An Investigation Behavior Into Dental Biomechanical Analysis

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Abstract

The aim of the study is to evaluate the Von Mises stress distribution of different human teeth model. Three-dimensional model of the maxillary central incisor, mandibular first molar and mandibular central incisor were constructed using Auto CAD (Auto CAD 2007) software and then imported to ANSYS software (ANSYS V.10) to get finite element model of each teeth. A loading simulating the 200N force was applied vertically and with different inclination to the crowns. Then same loading was applied vertically but the load was distributed along the incisal area for the incisors and at occlusal margin for the molar. Finally the crown was considered as porcelain material and the vertical load was distributed along each tooth and the Von Mises stresses were calculated. The results showed that the increase in the loading angle from 0°, 26° to 45° resulted in an increase in tooth Von Mises stress which means increase the probability of tooth failure. When the load distributed along wide region the ability of model to fail for the same loading will be decreased. Also when the crown consider as porcelain material there will be increasing Von Mises stress compare with the enamel crown for the same load region and load value

Introduction

In a three-dimensional Finite Element Analysis, the system is divided into a large number of elements and each finite element is assigned a predetermined number of nodes. Those elements are then connected at their nodes. The element stiffness matrix is formed by considering the force–displacement relations of the nodal displacements and the rotations of each element. These element matrices are then combined to give the global stiffness matrix. The utilization of the initial conditions, boundary conditions, and given loading characteristics yields the nodal displacements. The resulting strains are obtained from the strain– displacement relations, and the required tensile, compressive, and shearing stresses are found through the stress–strain relationships. Those values are further manipulated to obtain the resultant element stresses [1]. In this study, the geometry of the each dentition was adapted from Wheeler [2]. The elements used were twenty-node solid elements, which are well suited to three-dimensional analysis was used for meshing the imported AutoCAD structural model for each tooth.

Tooth Anatomy

The human teeth arranged into arches the maxillary arch, which is fixed and the mandibular arch, which is movable. The teeth aligned in the form of a curve in both arches, and the maxillary arch is somewhat larger than the mandibular arch. In the human mouth there are four different types of teeth, each specialized for different functions. Each tooth composed of connective tissue, the pulp covered by three calcified tissue, dentine, enamel and cementum. The anatomical crown of a tooth is a part covered by enamel, where as the clinical crown of a tooth is the part that project in to the oral cavity. [3]

The root is the part of the tooth, which hidden under the gum. The root makes up two thirds of the tooth, and serves to fasten the tooth into the jawbone it covered by cement and includes the neck, adjacent to the crown. The number of roots range from one to three. In addition, there is the periodontal membrane/ligament, which is a fleshy tissue between tooth and the tooth socket; it holds the tooth in place. The fibers of the periodontal membrane embedded within the cementum. Figure (1) shows the structure of the tooth includes dentin, pulp and other tissues, blood vessels and nerves imbedded in the bony jaw. Above the gum line, the hard enamel covering protects the tooth[4].

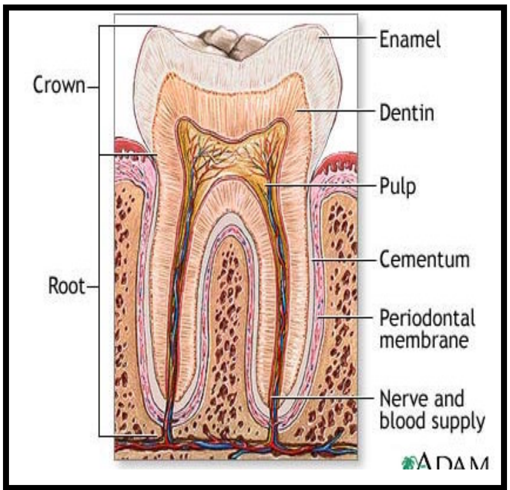

Figure (1) shows the structure of the tooth [5]

Teeth Classification

The teeth classified as incisors, canines, premolars and molars. The incisors cut food by their edges. The canines ("cuspids" or "eye-teeth") and this have a pointed cusp for tearing and assist in cutting. The premolars ("bicuspids") assist in crushing food. The molars crush and grind food. The third molar ("wisdom teeth") is highly variable teeth appearing in the late teens or early twenties.[3] At birth, the individual has no functioning teeth in the mouth, the diet in early infancy is fluid or semi-fluid; therefore there are unnecessary until the reduction of solid food is required. Human teeth classified into two types: deciduous or primary teeth "milk teeth" which are appear in the oral cavity between the ages of 6 months and 2.5 years. The second type is the permanent or adult teeth begin to appear in the oral cavity at the age of about 6 years and they have replaced the deciduous teeth by about 12 years.[2] Figure (2a) shows primary dentition, figure (2b) shows permanent dentition.

