A TWO DIMENSIONAL STRESS ANALYSIS COMPARING FIXED PROSTHETIC APPROACHIES TO THE TILTED MOLAR ABUTMENT

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Ⅰ. Introduction

A mandibular molar abutment that has tilted mesially into the edentulous is a common problem in fixed prosthodontics. Although an upright sturdy tooth., well supported by the healthy periodontium is an ideal abutment for a fixed prosthesis, such a situation is rare, and the dentist must edcide whether the extent of the bone resorption and degree of abutment tilting is acceptable for a fixed retainer.

Some authors[1, 2] claim that for tilted molar abutment for a fixed prosthesis will induce an unusual strain and will eventually destroy the supporting tissues. Yet, Hood et al[3] suggested that mesial tilting of less than 30 degrees should not be a limiting factor for the molar abutment, since the stresses induced in the periodontium were markedly reduced following the placement of a fixed partial denture. Many textbooks[4-6] propose that crown/root ratio of more than 1 : 1 should be avoided for abutments. Another study[7] has shown that the teeth with considerably reduced bone support can be successesfully used as abutments for fixed prostheses. Threr are arguments[8, 9] regarding these theories on abutment selection. No clearly examined scientific guidelines have presented for the selection of abutments with the reduced alveolar bone level and/or severe inclination of one of the abutment tooth.

The purpose of this study was to analyze the stress levels in the supporting structures with increasing bone loss and abutment tilting and ascertain how addition of a fixed prosthesis modified these stresses and their distribution. A two dimensional finite element method was used to determine the stresses in the prosthesis and surrounding structures as well as the displacement of the abutment teeth in occlusion.

Ⅱ. Material and Methods

The finite element model was constructed of a mandibular posterior segment which included a canine, premolars, second molar(first molar missing and supporting structures. A standard intraoral radiograph was made of a periodontally healthy lower premolar-molar area using the paralleling technique. There was no bone resorption and no abutment tilting. The radiograph was used to trace the outlines of each components and to construct the standard model(OH). Three variations of the two dimensional finite element models were made ; two with upright abutments and a crown/root ratio for each tooth of 1 : 1.5 and 1 : 0.6, the other with upright premolars but with 35 degrees of mesial tilt of the second molar and a crown/root ratio of 1 : 0.6. Each of these three models was considered and analyzed with the following variations ; 1) no restoration, 2) three unit fixed prosthesis, and 3) a four unit fixed prostheses. Additionally, a model of a gold crown on the tilted second molar(OTL) to restore the normal occlusal plane was analyzed. The designs and their symbols are given in Table 1.

In all models, the lower border of the mandible was considered fixed, and the mesial border was supported. A 1 kg unit biting force with 15 degrees mesial vector was applied on all of the fossae, marginal ridges and cusps of the occlusal surface of each tooth(Fig. 1). When a prosthesis was present loading of its fossae, and cusp tips was added to the total loading of the structure(Figs 15, 16) Mechanical properties of the materials were taken from the previous literatures(Table 2, Fig. 2). The amount of tooth mobility in the model after finite element analysis calculation with the material data set selected was suited to the actual amount of mobility observed in the mouth. The elastic constant and Poisson's ratio of the materials, the data concerning coordinate and geometry of each node and element were recorded in a personal computer. The basic model(Fig. 1) was comprised of 413 elements and 476 nodes which varied with bone level and restoration. The linar plane stress analysis program of Supersap Ver. 9.01/387E(Algor Inc. Pittsburgh, PA) was used to solve the two dimensional static stress analysis problems.

The calculated numeric data were transformed into the color graphics to better visualize mechanical

Table 1. Symbols for finite element designs

Symbol	Design
OH ;	No restoration, High bone level(C/R ratio of 1 : 1.5).
OL ;	No restoration, Low bone level(C/R ratio of 1 : 0.6.
OTL ;	Gold crown on 2nd molar, Tilting of 2nd Molar, Low bone level.
3H ;	3 unit bridge, High bone level.
3L ;	3 unit bridge, Low bone level.
3TL ;	3 unit bridge, Tilting of 2nd molar, Low bone level.
4H ;	4 unit bridge, High bone level.
4L ;	4 unit bridge, Low bone level.
4TL ;	4 unit bridge, Tilting of 2nd molar, Low bone level.

