Influence of Abutment Selection in Maxillary Kennedy Class II RPD on Elastic Stress Distribution in Oral Mucosa: An FEM Study

Seiji Wada, DDS;[1] Noriyuki Wakabayashi, DDS, PhD;[2] Takehisa Tanaka, DDS;[1] and Takashi Ohyama, DDS, PhD[3]

Purpose: The aim was to study the influence of abutment selection on elastic stress distribution in oral mucosa in a maxillary removable partial denture (RPD) by means of 3-dimensional finite element models.

Materials and Methods: Four RPD framework models of an equal size (by area) and underlying oral mucosa were produced for a Kennedy Class II arch. Each framework included an occlusal rest as part of a clasp assembly on one of four abutments (canine, first, and second premolars, and first molar) on the side contralateral to the edentulous ridge (tooth-supported side). Movement of the alveolar surface of the mucosa and the occlusal rest on the abutment adjacent to the ridge were fixed in a vertical direction. Movement of the rest on the tooth-supported side was restricted in all directions. Vertical or buccally oblique biting force was applied simultaneously on each of the locations representing three missing teeth.

Results: The frameworks with the contralateral side rest on the canine or the first premolar were less resistant to lateral forces than other framework designs, showing greater saddle displacements under the oblique force than the vertical force. The framework with the rest on the second premolar demonstrated relatively good resistance to deflection; however, both vertical saddle intrusion and the maximum equivalent stress in mucosa shown in all the models were within small ranges.

Conclusion: The saddle movement was influenced by the abutment selection on the tooth-supported side, although resultant stress in the mucosa was insensitive to the abutment location.

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INDEX WORDS: finite element analysis, abutment, oral mucosa, removable partial denture

THE MAJOR connector of a removable partial denture (RPD) plays a critical role in transmitting applied occlusal forces from artificial teeth to all the supporting structures. The connector must be rigid if it is to be successful in transmitting lateral forces to the RPD abutments on the other side of the dental arch.[1-3] Some clinical studies indicate that there is no adverse effect on the abutment teeth if RPDs include rigid major connectors and the other essential requirements in their design and are maintained with a comprehensive recall program.[4,5]

The rigidity of an RPD framework is influenced by its width, thickness, design of the connector,[6,7] curvature of the ridge arc span,[7,8] and the elastic modulus of the alloy used in the framework. Our previous study[9] indicated that the posterior palatal strap with an increased anteroposterior width has comparable rigidity in framework displacements to the anterior-posterior bar, which was claimed to be the most rigid connector.[7,10] Since the palatal strap for a maxillary Kennedy Class II RPD is designed to connect both sides of the arch, the abutment selection on the dentate side of the arch determines the shape of the strap, and therefore affects rigidity and movements of

[1]*Postgraduate Student, Removable Prosthodontics, Department of Masticatory Function Rehabilitation, Division of Oral Health Sciences, Tokyo Medical and Dental University, Tokyo, Japan.*

[2]*Research Assistant, Removable Prosthodontics, Department of Masticatory Function Rehabilitation, Division of Oral Health Sciences, Tokyo Medical and Dental University, Tokyo, Japan.*

[3]*Professor and Chair, Removable Prosthodontics, Department of Masticatory Function Rehabilitation, Division of Oral Health Sciences, Tokyo Medical and Dental University, Tokyo, Japan.*

Accepted December 13, 2004.

Correspondence to: Noriyuki Wakabayashi, Removable Prosthodontics, Department of Masticatory Function Rehabilitation, Tokyo Medical and Dental University, 1-5-45 Yushima, Bunkyo, Tokyo 113-8549, Japan. E-mail: wakabayashi.rpro@tmd.ac.jp

1059-941X/06

doi: 10.1111/j.1532-849X.2006.00080.x

the denture framework. However, the influence of abutment tooth location on the rigidity of the major connectors with reference to the stress created in underlying oral mucosa has not been sufficiently evaluated. Since excessive movements of an RPD under occlusal loading may cause injury to the mucosa covering the residual ridge[11] and to the periodontal tissues around the abutment teeth, the rigidity of the RPD frameworks should be analyzed in relation to the denture movements and stress distribution created in the mucosa.

