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# Progress of finite element analysis method for oral implantology

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***Abstract:*** *At present, three-dimensional finite element analysis method is applied in the field of dental implantology because of its accurate modeling, high repeatability, wide range of applications, efficiency and flexibility, and intuitiveness, and has become an important tool for studying oral biomechanics in dental implantology. The mechanical complications of implant restorations are related to the implant structure, implant placement design method, occlusal loading and other reasons; in recent years, many scholars have used the finite element analysis method for implant biomechanics research. This paper reviews the progress of the research of 3D finite element analysis method for oral implantology in recent years.*

***Keywords:*** *three-dimensional finite element analysis; oral implant; biomechanics*

## 1. Introduction

The finite element analysis (FEA) method is a widely used mechanical analysis method. By dividing the research target into a finite number of units and setting different nodes for each unit, simulating experimental conditions, integrating various mechanical properties and characteristics of each unit, and obtaining approximate values, it can effectively simplify the analysis of objects with more complex structures. It is one of the common methods for biomechanical analysis. Compared with the complex model in the patient's mouth, the 3D finite element technique is more economical, simple, non-invasive and efficient, and is widely used in the biomechanical study of oral implant restoration [1-4].

Nowadays, with the development of implantology, more and more doctors and patients choose implant restorations, however, among the many factors affecting the mechanical complications of implant restorations, biomechanical factors play a major role [5-8]. At the same time, the establishment of different types of 3D finite element models to simulate the influence of different loading conditions on the mechanical distribution characteristics, the analysis of their mechanical distribution and force patterns can optimize implant restoration solutions and provide more theoretical guidance for clinical work personalized implant restoration.

A review of the recent analytical studies on 3D finite elements in oral implantology is presented through implant restoration methods and implant morphology.

Finite element analysis of implant restoration methods

## 2. Finite element analysis of planting and restoration methods

### *2.1 Application in dental defects*

#### *2.1.1 Implant restoration for single missing tooth*

Through the summary of implant cases[9] , it was found that for the implant site, the reason of missing teeth, bone quality, implant diameter, length, and material all affect the success of implant restoration. Li X[10] compared the implant stresses in the maxillary posterior region with different angles by FEA, and found that the Von-Mises stresses in the bone around the tilted implant were the

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highest, and concluded that in the maxillary posterior region with insufficient bone volume, the increased tilted angle of the implant would have a negative effect on the surrounding bone tissue. Similarly, Bassir[11] concluded that when immediate implant loading is performed in different alveolar sockets, different implant placement and orientation will affect the stresses on the implant and the superstructure; at the same time, modifying the implantation axis in non-central sockets will reduce the maximum stresses on the implant and the jawbone, resulting in a more uniform force distribution and thus reducing mechanical complications. In a study by Lopez[12].it was found that the peak stresses of axial and oblique loading were reduced when using zirconia implants.

***2.1.2 Implant-fixed bridge repair***

The bone stress distribution of implant-supported fixed bridges is closely related to the arch curvature, the overhanging wall, the force loading method, and the implant axis.[13-14] . María[15] found by FEA that the stresses in the jaws are minimized when the load is parallel to the long axis of the tooth; it is believed that different implant placement sites and numbers should be designed for jaws with different arch curvatures. Marcián[16] found the maximum stress was found to be 3-4 times higher on the proximal side than on the distal side; increasing the implant length allowed to reduce the negative effect of the cantilever on the restoration; and the maximum stress value was concentrated on the implant neck, indicating that this is the weak zone of the restoration.

***2.1.3 Combined implant-natural tooth restoration***

Implant prosthesis is a good option for restoring tooth loss, but there are individual differences in patients, limitations of local anatomical characteristics, etc. Clinicians often combine natural teeth and implants for restoration. However, there are mechanical property differences between natural teeth and dental implants that are detrimental to the stability of the implant[17-18]. The short-term efficacy of combined implant-natural tooth restorations has been reported, but there are different views on which restorative approach is more biomechanical. Takashi[19] developed a combined natural tooth-implant supported mandibular sleeve crown denture FEA model to verify its feasibility from a biomechanical point of view and concluded that the maximum concentrated stress values of the restoration and jawbone were substantially reduced with the complementary placement of two implants. V. S[20] et al. compared the stresses of the implant single-end fixed bridge model and the FEA model of the combined natural tooth-implant restoration, and found that the Von-Mises stress distribution was more reasonable in the latter approach; however, small diameter implants should be avoided, as they may cause stress concentration. Luigi[21] designed the implant-covered combined natural tooth restoration by modeling a Kennedy Class I tooth loss. The stress distribution of the implant, jawbone, and the upper part of the restoration was analyzed; it was concluded that this restoration method has a more favorable stress distribution for patients with sparse bone.

