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Original

Finite element analysis of forces created by root separation and resection modelling

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Abstract: Natural teeth with a healthy periodontal support exhibit stress transfer when functional forces are applied to them. These stress patterns show considerable variations during differing treatment modalities, which may influence both the tooth and supporting alveolar bone. The purpose of this study was to evaluate variations in the stress transfer under functional loads on first molars with periodontal furcation involvement, which were treated either with by root resection or root separation. This study used a two dimensional mathematical model of a mandibular first molar that was subjected to either a root separation or a root resection procedure. An evenly distributed dynamic load (600 N) was applied on two buccal cusps and distal fossae of the molar in centric occlusion. The analysis was performed using an IBM-compatible computer running standard analysis software. It was found that in the root resection model the stress values were maximum on the centre of rotation, and compressive stresses increased towards the middle of the cervical line. For the root separation model, the maximum shear stress values were observed in the distal portion, and a uniform stress distribution was observed in the mesial portion. Shear stress values for bone increased towards the centre in the bifurcation area. The outcomes of this study may be useful as a guide in clinical restorative procedures. (J. Oral Sci. 44, 79-84, 2002)

Key words: Finite element; stress analysis; biomechanics; periodontal treatment.

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Introduction

In response to plaque irritation and microscopic destructive episodes, periodontal pocketing deepens, plaque continues apical downgrowth and an inflammatory cell infiltrate extends laterally and further apically into the adjacent connective tissues. Alveolar bone loss occurs, fibre damage is extensive and the junctional epithelium migrates apically from the cementoenamel junction (1). When periodontal disease progresses around multi-rooted teeth, the destructive process may involve the supporting structures of the furcation area. Elaborate therapeutic techniques may be necessary to treat such furcation, and precise identification of the presence and extent of periodontal tissue breakdown within the furcation area of each multi-rooted tooth is of importance for accurate diagnosis and planning of treatment. In the past these situations were considered untreatable, and hence extraction was common. However, effective treatment methods have now been developed following improvements in the understanding of the pathogenesis of periodontal disease and the anatomy of furcations.

A major principle in the treatment of affected furcations is to eliminate their involvement wherever possible. A variety of methods are available, such as scaling and root planing, furcation plasty, tunnel preparation, root separation

and resection, regeneration of furcation defects, and extraction. Not all of these eliminate the furcation lesion: some provide only for increased accessibility for plaque removal. Many factors such as the degree of involvement, length of roots, degree of root separation, mobility and prosthetic requirements must be taken into consideration when deciding on a mode of therapy (2,3).

Root resection is often the treatment of choice for severe grade-II and grade-III furcations when regeneration is unpredictable (4). It may consist of root amputation, the removal of a root from a multi-rooted tooth, or hemisection, which is the surgical separation of a multi-rooted tooth through the furcation area so that a root or roots may be removed along with the associated portion of the crown (5,6). These management techniques have biomechanical as well as surgical aspects. Natural teeth show optimal stress transfer and absorption of the functional forces due to their structure and morphology. However, following modification of supportive structures by root separation or resection, stress transfer and absorption patterns show considerable variations. This may be a significant factor in determining tooth longevity following these treatment modalities.

The tooth structure is composed of enamel, dentin, pulp, cementum and periodontal ligament, which are non-homogeneous, anisotropic and unsymmetrical with respect to any axis. For these reasons, conventional methods of investigation such as photoelasticity and strain-gauge techniques are unable to provide reliable data on the true stress distribution in the tooth (7).

