Stress distribution in compromised abutments – a comparative study using three dimensional finite element analysis

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CERTIFICATE

Certified that the dissertation on **"STRESS DISTRIBUTION IN COMPROMISED ABUTMENTS – A COMPARATIVE STUDY USING THREE DIMENSIONAL FINITE ELEMENT ANALYSIS"** done by **Dr. CHITUMALLA RAJKIRAN,** Part II Post Graduate student (MDS), Branch VI – Prosthodontics, Saveetha Dental College and Hospitals, Chennai submitted to The Tamil Nadu Dr. M.G.R. Medical University in partial fulfillment for the M.D.S. degree examination in February 2005, is a bonafide research work done under my guidance and supervision.

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INTRODUCTION

In recent years fixed prosthesis has obtained an increasing acceptance from partially edentulous patients as it regains health, appearance and normal function of dentition. Planning a fixed prosthesis requires a thorough knowledge of available treatment methods and a sharp acumen to diagnose the presenting conditions.

Abutment plays an important role in the success of fixed partial denture. Success also depends on type of occlusion, amount of bone present, and periodontal health of the abutments. When a fixed partial denture is planned, many practitioners follow Ante's law as a clinical guide to select and determine the number of abutments.

In 1926, Ante suggested that total pericemental area of abutments should be equal or greater than the pericemental area of the tooth being replaced. However, in 1982 Nyman and Ericcson in their study suggested that this principle need not always be followed during selection of abutments. In clinical situations we often come across patients with compromised abutment teeth. When a tooth has less support from periodontium, validity of its being considered for an abutment should be taken seriously. Very often it is necessary either to modify the treatment plan or change the design of restoration depending upon the amount of stress taken up by individual abutments. When tooth has less support from periodontium, it looses it's load bearing capacity. The existing normal occlusal load now becomes pathological for this tooth and it may not be able to take up the same load.

Another aspect of fixed prosthesis is its splinting action on periodontally compromised abutments. It has been said[15,41] that when strong abutment is connected to a moderately damaged tooth with rigid fixed partial denture, load is distributed more to the strong abutment, thereby stabilizing the weak tooth, whereas if one of abutment teeth has lost about 2/3[rds] of periodontal support, the rigid prosthesis will hasten its exfoliation. However, there is no conclusive decision regarding the nature of splinting action of fixed prosthesis in periodontally involved teeth. Considering the above mentioned factors, the following study was undertaken :

1. To determine the ratio of load taken up by each abutment, whether normal or periodontally compromised.
2. To prove / disprove Ante's law
3. To evaluate splinting action of prosthesis through finite element method.

Finite element method was chosen to determine the above factors, as it is a very recent method of analyzing the stress distribution among teeth and their supporting periodontium.

Umpteen number of studies have utilized this tool to evaluate the stress patterns in various dental prostheses. However, none of them have been a three-dimensional analysis. Since a three-dimensional model closely resembles any dental structure, it was opted as the method of creating the models used in this study.

REVIEW OF LITERATURE

Farah et al in (1974)[9] were the first to use finite element study in dentistry. They analysed the stresses in a restored axisymmetric molar. They said that for calculation following information were needed

1. Total number of nodal points
2. Total number of elements
3. A numbering system identifying each element
4. Young's modulus and poisons ratio of each element.
5. A numbering system identifying each nodal point.
6. Co-ordinates of each nodal point
7. Evaluation of strains at external nodes
8. Types of boundary elements

Lundgren D, Nyman S, Heijl L, Carlsson GE (1975)[24] examined the function of fixed bridges on abutment teeth with reduced but non-inflamed periodontal tissues. The results of the study show that the functional capacity of the type of extensive bridgework discussed is good and that the patients in spite of severe loss of periodontal tissue achieve bite force values that are almost comparable to those in individuals with natural teeth.

Nyman S, Lindhe J, Lundgren D. (1975)[30] investigated how occlusion may be utilized to establish and maintain stability of fixed bridges in patients with markedly reduced periodontal tissue support. After periodontal treatment, the patients were rehabilitated with fixed bridges, whose stability was evaluated once a year for 2 to 6 years. The results show that permanent stability of bridgework can be obtained in patients where there is a minimum of remaining periodontal tissue support, even in combination with marked hypermobility of individual abutment teeth.

