〔**Original**〕 Matsumoto Shigaku, 21 : 39~47, 1995
key words : finite element method — dowels — bridges

A Stress Analysis on Abutment Teeth of Dowel Cemented Fixed Partial Dentures
—On the effect of the resorption of alveolar bone—

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Summary

Stress in abutment teeth with cemented dowels and those with crown margins in fixed-fixed and cantilever bridges that resorp alveolar bone were analyzed by a two dimensional finite element method. Stress in all parts of the dentin in both bridges increased with the resorption of alveolar bone. Moreover, in th dentin and apex of the dowel in cantilever bridges, extreme stress when there were large amounts of resorption of alveolar bone, was seen. Therefore, in cantilevers bridges, cemented dowels must be created by large materials of Young's modulus. Furthermore, as much dentin as possible must be retained and the lever effect must be reduced.

Introduction

Missing teeth nodes and the resorption of alveolar bone are frequently observed in abutment teeth of fixed partial dentures (FPD). When teeth with markedly missing teeth nodes are applied to abutment teeth of a FPD, dowels are often used in order to prepare an optimal design [1]. This is because they are burdened with the added pressure and force that has attacked the pontic section in between the abutment teeth. These additional strains on abutment teeth and alveolar bone support are caused by the resorption of the alveolar bone. Although there have been many studies on the stress analysis of FPD abutment teeth, pontic, supporting structures and dentin in teeth with cemented dowels[2~6], analysis on stress distributions in abutment teeth with cemented dowels of FPD are limited in number[7~9]. Therefore, using a two dimensional finite element method and taking into account the resorption of alveolar bone support, the stress distributions in abutment teeth with cemented dowels of fixed-fixed bridges and cantilever bridges were analyzed in the present study. In addition, endodontically treated teeth applications for abutment teeth were also studied.

(accepted for publication on March 23, 1995)

Methods

A two dimensional finite element method was utilized to determine the stress distributions in the model of abutment teeth composed of mandibular second molars, second premolars with cemented dowels and missing first molars. The abutment teeth in this model were cemented with a full cast crown and for the dowel, zinc phosphate cement was used. This three-unit construction creates the fixed-fixed bridge as shown in Fig. 1. Moreover, mandibular second molar excluded models of the cantilevers bridge were also analyzed by the same method.

The sizes of these models are estimated from the numerical values of Fujita and Kirino[10]. The dowels had a length of two-thirds and a thickness of about one-third that of the root. The thickness of the taper of the canals' walls was 1/20th that of the root. The thickness of the cement was 0.1 mm. The periodontal ligament had a 0.4 mm, 0.2 mm and 0.3 mm thickness at the cervical, mid and apical part, respectively.

In order to study changes in the stress distributions of these models with increasing resorption of supporting alveolar bone, patterns of the stress distributions were analyzed according to bone resorptions of 0, 1/3, 1/2, 2/3 and 5/6 times the length of the root.

The finite element models of the fixed-fixed bridgs were composed of 1020 elements with 577 nodes at 0 resorption (Fig. 2), 955 elements with 544 nodes at 1/3 resorption (Fig. 3), 890 element with 513 nodes at 1/2 resorption (Fig. 4), 817 elements with 481 nodes at 2/3 resorption (Fig. 5) and 730 elements with 440 nodes at 5/6 resorption (Fig. 6). The finite element models of the cantilever bridges had 603 elements with 343 nodes at 0 resorption, 567 elements with 325 nodes at 1/3 resorption, 531 elements with 307 nodes at 1/2 resorption, 501 elements with 293 nodes at 2/3 resorption and 465 elements with 275 nodes at 5/6 resorption. For the fixed-fixed bridge, a vertical total force of 1.0 kg acted upon five nodal points of the buccal cusp at equally distributed vertical loads of 0.2 kg (Fig. 7), and for the cantilever bridge, a vertical total force of 0.6 kg was applied to three nodal points of the buccal cusp at equally distributed loads of 0.2 kg (Fig. 8). The peripherial lines of the bone in both types of bridges were fixed for support (Fig. 7, 8). The mechanical properties of the various materials used in the stress analysis are shown in Table I. These materials constructed a bridge as shown in Fig. 9. The stress distributions under each condition were calculated using a PC9801RA (NEC) and a two dimensional finite element analysis system CR-X (Quint Co.)[5].