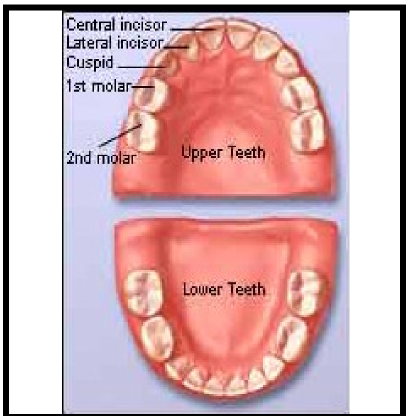

Figure 2a: primary dentition [6]

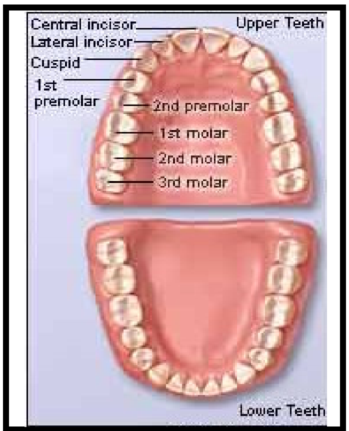

Figure 2b: permanent dentition [6]

The Crown and Root

Each tooth has a crown and root portion. The crown covered with enamel, which is the hard and brittle outer portion of the tooth that envelops the softer dentin; it comprises defective carbonate rich apatite crystals arranged in enamel rods or prisms that lie nearly perpendicular to the DEJ [7]. In addition, the root portion covered with cementum, the calcified connective tissue. Cementum is the thinnest at the cementoenamel junction and is thickest at the apex. The cementum, anchors the tooth to the alveolus via the periodontal ligament.[8]

The crown and the root join at the cementoenamel junction. The main bulk of the tooth is composed of dentine, dentin, conversely, is a biological composite that is tougher than enamel and similar at the nano structural level to bone. It has a unique architecture consisting of dentinal tubules.[7] Table (1) shows the material properties of the teeth tissue.

The DEJ is a complex and poorly defined structure that unites the brittle overlying enamel with the dentin that forms the bulk of the tooth. This junction, also called the cervical line In addition, this structure appears to confer excellent toughness and crack deflecting properties to the tooth.[9] Cross section displays a pulp chamber and a pulp canal, which normally contain the pulp tissue. The pulp chamber in the crown portion mainly, and the pulp canal is in the root. The four tooth tissues are enamel, cementum, dentine and pulp. The first three are known as hard tissues, the last as soft tissue. The pulp tissue furnishes the blood and nerve supply to the tooth.

Table (1) Material properties assigned to natural human teeth tissue		
Materials	Young Modulus (E) (GPa)	Poisson ratio (υ)
Enamel	84.1 [10]	0.33 [10]
Dentin	14.7 [10]	0.31 [11]
Cementum	13.7 [12]	0.35 [12]

The root portion of the tooth may be single or multiple, with one apex or terminal end, as usually found in anterior teeth and some of the premolars; or multiple, with a bifurcation or trifurcation dividing the root portion in to two or more extensions or roots with their apices or terminal ends, as found on all molars and in some premolars. That portion of the jaw which serves as a support for the tooth is called alveolar process. The bone of the tooth socket is called the alveolus (plural, alveoli). Both maxillary and mandibular anterior teeth have only one root.

Mandibular first and second premolars and the maxillary second premolar are single-rooted, but the maxillary first premolar has two roots in most cases, one buccal and one lingual. Maxillary molars have three roots, one mesiobuccal, one distobuccal and one lingual. Mandibular molars have two roots, one mesial and one distal. It must be understood that description in anatomy can never follow a hard and fast rule. Variations frequently occur. This is especially true tooth roots. The crown portion never covered by bone tissue after it is fully erupted, but it partly covered at the cervical third in young adults by soft tissue of the mouth known as the gingival or gingival tissue, or gum tissue. In older persons, all of the enamel may be exposed in the oral cavity, and frequently some cervical cementum. [2]