Yettaram A.L., K.M.J.Wright (1976)[48] studied stress distribution patterns for a normal and a restored mandibular second premolar under masticatory type forces using finite element method of stress analysis applied to two dimensional models. Force was applied at two points to simulate active centric occlusion. The structure was also subjected to single point load, which was applied to lingual side of the buccal cusp of the tooth. Results concluded that greater stiffness of enamel over dentin enabled it to react to the larger proportion of the applied loads. Dentin core was relatively lightly stressed.

Sutherland JK, Holland GA, Sluder TB, White JT (1980)[43] investigated stress distribution in bone supporting fixed partial dentures of rigid and nonrigid design. It was concluded that

1. Under conditions of vertical loading, the rigid fixed partial denture design does not permit independent response by either abutment. The nonrigid fixed partial denture design allows the abutments some independence in response to vertical loading
2. The stress distributions and concentrations produced in the supporting bone are favorably altered by the placement of a fixed partial denture of rigid or nonrigid design.
3. The distribution of stresses in the supporting bone varies with the number and location of the loading sites.

Sulik WD, White JT. (1981)[44] investigated stress distributions and concentrations produced in the periodontium of abutment teeth of a fixed partial denture. Stress concentrations produced in the periodontium of abutment teeth were notably altered by a moderate (20%) loss of support.

Further (40%) loss of periodontium did not result in appreciably additional change. The stress patterns produced by loss of periodontium were favorably altered by the placement of a fixed partial denture

Gobind. H Atmaran, Hamdi Mohammed. (1981)[13] determined the physiological stress values in natural tooth and the underlying bone using finite element analysis. In addition to modeling the PDL as a contiuous structure, PDL is modeled more accurately in a novel fashion as a fibrous structure. The results indicate that type of PDL has a significant effect on nature and magnitude of alveolar stresses,and that fibrous PDL modeling shows higher and more widely distributed lateral stresses in alveolar bone than those resulting from continuous periodontal modeling.

Nyman S, Ericsson I et al (1982)[33] studied the total area of periodontal ligament around the abutment teeth in fixed bridges, inserted in patients treated for advanced periodontal disease, was calculated and compared with the total "periodontal ligament area" of the teeth replaced by pontics. Despite the fact that the periodontal support for the restorations was dramatically reduced, all bridges have functioned properly for 8-11 years and the periodontal tissues around the abutment teeth have not suffered further loss of attachment during the period of maintenance care.

Laurell L, Lundgren D (1986)[25] study was done to elucidate the occlusal force pattern and the functional capability of a dentition during chewing and biting. The method is based on the use of strain gauge transducers mounted into preformed matrices evenly distributed over the tooth-arch. The magnitude of the occlusal forces developed during chewing and swallowing was below all biting forces.

Farah J.W. R.G Craig (1988)[10] conducted a two dimensional Finite element analysis of a mandibular quadrant was used to examine the stresses and displacements resulting from a 100N load. It was distributed in second premolar and second molar concentrated at 30˚ to the vertical on second molar . Young's Modulus and poissons ratio for each material were selected from accepted values. The Principal stresses were determined through out the model, with special emphasis being placed for elements in immediate vicinity of teeth mentioned above. Resulting stresses were approximately 4-5 times greater than those resulting from a vertically distributed load.

Farah J.W. Craig R.G (1989)[11] examined the principal stresses from placement of 3 and 4 unit bridges, spanned from first premolar to second molar using two dimensional finite element method. He concluded that the addition of a bridge resulted in lower and better distributed stresses. From a stress standpoint the bridges resulted in more uniform stress distribution around the abutments and an increase in the tensile stress distal to the abutments. Such findings support the placement of a fixed bridge to maintain bone in an edentulous area.

Freilich MA, Breeding LC, et al (1991)[12] conducted a study to find out the effect of fixed partial dentures on hypermobile abutment teeth with substantially reduced levels of periodontal attachment.. Treatment consisted of periodontal therapy and a 3- or 4-unit fixed partial denture, after which all subjects were placed on a quarterly maintenance schedule. No differences were found between the mean baseline and 24-month measures for all dependent variables at test or control sites.

Kim.l. Andersen, Erik. H. Pedersen (1991)[21] evaluated the validity of finite element method for determining stress /strain conditions in the periodontal tissues after the application of force and the use of this method for determining initial stress levels and profiles in periodontal ligament.

Strain gauges were also used for measuring the stress/ strain condition for the horizontal force of 100N applied. The elastic stiffness was determined to be 0.007Mpa and the corresponding poissons ratio was 0.49 for the autopsy material.