The purpose of this study was to investigate the influence of abutment tooth selection on the tooth-supported side on stress distribution in the mucosa supporting a maxillary Kennedy Class II RPD saddle. It was hypothesized that modification of the abutment tooth location would not have a significant effect on the saddle movement and stress distribution in the mucosa.

Materials and Methods

An FEA program (ANSYS 6.1, ANSYS, Canonsburg, PA) was used to construct 3-dimensional (3D) finite element models of maxillary oral mucosa and Kennedy Class II RPD frameworks designed for the edentulous area distal to the left first premolar. Each framework included a posterior palatal strap, an extension denture saddle on the left side, an occlusal rest as part of a clasp on the left first premolar, and one other rest on an abutment on the right side of the arch (Fig 1). Each strap was of an equal area (860 mm^2) on a horizontal plane for standardization. The rest on the right side was located on one of four abutment teeth; the canine (Model-C), the first premolar (Model-FP), the second premolar (Model-SP), and the first molar (Model-M) (Fig 2). Dimensions of the palate used for the modeling were the same as in the previous study.[9] The vertical depth of the palatal vault was 16 mm from the top of the edentulous ridge and 20 mm from the occlusal plane. The distance across the palate between the right and left crests of the ridge was 55 mm. The thickness of the frameworks was 0.5 mm at the center of the palate and 1.5 mm at the top of the ridge. The thickness of the mucosa at the same locations was 1.5 mm and 3.0 mm, respectively.[12] Clasp arms, artificial teeth, and resin denture base material were excluded from the model. Movement of the rest on the right side (tooth borne side) was restricted in all directions. This complete fixation was based on an assumption that a clasp placed on a healthy abutment was rigid enough to retain this part of the framework immovably. The rest on the left side was fixed only in a vertical direction to allow for horizontal movements of this component. This boundary condition was employed to achieve a reasonable simulation of the mucosa and the abutment, which are considerably different in their resilience.[9] The calculated vertical displacement and stress might be smaller than those seen in reality, partially because of the experimental condition.

The alveolar surface of the oral mucosa was also fixed vertically based on an assumption that the maxillary bone was a rigid structure, but it allowed horizontal distortion of the overlying mucosa. Although the bone surface may also present an elastic behavior in reality, the constraint of the bone surface was employed for simplicity based on the large difference in rigidity between the bone and the mucosa. This extreme boundary condition may result in relatively high stress in the mucosa equally in all the models. Because movement of the clasp assembly was restricted in this study, it was necessary to create only the rest portion and not a complete model.

Each model was meshed by elements defined by eight nodes with three degrees of freedom in hexahedral bodies. Poisson's ratio of 0.3 and a modulus of elasticity

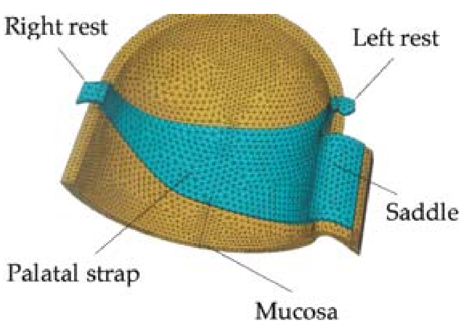

Figure 1. A meshed finite element model of a framework includes an extension denture saddle, two occlusal rests, and a posterior palatal strap with underlying oral mucosa.