Incision Force

This is the function of rasping or biting off a portion of food introduced into the mouth that is of suitable size for chewing 13. Bite force is compressive force as a result of the coordination between different components of the masticatory system (muscles, bones and teeth) as shown in Fig. (3). According to Hatch, et al., in 2000, the bite force and the number of occluding teeth are determinant factors in the chewing performance. Maximum bite force understood as the capacity of the mandibular elevator muscles to perform a maximum strain of mandibular teeth against the maxillary teeth, under favorable conditions. [14]

During incision the mandible bites in a protrusive, or more frequently, a lateral protrusive position so that the anterior teeth, which present chisel-like cutting edges well designed for this purpose, can readily penetrate the food mass as the mandible is further closed in a retruded direction. It believed that the anterior teeth serves as a tactile sensory organ during incision in primates for the testing of physical properties of food and that they must be able to perform this function free of posterior tooth contact. At the completion of the incisive bite, the food rests upon the tongue so that it can be directed to the posterior teeth for chewing. [13]

The average biting force of a person with natural dentition is approximately 77 kilograms (170 pounds) in the posterior part of the mouth. At first glance, force of this magnitude does not appear to be particularly great. The bite force depends on muscle volume, jaw muscle activity, and the coordination between the various chewing muscles.[15] However, this is a measure of the force when it distributed over a number of teeth. Incidentally, the biting force that can be exerted with artificial dentures is markedly less than that of the normal dentition, another reason for preserving the natural dentition for as long as possible.[16]

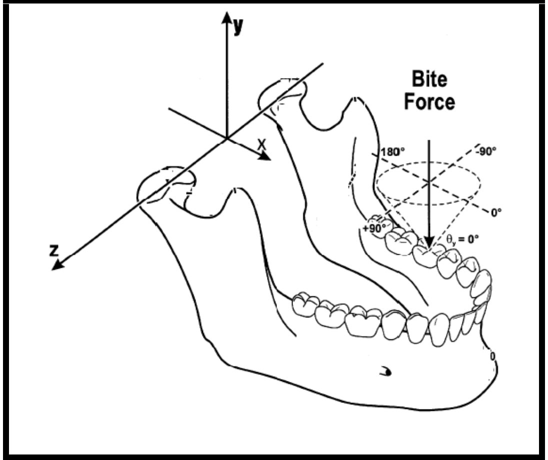

Figure 3: Biting force in human dentition [17]

Chewing Force

The chewing force is vertical force and cyclic in nature. The chewing phase serves to reduce the particle size of the food and mix it sufficiently with saliva so that the consistency of the resultant bolus will allow the swallowing act to take place.[13] Chewing consider the first step in the process of digestion and is meant to prepare the food for swallowing and further processing in the digestive system. During chewing, the food bolus or food particles reduced in size, saliva produced to moisten the food and flavors released. Taste and texture of the food are perceived and have their influence on the chewing process.[15]

Stress Analysis of Human Dentition

The problem of tooth stresses is very complicated because of the non-homogeneous character of tooth material and the irregularity of tooth contours.[18] The tooth structure is composed of several different materials: enamel, dentin, pulp, cementum, periodontal ligament, and bone. Each of these has widely varying properties. The problem is further complicated by large variations (both in magnitude and in direction) of chewing forces. Conventional methods of stress analysis in which exact solutions may be obtained are not useful in problems as complicated as this. The non-homogeneities and discontinuities, as well as the three-dimensional nature of the tooth and the forces acting on it, preclude the derivation of a description of the structure using differential equations.[19] However, computer techniques, such as finite element analysis, lend themselves to problems of this nature. The FEM is a computerized numerical iteration technique used to determine the stress and displacements through a predetermined model.[20]

Materials and Methods:

Three-dimensional structural models of maxillary central incisor, mandibular first molar and mandibular central incisor were created by Auto CAD software. The geometry used for the tooth model was described by Wheeler. Then these model imported ANSYS software and get finite element model of each teeth under study. All of the materials were treated as homogenous, isotropic and linear elastic.[19] The effects of the periodontal ligament and cementum were omitted, the dental pulp was modeled as avoid4. The model was assumed to be fixed at all the root region. The material properties of the various simulated components were assigned according to Table (1).