Yang HS, Thompson VP (1991)[54] investigated the changes in mechanical behavior of the supporting structures when a fixed prosthesis replaced a missing mandibular first molar through finite element method. In the unrestored situation, as the degree of bone resorption increased, there was a corresponding increase of stress in the periodontium. The presence of a fixed prosthesis markedly reduced the magnitude and distribution of stress in periodontium

Aydin AK, Tekkaya AE (1992)[1] studied stresses and deflections of abutments induced by various loadings analysed with two dimensional finite element model. The biomechanic system consisted of three unit posterior fixed partial denture (1) a distributed force of 600 N (2) concentrated nonaxial and (3) axial 300 N forces at the marginal ridge of the molar; and (4) a concentrated vertical 300 N force at the center of the pontic. All computations were conducted for three different alveolar bone levels. According to the stresses induced in the alveolar bone, the most critical loading was the distributed force. With diminishing periodontal support, stresses elevated in the biomechanic system and critical increases were noted for the concentrated non axial load on the molar

Darendeiller S., H. Darendelliler (1992)[6] determined the stress distribution in a maxillary central incisor by using three dimensional finite element method. The tooth is assumed isotrophic, homogenous, elastic and unsymmetrical. A load of 450 N, 26˚ to the longitudinal axis is applied on the incisal margin of the tooth. The distribution of compressive, tensile and shear stresses were plotted for the whole tooth structure. It was found that compressive stress values are comparatively larger than tensile and shear stress values in both enamel and dentin. Tooth structure is more resistant to compressive loads. The obtained cracks are caused by maximum tensile and shear stresses due to low strength of tooth against these stresses.

Yi SW, Ericsson I, Carlsson GE, et al (1995)[49] photoelastic study was done to evaluate the periodontal conditions in patients treated more than 10 years ago for advanced periodontal disease and rehabilitated with cross-arch fixed partial dentures (FPDs). It was concluded that combined periodontal and prosthodontic treatment of patients with advanced loss of periodontal support may provide a high rate of long-term successful outcome, provided proper adequate periodontal and prosthetic treatment and maintenance care are given.

Lee C.H., Wang, et al (1995)[27] a photoelastic study was done with various levels of periodontal support in a four unit fixed partial denture replacing second premolar, first molar with second molar and first premolar as abutments. Stress concentration effects produced by second molar were more prominent and determinant than that by first premolar in the periodontium of the abutments.

Kamposiora P, Papavasiliou G. et al (1996)[23] studied levels and distribution patterns of stress within three-unit fixed partial dentures (mandibular first premolar to first molar) constructed of different materials (Type III gold alloy, Dicor, and In-Ceram) and with different connector heights (3.0 mm versus 4.0 mm) based on a two-dimensional finite-element analysis model. They concluded that In-Ceram would appear to be the best choice for posterior fixed partial dentures.

Yi SW, Carlsson GE, et al(1996)[50] investigated occlusal factors in fixed partial dentures (FPDs) still in service for more than 10 years, and to assess the patient's opinions regarding oral function with these constructions. The great majority of patients were satisfied with the function of their FPDs (mastication, phonetics, aesthetics, comfort, and hygiene). Subjective function was not significantly influenced by FPD design, occlusal factors or number of FPD units. The only significant difference observed was that patients with a small amount of supporting tissues said they had more difficulties with hard foods than the others had. Although a stable occlusion was found in all Fixed partial dentures none of the other occlusal parameters examined were related to the long-term results.

Yamashita J, Shiozawa I, Takakuda K (1997)[52] study was done to determine the strain distribution of fixed partial dentures during function and to compare the biomechanical behavior of fixed partial dentures in vivo and in vitro. Three conventional posterior fixed partial dentures and two complete crowns were fabricated. The results of this study suggest that serious problems with strain may occur in a long-span mandibular posterior fixed partial denture.

Yang HS, Lang La, Felton DA (1999)[16] investigated the effect of splinting in long span fixed partial denture using finite element analysis. In this study stress levels in teeth and supporting structures of fixed prosthesis were analysed for modification of stresses and their deflection by addition of multiple abutments. A reduction of stress and deflection was observed in supporting structures when F.P.D is fabricated and teeth were splinted together. Increasing the number of splinted abutments did not reveal a proportional reduction of stress in periodontium. Stress concentration was seen in connector of prosthesis and in edentulous ridge.