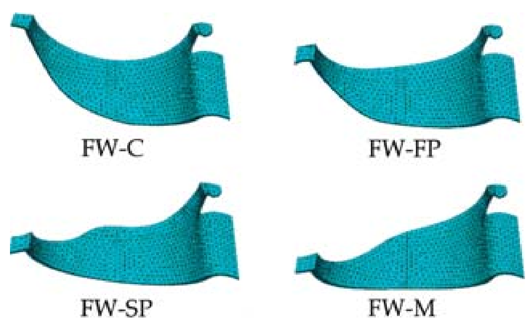

Figure 2. Frameworks with different rest locations: canine (Model-C), the first premolar (Model-FP), the second premolar (Model-SP), and the first molar (Model-M) on the contralateral side of the saddle.

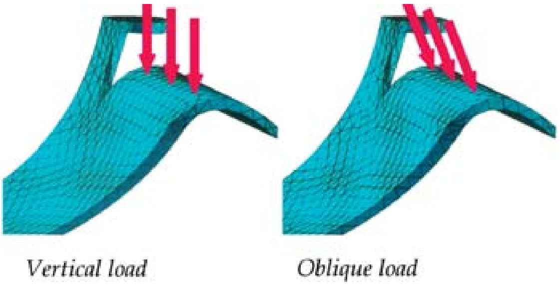

Figure 3. Vertical (left) or buccally oblique (right) biting force was directed simultaneously toward each of the three missing posterior teeth locations on the saddle (total 60 N).

of 200 GPa were input into the program to simulate a cobalt-chromium partial denture alloy.[13] Poisson's ratio of 0.45 and a modulus of elasticity of 3.4×10^{-3} GPa were used for the mucosa.[14] We conducted the linear elastic analysis, while the nonlinear time-dependent viscoelastic properties of the mucosa[15] and the sliding and friction phenomena that usually occurred between the denture saddle and the mucosa were not considered in the calculations. Because relative evaluation of the RPD framework deflection and its influence on the stress in mucosa were emphasized in the study, the influence of those nonlinear phenomena was assumed to be negligible.

A biting force of 20 N was directed simultaneously toward the center of each of the three missing posterior teeth (60 N total)[9] either vertically or 10° obliquely to the buccal (Fig 3). Under the simulated occlusal loadings, the framework displacements and the equivalent stress in the mucosa were calculated.

Results

The maximum displacements were observed at the posterior edge of the saddle for all the frameworks. The magnitude of the maximum displacement, vertical element of the maximum displacement (vertical intrusion to the ridge), and the maximum equivalent stress in mucosa for all the frameworks are shown in Table 1. The maximum displacement ranged from 71 μm (Model-SP) to 80 μm (Model-M) under the vertical load, and from 88 μm (Model-SP) to 168 μm (Model-C) under the oblique load. The vertical element of the maximum displacement ranged from 63 μm (Model-SP) to 71 μm (Model-M) under the vertical load, and from 72 μm (Model-SP) to 81 μm (Model-M) under the oblique load.

Displacements in Model-C and Model-SP at the edentulous ridge vicinity were transformed into vector graphics to better visualize their deflections (Fig 4). Under the vertical load, the saddle in Model-C displaced buccal distally on a horizontal plane; however, the vector clearly shifted to a buccal-medial direction as the load shifted to the buccally oblique direction. On the other hand, the saddle in Model-SP demonstrated buccal-distal displacement on a horizontal plane regardless of the loading directions. The displacement direction seen in Model-FP was similar to that in Model-C, while the direction in Model-M was analogous to that in Model-SP.

Figure 5 shows contour graphics of stress distributions in the lower surface of the mucosa for Model-C and Model-SP. The other models (Model-FP and Model-M), though not shown in the figure, also demonstrated a similar contour view. Under both loading directions, the maximum equivalent stress was shown in the depth of the mucosa directly above the top of the posterior edentulous ridge. The maximum stress ranged from 0.13 MPa (Model-SP) to 0.14 MPa (Models-C, FP, and M) under the vertical load, and from 0.14 MPa (Model-SP) to 0.15 MPa (Models-C, FP, and M) under the oblique load (Table 1).