Table 2. Mechanical properties of materials

Materials	Young's Modulus (kg/cm²)	Poisson's Ratio
Enamel[11]	8.26×10^5	0.33
Dentin[12]	2.14×10^5	0.31
PDL[13]	7.03×10^1	0.45
Compact Bone[14]	1.45×10^5	0.30
Cancellous Bone[15]	2.15×10^3	0.30
Casting Gold[13]	8.46×10^3	0.40

phenomenon in the models. The maximum compressive stress, maximum tensile stress and maximum shear stress in each elements of the models were calculated and plotted.

Ⅲ. Results

The stress distribution patterns of each stress types were similar and maximum shear stress well represent the other stress patterns. Only plots of maximum shear stress were presented in this paper(Fig. 3-12). In the supporting structures, relatively high stresses were found in the cortical bone. As the height of alveolar bone around the free standing teeth reduced, a localized stress in the periodontium increased(Figs 4, 5). There was some difference in its location and distribution of stress concentration between the upright and tilted abutments. The free standing, mesially tilted molar abutment induced additional stress on the mesial side of the root and in the periodontium(Fig. 6). All the fixed partial dentures modified and reduced the stress in the periodontium. But high stress concentration atound the connector ares(Figs 7-12). For comparison of the magnitude of stresses in each models, the peak stress of each material was tabulated(Table 3). The maximum compressive stresses of the free standing teeth in normal and reduced bone group(OH, OL) were 129, 225 Kg/㎠ in the bone and 9, 32Kg/㎠ in the PDL respectively. While the maximum compressive stresses of the 4 unit fixed partial denture in reduced bone level(4L, 4TL) were 112, 126Kg/㎠ in the bone and 13, 17Kg/㎠ in the PDL respectively. The maximum compressive stresses of the 3 - unit and 4 - unit FPD in high bone level group(3H, 4H) were 10, 8Kg/㎠ in the bone respectively.

In order to compare the mobility of an abutment teeth from model to model, the deflections were treaced and shown in Figures 13-16. Note that the displacements were all magnified by a factor of ten for easy of visualization. The greatest mobility of the second molar abutment was observed on the tilted molar abutment with no fixed partial denture(Fig. 15). A marked reduction in the abutment mobility was observed in the abutment mobility after placement of a FPD(Fig. 15). The mesial and apical displacement in

Table 3. Maximum stresses in the material of each design

			OH	OL	OTL	3H	3L	3TL	4H	4L	4TL
Bone	Comp.	St.	129	225	225	147	177	195	113	112	126
	Tens.	St.	82	157	197	94	152	160	63	79	81
	Shear	St.	64	112	113	73	89	97	56	56	63
PDL	Comp.	St.	9	32	35	10	17	21	8	13	17
	Tens.	St.	4	15	17	3	12	12	2	7	7
	Shear	St.	5	16	17	5	9	11	5	8	10
Tooth	Comp.	St.	62	116	135	134	165	168	124	152	149
	Tens.	St.	45	80	138	55	68	74	55	72	78
	Shear	St.	33	58	79	67	83	84	62	76	75
Gold	Comp.	St.			108	136	156	148	148	167	169
	Tens.	St.			71	146	166	128	152	173	129
	Shear	St.			89	81	93	104	87	100	114

(unit ; kg/㎠)

microns at the mesial cusp tip of the 2nd molar and the cusp tip of the second premolar subjected to the standard loading conditinos are listed in Table 4. The displacements of the free standing molar abutment in normal bone level, low bome level and tilted molar group(OH, OL, OTL) were 87, 225, 408 microns to mesial direction and 64, 155, 365 microns to apical direction respectively. The mesial displacement of the molar abutment after installation of a FPD in normla bone height, reduced bone height and tilted molar abutment with single anterior abutment(3H, 3L, 3TL) were 36, 55, 75 microns while 28, 42, 52 microns in multiple anterior abutments(4H, 4L, 4TH) respectively(Table 4).

Ⅳ. Discussion

Finite element method of stress analysis is a mathematical engineering method of approximation to divide a structure into a finite number of elements whose mechanical behavior is specified by a finite number of parameters. If input data and assumptions in making a finite element model are appropriate, the output will be accurate ever possible with other stress analysis methods. It has long been used in the field of biomechanics and its validity in designing and analyzing prostheses has been established in dentistry[13].