Peter.D.Jeon, Patrick. K. Turley (1999)[36] studied the stress in periodontal ligament, root, and alveolar bone changes in response to different moment to force ratio by establishing a three dimensional finite element model of maxillary first molar. The results demonstrate that periodontium is sensitive to load changes. High stress concentrations were observed on the root surface at the furcation level in contrast to the anterior teeth that displayed high concentration at apex. The stress pattern in the periodontal ligament corresponded with the load types. Those on the root appeared to be highly affected by bending and the high stiffness of root.

Isaac L, Joseph M, Bhat S, Shetty P. (2000)[19] analysed the stress variations in a mandibular posterior fixed partial denture (FPD), made of recast nickel-chromium alloy through finite element analysis. The analysis revealed that the connectors experienced maximum stresses and the generated stress values decreased within the fixed partial denture made of recast Ni-Cr alloy. It seemed unlikely that FPD inspite of being made of recast alloy might fail before the other tissue components show signs of degeneration thus establishing the potential for recycling the Ni-Cr alloy in actual dental practice

Rees JS (2001)[40] studied to examine which of the supporting structures was important to the finite element model when analysing the stress distribution within a tooth. A two-dimensional plane finite element model of a lower second pre-molar was developed, which included the supporting periodontal ligament and alveolar bone. It was found that it was particularly important to include both the periodontal ligament and alveolar bone when undertaking the finite element analyses of teeth.

Yi SW, Carlsson GE, Ericsson I. (2001)[51] study was done to longitudinally evaluate, after periodontal and prosthodontic treatment that included cross-arch Fixed partial dentures, treatment outcomes in korean patients who suffered from severe periodontitis. It was also done to evaluate the patients' treatment assessments and the Fixed partial dentures after 3 years. Patients with advanced periodontal disease demonstrated successful outcomes over a 3-year period and reported satisfaction with combined periodontal and restorative treatment that included cross-arch Fixed partial dentures.

Kleinfelder JW, Ludwigt K (2002)[22] study was done to evaluate the influence of reduced periodontal tissue support on maximal bite force in natural dentitions and to study the effect of splinting on maximal bite force. Bite force was assessed at 4 mm mouth opening without splinting in the premolar region and following splinting of the posterior teeth and teeth were transduced using a strain-gauge (full-bridge circuit). It was concluded that reduced periodontal tissue support does not seem to limit bite force with maximal strength in natural dentitions as measured by a device that opens the bite by 4 mm. Furthermore, maximal biting forces at 4 mm mouth opening are increased when molar teeth are included in a posterior splint.

SUMMARY AND CONCLUSION

A three-dimensional finite element analysis study was carried out to compare the stress distribution among normal and periodontal compromised abutments. Normal models were created with and without prosthesis. Experimental models were designed with different amounts of periodontal loss simulating clinical situations. An additional abutment was added to verify Ante's law and also check if splinting reduces the stress distribution in compromised abutments. All the models were generated using IDEAS software.

The occlusal load was standardized 200 N both axially and non axially at 15° to mimic clinical conditions. The reference point of measurement of stress was fixed at abutment retainer cemental interface. The results were analyzed an interpreted for stress distribution and to check the splinting action of the prosthesis with an additional abutment in various simulations.

They were also analyzed to check the validity of Ante's law From the above study it was concluded that :

1. When fixed partial denture was placed on normal teeth and subjected to loading stress generated was less compared to individual teeth.
2. When periodontally compromised abutment teeth was splinted with an additional abutment stress generated was more due to loss of bone support. In addition forces applied to supporting bone may be magnified because of greater leverage associated with lengthened clinical crown which explains the increased stress generated with less periodontal support.
3. Following an increase of loss of periodontal support on second molar abutment (with normal first premolar) stress concentration of first premolar was more than molar. Although there was loss of periodontal support on both abutments stress concentration of first premolar was more than molar. This is because of the reason that second molar has two roots and first premolar has one root. Hence surface area of tooth influences stress concentration.
4. Although the combined pericemental area of periodontally compromised abutments with an additional abutment (canine) was

more than combined pericemental area of pontics to be replaced, stress generated was more on abutments. This disproves Ante's law. Hence, it may be a reference, but should not be ultimate criterion in determining the number of multiple abutments.

1. Splinting an additional abutment to periodontally compromised abutments is not required.
2. Ante's law may be a reference, but should not be an ultimate criterion in determining the number of abutments.

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