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A Marvel Of Modern Technology: Finite Element Model

Abstract:

In the last decade the application of a well proven predictive technique the Finite Element Method, originally used in structural analysis has revolutionized dental biomedical research. The finite element method is a highly precise technique used to analyze structural stress. It has been used in civil and aerospace engineering for years. This method uses computers to solve large number of equations to calculate stress on the basis of physical properties and the structures being analyzed. Finite Element analysis has also been applied to the description of physical form changes in biologic structures particularly in the area of growth and development and orthodontics. Finite element method which is an engineering method of calculating stresses and strains in all materials including living tissues has made it possible to adequately model the tooth and periodontal structure for scientific checking and validating the clinical assumptions.

Key words: Finite element method, stress-strain level, orthodontic tooth movement.

Introduction

Since the beginning of history of humanity health and beauty has been the most important issue for human ambition and action. In that context teeth have a special meaning in esthetics. This makes it essential to carefully consider tooth movement in orthodontic therapy[1]. The study of orthodontic biomechanics requires the understanding of the nature of stress and strain in the periodontium induced by orthodontic forces[2]. The Finite Element Method (FEM) is a powerful computer-simulation tool in solving stress-strain problems in the mechanics. The finite element method (FEM) was introduced in the late sixties in the aerospace industry and it was applied in dentistry in the early seventies. Finite element method has been used successfully to predict the response of systems across a whole range of industries including aerospace and automotive, biomedical, chemical processes, geotechnical engineering and many others. This method uses computers to solve large number of equations to calculate stress on the basis of physical properties and the structures being analyzed. This technique can be used to analyze small or even large-scale deflection under applied or loading displacement. This method provides the orthodontist with the quantitative data that can extend the understanding of the physiologic reactions that occur. The finite element method is a numerical method of analysis that allows the study of stress distribution in biological system[3]. This method offers accurate modeling of tooth and its surrounding structures with its complicated geometry. However it is extremely expensive and can be used only with the help of an expert engineer who has mastered this technique.

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Still this methodology of stress analysis has become extremely popular in dentistry[4,5] as various properties of dental tissues and materials can be just fed into it and with the ease and accuracy the analysis is done is just remarkable.

What is FEM ?

The finite element method has been successfully applied to the mechanical study of stress and strain in the field of engineering. It is a method for numerical analysis based on material properties. Finite element modeling is the representation of geometry in terms of a finite number of elements and their connection points known as nodes. These are the building blocks of numerical representation of the model. The "elements" present are of finite number as opposed to a theoretical model with complete continuity. The object of interest has to be broken up into a "meshwork" that consists of a number of nodes on and in the object. These nodes or points are then connected to form a system of elements. For a two dimensional example, if the brick wall is the network, the bricks are the elements and the four corners where the bricks meet each other are the "nodes". By knowing the mechanical properties of the object such as modulus of elasticity and Poisson's ratio one can determine how much distortion each part of the cube undergoes when other part is moved by a force. Steps Involved In the Generation Of Finite Element Model are :

1. Construcion of a geometric model : The purpose of the geometric modeling phase is to represent a geometry in terms of points (grids), Line surfaces (patches) and volume (hyper patches). First the points are plotted and connected to represent facial and proximal surfaces followed by combining the surfaces to construct a 3-Dimensional image.

2. Conversion of the geometric model to a finite element model: The geometric model was converted into the finite element model. The finite element model generation can be achieved with the help of ANSYS software.

3. Material property data representation: In this each structure is assigned a specific material property. The different structures in the finite element model are enamel, dentine, periodontal ligament and alveolar bone. The material properties used for this are taken from finite element studies previously conducted and are the average values reported in the literature[6]. (Table 1)

4. Defining the boundary condition: The boundary condition, in the finite element model is defined at all the peripheral nodes of the bone, of tooth structure and surrounding PDL. It is very important to keep in mind that the finite element model will give the results based upon the nature of the modeling system and for that reason, the procedure for modeling is most important.

Applications of finite element method in Orthodontics :

Orthodontic biomechanics started in the early 1960s with the work of Burstone and later Nikolai[7]. Due to the complex structure of the system tooth/periodontal ligament/alveolar bone and because of the limited power of computers, the first numerical models were quite simple. Improved FE software, sophisticated programs for model generation and the explosion of computer power in the last decade resulted in more complex tooth-periodontium models and model assumptions.Various applications of FEM are:

1. Finite element analysis has been applied to the description of form changes in biological structures (morphometrics), particularly in the area of growth and development[8].

2. Finite element analysis as well as other related morphometric techniques such a the macro-element and the boundary integral equation method (BIE) is useful for the assessment of complex shape changes.

3. Analysis of stresses produced in the periodontal ligament when subjected to orthodontic forces[9].

4. Finite element method is also useful for structures with inherent material homogeneity and potentially complicated shapes such as dental implants[10.11].

5. The type of predictive computer model described may be used to study the biomechanics of orthodontic tooth movement[12-14,] whilst accurately assessing the effect of new appliance systems and materials without the need to go to animal or other less representative models.

6. The mechanical behavior of the orthodontic wires and different design of brackets and its contact problem can be well modeled and simulated by the finite element method. This method is an important tool in the development and improvement of orthodontic bracket and wires design[15].

ADVANTAGES OF FINITE ELEMENT MODEL

- It is a non-invasive technique
- The object of interest can be studied in 3-dimension.
- Actual stress experienced at any point can be measured
- It provides a solid, workable foundation for modeling a system.
- The FEM model can be magnified infinitely both in terms of the actual volumetric construction itself and the mathematical variability of its material parameters.
- The finite element model is the most suitable means of analysis because of its ability to handle various shapes and materials of non homogenous nature.
- FEM provides the orthodontist with quantitative data that increases the understanding of the physiologic reactions that occur after force application and may yield an improved understanding of the reactions and interactions of individual tissues.

LIMITATIONS OF FINITE ELEMENT MODEL

FEM may give results with a reasonable degree of accuracy, but this approach has certain
limitations, such as it's inability to simulate accurately the biological dynamics of the tooth and its supporting structure. As with any theoretical model of a biologic system there are some limitations with FEM.

The results of the finite element method analysis must be interpreted with great care. The accuracy of the analysis is dependant on the modeling structures as closely as possible to the actual. However, a certain amount of approximation manifested chiefly in terms of type and number of arrangement of elements is inevitable in complex designs. Apart from this, one must be aware of the assumption used in the formulation, material characterization, nature of boundary conditions and the representations of loads. All these factors affect the validity of the results.

The tooth is treated as pinned to the supporting bone, which is considered to be rigid, and the nodes connecting the tooth to the bone are considered fixed. This assumption will introduce some error however maximum stresses are generally located in the cusp area of the tooth.

The progress in the finite element analysis will be limited until better defined physical properties for enamel, dentin and periodontal ligament and cancellous and cortical bone are available

CONCLUSION

Finite element method (FEM) has become commonplace in recent years. Numerical solutions to even very complicated stress problems can now be obtained routinely using FEM. Finite element method has proved to be the most adaptable, accurate, easy and less time consuming process as compared to the other experimental analysis. Inspite on certain limitations out of which the most important is the cost factor and requirement of an expert to operate the analysis, this technique has taken the field of dentistry to great heights and provided results which couldn't have been possible with any other technique. FEM helps in basic orthodontic biomechanics to possible future applications in treatment planning using bone remodelling theories: determination of the mechanical properties of the periodontal ligament in a combined numerical and experimental study, calculation of the centers of resistance of different teeth, and simulation of orthodontic tooth movements.

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