FINITE ELEMENT METHOD (FEM) : A RESEARCH TOOL IN DENTISTRY

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Abstract

The scientific alliance between the fields of engineering & dentistry has yielded a worthy progeny of validated concepts.

Finite element method (fem) which is a computerised predictive method to analyse the biological form has been borrowed from the domain of engineering where it is a well established procedure for measuring the effect of stress & displacements on engineering materials.

From revealing the concepts of centre of resistance & moment to force ratios, to determining the effect of implants on bone, & from modelling craniofacial growth to the analysis of stress & success of fixed & removable partial dentures, the fem has been a real boon to the field of dentistry in general & Prosthodontics & Orthodontics in particular.

The following text to decipher the various dimensions of Dental research, that have been enlightened by finite element method & thereby have helped the field of dentistry to grow & blossom as a science.

Introduction

The FEM is a fairly well-known research adjunct in Orthodontics. It can be used to analyze the stress distribution patterns in the tissues after application of force. It is a numeric analysis technique done on high-fidelity computers with powerful software, allows a reasonable approximation of the biologic tissues through computer aided designing (CAD), and permits detailed analyses of various force applications on structures such as teeth, bones, and joints. With the help of recent experiments on animal and human cadavers, quantification of mechanical behavior of various tissues is possible. The properties elucidated from these experiments are mostly homogenous and isotropic but can be relied on safely. The essence of the FEM study of biologic tissue is its ability to elucidate the qualitative nature and relative trends of the process rather than specific values. Therefore, the FEM is reasonable for elucidating the biomechanical effects occurring on tooth movement.[1] Apart from Orthodontics, the FEM has been applied to other branches of dentistry as well to expand research work in prosthodontics, implantology, and surgical procedures.

Historical Background

1678-Robert Hooke set down the basis for modern finite element stress analysis as Hooke's law.

1941-Hernikoff presented a solution of elasticity problems using "frame work method".

1943- Courant's presented a paper, which used piecewise polynomial interpolation over triangular sub regions to model torsion problems.

1955- Book by Argyris on energy theorems and matrix methods laid a foundation for further developments in finite element studies.

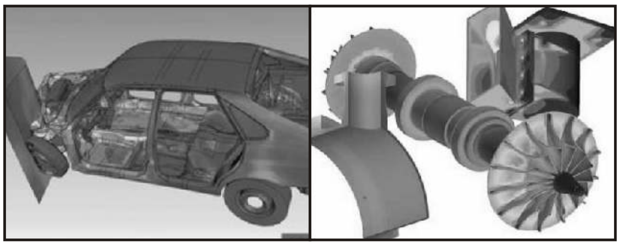
1956-Turner et al derived stiffness matrices for truss, beam and other elements.

1960- Term finite element was coined by Clough. Engineers used the method for approximating solution of problems in stress analysis

1967-Zienkiewicz and Chung published the first book on finite element methods

1970-mathematical foundations were laid

1976-Weinstein et al was first to use FEA in implant dentistry



Finite element method was firstly used in automobile industry to analyse crash testing of cars and assess structural behaviour of machines.

Applications of FEM

In the general field of Medicine, FEM has been applied mainly to orthopedic research[2-7] in which the mechanical responses of bony structures relative to external forces were studied.