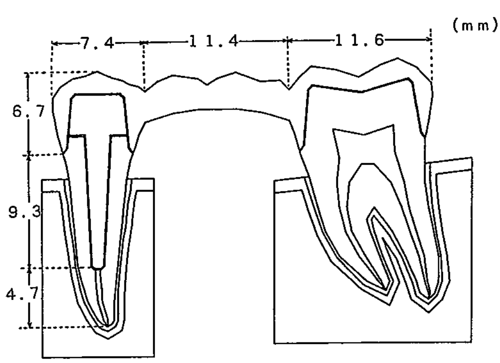

Fig. 1: The fixed-fixed bridge.

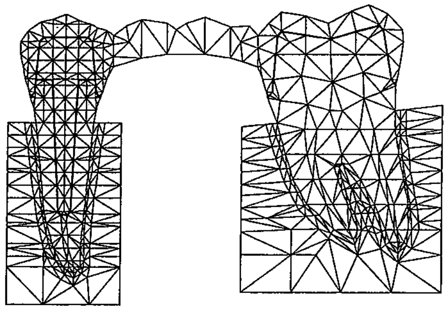

Fig. 2 : Two dimensional models partitioned into triangular elements for finite elements analysis (The loss of supporting bone 0).

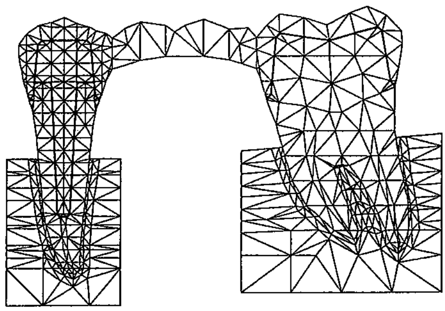

Fig. 3 : Two dimensional models partitioned into triangular elements for finite elements analysis (The loss of supporting bone 1/3).

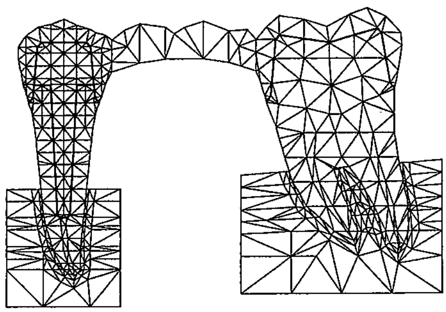

Fig. 4 : Two dimensional models partitioned into triangular elements for finite elements analysis (The loss of supporting bone 1/2).

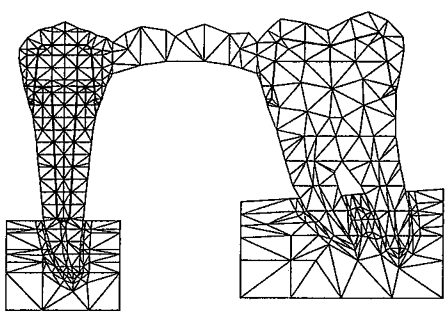

Fig. 5 : Two dimensional models partitioned into triangular elements for finite elements analysis (The loss of supporting bone 2/3).

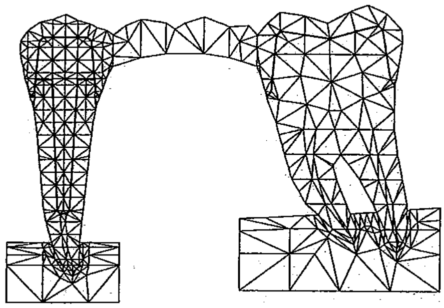

Fig. 6 : Two dimensional models partitioned into triangular elements for finite elements analysis (The loss of supporting bone 5/6).

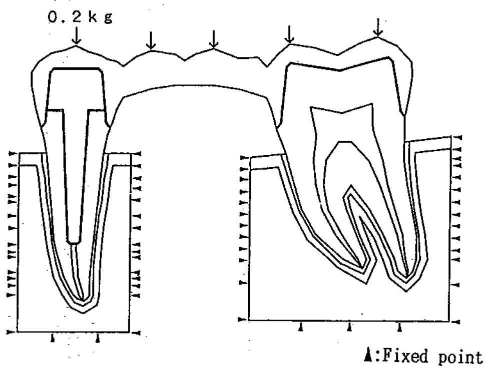

Fig. 7 : The analysis conditions (The fixed-fixed bredge).
The vertical total force of 1.0 kg acts upon five nodal points of the buccal cusp.