The finite element method is widely used in the solution of engineering problems. In finite element analysis a continuous structure is modelled with discrete-element mathematical representations by subdividing the continuum into simple geometric elements. The elastic constants E (Young's modulus of elasticity) and v (Poisson's ratio) are specified for the materials modelled, with each element retaining the mechanical characteristics of the original

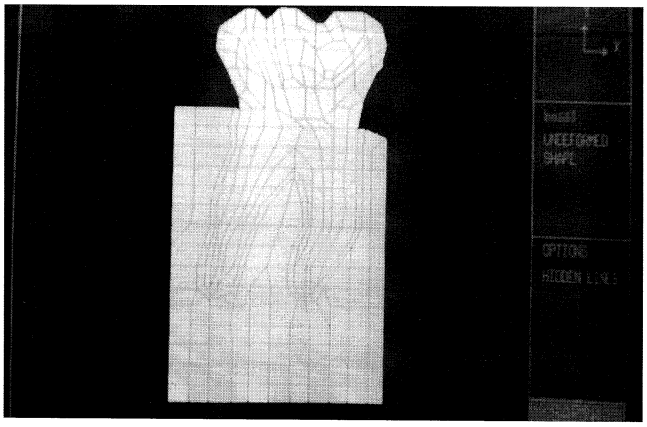


Fig. 1 Mandibular first molar with supporting structure: 329 nodes, 305 elements.

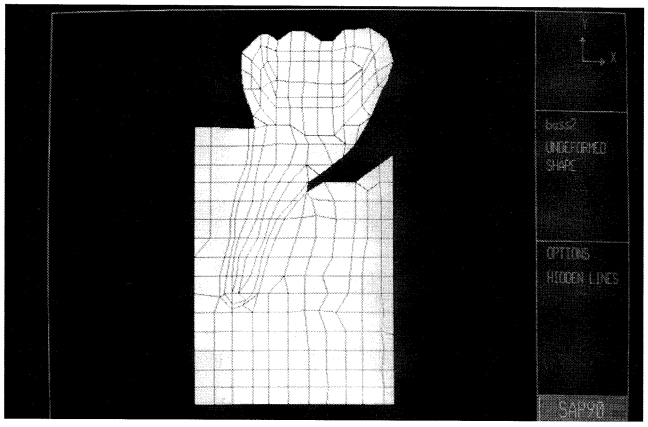


Fig. 2 Same molar as in Fig. 1 following root resection, with the remaining root canal filled with gutta-percha: 320 nodes, 305 elements.

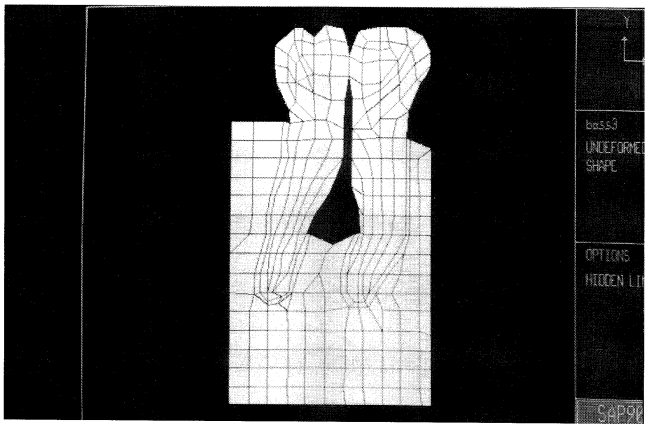


Fig. 3 Same molar as in Fig. 1, with root canals filled with gutta percha, roots separated and clinical crowns restored with ceramic onlays: 295 nodes, 267 elements.

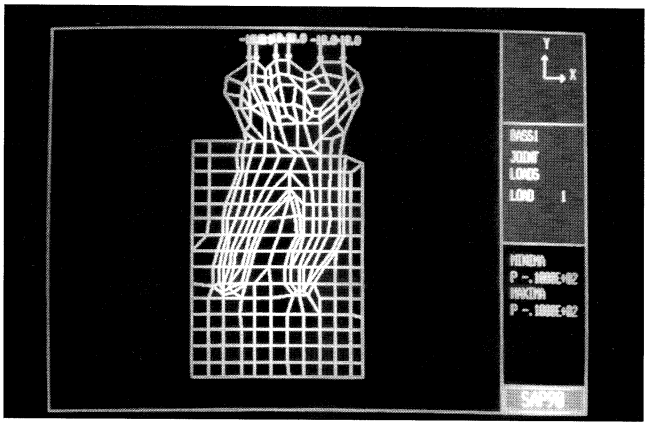


Fig. 4 Evenly distributed 600 N load was applied on six centric stop points.

structure. Equilibrium equations in terms of stresses and/or displacements are written for each of the nodal points and then solved simultaneously on a computer. This approach has also made it possible to quantitatively analyse complex biological systems for which other strategies are usually impractical (8,9).

