Applications of Finite Element Methodology in Orthodontics : A Review

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Abstract

In orthodontic research, FEM, a tool used in engineering to evaluate the stress, force and deformation of compound structures, is been extensively used. The FEM application has the advantage of being a precise, non-invasive technology that offers quantitative and comprehensive data on the physiological processes that might take place in tissues. Through the examination of areas of stress caused by the utilised orthodontic mechanics, one is able to obstruct the visualisation of these tissue responses. The finite element method's steps and uses in orthodontics are the main topics of this article. FEM may evaluate the stress distribution at the intersection of the periodontal ligament and the alveolar bone as well as the ebb and flow of various types of tooth movement when using various orthodontic devices. As a result, knowledge of certain software is needed for this. FEM is an essential experimental method that gets around the drawbacks of other experimental methods to provide insights on tooth movement.

Keywords: FEM, Orthodontics, stress distribution, orthodontic appliance

Introduction

It is commonly questioned if the (FEM) is applicable to health research, notably in the fields of dentistry and orthodontics. In order to clarify the concepts, principles, objectives, and application of this technology, a research project was started as part of postgraduate studies at the University of Estadual Paulista (UNESP) in Araraquara. In biomedical research, the FEM is a common engineering method for analysing stress and deformations in challenging locations.[1,2]

The goal of using FEM in the context of structural engineering is to determine the tension and breakage of an arbitrary-geometry solid that has been subjected to external processes. This form of calculation, known scientifically as "analysing structures," is frequently used in studies on structures such as buildings, bridges, dams, etc. In order to arrive at a suitable solution for either the economics or the attestation of functional and regulatory demand, it is standard practise to go forward with a series of analyses and adjustments of a structure's characteristics when one is required to be projected.[3]

According to Azevedo, Ray Clough is the author of the earliest written record utilising the term "finite element," which was published in 1960; the FEM already included a few other previously known approaches. The major advances in the development of FEM that led to the methodology's current, widely accepted formulation were made in the 1960s and the early 1970s.

By using the FEM, orthodontics may shape and analyse any material or dentomaxillofacial structures.[4] The division of a complicated structure into smaller, so-called elements is the foundation of FEM[5]. In which physical characteristics, such as the elasticity modulus, are used to demonstrate an object's response to an external stimulus, such as an orthodontic force. It illustrates how the strategy's ability to control the degree of simplification has a substantial advantage[6].

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Review of Literature And Fem Applications In Orthodontics

Utilizing experimental animal models, several research on orthodontic force-induced tooth movement were carried out[7-11]. The results of using orthodontic forces on human tissues are indicated by these investigations. Ethics issues arise frequently since this form of experimentation necessitates the use of living animals in laboratories. FEM makes it possible to foresee how the tissue will react to the use of orthodontic mechanics. Photoelastic models are another type of experimental model that can be used to study the biomechanics of tooth movement[12]. However, they have the drawback of simply looking at the model's exterior, leaving behind internal features like the periodontal ligament.

In orthodontics FEM has changed biomechanical advances by eliminating the aforementioned drawbacks. It stands for a precise, non-invasive procedure that offers quantitative information about the physiological reactions taking place in tissues like the periodontium and the alveolar bone[13]. The communication between surrounding tissues and the individual reaction makes it challenging to accomplish this precise measurement of potential stress and tension occurring in dental tissues using any other experimental technique, according to **Middleton et al.**[14]

The FEM also has the benefit of allowing homogeneous samples to be studied while keeping all other study variables under control. The FEM has been used in several research to examine how orthodontic forces affect the craniofacial complex.[15-20]

To estimate the pressure exerted by the distribution of othrodontic Edgewise appliance, Mc Guinness et al15 employed the FEM. The scientists utilised a wire to fill a 0.022-inch slot in an upper canine bracket. Only the mesiodistal direction, parallel to the orthodontic wire, received a force of 98.1 gF. The periodontal ligament's cervical boundary and the tooth tip had larger stress concentrations, according to the scientists. By using a passive BTP, **Kojima and Fukui**[17] looked at potential orthodontic movements for anchoring teeth. Because molars can shift mesially when a mesial force is applied, the FEM results showed that passive BTP had essentially no impact on anchoring maintenance.