A 200 N force was applied vertically at two incisal point with different inclination; a) vertical load on the incisal edge, b) 26 degree inclined vertically, c) 45 degree inclined vertically. Then the 200 N vertical load was distributed vertically along the incisal edge for incisors and occlusal edge for molar. And finally the crown considered as porcelain crown and 200N vertically distributed load was applied. Stress distribution and stress values were then calculated by considering Von Mises stress criteria.

Result:

When 200N load was considered and the loading angle was increased from 0° to 26° to 45° with the longitudinal axis of the tooth there would be an increase in the Von Mises stress which indicate an increase in the probability of failure of the tooth model as the load angle increase from 0° to 26° to 45°. ANSYS software used three main steps to perform result of model analysis as follows: the preprocessing, the solution, the post processing; the preprocessing stage consists of geometric modeling of a structure, discretization of a model into smaller elements by the proper selection of an element type, and assigning the material properties. The elements are connected by nodes. The final step in preprocessing is the application of boundary conditions, that is, forces and displacement constraints are applied at specified nodes. Depending on the complexity of the model, computer software can process the discretized model in different stages. A set of simultaneous equations with thousands of variables are solved to achieve the desired results. The postprocessing stage consists of the graphical presentation of results. Typically, the deformed configurations, stress distributions at nodes and elements are computed and displayed at this stage 18. The result viewed in different methods but the simplest known as (contour value) which used to describe the results in our model. This technique used the color code to represent the results. The contour colors represent the range of the stresses, from the low value (blue color) to the high value (red color). The area with red color is the maximum value of the stress which is the first region to be failed when the teeth model is loaded by high stress.The maxillary central incisor model was applied by 100N compression vertical loading at two points of incisal edge. The maximum value for the Von Mises stress occurred in the region where the load was applied. With incisal loading, the stress was locally and drastically increased toward the incisal edge. The result of Von Mises for the each loading angle will be shown in figure (4 a, 4b, 4c) in which nodal contour value represented as a color coded for different faces of the maxillary central incisor. The dark blue color represents the compression stress while the red color represents the tensile stress. The result for the maximum and minimum Von Mises stress for the three loaded case will be shown in Table (2).

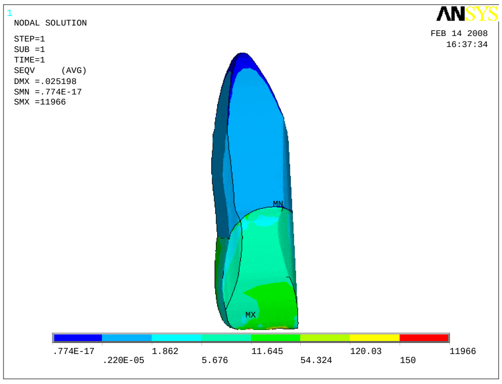

Figure 4a: Von Mises stress in maxillary central incisor with vertical loading

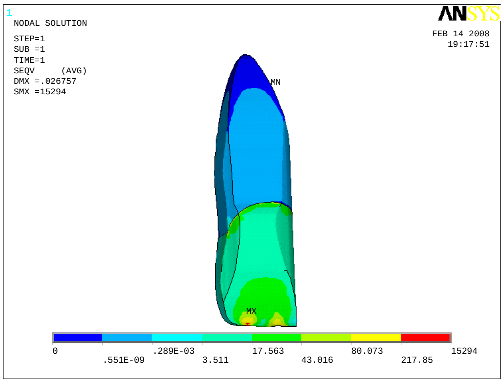

Figure 4b: Von Mises stress in maxillary central incisor with inclined loading with 26

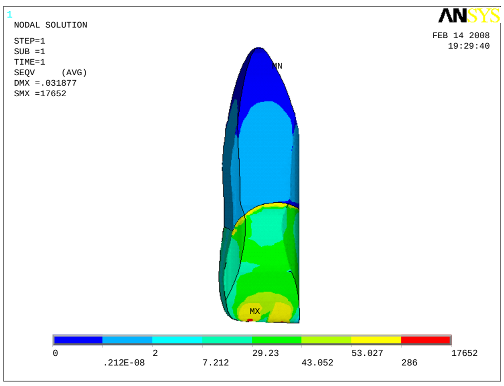

Figure 4c: Von Mises stress in maxillary central incisor with inclined loading with 45
°

Table (2) Maximum and minimum Von Mises stress for the maxillary central incisor

Load angle	Von Mises stress Maximum value (N/mm^2)	Von Mises stress Minimum value (N/mm^2)
Vertical loading angle	11966	0.774E-17
inclined loading with 26°	15294	0
Inclined loading with 45°	17652	0