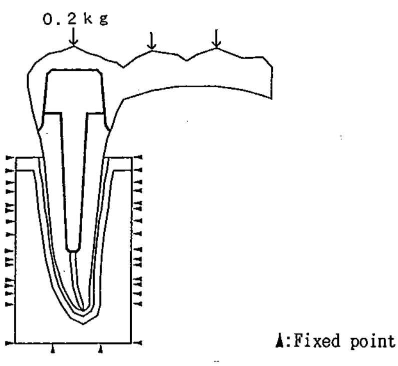

Fig. 8 : The analysis conditions (The cantilever bridge).
The vertical total force of 0.6 kg acts upon three nodal points of the buccal cusp.

Results

1. Stress arising in dentin

The remaining dentin was divided into six parts I ~VI as shown in Fig. 10. In each part, the equivalent stress was estimated by combining into one the stresses appearing in the dentin.

1) Fixed-fixed bridge

The calculated results of the equivalent stress in the six parts are shown in Table II according

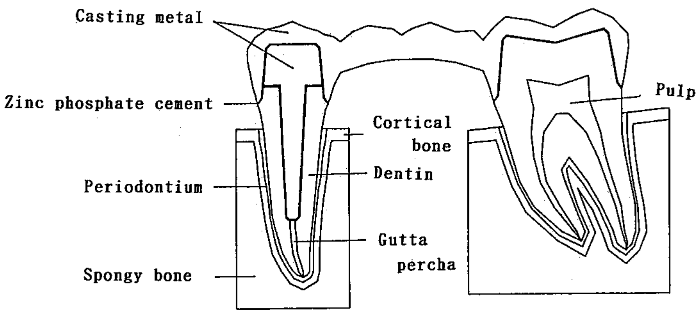

Fig. 9 : Materials.

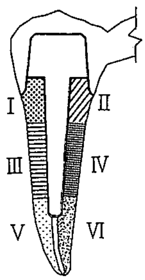

Fig. 10 : The parts of the abutment tooth.

Table I : Physical properties of each material

Material	Young's modulus (kg/mm^2)	Poisson's ratio
Casting metal	9500.0	0.33
Dentin	1200.0	0.30
Cortical bone	2000.0	0.30
Spongy bone	150.0	0.30
Periodontium	1.0	0.45
Zinc phosphate cement	900.0	0.35
Gutta percha	10.0	0.39
Pulp	0.1	0.49

to the resorption of alveolar bone. In each part, the ratio of the equivalent stress to that of zero resorption of alveolar bone is given in the brackets. The values of the equivalent stress increased in all parts with increasing resorption. The ratios of the equivalent stresses for 1/3 and 1/2 resorption to that of zero resorption show the largest values in part I. For those of 2/3 and 5/6 resorption, the largest values were found in part VI.

2) Cantilever bridge

As shown in Table III, the values of the equivalent stress are almost unchanged in parts I and II. However with increasing resorption in parts V and VI a remarkable increase was seen.

2. Stress arising in dowel

The dowel was divided into an upper part I, a middle part II and a lower part III, as shown in Fig. 11.

In each part, the equivalent stress was obtained by combining into one the stress seen in the dowel.

1) Fixed-fixed bridge

The values of equivalent stress in the three parts of the dowel are given in Table IV. They all showed an increase with resorption of alveolar bone. The ratio of the equivalent stress to that of zero resorption is shown in the brackets. The largest values were observed in the lower part III.

2) Cantilever bridge

As shown in Table V, for the upper part I, the majority of stress was seen to be independent of resorption. However, in the lower part III, the value of stress decreased at the largest resorption of five-sixths. The stress in the lower part III had the highest values seen through out all parts and all values of resorption.

Table II: The equivalent stresses in fixed-fixed bridges' dentin (kg/mm²)

Five levels of bone support	The parts of the abutment tooth						Total
	I	II	III	IV	V	VI	
0	0.60	2.09	0.58	1.24	1.50	1.62	7.63
	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)
1/3	0.72	2.18	0.59	1.42	1.73	1.87	8.51
	(1.20)	(1.04)	(1.02)	(1.15)	(1.15)	(1.15)	(1.12)
1/2	0.85	2.32	0.63	1.61	2.11	2.29	9.81
	(1.42)	(1.11)	(1.09)	(1.30)	(1.41)	(1.41)	(1.29)
2/3	1.18	2.52	0.75	1.85	2.91	3.27	12.48
	(1.97)	(1.21)	(1.29)	(1.49)	(1.94)	(2.02)	(1.64)
5/6	1.28	2.84	1.06	2.24	4.72	5.13	17.27
	(2.13)	(1.36)	(1.83)	(1.81)	(3.15)	(3.17)	(2.26)

The ratio of the equivalent stress to that of zero resorption of alveolar bone is given in the brackets.