***2.2 Application of implant restoration for missing teeth***

***2.2.1 Implant covered denture***

Overdentures are one of the popular restorative modalities for dental patients due to their improved masticatory effectiveness, high preservation of remaining alveolar bone, and affordability. In implant overdenture design, attachment type and implant position are directly related to the overhang length and also directly affect the biomechanical distribution of the restoration. A study by Aktas et al.[22-24] compared the stresses in implant overdenture with different attachments, and Locater and ball-$^{cap}$ type attachments showed superior biomechanical performance. However, regardless of the attachment type chosen, the weak zones of implant restorations during lateral loading were located on the working side of the implant neck and on the cortical bone. Barua[25] et al. were analyzing the effect of different attachment types on the peri-implant stress distribution in FEA and found that the stresses were higher in the bar-card group than in the magnetic group and lowest in the ball-cap group.

***2.2.2 Conventional implant fixed denture***

Compared to traditional complete and overdenture, full implant fixed denture can obtain better retention, no need to remove and wear, uniform force transmission, small size and less foreign body sensation, thus improving the patient's mastication and pronunciation. For full implant prostheses, mechanical complications are mainly influenced by the number and position of implant connectors and implants. Herráez[26] found a significant reduction in the combined Mises stress values in the restoration and surrounding jaws by designing inclined implants for the maxillary posterior region, probably due to the altered stress transfer axial and improved stress transfer range with inclined implants in the maxillary posterior. However, Mendes[27] compared the modified implant finite element model with short implants to the all-on-4 implant solution with conventional length implants and found that the stress distribution was better with the modified short implant solution. It was concluded that the influence of the implant axial direction on the stress distribution in the jaw was greater than the influence of the implant diameter on the stress. Homossany[28] compared the implant fixed restorations with one-stage implants and two-stage implants by finite element modeling and found that the stress concentration was mainly concentrated in the posterior region of the denture and the stress was higher in the two-stage implants.

### *2.2.3 Through-zygomatic-through-wing implants*

Since the discovery of zygomatic-through-wing implants, domestic and foreign scholars have improved them, however, there is still a lack of consensus on the best treatment structures for different zygomatic-through-wing techniques commonly used in relation to conventional implants. Gözde,[29、30] et al. found that pterygomaxillary implant solutions and zygomatic-through implants have shorter hanging walls and lower Von-Mises stress values in the mechanical distribution of reasonable bone tissue than conventional implant solutions, and are more restorative and less structurally deformed than conventional implants. Martin[31] found that the stresses were mainly concentrated in the anterior part of the restoration through the FEA design of implant fixation combined with pterygomaxillary implants; the stress distribution was basically similar when the tilt angle of the pterygomaxillary implant was changed; on the contrary, the implantation site had a greater influence on the stress distribution and the location of the stress concentration. However, there is a lack of clinical consensus on the pterygomaxillary and temporomaxillary implant sites, and there are few relevant studies.

## 3. Finite element analysis of implant restoration morphology

Long-term stability of the implant requires that the implant bone-to-bone interface must be able to withstand occlusal forces without adverse tissue reactions. Many factors influence the transmission of occlusal forces by the implant, including: the site of the implant, the number, material and shape of the implant, the design of the restoration, the height, width, shape and density of the alveolar bone, and the loading method of the occlusal forces. Compared to other factors, the implant profile design has a greater impact on the performance of the implant in transmitting dispersed forces. A proper implant profile can increase the support and retention capacity of the implant, reduce the concentration of stress in the alveolar bone around the implant, slow down the resorption of the alveolar bone, and increase the success rate of the implant. The implant design includes the length, diameter, contour, neck, abutment connection, and thread design of the implant. Studies have shown that the incidence of mechanical complications of implants is related to the implant diameter, length, root surface profile, and thread structure[32-33] .