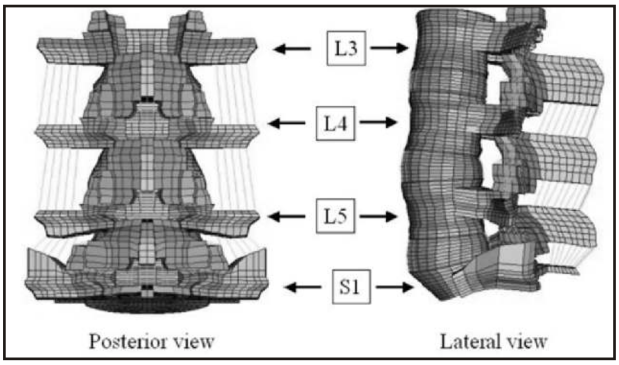


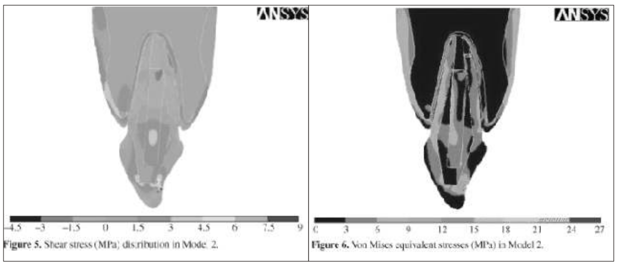
Figure showing effect of stress over spine. The spine structures are modelled in computer environment and environmental factors are applied.

The FE method was introduced into Dental Biomechanical Research in 1973 (Farah et al., 1973) and since then has been extensively applied to analyze the stress and strain fields in the alveolar support structues

(Tanne et al., 1987, 1998; Middleton et al., 1990, 1996; Cobo et al., 1993; Bourauel et al., 1999; van Driel et al., 2000; Provatidis, 2000; Qian et al., 2001; Toms and Eberhardt, 2003).[8]

Finite element method has been used in the field of dentistry to study a wide range of topics, such as the tooth structure,[9-12] biomaterials[13-15] dental implants[16-19] and root canals.[20]

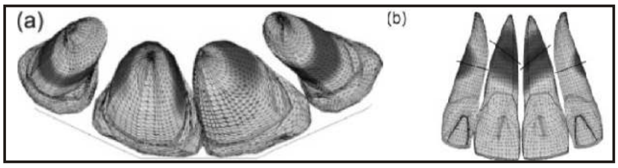
Finite Element Analysis used to analyse endodontic restorations



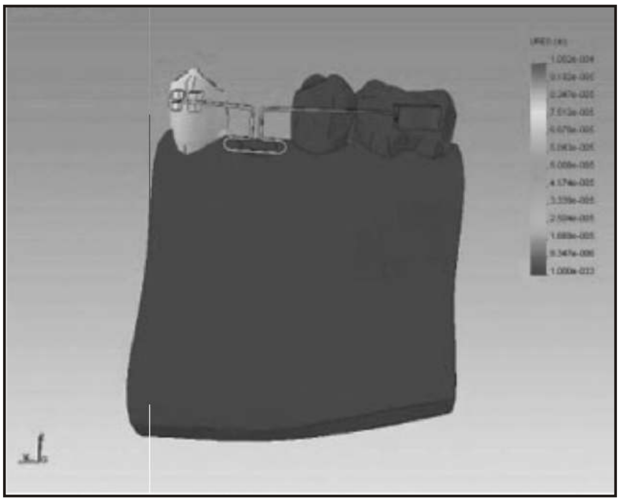
FEM analysis to assess success of Root canal treatment

FEM used to plan and analyse difficulty of treating third molar impaction

In Orthodontics, FEM has been used successfully to model the application of forces to single-tooth systems & multi tooth models. Alveolar bone loss was shown to lower the center of resistance of the tooth and alter the stress patterns on the root.[21-23] Similar changes were observed in altering root length.[24]



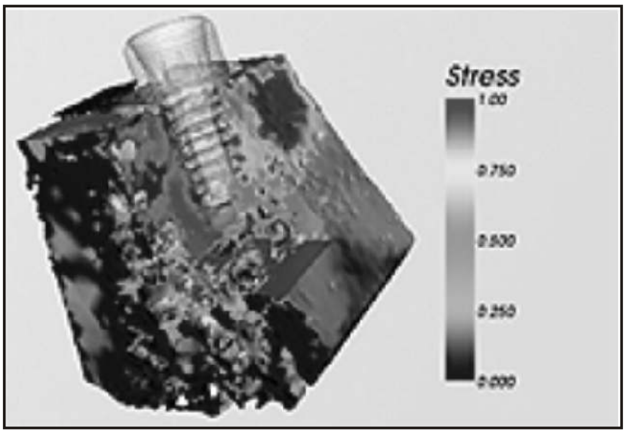
FEM analysis to analyse stress on tooth after Orthodontic load application