Table III: The equivalent stresses in fixed-fixed bridges' dentin (kg/mm²)

Five levels of bone support	The parts of the abutment tooth						Total
	I	II	III	IV	V	VI	
0	5.81	7.81	5.45	6.63	7.43	7.33	40.46
	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)	(1.00)
1/3	5.91	7.80	6.44	7.90	11.01	10.86	49.92
	(1.02)	(1.00)	(1.18)	(1.19)	(1.48)	(1.48)	(1.23)
1/2	5.92	7.80	7.07	8.66	15.84	15.71	61.00
	(1.02)	(1.00)	(1.30)	(1.31)	(2.13)	(2.14)	(1.51)
2/3	5.93	7.80	7.37	8.92	23.42	23.62	77.06
	(1.02)	(1.00)	(1.35)	(1.35)	(3.15)	(3.22)	(1.90)
5/6	5.93	7.80	7.30	8.93	28.39	31.90	90.25
	(1.02)	(1.00)	(1.34)	(1.35)	(3.82)	(4.35)	(2.23)

The ratio of the equivalent stress to that of zero resorption of alveolar bone is given in the brackets.

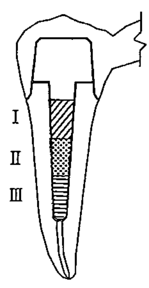

Fig. 11: The parts of the dowel.

Table IV: The equivalent stresses in fixed-fixed bridges' dowels (kg/mm²)

Five levels of bone support	The parts of the dowel			Total
	I	II	III	
0	2.83	2.99	3.11	8.93
	(1.00)	(1.00)	(1.00)	(1.00)
1/3	3.07	3.39	3.60	10.06
	(1.08)	(1.13)	(1.16)	(1.13)
1/2	3.28	3.79	4.30	11.37
	(1.16)	(1.27)	(1.38)	(1.27)
2/3	3.57	4.24	5.38	13.19
	(1.26)	(1.42)	(1.73)	(1.48)
5/6	4.05	4.95	6.52	15.52
	(1.43)	(1.66)	(2.10)	(1.74)

The ratio of the equivalent stress to that of zero resorption of alveolar bone is given in the brackets.

3. Stress arising in crown margin

The crown margin consisted of a mesial part M and a distal part D, as shown in Fig. 12.

1) Fixed-fixed bridge

The values of the equivalent stress in both parts M and D are given in Table VI. They both increased with the resorption of alveolar bone. The ratio of equivalent stress in part M to that of zero resorption is shown in the brackets and it was seen that it had larger values than those of part D.

2) Cantilever bridge

The values of the equivalent stress in both parts M and D are shown in Table VII, and were seen to be independent of the resorption of alveolar bone.

Table V: The equivalent stresses in cantilever bridges' dowels (kg/mm²)

Five levels of bone support	The parts of the dowel			Total
	I	II	III	
0	11.87	15.44	15.12	42.43
	(1.00)	(1.00)	(1.00)	(1.00)
1/3	12.07	17.70	20.82	50.59
	(1.02)	(1.15)	(1.38)	(1.19)
1/2	12.05	17.99	25.65	55.69
	(1.02)	(1.17)	(1.70)	(1.31)
2/3	12.04	17.90	26.16	56.10
	(1.01)	(1.16)	(1.73)	(1.32)
5/6	12.04	17.91	23.81	53.76
	(1.01)	(1.16)	(1.57)	(1.27)

The ratio of the equivalent stress to that of zero resorption of alveolar bone is given in the brackets.

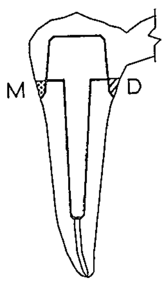

Fig. 12: The parts of the crown margins.

Table VI: The equivalent stresses in fixed-fixed bridges' crown margins (kg/mm²)

Five levels of bone support	The parts of crown margin	
	M	D
0	0.45	1.26
	(1.00)	(1.00)
1/3	0.52	1.32
	(1.16)	(1.05)
1/2	0.59	1.40
	(1.31)	(1.11)
2/3	0.67	1.51
	(1.49)	(1.20)
5/6	0.81	1.69
	(1.80)	(1.34)

The ratio of the equivalent stress to that of zero resorption of alveolar bone is given in the brackets.