The purpose of this study was to compare the stress transfer variations under functional loads using finite element stress analysis on a modelled mandibular first molar treated by root resection or root separation, and compare these data with those for an intact tooth.

Materials and Methods

A two-dimensional mathematical finite element model of a mandibular first molar and its supporting structures was used in the study. The geometry of the tooth model has been described by Wheeler (10). The model was made 1 mm thick along z-axis to create a pseudo third dimension. The three variations of the model included the following nodes and thick shell elements:

Model A: Mandibular first molar with supporting structure: 329 nodes, 305 elements (Fig. 1).
Model B: The same molar as model A, but following root resection, with the remaining root canal filled with gutta-percha: 320 nodes, 305 elements (Fig. 2).
Model C: The same molar as model A, but with root canals filled with gutta-percha, roots separated and clinical crowns restored with ceramic onlays: 295 nodes, 267 elements (Fig. 3).

The following assumptions were made regarding the properties of tooth material and its geometry. All the individual vital tissues and materials were presumed elastic, homogenous and isotopic. The corresponding elastic properties such as Young's modulus and Poisson ratio were determined from a literature survey(11), using information from studies by Rubin et al. (12), Petres et al. (13), Tanne et al. (14) and Anusavice (15), and are summarised in Table 1.

Table 1 Typical tooth and material properties

Material properties	**Young's modulus** *(E)***MPa**	**Poisson ratio** *(v)*
Enamel	41400.0	0.30
Dentine	18600.0	0.32
Pulp	0.03	0.45
Periodontal ligament	50.0	0.30
Bone	13800.0	0.26
Ceramic	70000.0	0.25
Gutta-percha	0.69	0.45

It was assumed that perfect bonding existed between ceramic and dentin, and that the influence of the physical properties of the bonding material would be negligible. An average biting force of 600 N was determined from the current literature (16,17). An evenly distributed vertical dynamic load (of 600 N) was applied on the centric stop points on two buccal cusp and distal fossae in centric occlusion. The final element on the x-axis for each model was assumed to be fixed, which defined the boundary condition for our model. The remaining bone structure, which supported the root structure, was assumed to have a rigidity similar to that of natural teeth. The analyses were performed on an IBM-compatible computer running SAP 90 software, and the outputs were transferred to SAPLOT to display stress values (Computers and Structures, Berkeley, California, USA).

Stress values seen in SMAX (maximum stress value observed on the element: -,compressive stress; (, tensile stress) were recorded as principal stresses and were highlighted using colour bars. SVM (von Mises stress value) represents the shear stresses created.

Results

Model A: the shear stress distribution on the molar with healthy periodontium

It was found that shear stress values were maximal around on the upper side of pulp horn (joint 46, 57.8 MPa). The stress distribution around the roots showed a slight increase in the distal portion of the distal root (36-40 MPa), and this finding can be attributed to normal stress transfer to the alveolar bone. A slight increase in the compressive stress above the mesial pulp horn was observed, and in the cervical region this resulted in an increase in the tensile stress on the mesial and distal areas. Towards the roots a compressive stress was evident, and although the stresses on the distoapical part of the distal root were shown to be compressive, they were tensile in the apical region. The adjacent bone showed low and uniform tensile stresses in this region. The distribution of shear, tensile and compressive stresses could be regarded as uniform and at physiological levels, as shown in Figs. 4 and 5.

Model B: distribution of stresses following root resection

During the evaluation of stresses of the remaining root structure it was interesting to observe that the stress was

maximal at the centre of rotation, and zero in the bone surrounding the root. In the root, compressive stresses increased towards the centre of the cervical line, while the mesial and distal aspects showed tensile stresses. Minimum stresses were observed at the tip of the septum, where as maximum compressive stresses were observed on the root structure (Figs. 6,7).

