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Finite Element Analysis and its Implementation in Surgery: Literature Review

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Abstract

Biomechanics refers to the study of structure and function of biological systems, using methods obtained from mechanics, which is concerned with the effects that forces have on the motion of bodies. Recently, there has been a development of implementation of various virtual studies in the field of biomechanics. One such remarkable development is the technology of finite element analysis (FEA). Through this technology, complex mechanical systems in human body, which otherwise are difficult to understand in vivo, could be studied using mathematical conversion of the geometrical model in question. This has its implications in the field of trauma surgery, especially oral and maxillofacial surgery, reconstructive surgery and implantology. The available literature indicates FEA to be an important instrument in understanding and reconstructing complex human mechanical systems.

Keywords: Finite Element Analysis (Fea); Maxillofacial Surgery; Traumatology; Reconstructive Surgery; Implantology.

Introduction

Understanding stresses and strains in living tissues, are required in the field of surgery. Due to its complex nature and difficulty in measuring the parameters in vivo, the actual mechanisms of such biomechanics have not been fully understood. Finite element analysis (FEA) is a computer aided mathematical technique that analyses stresses and strains in complex mechanical systems.[1]

The finite element method of stress analysis (FEM) functions by deducing numerical solutions to the abstract equations of calculus that predict the response of physical systems subjected to external influences.[2,3] With the increasing availability and decreasing costs of suitable software and hardware for virtual analyses makes wider applicability of this technology possible. Finite element analysis has been used in fields such as trauma surgery, especially oral and maxillofacial surgery, reconstructive surgery and implantology. In this article, we intend to review the available literature on FEA and discuss regarding the method, applications and limitations and the various research on application of FEA in modern surgery.

Materials and Methods

Research articles based on the subject of finite element analysis from reputed journals were

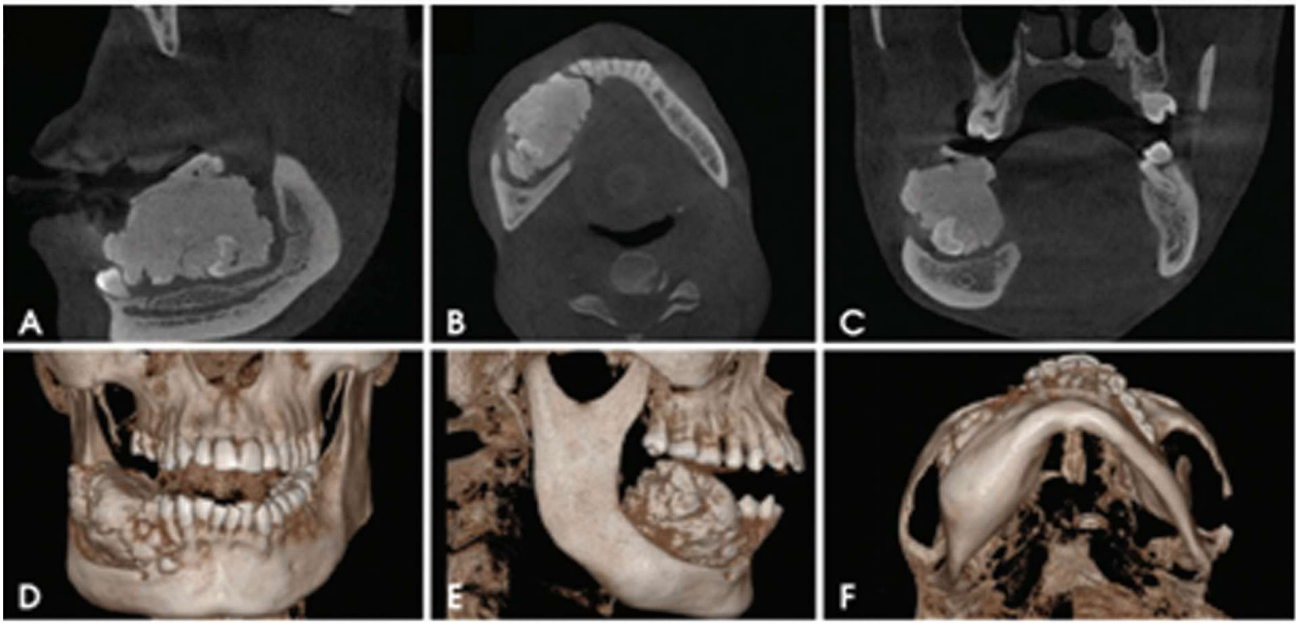


Fig. 1: Cone Beam Computed Tomography (CBCT) of human mandible.

Source: Bagewadi, Shivanand & Kukreja, Rahul & GN, Suma & Yadav, Bhawna Yadav & Sharma, Havi. (2015). Unusually large erupted complex odontoma: A rare case report. Imaging science in dentistry. 45. 49-54.