Table VII: The equivalent stresses in cantilever bridges' crown margins (kg/mm²)

Five levels of bone support	The parts of crown margin	
	M	D
0	3.25	4.60
	(1.00)	(1.00)
1/3	3.28	4.60
	(1.01)	(1.00)
1/2	3.28	4.59
	(1.01)	(1.00)
2/3	3.28	4.59
	(1.01)	(1.00)
5/6	3.28	4.59
	(1.01)	(1.00)

The ratio of the equivalent stress to that of zero resorption of alveolar bone is given in the brackets.

Discussion

1. On the stress arising in dentin

Aydin and Tekkaya[6] suggested from the stress analysis on the fixed partial denture using a finite element method that the resorption of the supporting alveolar bone increases the stresses in the alveolar bone and the roots of abutment teeth. For the present model of the fixed-fixed bridge, the stresses in all parts of the remaining dentin of the mandibular second premolars increased with the resorption of supporting alveolar bone. In the mesiodistal parts of the apex, the stress increased most remarkably. In the case of cantilever bridge, the stresses in all parts of the dentin increased with resorption and in particular, the stress in the distal part of the apex increased dramatically. However, the stress in the mesio-distocervical part of the dentin did not change markedly with increased resorption. On both the fixed-fixed and the cantilever bridge, the stress in the root apex increased with resorption and caused the fractures in the dentin. However; the stress in the mesio-distocervical part of the dentin for the cantilever bridge was not affected by the resorption.

2. On the stress arising in the dowel

The stress in the dowel for the fixed-fixed bridge increased with resorption. Moreover, throughout the dowel, the most dramatic observed increased stress occurred in the dowel apex for both the fixed-fixed and the cantilever bridge. Therefore, it is important that the dowel is prepared with large materials of Young's modulus and that the dowel apex is thick[1].

3. On the stress arising in crown margin

In a previous paper, it had been reported that for both the fixed-fixed and the cantilever bridge with zero resorption of alveolar bone, the stress concentration appears in the crown margin[5]. In addition, Wright and Yettram had reported that for the cantilever bridge the maximum stresses occur in the alveolar crest tip and root apex regions [3]. In the present study taking into account the resorption of alveolar bone, the result showed that the stress in the mesial and the distal part of crown margin increased with resorption for fixed-fixed bridges. The stress in both parts of the crown margin of cantilever bridges had the same recorded values. These values were larger at all levels than those values of fixed-fixed bridges. However, the magnitude of these stress concentrations were higher in cantilever bridges of fixed-fixed bridges. Therefore, it becomes important to add the abutment teeth to any bridge.

Conclusions

The stress distributions in abutment teeth including cemented dowels and the resorption of alveolar bone support were analyzed for both the fixed-fixed and the cantilever bridge using a two dimensional finite element method. The results obtained are as follows.

1. For the fixed-fixed bridge, the stress in the whole dentin increased with the resorption of alveolar bone. The increments of change in stress was most remarkable in the mesiodistal parts of the apex.
2. For the cantilever bridge, stresses in all the parts of the dentin increased with the resorption of alveolar bone. The stress in the distal part of the apex increased most remarkably. In the case of the mesio-distocervical parts of the dentin, this section appeared to be almost fully independent of resorption.
3. The stresses in all the parts of the dowel for the fixed-fixed bridge increased with resorption. The stress in the dowel apex was observed to have the most noticeable increase.
4. In the cantilever bridge, the stress in the base of the dowel did not change dramatically with increasing amounts of resorption. The stress in the dowel apex, however, increased remarkably with increases in resorption.
5. The stress in the crown margin for the fixed-fixed bridge increased with resorption. The mesial part of the fixed-fixed bridge showed the most noticeable increase.
6. The stresses in the mesiodistal parts of the crown margin of the cantilever bridge are almost fully independent of resorption.

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抄録：合釘を装着した架工義歯支台歯の応力解析―歯槽骨の吸収による影響について―

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2次元有限要素法を用いて，中間および延長架工義歯について支持歯槽骨量の違いにより，合釘を装着した架工義歯支台歯，合釘および支台装置辺縁部に生じる応力がどのように変化するのかを解析した．結果は，両方のブリッジともに歯槽骨量の増加に伴い，どの部位でも応力の増加が見られたが，延長架工義歯では特に支台歯歯質全体，合釘先端部での増加が著しかった．よって，骨吸収量の多い架工義歯に合釘を装着する場合，合釘の材質はヤング率の高いものにし，残存歯質を多く残すことや，延長架工義歯では，槓杆作用を軽減するなどの設計上の必要性が示唆された．