### *3.1 Implant diameter and length*

In recent years, many scholars have concluded that excessively long implants are not conducive to intraoperative cooling and cause bone burns, while shorter implants with higher implant success rates have become the new choice[34]. Wenbo Gao[35] et al. found that the implant diameter has a greater effect on the micromobility variables of the implant under vertical and lateral loading than the implant length. Similarly, Mihai[36] concluded that short implants are biomechanically better for Class IV bone mandibles by comparing the stress effects of different implant lengths on different bone qualities. In a finite element study by Moreira[37] it was found that 2.9 mm diameter implants have higher axial load values on peri-implant bone, implants and abutments than 3.5 mm implants.

### *3.2 Implant profile*

As implant concepts continue to evolve, cylindrical and conical implants are considered to have a high success rate and are widely adaptable to occupy most of the current market. In a study by Eduardo[38] , it was found that tapered implants are more conducive to the distribution of occlusal forces than cylindrical implants; at the same time, the stresses inside tapered implants are lower. Similarly JaeHyun[39] concluded that cervical tapered contoured implants have a more reasonable mechanical distribution. Geramizadeh[40] also concluded that tapered implants have the most uniform and ideal stress distribution in the surrounding cortical bone and is considered to be the preferred choice for future applications. The results of other scholars are different. Kim[41] found that cylindrical expansion implants reduce excessive stresses in the jawbone and that the stress distribution is better to avoid undesirable stress absorption in the jawbone. Sabri LA[42] obtained similar results for tapered implants with higher peak cortical bone stresses than cylindrical implants.

### *3.3 Implant threads*

Both Vigolo[43] and Lima de Andrade[44] found that the stress distribution in the alveolar bone around implants with a threaded surface was more uniform than that of implants without a threaded surface, and that the effect of implant threads on the stress distribution in the jaw bone was mainly in the cancellous bone, with little effect on the bone cortex. Ayranci[45] et al. compared the effect of different implant threads on stresses and found that flat-finned implants had better mechanical properties than threaded implants. Chowdhary[46] found that the thread design had a significant effect on the stress distribution in the alveolar bone under immediate loading, probably because no osseointegration was formed between the implant and the jawbone and the initial stability of the implant was affected by the implant micromobility.

### *3.4 Personalized root-shaped implants*

In recent years, with the development of implant concepts and 3D printing technology, personalized root-shaped implants are gradually being noticed. Unlike conventional implant placement, personalized root-shaped implants do not require preparation for implant placement and mimic the biological behavior of natural teeth [47]. The biomechanical performance of the personalized root-shaped implant was studied by FEA, and it was found that the main set of stresses during inclined loading of the personalized root-shaped implant was located around the neck of the implant on the stressed side, and the stress maximum in the jawbone was located in the labial cortical bone region.[38] Furthermore, there was no statistically significant effect of the presence or absence of thread design on the stress distribution inside the personalized root implant. Similarly, Moin[48] et al. found that the stress distribution in personalized root-shaped implants did not correlate with the implant thread morphology and thread spacing.

## 4. Expectation

With the national attention to oral problems, the development of implant theory and manufacturing process, personalized implant solutions and personalized implant restorative structures have potential application prospects. The finite element analysis method provides more fundamental guidance for the biomechanical research of oral implantology and offers more possible solutions for the clinical work. At this stage, although the research of 3D finite element analysis in the field of oral implantology is still limited to static and ideal conditions, it has certain advantages in scientific research because of short experimental time, high repeatability, comprehensive mechanical properties testing and the ability to simulate various complex conditions, and non-invasive testing. However, how to integrate the modeled results with clinical work is still a problem that needs to be solved nowadays. Living soft tissues are nonlinear and mechanical in nature, and their deformation dynamics and other conditions should also be considered when studying oral structures. The finite element analysis method has its limitations and may not fully reflect the real situation, and further clinical studies are needed to supplement the validation. The data simulated by the existing computer is far from covering the complex human biological behavior, and a lot of research accumulation and summary are still needed in the clinical work to supplement and improve the deficiencies of 3D finite element analysis and provide more basis for theoretical guidance of clinical practice.

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