For mandibular first molar a load of about 100N compression vertical loading was applied at two points of occlusal edge. The maximum value for the Von Mises stress occurred in the region where the load was applied. With occlusal loading, the stress was locally and drastically increased toward the occlusal edge. The result of Von Mises for the for each loading angle loading will be shown in figure (5 a, b, c, d) in which nodal contour value represented as a color coded the model. The dark blue color at the tip of the root represents the compression stress while the red color at the occlusal area represents the tensile stress. As the load angle was inclined with an angle of 26° there will be an increase in the Von Mises stress. The result for the maximum and minimum Von Mises stress for the three loading angle will be shown in table (3).

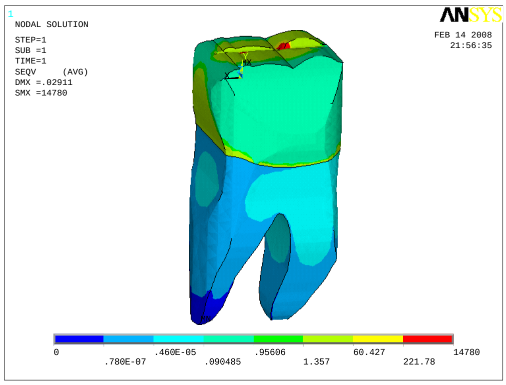

Figure 5a: Von Mises stress in mandibular first molar with vertical loading

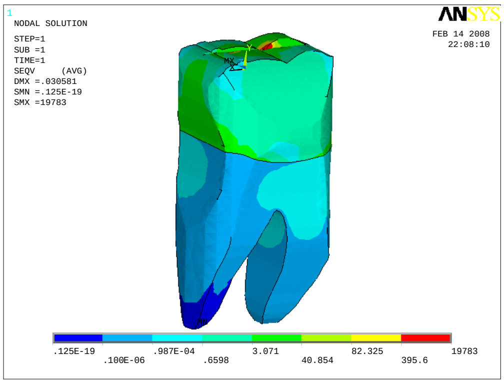

Figure 5b: Von Mises stress in mandibular first molar with inclined loading with 26

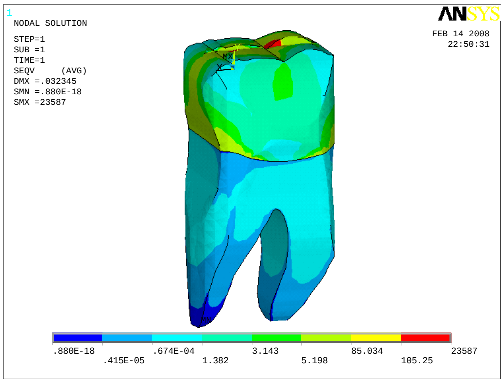

Figure 5c: Von Mises stress in mandibular first molar with inclined loading with 45°

Table (3) Maximum and minimum Von Mises stress for the mandibular first molar.		
Load angle	Von Mises stress Maximum value (N/mm^2)	Von Mises stress Minimum value (N/mm^2)
Vertical loading angle	14780	0.87951E-20
inclined loading with 26°	19783	0.125E-19
Inclined loading with 45°	23587	0.880E-18

For mandibular central incisor a load of about 100N compression vertical loading was applied at two points of incisal edge. The maximum value for the Von Mises stress occurred in the region where the load was applied. With occlusal loading, the stress was increased toward the incisal edge. The result of Von Mises stress for the each loading angle will be shown in figure (6 a, b, c) in which nodal contour value represented as a color coded for the mandibular central incisor model. The dark blue color represents the compression stress while the red color at the incisal edge represents the tensile stress. When the load was inclined with an angle of 26° there will be an increase in the Von Mises stress. The result for the maximum and minimum Von Mises stress for the three loaded case will be shown in table (4).

