to approximately half of that in the two-unit splint model. Under load-V, there was little difference in horizontal displacement among the models.

Under load-V and load-B, the vertical displacement in the two-unit splint model was approximately half of that in the single abutment model.
Under load-L, the displacement was slightly reduced in the splinted model.

**Displacement of abutments under 200 N loading in the normal periodontal support models** (Fig. 8)
Under load-B and load-L, the horizontal displacement in the two-unit splint model was approximately half of that in the single abutment model, being approximately 50 µm. Although there was little difference in the horizontal displacement between the two-unit splint and the three-unit splint models, the displacement in the six-unit splint model was reduced to approximately half of that in the two-unit splint model.

Under load-V and load-B, the vertical displacement in the two-unit splint model was approximately half of that in the single abutment model, whereas there was little difference in the vertical displacement among the splinted models. Under load-L, the displacement was slightly reduced in the splinted model.

**Displacement of abutments under 200 N loading in the reduced periodontal support models** (Fig. 9)
Under load-B and load-L, the horizontal displacement in the two-unit splint model was approximately 80 µm, half of that in the single abutment model. Although there was little difference in the horizontal displacement between the two-unit splint and the three-unit splint models, the six-unit splint model reduced the displacement to approximately half of that in the two-unit splint model. Under load-V, the horizontal displacement of abutments in the splinted models was much smaller than that in the single abutment model. Under load-V and load-B, the vertical displacement was reduced to two-thirds and half of that in the two-unit splint model respectively. There was little difference in vertical displacement among the splinted models. Under load-L, the displacement was slightly reduced in the splinted model.

**Discussion**

**Loading conditions and material properties**
The prognosis of the abutments probably depends on occlusal force to some extent because it directly affects total load on artificial teeth and abutments. Therefore, we assumed two extreme cases: a large occlusal force of 200 N on the assumption that all mandibular teeth remained, and a small one of 50 N on the assumption that a mandibular complete denture opposed the maxillary RPD. However, because the tooth mobility curve was biphasic and the PDL was regarded as a nonlinear material, appropriate material property was used for the PDL according to the amount of load. In the same way, the material property of the mucosa was changed according to the amount of load.

**Physiological limitation of the loads for maxillary canines**
According to the amount of horizontal load on a maxillary central incisor that causes pain and the area of the PDL of maxillary central incisors
and maxillary canines, we estimated the amount of horizontal displacement of canines regarded as a pain threshold at 111.3 µm, which was caused by a load of 20.6 N (2.1 kgf). This is described in detail in our previous study. Although the physiological limitation of horizontal displacement of canines is not clear, it was considered to be at least much less than a pain threshold. The evaluation of the displacement of canines in each model with reference to the pain threshold assumed will be described later.

With regard to the axial displacement, the physiological limitation is also unclear. In this study, maximum axial displacement of a single abutment was approximately 87.3 µm, which was considered to be equivalent to 78.4 N of axial load.

On the other hand, the area of the PDL of a canine was 1.7 times less than that of a first molar. Since the masticatory force on a first molar was approximately 200 N, it was quite probable that the vertical displacement of the abutments in this study was not critical.

Result of analysis

According to our previous study, maxillary canines were considered to be inadequate for single abutments in Kennedy class I RPDs when periodontal support was reduced and/or occlusal force was relatively large.

The horizontal displacement could be kept clearly within the pain threshold by means of splinting more than two teeth in the models with reduced periodontal support under 50 N loading and in the model with normal periodontal support under 200 N loading. However, in the model with reduced periodontal support under 200 N loading, the horizontal displacement was close to the pain threshold with the two-unit splint and three-unit splint models. In other words, the abutments could still be overloaded because of the variations of the magnitude and the direction of occlusal force. In this case, the six-unit splint model was considered to be adequate because the horizontal displacement was much smaller than the pain threshold. Increasing the number of splinted abutments did not result in a proportional reduction of displacement.

There was no significant difference in the effect between the two-unit splint and three-unit splint models. This finding is in agreement with the stress analysis by el Charkawi et al using strain gauges. Splinting two single-rooted teeth offers resistance to mesiodistal but not to buccolingual displacement because they are aligned in a straight line. To accomplish buccolingual resistance, three noncolinear teeth must be splinted.

In this study, the three splinted teeth formed a gentle curve. This was considered to be a cause of the minimal difference in the effect between the two-unit splint and three-unit splint models.

Splinting around an arch has a distinct advantage over splinting teeth in a straight line. The curvature of the splinting effectively reduces not only mesiodistal displacement but also buccolingual displacement. The cross-arch splint with six splinted teeth creates a multi-rooted unit with a center of rotation located within the space bound by the abutments. Splinting six teeth would be recommended in the case of quite unfavorable conditions such as cortical bone loss of more than 3 mm and under large occlusal force.

Itoh et al evaluated the effects of periodontal support and splinting on load transfer by bilateral distal extension RPDs using photoelastic analysis, and reported that extensive cross-arch splinting might not be effective or appropriate. However, this disagreement with the present study might have been caused by the difference in the inclination of the abutments. They modeled RPDs retained by the mandibular first premolars, which had axes perpendicular to the occlusal plane.

The benefit of splinting depends to a great extent on the direction of forces relative to the alignment of splinted teeth. Splinting six anterior teeth might also be recommended when there is mobility of the denture base due to conditions such as severe absorption of the residual ridge and high compressibility of the mucosa.

Conclusion

Within the limitations of this study, the following conclusions were drawn: In cases of reduced periodontal support, large occlusal force, or laterally directed occlusal force, maxillary canines should be splinted to an adjacent tooth. In cases of a coincidence of these unfavorable conditions, it is considered to be necessary to splint six anterior teeth.

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References