FINITE ELEMENT ANALYSIS

NEW TRENDS AND DEVELOPMENTS

Edited by **Farzad Ebrahimi**

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Finite Element Analysis – New Trends and Developments
http://dx.doi.org/10.5772/3352
Edited by Farzad Ebrahimi

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Published by InTech
Janeza Trdine 9, 51000 Rijeka, Croatia

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Publishing Process Manager Oliver Kurelic
Typesetting InTech Prepress, Novi Sad
Cover InTech Design Team

First published September, 2012
Printed in Croatia

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Finite Element Analysis – New Trends and Developments, Edited by Farzad Ebrahimi
p. cm.
ISBN 978-953-51-0769-9

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Preface

Finite Element Analysis (FEA) was developed as a numerical method of stress analysis, but now it has been extended as a general method of solution to many complex engineering and physical science problems. In the past few decades, the FEA has been developed into a key indispensable technology in the modeling and simulation of various engineering systems. In the development of an advanced engineering system, engineers have to go through a very rigorous process of modeling, simulation, visualization, analysis, designing, prototyping, testing, and finally, fabrication/construction. As such, techniques related to modeling and simulation in a rapid and effective way play an increasingly important role in building advanced engineering systems, and therefore the application of the FEA has multiplied rapidly.

This book reports on the state of the art research and development findings on this very broad matter through original and innovative research studies exhibiting various investigation directions. The book has been grouped into three major domains: Biomedical engineering, electrical engineering, civil engineering. It is meant to provide a small but valuable sample of contemporary research activities around the world in this field and it is expected to be useful to a large number of researchers. Through its 17 chapters the reader will have access to works related to Dental Medicine, Implants, Sandwich Panels, Tunnel excavation, Stiffener run-outs, Tubular Footbridges, DC circuit breaker, Permanent Magnet Motors, MEMS and several other exciting topics.

The present book is a result of contributions of experts from international scientific community working in different aspects of Finite Element Analysis. The introductions, data, and references in this book will help the readers know more about this topic and help them explore this exciting and fast-evolving field. The text is addressed not only to researchers, but also to professional engineers, students and other experts in a variety of disciplines, both academic and industrial seeking to gain a better understanding of what has been done in the field recently, and what kind of open problems are in this area. It has been written at a level suitable for the use in a graduate course on applications of finite element modeling and analysis (Electrical, civil and biomedical engineering studies, for instance).

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I am honored to be editing such a valuable book, which contains contributions of a selected group of researchers describing the best of their work. I would like to express my sincere gratitude to all of them for their outstanding chapters. I also wish to acknowledge the InTech editorial staff, in particular Oliver Kurelic, for indispensable technical assistance in book preparation and publishing.

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Recent Advances of Finite Element Analysis in "Bio-Engineering"

Chapter 1

Finite Element Analysis in Dental Medicine

Josipa Borcic and Alen Braut

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http://dx.doi.org/10.5772/50038

1. Introduction

Studying dental structures and surrounding tissues in the oral cavity presents the basis for understanding the occurrence of pathological process and enables the correct approach and treatment. Oral rehabilitation is inherently difficult, due to the functional and parafunctional forces within the mouth that result in extremely complex structural responses by the oral tissue [1]. The success of restorative materials depends on their properties to withstand and resist occlusal forces and successfully support the remaining oral structure [2]. Studies examining the biomechanical behavior of oral structures require sophisticated simulations of the fundaments of the stomatognathic system [3].

There were numerous ways and attempts of experimental research, but due to the complexity of dental structures, composed of various tissue materials mechanically and chemically interconnected, and due to complex tooth morphology and surrounding structures, these attempts failed to obtain precise and reliable results. Researches have used photoelastic methods, computer simulation methods and finite element analysis to conduct stress analyses of sound and restored teeth in order to predict their fracture resistance. Conventional methods such as photoelasticity and the strain-gauge methods are inadequate to predict reliable stress distribution in the tooth [4]. The use of traditional load-to-failure bench-top testing is unable to recreate the failure mechanisms seen clinically; hence the use of FEA is gaining popularity because of its ability to accurately asses the complex biomechanical behavior of irregular prosthetic structures and heterogeneous material in a non-destructive, repeatable manner [5].

2. Finite element analysis

Finite element analysis (FEA) is a numerical method of analyzing stresses and deformations in structures which originated from the need for solving complex structural problems in civil and aeronautical engineering. In order to achieve this goal, the structures are broken

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down into many small simple segments or elements, each with specific physical properties (figure 1). Than, an operator uses a computer program in order to obtain a model of stresses produced by various loads [6,7]. A major advantage of finite element analysis (FEA) is its ability to solve complex biomechanical problems for witch other study methods are inadequate. Stress, strain and some other qualities can be calculated in every point throughout the structure. FEA is also being used as part of the design process to simulate possible structure failure, as a mean to reduce the need for making prototypes, and reducing a need for performing actual experiments, that are usually expensive and time-consuming [8]. This method allows researches to overcome some ethical and methodological limitations and enables them to verify how the stresses are transferred throughout the materials [9].

