J Korean Acad Prosthodont : Volume 38, Number 3, 2000

Stress analysis of anterior cantilever bridge

Hong-So Yang, DDS, PhD, Chul-Whoi Ku, DDS, MSD
Department of Prosthodontics, College of Dentistry, Chonnam National University

State ment of Problems. Although some clinicians report long-term success with fixed partial denture (FPD) that contain cantilever pontic, the use of cantilever FPDs may be hazardous because of unfavorable leverages during mastication.
Purpose of Study. This study aims to compare the stress induced in the periodontium with normal and reduced bone support, and to analyze the stress distribution patterns of anterior cantilevered FPDs using the finite element method.
Results. Cantilever bridge with a reduced bone level generated the highest peak stresses in the periodontium. In the models of reduced bone support, a cantilever bridge exhibited the greatest mobility and a 3-unit fixed restorations induced the smallest mobility of canine. The highest peak stress level of a 3-unit bridge in the periodontium is similar to the unrestored situation. But stress distribution in the bone is modified.
Conclusion. In reduced bone support, a cantilever bridge exhibited the greatest mobility and stress.

When a tooth have been extracted and not replaced, the space usually closes by means of physiologic movement of the remaining opposing teeth. The anterior missing tooth is restored with a 3-unit fixed partial denture (FPD) or implant prosthesis. Cantilever fixed partial dentures may be an alternative treatment choice. Although some clinicians[1,2] report long-term success with FPDs that contain cantilever pontic, the use of cantilever FPDs may be hazardous because of unfavorable leverages during mastication. The leverage created by chewing force could damage both the FPD and the abutments or their supporting structures.

There are several factors that influence the clinical decision to fabricate a FPD or not, and which prosthetic designs to use[3]. The clinician uses a periapical radiograph and analysis of mobility to evaluate the supporting structures. A crown/root ratio of 1 : 1 has been suggested as the minimum for a prospective abutment under normal circumstances[4]. The clinical studies by Nyman et al[5,6] demonstrated that teeth with reduced bone support could serve as reliable abutments for extensive cantilevered FPDs. This success has been attributed to the maintenance of periodontal health and to splinting of the abutments with a carefully designed occlusion[7]. Conversely, other investigators[8,9] found that the cantilevered FPD is suspect due to the unusual stress demands placed on the abutments by the pontic.

The purpose of this study were: (1) to com-

Key Words : Stress analysis, Cantilever bridge, Bone support

pare the stress induced in the periodontium with normal and reduced bone support, (2) to analyze the stress distribution patterns of anterior cantilevered FPDs using the finite element method (FEM).

MATERIAL AND METHODS

The two-dimensional FEM was used and the finite element model was generated to represent a maxillary anterior segment, which included a central incisor, a canine, premolars and supporting structures. An intraoral standard radiographic film was taken by use of the paralleling technique of a periodontally healthy maxillary incisor-premolar region and a FPD. The film was used to trace the outlines of each material and to construct the basic model (HCB) (Fig. 1). Variations of this two-dimensional finite element model were made by changing bone support to the following ratios: (a) crown/root ratio of 1 : 1.5, or (b) crown/root ratio of 1 : 0.6.

For each of these models another variation was made by restoration (a) a cantilevered bridge with a maxillary canine abutment and (b) a 3-unit fixed partial denture with an upper canine and a central incisor abutments.

The designs and their symbols are presented in Table 1. The model included cortical and cancellous bone, the periodontal ligament, dentin and enamel and dental casting alloy.

In all models the lower border of the mandible was considered fixed in a vertical direction. The mesial border of the models was designed so that the structure could deform elastically in a mesial direction with an assigned stiffness value of 10 Kg/cm^2. A 1Kg unit biting force was applied vertically on all of the incisal edges and cusps of the occlusal surface of each tooth. When an additional pontic was present, loading on its incisal edge was added to the total loading of the structures. The elastic constant and Poisson's ratio of the materials and the coordinates and geometry of each

Table 1. Symbols and designs of finite element models.