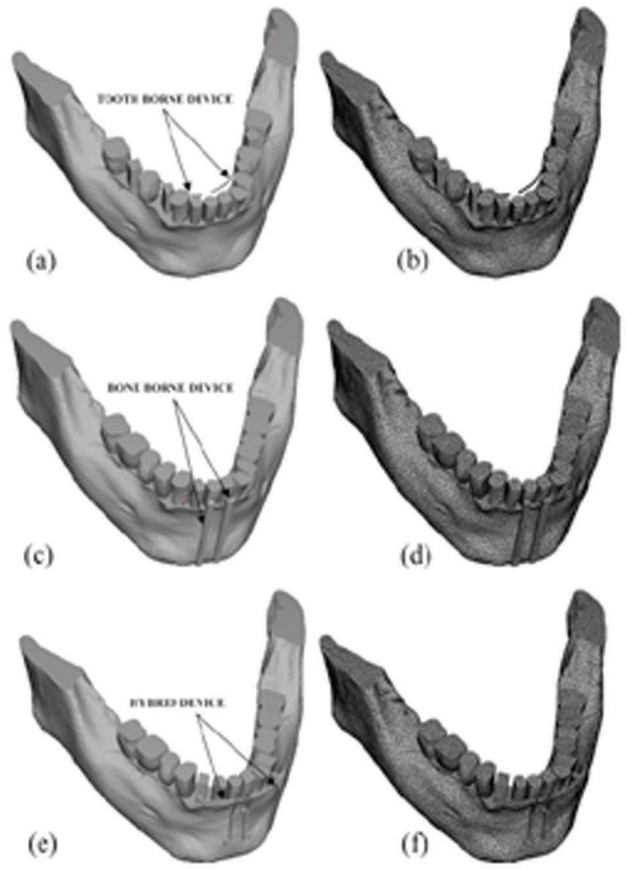


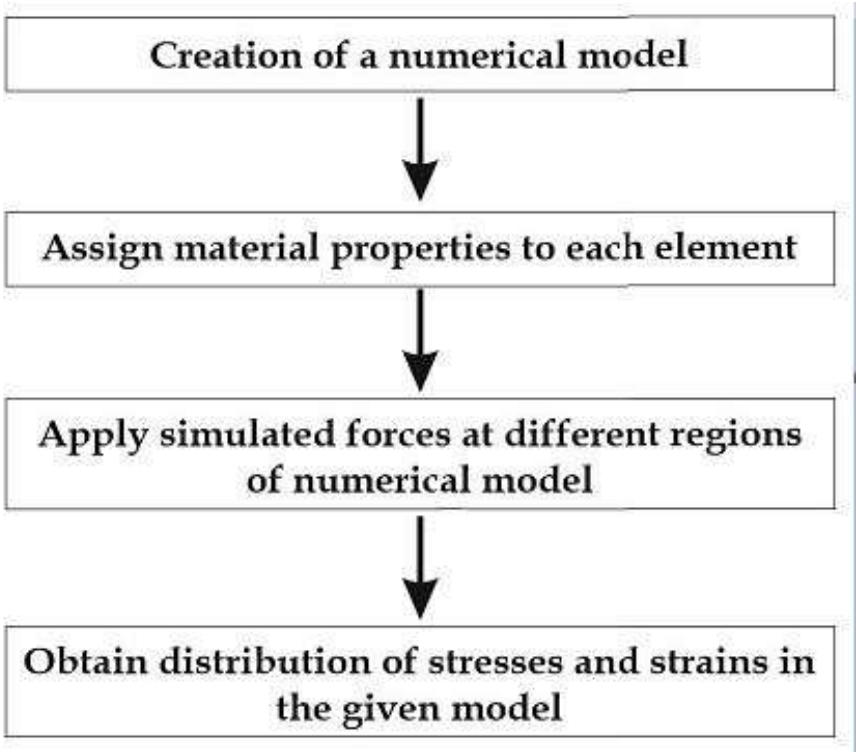
Fig. 2: Computer-aided design model of human mandible

Source: Boccaccio, Antonio & Cozzani, Mauro & Pappalettere, Carmine. (2011). Analysis of the performance of different orthodontic devices for mandibular symphyseal distraction osteogenesis. European journal of orthodontics. 33. 113-20.

thoroughly reviewed. Literature from principal fields associated with utilization of FEA, includingtrauma surgery, especially oral and maxillofacial surgery, orthognathic surgery, reconstructive surgery and implantology were studied and included in this article. The essence of application of FEA in the above mentioned fields were comprehended and presented in a concise manner in this article.