In the area of dentistry, FEA has been used to simulate the bone remodeling process, to study internal stresses in teeth and different dental materials, and to optimize the shape of restorations. Because of the large inherent variations in biological material properties and anatomy, mechanical testing involving biomaterials usually require a large number of samples. With FEA the necessity of traditional specimens can be avoided, and by using a mathematical model it also eliminates the need for large number of experimental teeth. It has been used to represent simulated tooth mechanical behavior under occlusal loads in details [8].

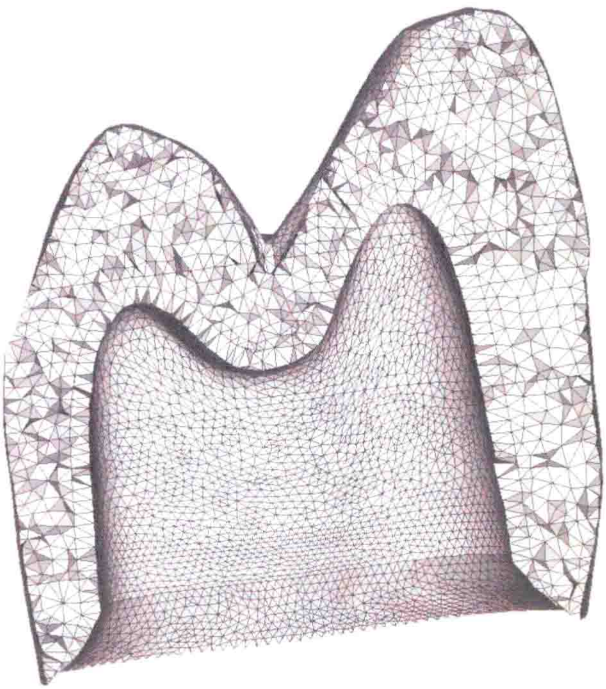

Figure 1. Elements of an FEA model.

2.1. Finite element model

The decision to use 2D or 3D models to investigate biomechanical behavior of complex structures, by FEA, depends on many inter-related factors, such as the complexity of the geometry, material, properties, mode of analysis, etc. Although 2D models are simpler, easier to build and less time consuming, they do not represent the complexity of the real problem. 2D model might be considered when studying the qualitative biomechanical behavior, but for the quantitative stress analysis the 2D models overestimate stress magnitudes and do not represent the realistic model. 3D model may provide more reliable data that more accurately represent non-linear and anisotropic materials. 3D models should be carefully created with appropriate mesh density [3]. Khera et al. were the pioneers in the utilization of 3D models. The models were obtained from sectional images of human mandible, but this is no longer required due to the use of a computerized tomography (CT) [10].

The 3D geometry of the tooth (figure 2) can be reconstructed in two ways. The old traditional method consists of embedding the tooth in red epoxy and sectioning it perpendicularly to the long axis by a precise saw (figure 3). Each section is than digitally photographed and the 3D geometry of the tooth is being constructed from these cross-sections using specialized computer program. The solid model is transferred into a finite element analysis program, where a 3D mesh is being created, and subsequently the stress distribution analysis performed (figure 4) [4, 25].