The stresses that occur in the periodontium are an important factor in regulating the remodeling process of the alveolar bone. It is well accepted theory that compressive stress reduces the blood supply in the periodontal menbrane and leads to bone resorption while tensile stress leads to bone deposition[16].

Although well distributed high stress were found in the cortical bone surrounding the abutment teeth, the hightest stresses in the periodontium of the upright teeth occurred around the root apex. The tilted molar without a fixed prosthesis induced an additional stress concentration in the periodontium around the alveolar crest on the mesial side of the mesial root. As the height of the alveolar bone decreased around the abutment without a fixed prosthesis, there was a corresponding increase in the magnitude of all stresses. The major difference between the tilted and upright abutment at the same bone height was the location and the distribution pattern of the stress concentration(Figs 4-6, Table 3).

The maximum compressive stresses of the 4 unit

Table 4. Displacement of mesial cusp tip in each design

Design	second molar		second premolar	
	mesial	apical	mesial	apical
OH	87	64	77	30
OL	255	155	283	54
OTL	408	365	280	53
3H	36	33	36	48
3L	55	43	55	72
3TL	75	55	78	89
4H	28	30	28	36
4L	42	37	41	50
4TL	52	40	53	57

(unit ; microns)

prosthesis in the low bone level group(4L, 4TL) were 112, 126Kg/㎠ in the bone and 13, 17Kg/㎠ in the PDL respectively. These magnitudes were similar to those of the high bone level without a fixed prosthesis. When comparing the stresses between the unrestored group and the 4-unit fixed restoration, the magnitude of compressive stress in the periodontium was reduced nearly 50% by the placement of a prosthesis in low bone level group(4L, 4TL), while a 10% reduction was seen in the high bone level group(4H Table 3, Figs 10-12). A fixed prosthesis not only reduced the stress level but also more uniformly distributed stresses in the periodontium. This result complements othere stress analysis research on fixed prosthesis[13, 17]. Also these resuls support the clinical report of Nyman and Ericsson[7] who question the validity of "Ante's law"[18]. When a prosthesis was present a major portion of the masticatiory forces applied were distributed within the metal structures. Relatively high principal stress ranging from 128Kg/㎠ to 173Kg/㎠ was seen in the region of the connectors(Figs 7-12). Note that when a fixed prosthesis was present, the 1Kg force was applied to all cusps, fossae and marginal ridges of the prosthesis(Note the vectors in Fig 16). This increased the total force borne by the abutments. Yet deformation in the prosthesis absorbed and distributed the forces and reduced the overall stress level within the periodontal structures in comparison to the unrestored situation.

When a tilted abutment was present, stress concemtration occurred within the gold alloy at the occlusal half of mesial surface of the molar abutment and the connector area between the pontic and 2nd premolar(Figs 9, 12). However, when a fixed retainer was present no stress concentration was seen in the periodontium including the region of the alveolar bone crest. This suggests that 35 degrees tilting molar abutment may not be detrimental to the periodontium as the magnitude of stresses in the periodontium was reduced by approximately 50% after insertion of a fixed prosthesis. Additionally, no stress concentration was observed on the lateral side of the root. Although the high stress concentration was found at the connector area, a fixed prosthesis markedly reduced the stress level in the supporting periodontal structures in all situations. The mechanical advantage(reduction of peak stress level in periodontium and tooth mobility) afforded by a fixed prosthesis was greatest for the tilted molar with a reduced bone level as compared to the higher bone level. Nyman and Ericsson's[7] long term study of fixed bridge abutment of reduced bone support showed that none of the patient showed recurrent periodontal breakdown or occlusal overloading. Only 8% from the 332 bridges were failed after 5-8 years recall, but all of these failures were from the loss of retention of retainer from the abutment(3.3%), fracture of bridgework(2.1%) and fracture of abutment teeth(2.4%). Based upon our stress analysis the possible problems associated with a fixed restoration on the tilted molar abutment with reduced bone support were ; 1) breakage of the connector area and 2) failure of comenting media of the second molar resulting from high stress concentrations in those regions. Deterioration of the periodontium as a result of increased occlusal loading seems unlikely.