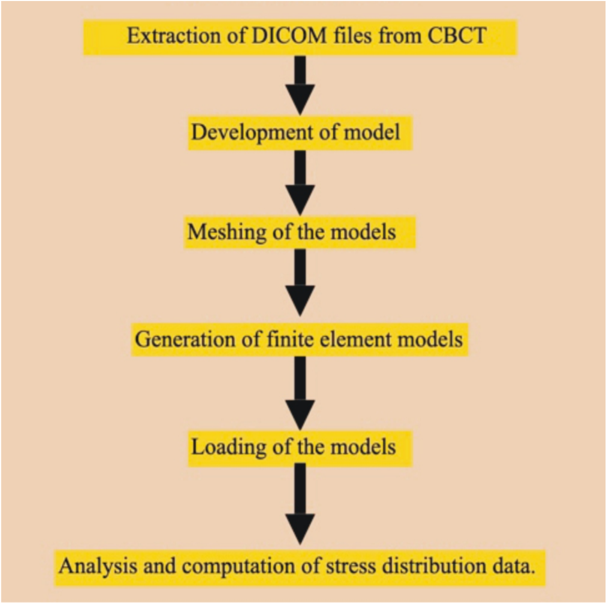
In their analysis of the mass retraction in sliding mechanics, **Tominaga et al**[18] **,** their findings showed that When the hook is placed utilising sliding mechanisms between the lateral and cuspid, the anterior segment's mass retraction is less erratic. The FEM was used by **Kanjanaouthaia et al.**[19] to demonstrate that upper incisors that were inclined more than those that were well-positioned in the buccolingual direction showed larger concentrations of stress on the apex after receiving force of 1 Newton in that way.

It is fascinating to employ this experimental methodology to build geometrically superior and accurate models using a source with structural data and changes in CAD software. Tools for image processing and digital reconstruction like Simple ware 4 software or Mimics must be used to develop a virtual model in order to accomplish this. Computed tomography is frequently used for these maxilla and mandibular reconstructions.

To get better resolution, CT should be used by cross sections that are at least 0.25 mm apart. The parts will be converted to DICOM format before being input into software for image processing It is impossible to determine the limits of structures like the peri-odontal ligament, enamel, or even the medullary and cortical bone due to the degree of disparity and clinical tomography's definition, which yields unsatisfactory results from the resources of automatic segmentation structures in the reconstruction programme. Micro CTs would enable the recording of details on a gauge scale, so the use of computed tomography is warranted. However, their radiation dose is above that which is recommended for people, in addition to being expensive and challenging to get[21].

In a test using computed axial tomography, a virtual model of the maxilla was created. The model depicted a maxilla with 956,196 faces, and each tooth had hundreds of polyhedral faces. Because the model wasn't yet finished, the number of faces was limited to a maximum of a few hundreds in order to carry out the edition. The simple reduction in the number of nonparametric faces dramatically distorts the model because the former are all flat and triangular.

Methodology



Flowchart showing methodology of FEM

Softwares Used

The parameters of models should be made using a software named Solidworks Premium software "scan to 3Dimensions" to allow for additional editing without substantial distortion. This will make it possible to transform nonparametric models into parametric models using NURBS faces with the least degree of distortion. Orthodontic parts also need to be totally recreated using just a digital microscope and a virtual calliper (Germany). The results are more accurate the more structures that are modelled, but it is harder to build the model and more complicated to analyse the results.

Therefore, simpler models ought to be used to get the same quantitative outcomes. Evaluation of modelling should be carefully estimated in order to maintain the accuracy of the outcomes and reduce complexity.