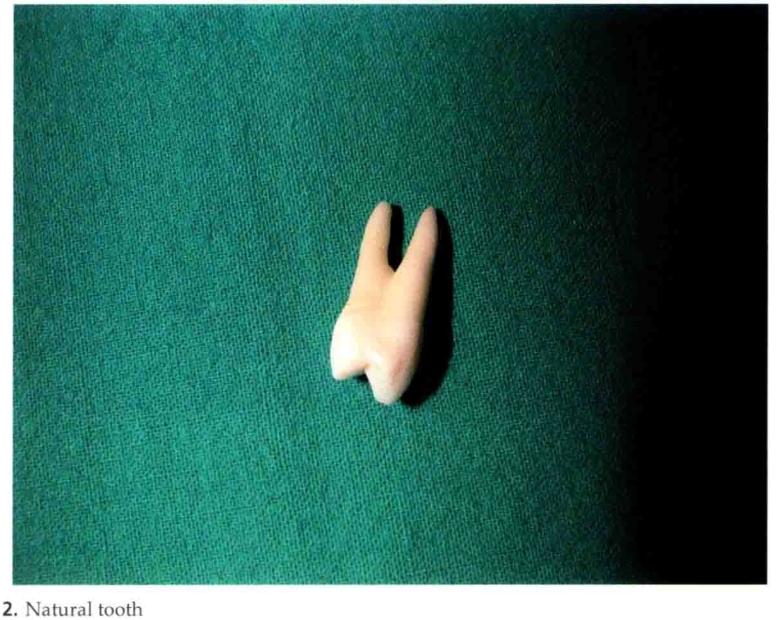

Figure 2. Natural tooth

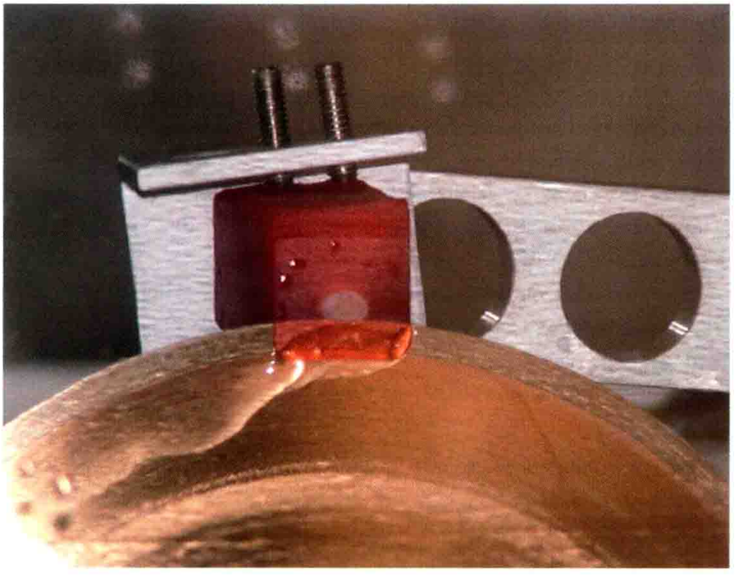

Figure 3. Embedded tooth in red epoxy.

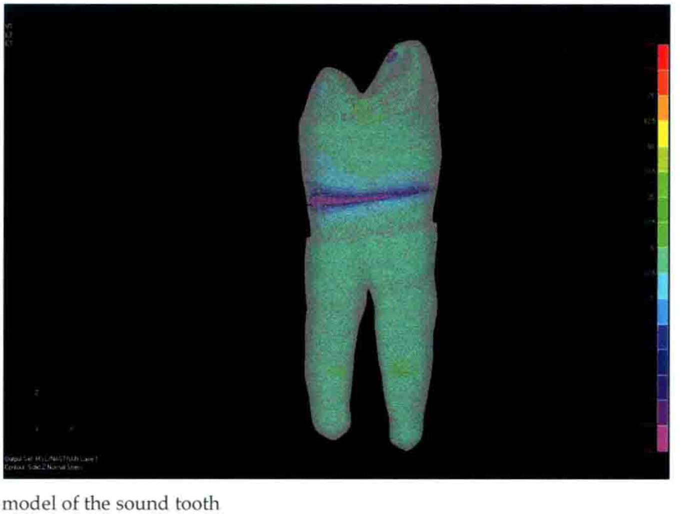

Figure 4. 3D model of the sound tooth

The second, latest method of reconstructing a 3D tooth model is performed with the aid of CT. It facilitates and speeds up the acquisition and produces more accurate model. With this method the surrounding soft structures can be also included, larger areas scanned and reconstructed, while the structures itself still remain in the patient mouth. The next big advantage of CT model rendering consists of the possibility to scan the same structure before and after the performed therapy procedures, and periodical follow-ups of the therapy success. Technologies such as micro-CT scanning open up the possibility for complex 3D modeling [11]. However, the process of going from image to mesh involves a number of processing steps, each with potential geometric errors [12].

2.2. Interpretation of the FEA results

The results obtained from a FEA on the restored system contain information about the stress distribution of each component of the restoration, instead of only a single value of failure load typical of in vitro results. A correct interpretation of FEA results should be based on the stresses and strength of each component of the system. To obtain accurate conclusions from these interpretations, three conditions must be fulfilled. First, FEA should adequately represent the real stress values; second, strength of the different materials must be known; third, an adequate failure criterion must be used [13].

It is not possible to implement the results from FEA directly into a clinical situation, but it has to design the model in such a way that is mimics the real situation as closely as possible. FEA analysis must be interpreted with a certain amount of caution. Most of the researches modeled dental structures as isotropic and not othotropic. The finite element model represents a static situation at the moment of load application and not an actual clinical situation. In reality, the loading of the structure is more dynamic and cyclic. The materials of the various tooth structures were assumed to be isotropic, homogenous and elastic, and that they remain such under applied loads. More precise measurements can be obtained if the material properties are set as anizotrophic and non-homogeneous, but such setup requires much more complex mathematical calculations. It is better to use a non-linear elastic-plastic material model than the linear models that are used in most FEA studies [14].

