

An Overview on the Applications of Finite Element Analysis in Orthodontic

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الخلاصة

المقدمة: في القرن الحادي والعشرين ، تحدى التقدم التكنولوجي أخصائيي الأسنان لأداء الإجراءات المحفوفة بالمخاطر والمتعددة الجوانب بطريقة أكثر موثوقية وغير ضارة باستخدام طريقة العناصر المحدودة (FEM) التي يمكنها محاكاة وتحليل هياكل الأسنان. نظرًا لأن تقويم الأسنان يدور حول القوى ، فإن FEM هي واحدة من أكثر الأدوات دقة للباحثين في هذا المجال. تلقي هذه المراجعة الضوء على استخدام طريقة العناصر المحدودة في أبحاث تقويم الأسنان والوجه القحفي. يخزن هذا البحث الأبحاث المختلفة التي تم إجراؤها باستخدام نموذج العناصر المحدودة لدراسة نمو بنية الجمجمة ، ورد الفعل الميكانيكي الحيوي لقوى تقويم العظام ، وحركة الأسنان التقويمية ، وتطبيق جراحات التقويم ، والغرسات التقويمية.

ABSTRACT

In the 21st era, technological progressions challenged the dental professional to perform extremely risky and multifaceted procedures more reliably and harmless way using the finite element method (FEM) that can simulate and analyze the dental structures. As orthodontic revolve about the forces so FEM is one of the most accurate tools for the researchers in this ground. This review highlights the use of the finite element method in orthodontics and craniofacial research. This stores the different researches performed by using the finite element model to study the growth of the cranial structure, biomechanical reaction to orthopedic forces, orthodontic tooth movement, orthognathic surgeries application, and orthodontic implants

Keywords: Finite element analysis, Stress, Orthodontic tool.

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Finite Element Method

The finite element method (FEM) is a computerized Analytical tool that estimates the deformation and the biomechanical response of a geometric model that results from a definite force upon a system a geometric model that results from a definite force upon a system ¹.

The finite element was firstly introduced in the early 1960s. Most commercial FEM software packages originated in the 1970s like Abaqus and Ansys².

FEM divides the analyzed structure into several partitions (elements). The elements are reconnected at “nodes” resulting in a set of simultaneous algebraic equations at nodes³.

Advantages of FEM

- FEM can be applied to non-linear and linear as well as fluid and solid structural⁴.
- It is a non-destructive technique⁴.
- By utilizing FEM, any biological condition can be simulated to get more accurate results¹.
- Assess the deformation in a repeatable manner, repeating the analysis does not distress the tested material properties⁴.
- Static and dynamic analysis are conceivable².
- Less effort and time consuming¹.
- No need for extensive instrumentation⁴.

Shortcomings of FEM

- Inaccurate details and information will result in misleading results⁴.
- Human biological structures are extremely challenging for modeling⁴.
- Accurate physical properties should be available⁴.
- Tooth is restrained to the surrounding tissue; this is presumed to be rigid. This assumption will introduce some error⁴.

Application of FEM in orthodontics

1-Craniofacial growth

According to Moss et al.⁵, FEM evaluates the cranium finer than previously available.

Diewert and Lozanoff⁶ executed a morphometric study of early human craniofacial development in the median plane through the period of primary palate growth using FE analysis suggested that morphogenetic growth changes in the cranial regions are closely associated with facial regions during primary palate formation. Montegi et al.⁷ in their study examine the facial skeleton changes with the aims of FEM. The results indicate that mandible growth was mainly in the early human period, and the path of growth directed backward and upward from the mental region to condylar joint.

According to McIntyre et al.⁸, FEM is a sensitive morphometric technique and it can estimate the shape change of the structure under examination, in all directions and at each landmark which is not possible with conventional cephalometric analysis.

2-Periodontal stress and tooth movement

The biomechanics of orthodontic movement has been explained by many researchers. Tooth movement essentially is governed by stress and strain in periodontal tissue⁴.

Williams and Edmundson⁹ studied the position of the instantaneous center of rotation of a maxillary central incisor using the FEM. It shows that the center of rotation is insensitive to the properties of the surrounding periodontal tissue. The position of the center of rotation is independent of load but dependent on the point of loading. Tanne K et al¹⁰ studied the stress in the periodontal tissue that results from orthodontic forces using the FEM. They found out

that the stresses in the periodontium from a specified level of force were different, depending on the center of rotation of the tooth.

McGuinness et al¹¹ found that the quantification of stress in the periodontal ligament is an important concept, as stress in the periodontal ligament is transmitted to the alveolus with subsequent bone remodeling and tooth movement produced by an edgewise appliance. Mestrovic et al¹² study the tooth movement resulting from orthodontic forces using FEM. They also concluded that the tipping tooth movement is greater if the force is applied more gingivally.

Kojima et al¹³ studied the difference in initial tooth movement and long-term tooth movement on finite element simulation of maxillary teeth connected with the archwire. According to them the location of the center of resistance could be estimated from the initial tooth movement, assuming the archwire to be a rigid material. Jing et al¹⁴, evaluated the stress patterns along tooth root, periodontium and surrounding bone during cuspid tipping and bodily movement in four consecutive therapeutic weeks by using 3D FEM.