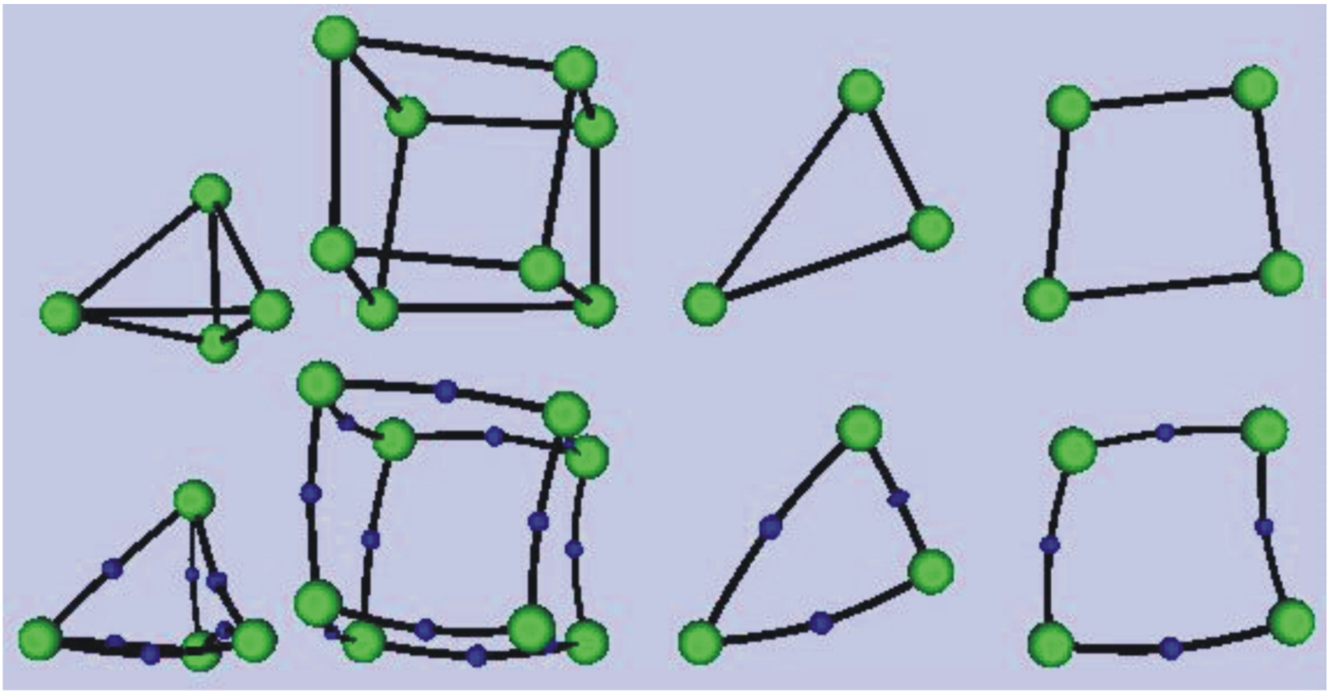


Figure 1. Different shapes of nodes.

The aforementioned software was also used to discretize the solid model, which is the process of converting it into a mesh of bonds and elements to allow analysis using FEM. Tetrahedrons and hexahedrons are the most prevalent shapes for the elements, which indicate spatial coordinates and may appear in a variety of formats. Each element's extremities have points or links that link the elements to one another to form an organised mesh. The bonds between the components are what transfer information between them. Mesh refinement is utilised to test the convergence of results while gradually increasingthe quantity of bonds and elements until the voltage peak difference between mesh refinements reached five percent or less, in order to achieve the optimum mesh of finite elements. These measurements reduce the geometric error unique to the mesh discretization process.

Software for simulating finite elements, Ansys Workbench Version 11.This software requires precise representation of the mechanical behaviour of each component; as a result, the model is set up with a Young's coefficient and Poisson's coefficient. The FEM data make it possible to examine the stress distribution brought on by forces acting on the periodontal ligament and bone, indicating the stress-prone regions and, as a result, the locations where tooth movement occurs. Additionally, it gives us information about regions that are more vulnerable to root resorption. Colors and patterns that can show the direction of tooth displacement following force application are used to expose these results.

By supporting the coloured picture of this experiment, a part of a study being undertaken at the School of Unesp-Araraquara, it demonstrated that the stress gradually declines toward the apex while the area next to the tooth fulcrum (red) has a increased concentration of pressures (blue). Additionally, the tooth's tendency is evaluated to move in opposition to the application of orthodontic force using Ansys 14 Software. To achieve this, coloured arrows were used to show (in red) the site with the greatest tooth displacement. Along with the stress distribution on the periodontium, the change in shape of the orthodontic wires & also its zone of higher stress concentration may be noticed.

Conclusion

The Finite Element Method (FEM) demonstrates its value as a tool in orthodontic research by highlighting a number of points, including: during tooth movement the stress distribution in the area of periodontium and alveolar bone; tooth displacement direction ; the correct position of orthodontic appliances during a particular mechanics, areas with root resorption, as well as the redistribution of stress on the archwires. Due to its accuracy, non-invasiveness, ability to regulate study variables, and ability to offer quantitative information regarding internal nasomaxillary complex structures such the periodontal ligament, FEM has the ability to overcome the drawbacks of other research approaches. The solution, however, requires computer engineering expertise because it runs on very specialised software.