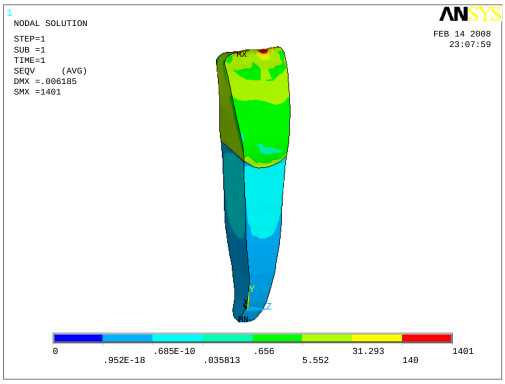

Figure 6a: Von Mises stress in mandibular central incisor with vertical loading

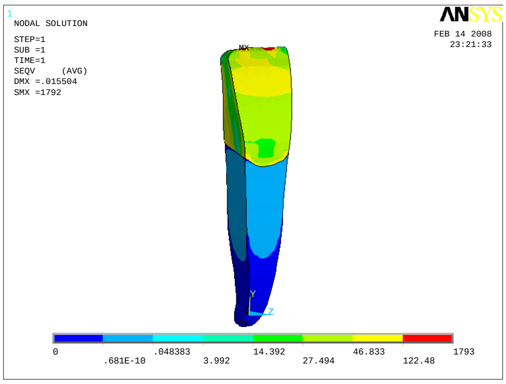

Figure 6b: Von Mises stress in mandibular central incisor with inclined loading with 26°

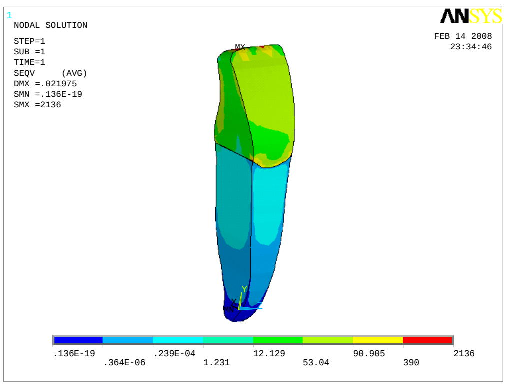

Figure 3c: Von Mises stress in mandibular central incisor with inclined loading with 45

Load angle	Von Mises stress Maximum value (N/mm^2)	Von Mises stress Minimum value (N/mm^2)
Vertical loading angle	1400.6	0
Inclined loading with 26°	1792.3	0
Inclined loading with 45°	2135.7	0.136E-19

Table (4) Maximum and minimum Von Mises stress for the mandibular central incisor.

Conclusion:

The result obtain by Von Mises stress criteria demonstrated that the increase in the loading angle resulted in increase in the Von Mises stress values which mean increase the probability of tooth failure. Based on assumption involved in this study with the fact that computer simulations were simplified, the results of the study might differ from the values of stresses encountered by teeth in real situation There fore the result were presented and considered qualitatively, not quantitatively, in order to offer more insight into the general mechanical performance of teeth. FEM is an effective tool that has been adapted to biomechanical research. The results of biomechanical research on computational models of biological structures are useful, because they enable us to locate the weak points in the material or in the design of any structure after loading.

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الخلاصة:

إنّ هدفَ الدراسةِ هو تقييمَ توزيعَ إجهادِ Von Mises لنماذج مختلفة من أسنان الإنسان وهي القاطع المركزي في الفك الأعلى والقاطع المركزي للفك السفلي والضرس الأول للفك السفلي. أستعمل برنامج (AutoCAD 2007) لرسم النموذج ثلاثي الأبعاد لكل سن من الأسنان التي أستخدمت للدراسة ومن ثم تحويلها الى برنامج العناصر المحددة (ANSYS V.10) للحصول على نموذج العنصر المحدد لكُلّ سن من الأسنان التي أستخدمت في هذه الدراسة.

تم تسليط حمل عمودي بمقدار ٢٠٠ نيوتن بشكل عمودي وبزوايا مختلفة على منطقة التاج. نفس الحمل سلط بصورة عمودية ولكن وزع على طول منطقة الحافة العليا للقواطع والاضراس لحالتين الاولى بأعتبار التاج مكون من المينا والحالة الثانية أعتبار التاج مكون من الخزف وتم أيجاد قيم اجهاد (VonMises).

وتم استنتاج انه الزيادة في زاوية التحميل (مِنْ صفر°، ٢٦° إلى ٤٥°) أدت الى الزيادة في اجهاداتVon Mises مما يؤدي الى زيادة فشل النموذج وعندما يتم توزيع الحمل على مساحة اوسع تقل احتمالية الفشل، وعند أستخدام الخزف بدلا من المينا زادت احتمالية فشل النموذج لنفس قيمة الحمل وبنفس منطقة تأثير الحمل