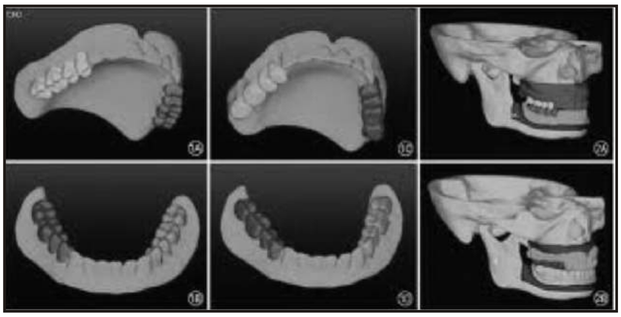
FEM used to assess tooth movement after Load application

FEM was also used to show that areas of bone remodelling in vitro corresponded with the same areas in vivo.[25] Canine retraction has been modeled by FEM. The stresses in the periodontal ligament (PDL) were quantified during canine retraction in several studies.[26-28] The center of rotation was determined to be two-fifths of the root length from the CEJ.[29] Recent work focusing on the more complicated rendering of the first molar has shown that stress is concentrated in the furcation, not the apex.[31]

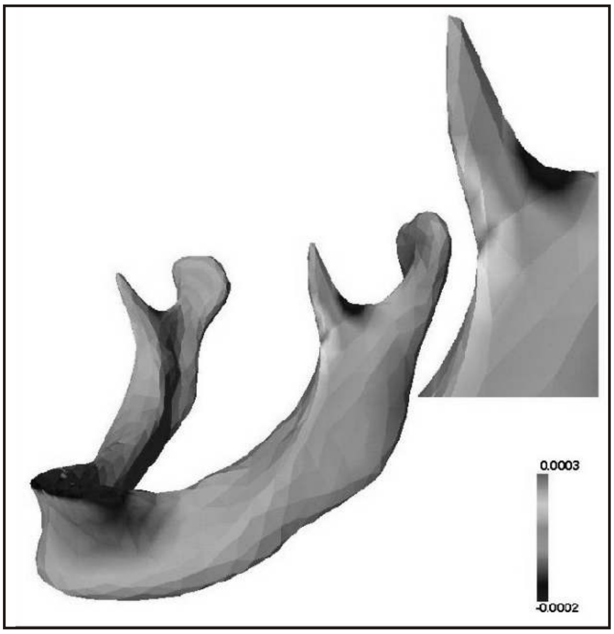
In Prosthodontics the finite element method has been widely used for assessing stress distribution and design evaluation of implants[32-34] and also for analysis of fixed and removable partial dentures[35-37] with an emphasis on the periodontal ligament[38]



FEM used to analyse area of placement and success of Prosthetic implant



FEM for analysis of dentures and stress areas



FEM for planning implant supported complete dentures

Though the FEM is a powerful tool for the analysis of complex structures, the outcome of the FE analysis is dependent on the formulation of the problem. Thus, FE analyses of the load transfer from the tooth through the PDL to the alveolar bone must account for the physical properties and morphology of the periodontium. Despite the fact that the PDL is known to be a nonlinear visco-elastic material, most of the previous FE models incorporate homogeneous, linear elastic, isotropic, and continuous PDL properties. At the same time, the morphology of the alveolar structures has been considered a 'solid' and has not been adjusted for differences in micromorphology.[8]

The Finite Element Method (FEM) makes it possible to analytically apply various force systems at any point and in any direction. Experimental techniques on patients are usually limited in applying known complex force systems. It is very important to keep in mind that the FEM will give the results based upon the nature of the modeling systems and, for that reason, the procedure for modeling is most important[39].