Stress distribution patterns were similar in the 3 unit and 4 unit bridges. When the 1st premolar was included as a second abutment, lower stress was observed in the tooth and periodontium around the premolars than before splinting(Figs 7-12). Splinting of the premolars increased the peak stress level in the internal structure of the fixed prosthesis, but decreased the stresses in the abutment teeth, periodontal ligament and the supporting bone(Table 3).

The mesial and apical displacement of the tooth increased with the increasing bone resorption and abutment tilting, and decreased after insertion of a fixed prosthesis(Figs 13-16). The four unit prosthesis exhibited slightly less displacement than the three unit prosthesis(Table 4). At the same bone level but without a fixed restoration, the tilted molar exhibited greater mobility than the upright molar. This implies that the periodontal ligament supports the load more effeiciently when the force is applied to the long axis of the root. The tilted second molar without a prosthesis exihibited the greatest mobility when occlusal force was applied. This vertical displacement was reduced to 1/8th the previous value by placement of a fixed prosthesis. The vertical displacement of the tilted 2nd molar supporting the 3 unit prosthesis was less than that calculated in the presence of a normal bone level without a restoration.

To construct a finite element model, it is usually necessary to simplity the system by making several assumptions. The assumption required for analysis of stress distributions by using a 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 and the result should be interpreted as qualitative. 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, isotopic, linearly elastic. The lack of good biological materials characterization data limits the accuracy of these results. Particularly, the physical properties for the PDL avaiable 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 betted defined physical properties for enamel, dentin, the PDL, and cancellous and cortical bone(19). We are not in a position to verify the model developed other to note clinical data which supports these results(7, 20, 21).

Although these two dimensional models of dental structures were not an exact representation of the clinical situation, the results obtained may have significant clinical implications. The better distribution of the occlusal force achieved with the fixed prosthesis as compared to the free standing teeth is noteworthy. Even in the extreme case of a crown/root ratio of 1 : 0.6 and 35° molar abutment tilting, a fixed prosthesis, by splinting the isolated abutment teeth, markedly reduced the amount of abutment displacement and the stress level in the periodontium. The fixed prosthesis appeared to have a functionally favorable effect on the abutment teeth and supporting structures.

Based on the above analysis it would appear that a fixed prosthesis can be a successful restoration on a tilted molar abutment tooth with severely reduced bony support. It must be assumed that in such a situation the periodontium is healthy, long-term maintenance has been assumed and connector areas are of adequate depth.

It is clear that a three dimensional model would yield more accurate stress values and distributions and further study is needed in this area. Only clinical trials can ultimately confirm the predictions made from finite element analysis presented here.

Ⅴ. Conclusions

Based on a two dimensional finite element analysis, the following conclusions are made ;

1. Reduction of alveolar bone support around free standing teeth caused a corresponding increased localized stress in the periodontium.
2. The free standing tilted molar induced additional stress on the mesial side of the root an in the local periodontium.

3. A fixed restoration reduced and modify the stresses in the periodontium by distributing the major portion of occlusal force within the metal structure.
4. The greatest improvement of the stress distribution in the periodontium and marked reduction of tooth mobility were achieved by the fixed prosthesis on the tilted molar abutment with reduced bone support.
5. Multiple abutments distributed the stress better than the single abutment and reduced the amount of cusp displacement.

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LEGEND

Fig 1. Two-dimensional finite element model at high bone level. Arrows indicate applied load. Triangle marked nodes are fixed in X and Y direction. Nodes with circle are fixed in X direction.

Fig 2. Color code for the materials present ; cancellous bone(green), compact bone(red), PDL(yellow), dentin(blue), gold alloy(pink) and enamel(brown).

Fig 3. Shear stress magnitudes and associated color for Figures 4-12. Unit ; kg/cm^2.

Fig 4. Stress distribution with no restoration and ideal bone height(OH). Stress are distributed widely in the cortical bone.

Fig 5. Stress distribution with no restoration and low bone level(OL). Stress concentration is observed in the periodontium around the root apex.

Fig 6. Stress distribution with low bone level, a gold crown and tilting of 2nd molar(OTL). Additional high stress in generated in the periodontium on the mesiall side of the 2nd molar.