Discussion

Finite element analysis is an emerging technology that deals with simplification of understanding complex mechanical. The first step in FEA is creation of a three-dimensional model of the part of human body in question which would form the basis for creation of a numerical model of the same. This can be achieved using cone beam computed tomography (CBCT) (figure 1), microtomography, intra- and extraoral scanners or computer-aided design (CAD) software (figure 2).[4] Following creation of a numerical model, discretization is done. Discretization refers to division of the model into numerous simple elements (finite elements), that are connected at a common nodal point. Material properties such as Young's modulus (E) or Poissons's ratio are then determined for each of the elements. Following these steps, we can determine the distribution of stresses and strains in the given model by application of simulated forces on various regions of the numerical model (figure 3).



Methodology of Finite Element Analysis Concept

It is challenging and ethically impractical to determine the consequences offacial trauma and its causes. In the field of trauma surgery, finite element analysis helps in determining the regions of skull that are particularly prone to fractures by precise mapping of stress distribution following trauma.[5] As a result of this there is greater understanding of the biomechanics which in turn helps in surgical planning.

Orthognathic surgery refers to correction of jaw bone irregularities and realignment of jaws with teeth to improve its function and probably facial appearance. An important determinant of successful outcome in orthognathic surgery is the selection of appropriate bridging elements and FEA has been used to compare the stability of bridging the bony segments with various fixation systems in bilateral sagittal split osteotomy procedure.[6-11]

Finite element analysis can also be used to reconstruct excised portions, for instance excision of jaw bone due to oral malignancy.Using the technology of FEA, studies have been done to compare the level of stress at bone graft interface

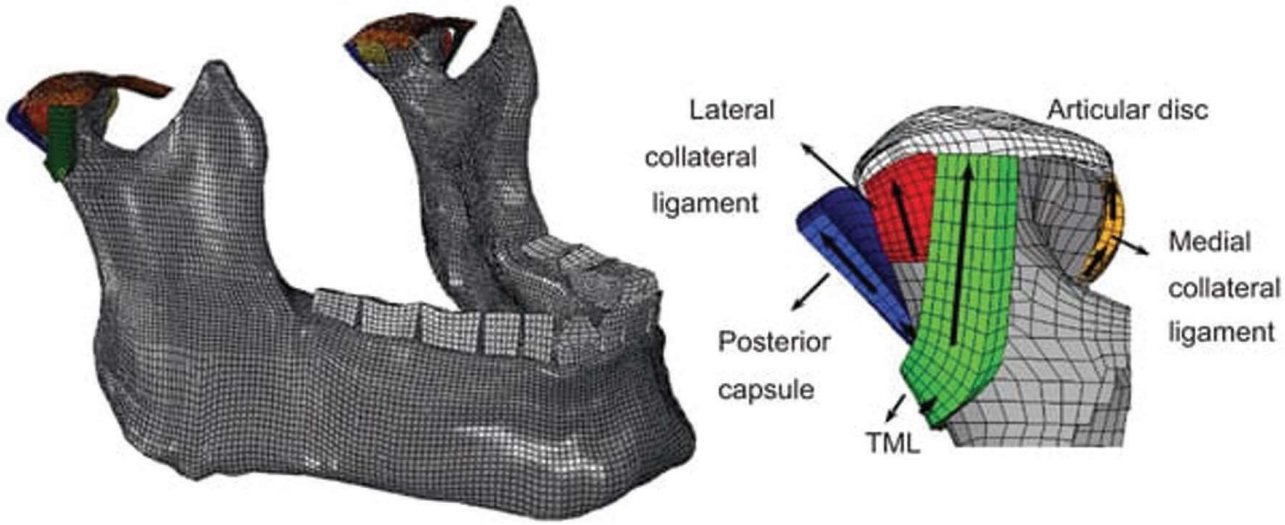


Fig. 3: Finite element analysis of mandible and temporomandibular joint

Source: Commisso, Maria & Reina, J. & Mayo, Juana. (2014). A study of the temporomandibular joint during bruxism. International journal of oral science. 6. 10.1038/ijos.2014.4.

to identify the most suitable type of transplant in a given condition.[12] In a different context of reconstructive surgery, Kuwahara et al utilised the technology of FEA in reconstruction of ear in a case of cryptotia (auricular muscle abnormality that causes the superior and posterior auricular area to be buried under the temporal skin) tocompare the Square flap method and the Cat's Ear flap method for reconstruction of cryptotia. Finite element analysis of these two historical procedures for cryptotiarevealed how the dynamics of each procedure led to morphological changes that induced extrusion of the buried helix.[13]

Though FEA has been used and appreciated in the aforementioned fields, it carries its drawbacks. The major disadvantage of FEA are its simplifications and assumptions. Attempts to improve geometrical accuracy could be made but only at the cost of time and resources.[4]

Conclusion

Following thorough review of available literature on finite element analysis, we conclude that FEA serves as an innovative and useful tool in understanding of various biomechanical intricacies in a simplified manner and allows practical application of the same in various fields of surgery. Current literatureindicates its popular application in maxillofacial surgery but this technology carries potential for wider applicability. Further studies are to be carried out to explore the potential of FEA in the field of surgery.

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