Symbol	Design
HCB	2-unit cantilever PFM bridge, High bone level (C/R ratio of 1 : 1.5)
LCB	2-unit cantilever PFM bridge, Low bone level (C/R ratio of 1 : 0.6)
H3B	3-unit PFM bridge, High bone level
L3B	3-unit PFM bridge, Low bone level
LNO	No restoration, Low bone level

Table 2. Mechanical properties of materials.

Materials	Young's Modulus(Kg/cm^2)	Poisson's ratio
Enamel	8.26×10^6	0.33
Dentin	2.14×10^5	0.31
PDL	7.03×10^1	0.45
Compact bone	1.45×10^5	0.30
Cancellous bone	2.15×10^3	0.30
Casting gold	8.46×10^5	0.40
Dental ceramic	7.03×10^5	0.28

PDL, Periodontal ligament

Table 3. Maximum stresses in the materials of each design.

		HCB	LCB	H3B	L3B	LNO
PDL	V.M Strsss	23	57	20	31	20
	Ten Stress	13	28	7	13	12
	Com Stress	25	61	22	35	23
Bone	V.M Strsss	284	442	178	179	173
	Ten Stress	181	327	113	151	143
	Com Stress	299	453	180	182	176
Tooth	V.M Strsss	456	513	173	190	153
	Ten Stress	324	354	29	29	41
	Com Stress	466	518	184	202	170
Bridge	V.M Strsss	2846	2846	774	874	-
	Ten Stress	2316	2316	286	323	-
	Com Stress	1210	1210	679	763	-

Table 4. Displacement of cusp tip in each design.

Design	First Premolar		Canine		Central Incisor	
	mesial	apical	mesial	apical	mesial	apical
HCB	90	92	297	159	57	85
LCB	250	118	980	268	58	107
H3B	31	89	39	100	34	118
L3B	167	122	62	129	57	163
LNO	167	118	143	106	53	100

node and element were recorded (Table 2). The linear plane stress analysis program (Algor Inc., Pittsburgh, Pa.) was used to solve the two-dimensional stress analysis problems. The basic model (HCB) was made up of 2811 two-dimensional elastic elements, 23 boundary elements, and 3017 nodes; the spatial distribution varied with bone level and design.

Since the FEM analysis is a mathematical calculation, repeated analysis will yield identical result. Therefore there was no need to make another models for statistical analysis.

The calculated numerical data were transformed into graphics to better visualize the mechanical phenomenon in the models (Figs. 2-6). The maximum principal stress, minimum principal stress, maximum shear stress and von Mises stress in each model were calculated and plotted. The stress distribution patterns of each stress type were similar and von Mises stress was well represented the other stress patterns. Therefore only plots of von Mises stress are presented. For comparison of the magnitude of stresses in each model, the peak stress of each material was tabulated (Table 3). To compare the mobility of the abutments from model to model, the deflections were traced and shown. The mesial and apical displacements (in micrometers) at the cusp tip of the pontic, incisor and canine subjected to the loading conditions are listed in Table 4.

By comparing these results, the effects of bone height, the cantilever and installation of a FPD on the stress distributions and mobility of the supporting structures were evaluated.

RESULTS

Stress

Stress concentrations were seen around the connectors of the fixed prosthesis and the abutment to the cantilever. The greatest stress for cantilevered prostheses was recorded in the connector area between pontic and retainer (Figs. 2, 3). High tensile stresses were observed on the occlusal surface of the rigid connector and along the distal surface of the root of the abutment. Compressive stresses were concentrated in the mesiocervical part of the retainer, and in the

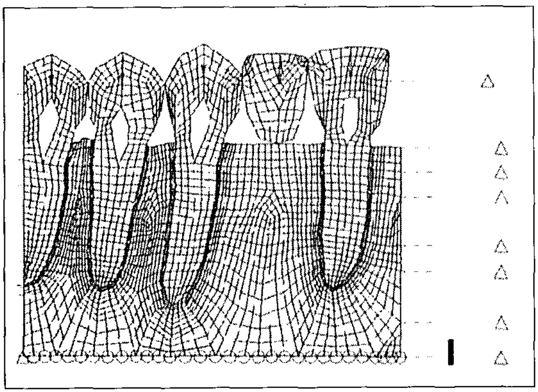

Fig. 1. Two-dimensional finite element model at high bone level (HCB), 10Kg loads are applied on the incisal edge and cusp tips.