FEM has many advantages over other methods unmasked by the ability to include heterogeneity of tooth material and irregularity of the tooth contour in the model design and the relative ease with which loads can be applied at different directions and magnitudes or a more complete analysis.[40]

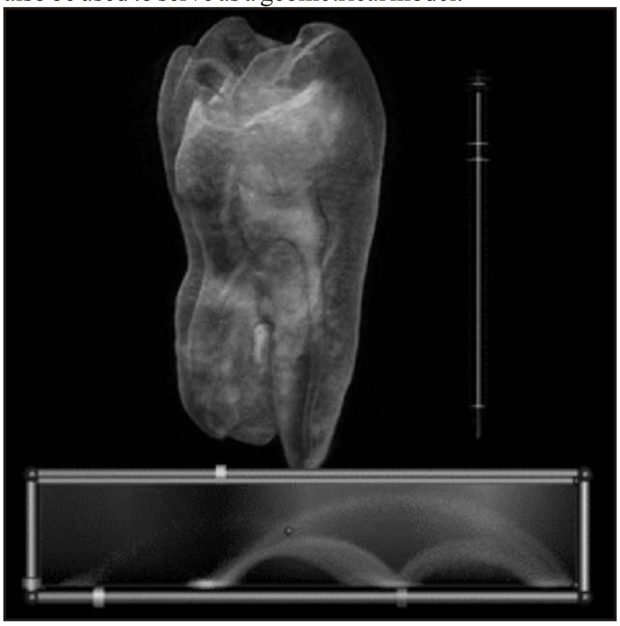
The advent of the mini-computers has made the technology to improve drastically and it has covered a wide area in engineering industries as well. In this case the computers obtain the solution, as they are faster and accurate. The solutions obtained are nearer to actual solution. Nowadays the numerical method has made its mark in all engineering industries as it is efficient, economical, reliable and faster in providing the solution. Some of the analysis packages in market are ANSYS, NASTRAN, ABACUS, NISA, WECAN, etc.

Basic Steps Involved In Finite Element Analysis

For any solution following are the steps involved in finite element to analyse a structure.

Construction Of Geometrical Models

The first requirement for the analysis is the geometrical model. These can be created either in analysis package itself or the model can be created in any CAD packages and can be imported to the analysis packages. In order to do this the model has to be saved with extension *.iges or *.igs or *.sat. A computed tomography image(fig ct img) can also be used to serve as a geometrical model.



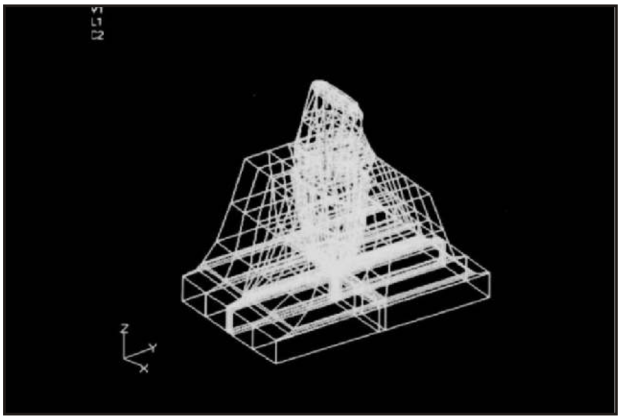
Geometric model obtained bt CT scanning

Although teeth are 3D structures, many of the reviewed tooth models are 2D. Two dimensional model offer excellent access for pre and post processing and because of the reduced dimensions, computations capacity can be preserved for improvement in element and simulations, quality on the other hand, 3D models, although more realistic with respect to dimensional properties, are generally are in are coarse with element that are far upon their ideal shapes.