Fig 7. Stress distribution with thigh bone level and 3-unit restoration(3H). Stress is relieved in the periodontium. But stress concentration is seen in the connectors of the fixed prosthesis.

Fig 8. Stress distribution with low bone and 3-unit bridge(3L). The fixed prosthesis marked reduce the stress in the periodontium.

Fig 9. Stress distribution with low bone level tilted 2nd molar and 3-unit fixed restoration(3TL). The fixed restoration not only reduces the stress level but also modifies the pattern of stress distribution. No stress concentration is found in the periodontium around the tilted molar.

Fig 10. Stress distribution with ideal bone height and 4-unit fixed prosthesis(4H). Splinting increases the stress in the gold restoration, but decreases the stress in the gold restoration, but dereases the stress in the supporting structures.

Fig 11. Stress distribution with low bone level and 4-unit prosthesis(4L). Stress level in the periodontium is reduced in both the premolars by using a second abutment.

Fig 12. Stress distribution with low bone level tilted molar and 4-unit bridge(4TL). The fixed prosthesis favored the tilted abutment with reduced bone support. No stress concentration occurs in the periodontium around the abutments. Compare to Figure 6.

Fig 13. Deflection of the dental structure with loading and normal bone level. Green lines indicate the outline before loading. White lines show the contour after loading. Magtnitude of displacement X10.

Fig 14. Deflection with reduced bone level and dupright molar abutment. magnitude of the displacement X10.

Fig 15. Deflection with reduced bone level and tilting of molar. The greatest mobility of the 2nd molar is seen. Magnitude of the displacement X10.

Fig 16. Deflection after the insertion of a fixed prosthesis in the case of reduced bone support and tilted abutment. A marked reduction in the abutment mobility is seen as compared to Figure 15. Magnitude of the displacement X10.

사진부도 1

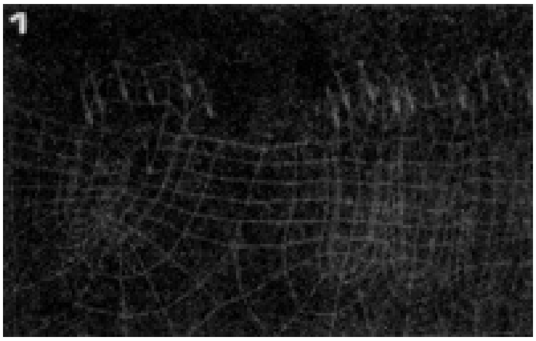


Fig. 1.

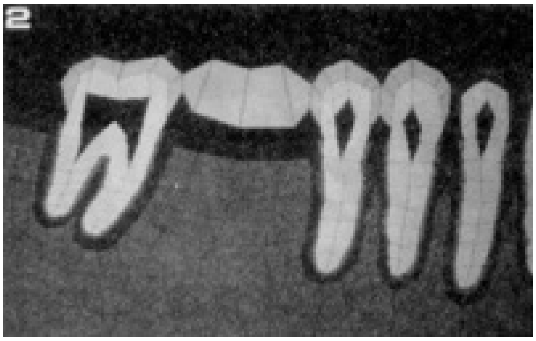


Fig. 2.

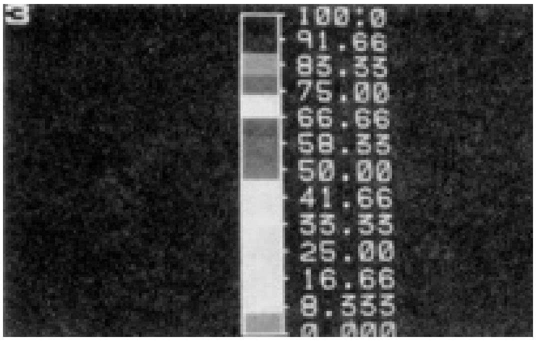
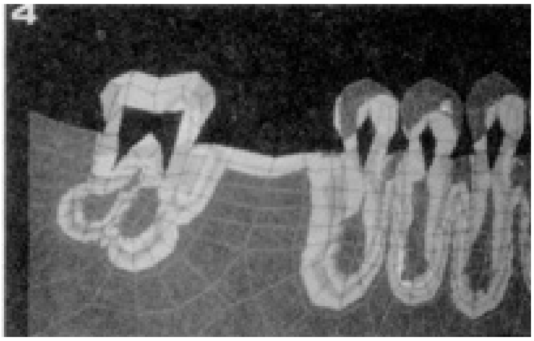


Fig. 3.