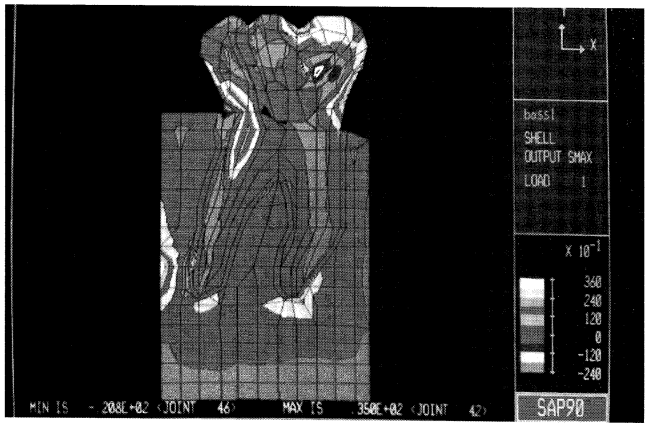


Fig. 5 Compressive and tensile stresses on a molar with healthy periodontium.



Fig. 6 Shear stress values for the same model as Fig. 5.

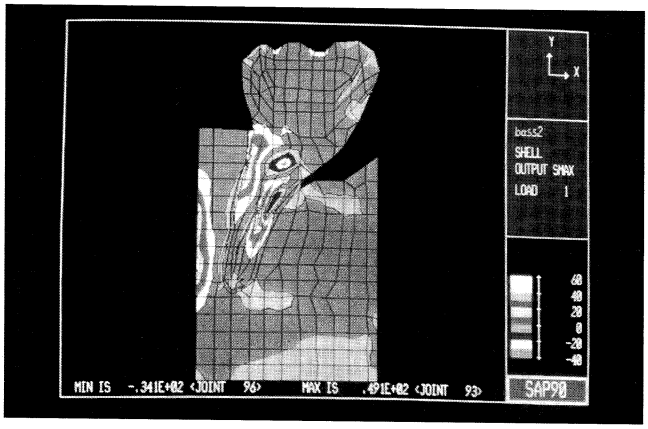


Fig. 7 Compressive and tensile stresses in the root resection model.

Model C: distribution of stresses in the root separation model

During the evaluation of stress the two parts of the tooth structure were examined separately. The maximum shear stress values were observed in the distal portion and mesial aspect of the cervical region. Shear stress values were nearly uniform at the disto-apical edge. Increased tensile

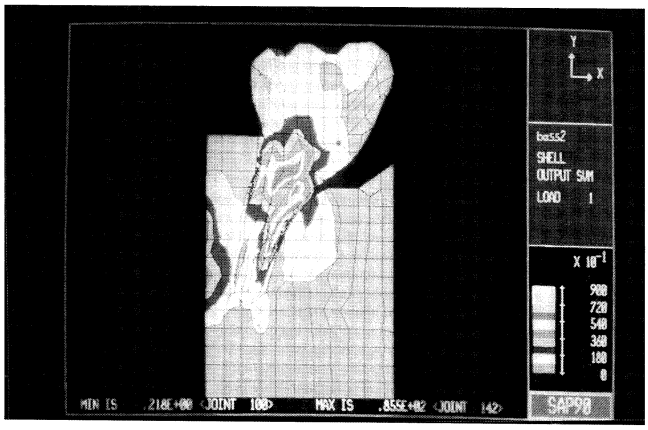


Fig. 8 Shear stress values for the root resection model.