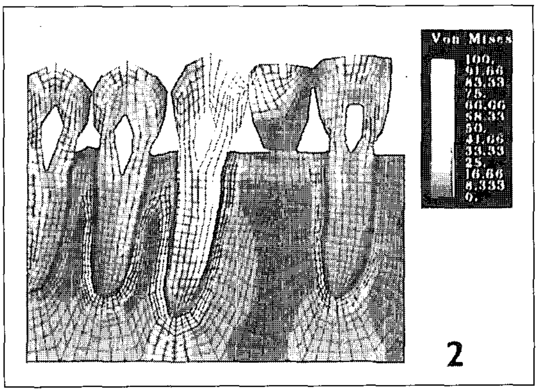

Fig. 2. Deflection of dental structure and stress distribution with cantilevered bridge and ideal bone support (HCB). The unit of von Mises stress magnitudes is Kg/cm^2. Stresses are distributed around the root apex and more widely in the cortical bone. High stress concentrations are seen around the connectors of the fixed prosthesis and canine abutment.

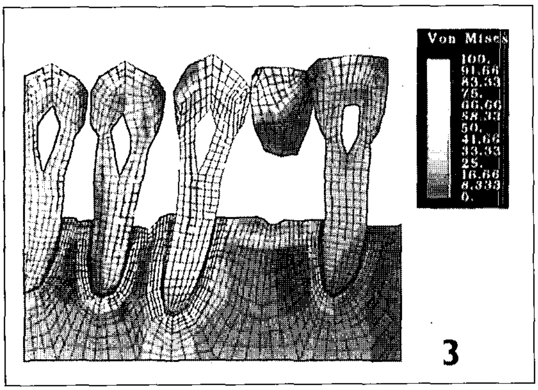

Fig. 3. Deflection of dental structure and stress distribution with cantilevered bridge and reduced bone height (LCB). Similar pattern of stress distribution to model HCB. Mesial rotation of canine and pontic is observed. Deflection of the abutment tooth increased and high stress area become wider.

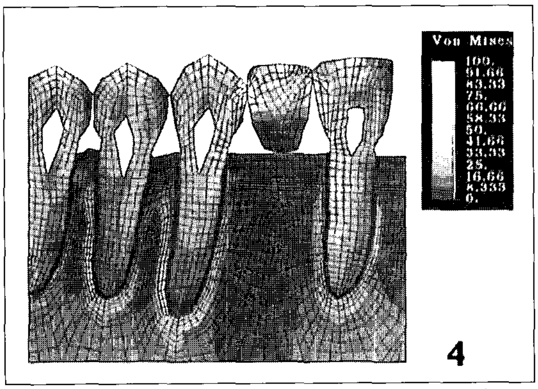

Fig. 4. Deflection of dental structure and stress distribution with a 3 unit fixed bridge and high bone level (H3B). The prosthesis markedly reduced the stress in the periodontium when compared to Fig. 2. No localized stress concentration is found around the canine abutment after installation of a 3-unit fixed partial denture.

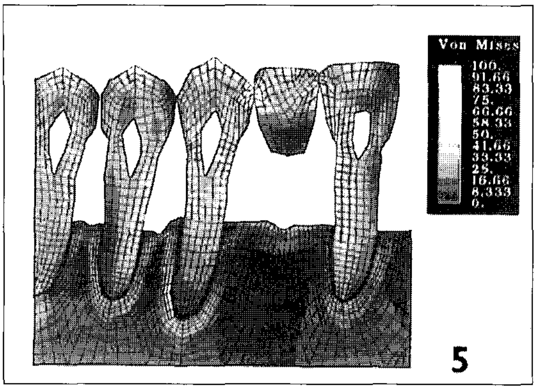

Fig. 5. Deflection of dental structure and stress distribution with a 3 unit fixed bridge and low bone level (L3B). Similar pattern of deflection and stress distribution to the FPD with high bone level (Fig. 2) is observed. But additional high stress area is seen in the alveolar bone under the pontic.