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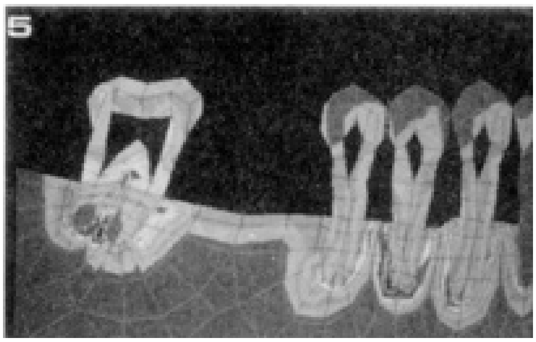
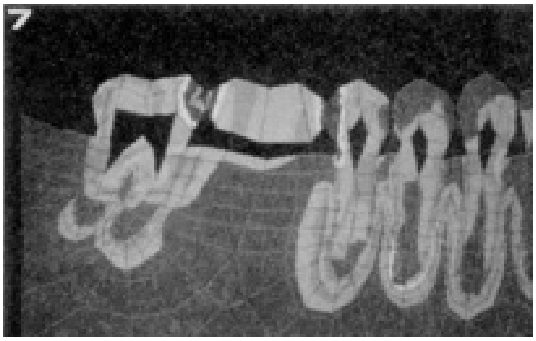


Fig. 5.

Fig. 6.



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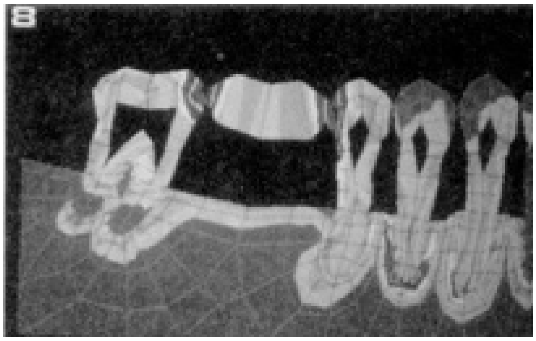

Fig. 8.

사진부도 2

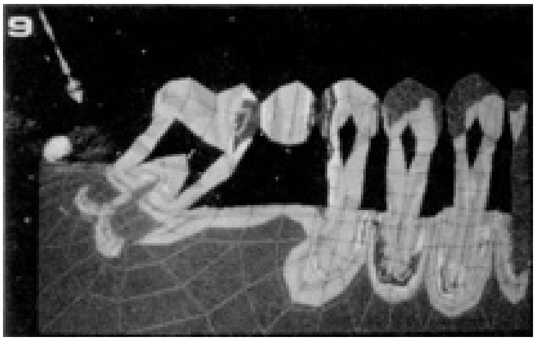

Fig. 9.

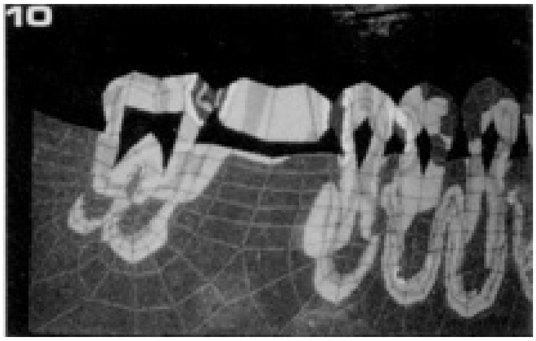

Fig. 10.

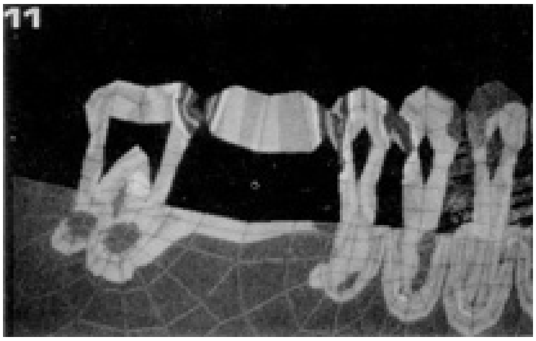

Fig. 11.