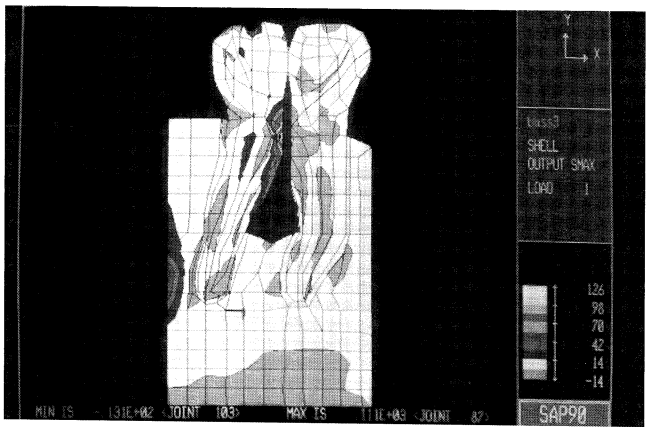


Fig. 9 Compressive and, tensile stresses in the root separation model.

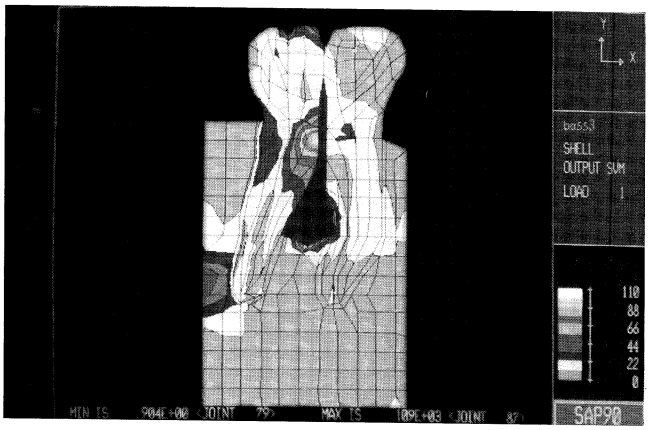


Fig. 10 Shear stresses for root separation model.

stress at the root structure were observed. For the mesial portion a uniform stress distribution was observed except for the distal aspect of bone, where the shear stress values showed a slight increase. The shear stress values for bone were nearly uniform in the bifurcation area, but a slight increase was observed towards the centre, as shown in Figs. 8 and 9.

Discussion

The finite element method has become a useful numerical technique for the analysis of stress in complex structures (14). Two- and three-dimensional finite element stress analysis has been extensively used in dentistry (18). Although the biological changes that occur in bone and tooth with orthodontic (14,19,20), prosthetic (11,21,22) and implant (20,9) treatments, have been described in many studies, few have investigated the outcomes of periodontal treatment (23). In the present study a finite element model was formed from two-dimensional mathematical models of root separation and root resection. A pseudo third dimension was created by making the model 1 mm thick along the z-axis, allowing analysis of the outcome of the treatment procedures as if a three-dimensional geometry existed. A molar with a healthy periodontium was created to act as a control. Three principle stresses on different regions for the tooth and bone were defined.

The stress distribution around the roots of the molar with a healthy periodontium was found to be uniform. The stress was concentrated around the cervical region of the crown, whereas the stress pattern moved to the root structures when the supporting bone was lost. The compressive, tensile and shear stress values were lower in model A than in models B and C.

In the root resection model (model B), low stress values were observed in the supporting bone tissue. This may have resulted from the stress values being collected once bone healing was assumed to be complete following the surgery. This finding indicates that the root was strong enough for it to be used as an abutment where necessary.

In the root separation model (model C), it was observed that the stress was smaller in the mesial root than in the distal root. The increased stress levels on the root structure may have been the result of recontouring the furcation area to gain access for hygiene procedures. The low stress values observed on the mesial root portion may suggest that this part is suitable for prosthetic restorations.

The results from this study are limited by the two basic models that are commonly used in periodontal treatment. Although the stress-strain relationships of the tissues and materials were analysed under the application of an evenly distributed dynamic load, it should be kept in mind that the real stress distribution would vary with load changes during mastication.

The accurate simulation of loading as well as the geometries of root morphology and bone contours may affect the distribution of stress, and this needs to be studied further.

The results reported here should therefore be interpreted qualitatively, but we suggest that they can be used as a guide for clinical work.

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