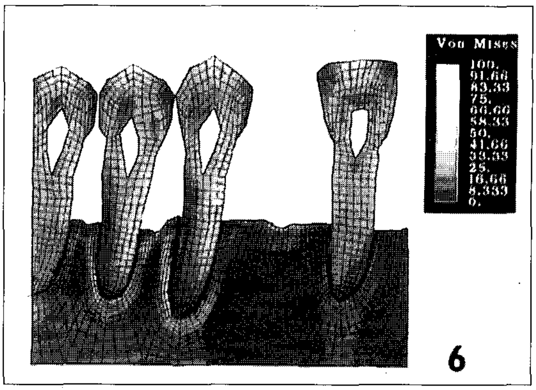

Fig. 6. Deflection of dental structure and stress distribution without restoration and low bone support (LNO). The magnitude of tooth mobility is slightly increased.

periodontal ligament (PDL) at the root apex.

The maximum von Mises stresses of the two-unit FPD with a cantilevered pontic in normal and reduced bone groups (HCB, LCB) were 284 and 442Kg/cm^2 in the cortical bone and 23 and 57Kg/cm^2 in the PDL respectively. The maximum stresses in the periodontium increased as bone support decreased. The values of maximum stresses in teeth and gold alloy were approximately the same in the single cantilevered pontic group, regardless of the bone level (Table 3 and Figs. 2, 3).

The maximum von Mises stresses of 3-unit FPDs in normal and reduced bone groups (H3B, L3B) were 178 and 179Kg/cm^2 in the cortical bone and 20 and 31Kg/cm^2 in the PDL, respectively. The maximum von Mises stress with edentulous missing space in reduced bone support (LNO) was 173Kg/cm^2 in the bone and 20Kg/cm^2 in the PDL. The highest peak stress level of a 3-unit bridge in the periodontium is similar to the unrestored situation. But stress distribution in the bone is modified.

The magnitudes of highest peak stress of periodontal ligament are similar between the cantilevered bridge with high bone support and the 3-unit bridge or no restoration with low bone level. A FPD with a cantilevered pontic and reduced bone level exhibited greater peak stress values in the PDL that was two times greater than a FPD without a cantilevered pontic (L3B, LNO) (Table 3, Figs. 3, 5, 6). A cantilever bridge with a reduced bone level generated the highest peak stresses in the periodontium. The area of high stress in the prosthesis and in the abutment was also greatly expanded (Figs. 2, 3).

Deflection

The mesial and apical displacements that resulted from a mesial load vector at the incisal edge of the pontic (lateral incisor), and the abutments subjected to the occlusal loading conditions are presented in Table 4 and Fig. 3.

The displacements of a free standing canine abutment with a reduced bone level (LNO) were 143 μm in the mesial direction and 106μm in the apical direction respectively. When the canine was used as an abutment of the 3-unit FPD with normal and reduced bone support (H3B, L3B), the displacement of the canine decreased to 39 and 62μm, respectively, in the mesial direction. All the models with low bone level exhibited greater cuspal displacement and stress in the periodontium as compared to the models with normal bone support. There was a reduction in displacement when the canine was used as an abutment of 3-unit FPD (Figs. 4, 5). When the canine was used as an abutment of a cantilever bridge with normal and reduced bone support (HCB, LCB), the displacement of the canine increased to 297 and 980μm, respectively, in the mesial direction. The cantilevered prosthesis (LCB) exhibited great mesial and apical deflection of canine than the three-unit prostheses (L3B) or freestanding tooth (LNO). In the models of reduced bone support, a cantilever bridge exhibited the greatest mobility and a 3-unit fixed restorations induced the smallest mobility of canine.