Despite the increasing request for clear aligners to treat maligned teeth, many concerns about the efficacy for this system in controlling tooth movement. The tooth movement achieved upon aligner therapy differs from tooth movement achieved with traditional fix appliance. Jiang et al¹⁵ studied tooth behaviors under upper anterior teeth retraction with clear aligner

therapy. A three-dimensional model of maxillary teeth with extracted first premolar was constructed for finite element analysis. They found that combining intrusion displacement on aligners led to a tendency of lingual root movement for incisor retraction.

The mechanical environment associated with orthodontic tooth movement and root resorption is more complex than is generally appreciated. In the same region of root, PDL and bone, there can be predominantly compressive stresses in one structure, but tensile stresses in another. Viecilli et al¹⁶ analyze the directions of tension and compression within the alveolar bone. An idealized tooth model was constructed with CAD for finite element stress analysis. They found highest principal stress magnitudes in the root, PDL and alveolar surface occurred predominantly in the longitudinal, radial and hoop directions, respectively. On the "compression" side, the only structure consistently in compression in all directions is the PDL; however, magnitudes are different in different directions.

3-Orthopaedic forces

Tanne K et al¹⁷ through three-dimensional FEA models of the mandible studied orthopaedic chin cup forces biomechanical effects on temporomandibular joint and mandible from. This study indicated that, remodelling of the mandible as a result of chin cup forces used for adolescent individuals with advance mandible. Jafari et al¹⁸, in their study used 3D FE model of a human dried skull to analyze rapid maxil-

lary expansion stress distribution within the craniofacial complex. According to this study, the expansive forces are also noticeable within the zygomatic and sphenoid region as well as in the intermaxillary suture.

4-Temporomandibular joint dynamics

Gupta et al¹⁹ used a 3D model to assess the of stress in the temporomandibular joint resulting from mandibular protraction. This study indicates that the tensile stresses noticed in the posterosuperior surface of the mandibular condyle this explains condylar progression in this direction. Also, the tensile stresses are generated in the posterior tissues for the glenoid fossa this explains the higher cellular activity for this area.

Katada et al²⁰, used 3D FEM to examine the stresses pattern on the mandible and temporomandibular joint consequential to the unilateral horizontal lengthening of mandibular body and vertical lengthening of the ramus. For the mandibular body lengthening, the stress was seen in the anterior area of the condyle and the condyle tilted backward. Conversely, for ramus lengthening the stress found in the posterior area of the condyle and the condyle tilted forward.

5- Orthognathic surgeries

In orthognathic surgeries aesthetic is of prime importance as patients are too much concerned about their post-operative facial morphology. The advent of facial 3D simulation models and virtual orthognathic surgery gives the patient

and the surgeon a new way to interact with each other.

Chabanas et al²¹, through 3D FE model of face soft tissue predicted facial soft tissue deformations resulting from bone repositioning in maxillofacial surgery. Obaidallah et al²², in their paper, designate surgical scheduling, simulation and expectation of facial soft tissue look consequential to mandibular advancement using FEM.

Hasan et al²³ deliberate the biomechanical effect of distractor force direction for mandibular corpus distraction osteogenesis. They found that the maximum von Mises stress, x and z displacement were associated within force parallel to the inferior border of the mandible.

Al-Khatib et al²⁴ found that Male and female models showed no significant difference for Von Mises stress value and distribution with the same force that associated with distraction osteogenesis of ascending ramus lengthening. The displacement was higher for males than females.

6- Orthodontic implants

Mini screws and mini-implants are being widely used as Anchorage unite in orthodontic treatment.

Gallas et al²⁵, examined 3D bone and implant FE model. Their study presented that the stresses were always concentrated around the cervical region. Jiang et al²⁶, carried out a finite element model to assess orthodontic mini-implant differences in the diameter and length

and to categorize their optimal choices for the maxillary posterior region. They found out that diameter exceeding 1.5mm in combination with the longest length in the safety range was the optimal biomechanical choice.

Qie et al ²⁷. study aim to explain the biomechanical effects of mutual loading of upper anterior teeth and posterior implants with the sliding method for en-masse anterior teeth retraction.

7-Brackets and wire designs

The FEA diminishes the need for samples and workshop experimentation and allows more design options to be tested easily. Ghosh et al ²⁸, compared six commercially available ceramic brackets with different designs, FEM was used in stress analysis of them subjected to various forces. They found out that stresses were concentrated at corners, edges and other areas of abrupt change in the shape of the bracket.

Huang et al ²⁹using the FEM, studied the torque abilities of conventional and self-ligating brackets. According to their study, the active clip of the Speed bracket diminishes torque performance but concurrently lowers the torque moment considerably below the active moment.

Kawamura et al ³⁰ found that as archwire size was diminished lingual tipping of the incisors was detected using a3D FEM.

Shyagali et al³¹ study the difference in stresses generated in the bracket-cement-tooth system utilizing a three-dimensional finite element

model. They found Adjusting the bracket base mesh by changing the distance of the mesh significantly effects the sum of stress generated in the bracket-cement tooth band.

Knox et al³² utilize a 3D dimensional finite element model to evaluate the stresses in the bracket-cement-tooth band when the physical and geometric properties of cement are varied. They found that the physical properties and thickness of the cement lute and the shape of the cement lute periphery contribute to the stress distribution within the bracket-cement-tooth band.

CONCLUSIONS

FEM provides a new pathway of research with less time, money, animal study models and experiments. Orthodontists can investigate about various things by mean of FEM. Although FEM does not exactly simulate the biological structures but at least some of the physical properties can be studied using it. It holds a special importance for orthodontic science concerned around forces and stress distribution.

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