References

1. Sameshima GT, Melnick M. Finite element-based cephalometric analysis. Angle Orthod. 1994;64(5):343-350.
2. Viecilli RF. Self-corrective T-loop design for differential space closure. Am J Orthod Dentofacial Orthop. 2006;129(1):48-53.
3. Lotti RS, Machado AW, Mazzieiro ET, Landre Jr J. Raquel S. Aplicabilidade cientifica do métodos dos elementos finitos. Rev Dent Press Ortod Ortop Facial. 2006;11(2):35-43.
4. Shaw AM, Sameshima GT, Vu HV. Mechanical stress generated by orthodontic forces on apical root cementum: a finite element model. Orthod Craniofacial Res. 2004;7(2):98-107.
5. Jones ML, Hickman J, Middleton J, Knox J, Volp C. A validated finite element method study of orthodontic tooth movement in the human subject. Am J Orthod. 2001;28(1):29-38.
6. Reitan K. Tissue behavior during orthodontic tooth movement. Am J Orthod. 1960;46(12):881-900.
7. Sari E, Olmez H, Gurton U. Comparison of some effects of acetylsalicylic acid and rofecoxib during orthodontic tooth movement. Am J Orthod Dentofacial Orthop. 2004;125(3):310-315.
8. Kalia S, Melsen B, Verna C. Tissue reaction to orthodontic tooth movement in acute and chronic corticosteroid treatment. Orthod Craniofac Res. 2004;7(1):26-34.
9. Jäger A, Zhang D, Kawarizadeh A, Tolba R, Braumann B, Lossdörfer S, Götz W. Soluble cytokine receptor treatment in experimental orthodontic tooth movement in the rat. Eur J Orthod. 2005;27(1):1-11.
10. Ong CK, Walsh LJ, Harbrow D, Taverne AA, Symons AL. Orthodontic tooth movement in the prednisolone-treated rat. Angle Orthod. 2000;70(2):118-125.
11. Caputo A, Chaconis SJ, Hayashi RK. Photoelastic visualization of orthodontic forces during canine retraction. Am J Orthod. 1974;65(3):250-259.
12. Kamble RH, Lohkare S, Hararey PV, Mundada RD. Stress distribution pattern in a root of maxillary central incisor having various root morphologies: a finite element study. Angle Orthod. 2012;82(5):799-805.
13. Middleton J, Jones M, Wilson A. The role of the periodontal ligament in bone modeling: the initial development of a time- dependent finite element model. Am J Orthod Dentofacial Orthop. 1996;109(2):155-162.
14. McGuinness N, Wilson AN, Jones M, Middleton J, Robertson NR. Stresses induced by edgewise appliances in the periodontal ligament-a finite element study. Angle Orthod. 1992;62(1):15-22.
15. Shaw AM, Sameshima GT, Vu HV. Mechanical stress generated by orthodontic forces on apical root cementum: a finite element model. Orthod Craniofac Res. 2004;7(2):98-107.
16. Kojima Y, Fukui H. Effects of transpalatal arch on molar movement produced by mesial force: a finite element simulation. Am J Orthod Dentofacial Orthop. 2008;134(3)
17. Tominaga JY, Tanaka M, Koga Y, Gonzales C, Kobayashi M, Yoshida N. Optimal loading conditions for controlled movement of anterior teeth in sliding mechanics. Angle Orthod. 2009;79(6):1102-1110.
18. Kanjanaouthai A, Mahatumarat K, Techalertpaisarn P, Versluis A. Effect of the inclination of a maxillary central incisor on periodontal stress Finite element analysis Angle Orthod. 2012;82(5):812-819.
19. Choi DS, Cha BK, Jang I, Kang KH, Kim SC. Three-dimensional finite element analysis of occlusal stress distribution in the human skull with premolar extraction Angle Orthod. 2013;83(2):204-211.
20. Andreaus U, Colloca M, Iacoviello D. Coupling image processing and stress analysis for damage identification in a human premolar tooth. Comput Methods Programs Biomed. 2011;103(2):61-73.