Loading on the occlusal surface of the abutments resulted in mesial and apical displacements, but loading on the cantilevered pontic increased the amount of deflection and caused mesial tipping forces in the pontic(Fig. 3).

DISCUSSION

The resistance of a FPD is influenced by the number and distribution of the abutments that support it, the shape of the arch to which it must conform, and the occlusal relationship it will have with the opposing teeth. There are several factors which have an influence on the decision whether to fabricate a FPD or not, what teeth to use as abutments, and what prosthetic design to use[2,10,11]. The root and supporting tissues should be evaluated for root configuration and crown/root ratio[4].

Generally the addition of a FPD resulted in more uniform stress distribution around abutments[12]. A cantilever FPD is one that has an abutment or abutments at one end only. This creates a class I lever system, which dramatically alters the direction and magnitude of forces on the abutment teeth[13]. Some investigators[8,9] demonstrated an increased risk of failure if the FPD is provided with cantilevered units due to the unusual stress demands placed on the abutments by the pontic. Contrary to traditional claims, another clinical investigation by Nyman et al[5,6] reported that teeth with reduced bone support serve as reliable abutments for extensive cantilevered prostheses. The effect of excess stress on a cantilever may influence the fracture and distortion of restorative materials and supporting bone resorption. If the prosthesis is to be designed properly, it is necessary to understand the mechanical behavior of cantilever FPDs when occlusal loads are applied.

High stress concentrations were seen around the connectors of the fixed prosthesis. Cantilevered FPDs should be designed so that occlusal forces are limited to the connectors' ability to accept them. The greatest stresses in fixed prostheses were recorded at the connectors and fractures may occur in this location. The results were consistent with the three-dimensional analysis of Awadalla et al[8]. Ideal bone support of the abutments decreased the magnitude of stress concentrations.

Palmqvist and Swartz[14] examined cantilevered FPDs and reported no negative influence of the one cantilever extension. However, Shackleton et al[15] claimed that longer cantilevers lead to increased risk of failure by examining the survival of fixed implant-supported prostheses using different cantilever lengths. In this study, forces transmitted through the cantilevered pontic caused tilting and rotational movements of the abutments. Cantilevered pontic caused tipping, and showed marked stress concentration (Figs. 2 and 3).

To construct a finite element model, it is usually necessary to simplify the system by making several assumptions. The assumption which was required for analysis of stress distribution by means of two dimensional finite element method was that the stress along a bucco-lingual direction were negligible and stress components in any direction were independent of the bucco-lingual dimension. In this regard the above analysis is a first approximation. In addition, although biological materials such as dentin, periodontal ligament and bone are anisotropic, inhomogeneous, and usually exhibit non-linear stress-strain relationships, the materials involved were idealized as homogeneous, isotropic, linearly elastic. The lack of good biological materials characterization data limits the accuracy of these results. Particularly, the physical properties for the PDL available in the literature exhibit a large variation. The PDL has viscoelastic properties and tooth mobility varies considerably with the individual. The mechanical behavior of PDL changes non linearly, depending on the magnitude and duration of load applied. As was recently noted, progress in FEA will be limited until we have better defined physical properties for enamel, dentin, the PDL, and cancellous and cortical bone. We are not in a position to verify the model developed other than to point to clinical data which supports our results.

Although two-dimensional models of dental structures were not an exact representation of the clinical situation, the results obtained have significant clinical implications. The stress level and distribution patterns of maximum stresses are important in anticipating the breakdown of the periodontium or prosthesis. From this study, it appears that cantilever bridge with a reduced bone level generated the highest peak stresses in the periodontium. So cantilever bridge can be used only when the abutment teeth has an ideal bone support.

Forces transmitted through the cantilevered pontic caused tilting of the abutments. The magnitude of rotational movement was increased as the crown/root ratio of abutment increased and the length of cantilevered pontic increased. To improve the prognosis of the FPD cantilever, alveolar bone support be acceptable, and the span of the pontic should be decreased.