Discussion

For the frameworks with the canine or the first premolar rest on the tooth-supported side, the

Table 1. The Maximum Displacement, Vertical Element of the Maximum Displacement (Vertical Intrusion to the Ridge), and the Maximum Equivalent Stress Shown Within the Mucosa for All the Frameworks

	Model-C		*Model-FP*		*Model-SP*		*Model-M*	
Loading Direction	*Vertical*	*Oblique*	*Vertical*	*Oblique*	*Vertical*	*Oblique*	*Vertical*	*Oblique*
Displacement (μm)	77	168	76	112	71	88	80	115
Vertical intrusion (μm)	69	78	68	77	63	72	71	81
Stress in mucosa (MPa)	0.14	0.15	0.14	0.15	0.13	0.14	0.14	0.15

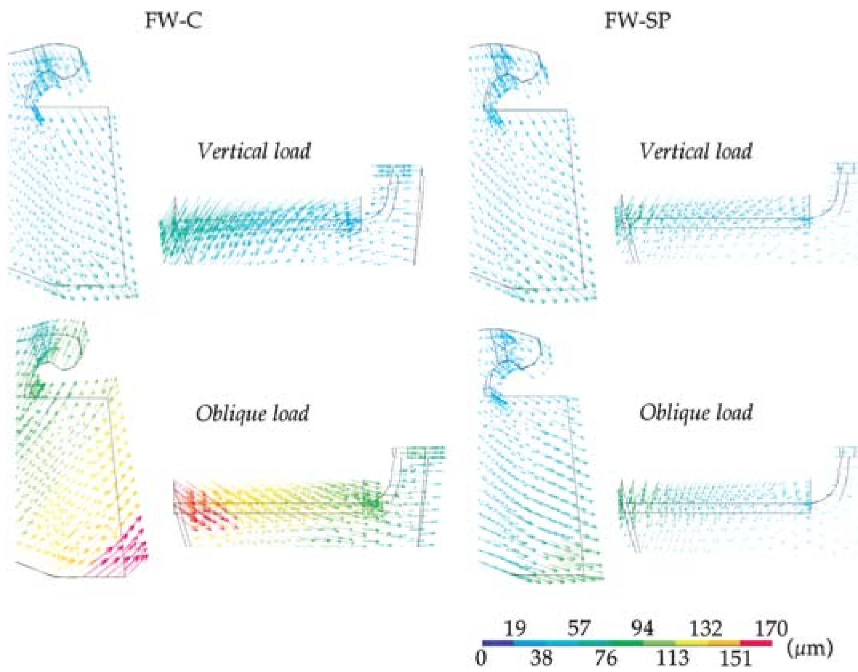

Figure 4. Vector graphics indicating lengths and directions of displacements at each node in the vicinity of the denture saddle of Model-C and Model-SP, viewed from the top (left) and buccally (right). Vector arrows were categorized into nine colors according to the displacement levels. The red arrow indicates the greatest displacement level, while the blue arrow indicates the smallest. Legend shows the maximum and minimum values as well as the boundary values between each level (μm). Solid outlines represent frameworks before loadings.

change of the loading direction from vertical to oblique caused a dramatic shift in the saddle displacement direction accompanied by increases in saddle displacement magnitudes.

With the canine rest the saddle displacement in the framework under the oblique load was more than twice that under the vertical load. It was suggested that those frameworks were less resistant to horizontal elements of the occlusal forces than the other frameworks with the posterior tooth rests, and were likely to deform in a horizontal plane under the lateral occlusal loads. Therefore, the first half of our hypothesis, that the abutment location would not have an effect on the saddle movement, has been rejected.