Moreover, examination of the model is far more difficult because of its dimension, time and memory regarding to analyse the problem. Depending on the investigated structures and boundary condition in same instance 2D modeling may be justified as reuse or even sensible simplification.

Discretization Process

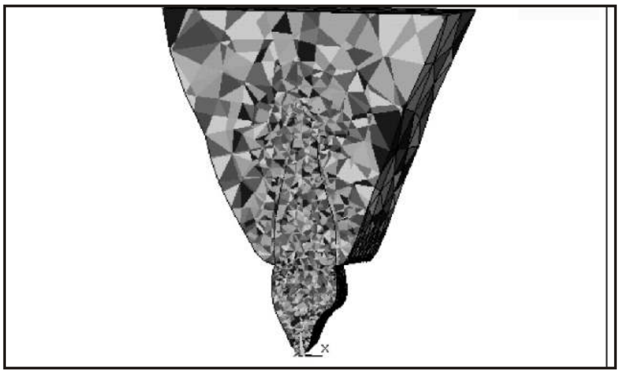
Discretization is a process of dividing the domain / component into number of elements & nodes. For this, an assumption is made that the elements are interconnected by nodes. The main idea behind the discretization process is to improve the accuracy of the results. This is because if the entire component is divided into number of elements, then the stress distribution in each element will be nearer to the actual results and the user gets accurate plot of the stress distribution in a component.



Discretization of the Model

Applying Material Properties

In this step the mechanical properties such as young's modulus, Poisson's ratio etc., are defined to the component. This is done to feed the values for calculation of the solution. These values impart the natural properties to the built up model so that it can behave and react in the same way as a natural biologic body would, when subjected to external stimuli(for ex stress).



Applying material properties to the FEM model

Applying Element Properties

Now the domain / component is divided into number of elements. For this element property is to be defined. First of all user has to define the type of element. There are several types of elements available to be implemented to the domain component.

Defining Boundary Conditions And Nature Of Problem

The boundary conditions here mean that whether the domain structure / component perform static or dynamic action. The boundary condition is selected based upon the mode of analysis such as structural, dynamic, thermal, fluid etc.

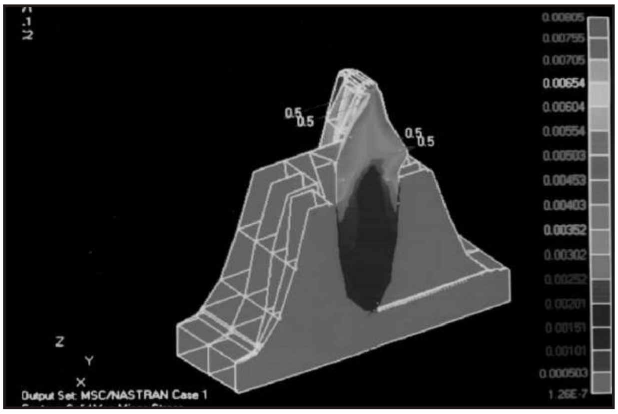
Application Of Load

After the application of boundary conditions, the discretized domain is subjected to known loads. The application of loads depends upon the geometry of the component. The load is applied on the nodes.

Different types of loads: Forces / Moments, pressure, gravity. - For structural problems. Gravity, radiation, convection, temperature For thermal problems.

Solution

The results can be obtained instantly and is most accurate. It consists of model images representing levels of stress by various colours which can be directly read from a color chart(provided below the image). The results can be tabulated and subject to analysis.



Application of load & solution

Conclusion

The finite element method (FEM) is an engineering tool that has shown friendly endeavours into the field of dentistry and dental and biomedical research. It is a highly precise technique aiming to unfold the various key research points in the field of research. So far it has proved to be a wonderful method for simulating conditions, occurring intraorally, directly into the computer environment and generating comparable results. It is supposed that in future the FEM would be a key research tool in dentistry.

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