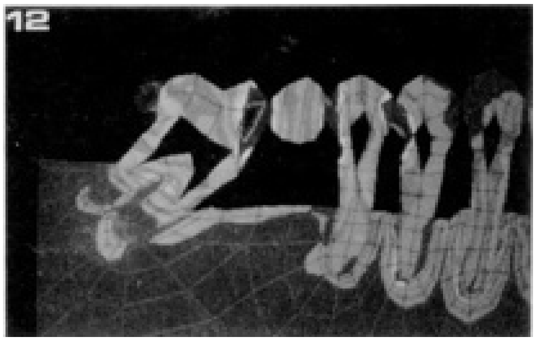

Fig. 12.

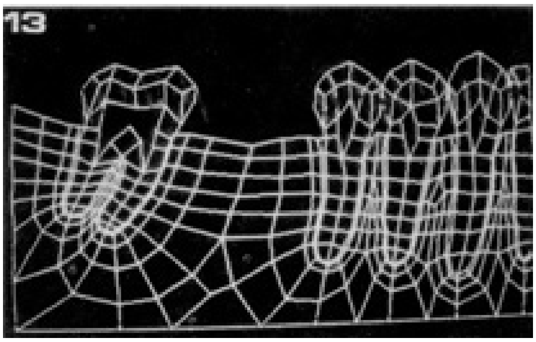

Fig. 13.

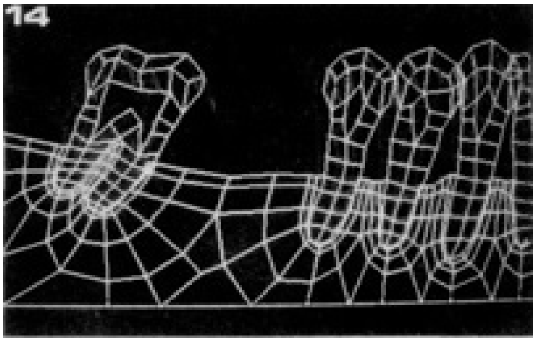

Fig. 14.

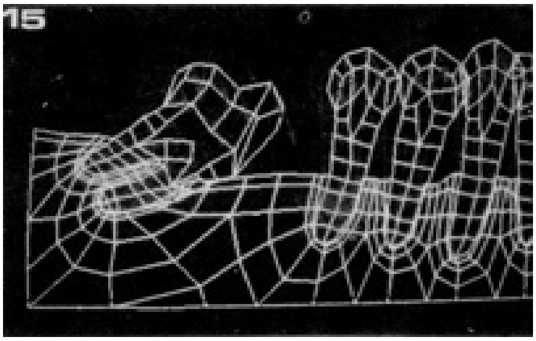

Fig. 15.

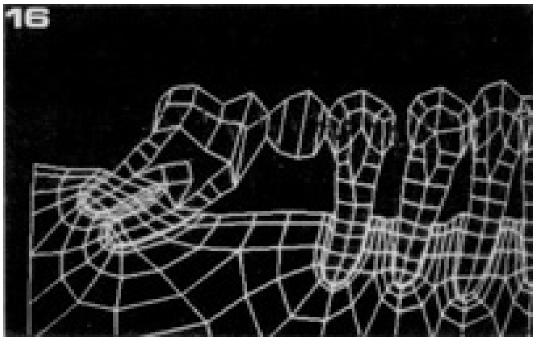

Fig. 16.

= Abstract =

A TWO DIMENSIONAL STRESS ANALYSIS COMPARING FIXED PROSTHETIC APPROACHES TO THE TILTED MOLAR ABUTMENT

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A two dimensional finite element method was used to analyze the changes in mechanical behavior of the supporting structures when a fixed prosthesis replaced a mandibular 1st molar. In the unrestored situation as the degree of bone resorption increased, there was a corresponding increase in stress in the periodontium. Tilting of the molar abutment induced the additional stress on the mesial side of the root. The presence of a fixed prosthesis markedly reduced the magnitude and distribution of stress in the periodontium. The mechanical advantage obtained by a fixed prosthesis was greater in the situation of a tilted 2nd molar with reduced bone support than with the higher bone levels.