CONCLUSIONS

A two-dimensional finite element model was constructed to analyze the mechanical behavior of a cantilevered bridge with a maxillary canine abutment and a 3-unit fixed partial denture with an upper canine and central incisor abutment. All fixed partial denture (FPD) were supported with both normal and reduced bone. 10Kg vertical forces were applied on the cusp tips of each teeth and pontic.

Within the limitations imposed by a two dimensional finite element analysis the following conclusions can be drawn:

1. Cantilever bridge with a reduced bone level generated the highest peak stresses in the periodontium.
2. In the models of reduced bone support, a cantilever bridge exhibited the greatest mobility and a 3-unit fixed restorations induced the smallest mobility of canine.
3. All the models with low bone level exhibited greater cuspal displacement and stress in the periodontium as compared to the models with normal bone support.
4. The highest peak stress level of a 3-unit bridge in the periodontium is similar to the unrestored situation. But stress distribution in the bone is modified.
5. The magnitudes of highest peak stress of periodontal ligament are similar between the cantilevered bridge with high bone support and 3-unit bridge or no restoration with low bone level.

REFERENCES

1. Isikowitz L. A long-term prognosis for the free-end saddle bridge. J Oral Rehabil 1985;12: 247-62.

2. Laurell L, Lundgren D, Falk H, Hugoson A. Long term prognosis of extensive polyunit cantilevered fixed partial dentures. J Prosthet Dent 1991; 66:545-52.
3. Reynold JM. Abutment selection for fixed prosthodontics. J Prosthet Dent 1968; 19:483-8.
4. Ante IH. The fundamental principles of abutments. Mich State Dental Soc Bul 1926; 8:14-23.
5. Nyman S, Ericsson I. The capacity of reduced periodontal tissues to support fixed bridgework. J Clin Periodontol 1982; 9:409-14.
6. Nyman S, Linde J. A longitudinal study of combined periodontal and prosthetic treatment of patients with advanced periodontal disease. J Periodontol 1979; 50:163-9.
7. Lundgren D. Prosthetic reconstruction of dentitions seriously compromised by periodontal disease. J Clin Periodont 1991; 18:390-5.
8. Awadalla HA, Azarbal M, Ismail YH, El-Ibiari W. Three-dimensional finite element stress analysis of a cantilever fixed partial denture. J Prosthet Dent 1992; 68:243-8.
9. Wylie RS, Caputo AA. Fixed cantilever splints on teeth with normal and reduced periodontal support. J Prosthet Dent 1991; 66:737-42.
10. Yang HS, Thompson VP. A two dimensional stress analysis comparing fixed prosthetic approaches to the tilted molar abutment. Int J Prosthodon 1991; 4:416-24.
11. Penny RE, Kraal JH. Crown-to-root ratio: its significance in restorative dentistry. J Prosthet Dent 1979; 42:34-8.
12. Farah JW, Craig RG, Meroueh KA. Finite element analysis of three and four-unit bridges. J Oral Rehabil 1989; 16:603-611.
13. Rodriguez AM, Aquilino SA, Lund PS. Cantilever and implant biomechanics: A review of the literature, Part I. J Prosthodon 1994; 3:41-46.
14. Palmqvist S, Swartz B. Artificial crowns and fixed partial dentures 18 to 23 years after placement. Int J Prosthodon 1993; 6:279-85.
15. Shackleton JL, Carr L, Slabbert JC, Becker PJ. Survival of fixed implant-supported prostheses related to cantilever lengths. J Prosthet Dent 1994; 71:23-6.

Reprint request to:
DR. HONG-SO YANG
DEPARTMENT OF PROSTHODONTICS, COLLEGE OF DENTISTRY,
CHONNAM NATIONAL UNIVERSITY
5, HAK-DONG, DONG-GU, KWANGJU, 501-190, KOREA
E-mail : yhsdent@chonnam.ac.kr