One may suspect that distance between the locations of the rest and the saddle would be the dominant factor determining the rigidity of each framework; however, this hypothesis was rejected because no significant relationship was found between the distance from the right rest to the center of each saddle (FP > SP > C > M) and their displacement values. Other factors such as connector shape differences secondary to the rest locations might produce differences in framework

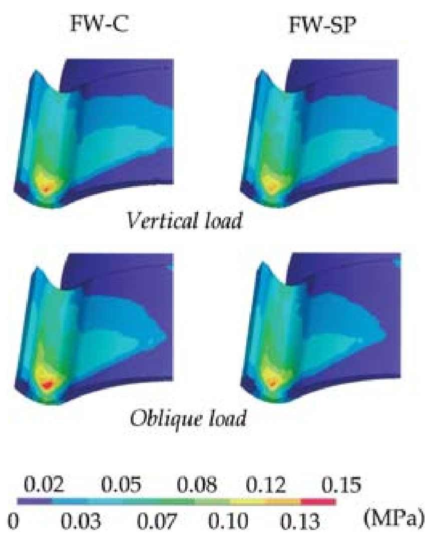

Figure 5. Inverted perspective of the stress contour in the lower surface of the mucosa for Model-C and Model-SP under the vertical and the oblique loadings. Each volume was divided into nine colors according to the stress levels. The red zone indicates the greatest stress region, while the blue zone indicates the smallest. For each model, the maximum equivalent stress was shown in the bottom surface of the mucosa directly above the top of the posterior edentulous ridge.

rigidity, even though an equal area size of each framework was assumed.

The lowest maximum stress created in mucosa was in the framework with the second premolar rest, regardless of the loading direction. This is consistent with the result that the saddle in the framework with the second premolar rest vertically displaced less than any other framework; however, the maximum stresses created under the framework with the second premolar rest (0.13 MPa for vertical load, 0.14 MPa for oblique) were only approximately 7% lower than those recorded under the other three frameworks (0.14 MPa for vertical load, 0.15 MPa for oblique). Although considerable differences in saddle movement are shown in the frameworks with different rest locations, the resultant stresses created in mucosa were within very small ranges. Design differences had a relatively weak influence on the stress in the mucosa; this suggested that the framework's ability to resist vertical distortion was insensitive to the location of the rest as part of a clasp assembly. The second half of the hypothesis, that the location would not have an effect on the stress distribution in the mucosa, has been supported. The displacements of the mucosa recorded in the calculations were less than 120 μm, which were all within the range of physiological intrusion with the maximum of approximately 0.5 mm under 4 N of vertical force.[16] In this context, it is also suggested that the displacements and stresses created by the loading conditions of the study were smaller than the critical stress that can cause a detrimental effect on the periodontal tissues and the bone.

The major connectors should be designed not only on the basis of their rigidity but also on their compatibility with anatomic structures of the maxilla in relation to comfort and discomfort to the patient. It has also been claimed that the clasps on the tooth-supported side of the arch should be placed as far posteriorly as possible so that the clasp axis will be furthest from the rest located on an anterior tooth; this might restrain a tendency of the denture to pivot about the axis.[17] However, since vertical or horizontal saddle displacements could lead to excessive stress in the oral mucosa and the supporting abutment teeth, constructing the RPD to prevent such movements under occlusal loads might be more important than avoiding pivoting. Although the abutment location did not have a significant effect on stress distribution in the mucosa, the result of this study still suggests that design consideration must also be focused on the mechanical aspect of the framework to avert excessive displacements of the denture saddle.

Conclusion

The influence of abutment selection on deflection in the maxillary Kennedy Class II RPD framework and stress distribution in the mucosa was investigated. Within the limitations of this study, the following conclusions can be made:

1. The framework with an occlusal rest as part of a clasp on the second premolar, on the side contralateral to the edentulous ridge, showed relatively good resistance to deformation.
2. Both vertical saddle intrusion and stress in the mucosa were shown in all the frameworks within small ranges.
3. The results suggest that the stress distribution in the mucosa was insensitive to the location of the contralateral abutment.

Acknowledgments

This study was supported by Grants-in-Aid for Scientific Research, 12771170 and 14571840, from the Ministry of Education, Science, and Culture of Japan.

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