The values from finite element analysis are presented as maximum and minimum principal stresses. Most of the previously published studies have analyzed the results from Von Mises maximal stress [15-19]. This is probably associated to the fact that this is the normal criterion for the most engineering analyses, which usually deal with ductile materials such as steel and aluminum [13]. It is known that the Von Mises criterion is only valid for the ductile materials with equal compressive or tensile strength, but materials exhibiting brittle behavior such as ceramics, cements or resin composites presents reported values of compressive strength significantly greater than tensile strength [20]. Positive and negative values indicate that the corresponding regions are subjected to tensile or compressive stresses (figure 5) [21].

The response of the structure is different if asymmetrical loading is considered. When the tooth is compressively loaded, displacements do not appear to be significant because of the rather large compressive yield strength. The situation is different if the asymmetrical loading is considered, when the tensile stress occurs. The dental tissues are more resilient to compressive than tensile forces. Any occlusal contact that can create tensile stress, also creates the possibility to create a lesion in tooth structure. When lateral loads are applied, tensile stresses generated in the areas are of higher values than when vertical loads are applied onto the same areas. The increase in the load does not cause a change in the overall stress pattern, but increases the values. The loading, that the tooth is subjected to, may cause cracks in the tooth, but not necessarily its immediate failure. Most of the failures of dental materials used for tooth restorations are caused by tensile stress. Precise occlusal adjustments of teeth occlusal surfaces should be performed to prevent such events. The average chewing force varies between 11 and 150 N, whereas force peaks are 200N in the anterior, 350N in the posterior and 1000N with bruxism [22].

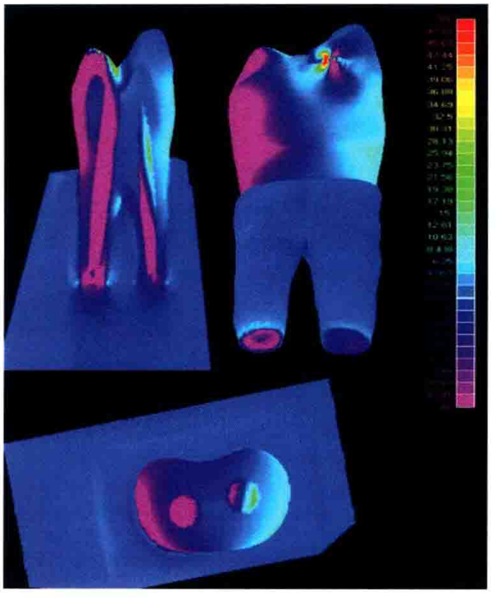

Figure 5. FEA model of a restored apicotomysed tooth

3. Materials and types of reconstructions in dental medicine

The use of different materials for restoration substantially modifies the stress distribution of an originally healthy tooth. The difference between the elastic modulus of tooth and restorative material may be a source of stress in the dental structures. If the stress exceeds the yield strength of the materials, fracture of the restorative materials or the tooth may occur. The occlusal force leaning against the tooth or dental implant axis causes the structure to bend, and the higher tensile stresses are produced. The oblique force loading on the dental structure is the major cause of dental damage and the further attention should be paid to the importance of the occlusal adjustment [4, 7, 25].

The way the chewing force application is much more important than the dentine and the enamel properties, or even the properties of the restorative materials. The consequences of the same chewing force for different teeth also need to be highlighted because structural changes can occur depending upon the magnitude of the force, which can affect the tooth morphology in extreme (premature contacts) or repetitive cases (fatigue) [11].

3.1. Natural tooth

The properties of tooth are not homogenous, but are anisptropic like dentin (due to its capillary morphological structure) or enamel (due to its prismatic structure) [23]. Various studies have shown that the failure was confined mostly to the occlusal walls and margins, and was usually seen on the buccal surfaces of lower molars and premolars (figure 6 and 7) [24,25]. Excursive mandibular movements place the buccal cusps in tension or in compression and open up the occlusal margins (figure 8). Enamel near the cemento-enamel junction is highly stressed because the reactive forces have to flow into and through this thin wedge of tissue for it to be transmitted into the root of the tooth and subsequently into the supporting alveolus bone [2]. This is the reason why the restorations inserted into the cervical region can be subjected to high compressive stresses even though these areas are not susceptible to direct contact during mastication [26,4].

Figure 6. FEA analysis in sound tooth in normal occlusion looking from outside

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