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Advances in Biomechanical Properties of Mandibular Fractures

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Abstract: *By consulting the relevant research data about the biomechanical properties of mandible at home and abroad, and combining with the relevant experimental operations of biomechanical tests, this paper aims to provide a basis for the treatment of mandibular fractures and the prevention and treatment of postoperative complications, further standardize the selection of treatment schemes for mandibular fractures, provide a theoretical basis for optimizing surgical schemes and preventing postoperative complications, and provide reference for related research in mandibular mechanics.*

Keywords: *mandibular fracture; biomechanical testing; three-dimensional finite element analysis*

1. Introduction

The lower collar bone is located in the lower third of the face. Anatomically, the mandible consists of the condyle, the coronoid process, the mandibular branch, the angle of the mandible and the mandibular body, which is a bilaterally linked joint that transmits through the central nerve to the masticatory muscles and ligaments and other soft tissues attached to the mandible to perform physiological activities such as chewing and swallowing. At the same time, the mandible bears and transmits loads due to muscle contraction-stretching during mastication. Therefore, elucidating the corresponding stress distribution and stress transmission in the lower collar bone after loading has always been a common problem discussed by domestic and foreign researchers[1]. In maxillofacial trauma, mandibular fractures are the most common, accounting for approximately 23-97% of all maxillofacial fractures[2]. Haug et al[3] showed in a 5-year study that most maxillofacial fractures occurred more frequently in men aged 16 – 30 years and were usually caused by quarreling with others, traffic accidents, or sports-related injuries. Maxillofacial fractures affect the quality of life of patients due to severe changes face, and even sometimes lead to psychological disorders[4]. At the same time, maxillofacial bone fractures are often accompanied by occlusal derangement, jaw displacement, tooth defects and even edentulism, which also affect the maxillofacial oromandibular system function of patients. Titanium alloys are now commonly used clinically as internal fixation materials, but have stress-shielding effects during fracture healing and reconstruction because titanium alloys have much higher modulus of elasticity than cortical bone. Removal of the internal fixation material is often required after surgery, which not only aggravates the patient 's pain, but also increases medical expenses. Because of the biodegradability and good biocompatibility, biodegradable polymer materials have been widely used in clinical practice and have received increasing attention in recent years. However, because of its insufficient strength, it is rarely applied clinically to the mandible, but more frequently to less stressed sites, such as the middle and upper face. Bone stiffness and load bearing capacity are most directly represented by the magnitude of its mechanical properties[5]. In bone tissue, osteocytes control the detection of mechanical afferent nerves and their conversion into biochemical information, so these cells can be considered as a mechanical sensor that guides osteogenesis to where increased bone strength is most needed. Stimulation of bone cells occurs in a variety of ways: shear stress and stretching, changes in extracellular pressure, strain, changes in electric fields within and around bone cell lacunae[6]. Under physiological conditions, the osteocyte network activates osteoclastogenesis, inhibits osteoblast function, enhances bone resorption, and inhibits bone formation. Under unloaded conditions, the function of the osteocyte network is enhanced, while exercise can reduce the inhibitory effect on bone mass by reducing osteoclastogenesis and inhibiting osteoblast function[7]. In recent years, the biomechanical properties of

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lower collar bone stress analysis mainly include biomechanical tests, mandibular microstructure related studies and three-dimensional finite element model analysis, which will be described below[8].

2. Biomechanical tests

Biomechanical tests is one of the most direct methods for performing bone mechanical properties testing, and the quality of experimental studies can be improved by selecting suitable test methods[9] . In recent times, due to the increased research on force science and the progress of detection methods, domestic and foreign researchers have gained more understanding of the mechanical properties of the mandible at the macroscopic and microscopic levels, providing more and more effective basis for selecting treatments for mandibular defect repair and protocols for mandibular internal fixation.

2.1 Bending test

Bending test mainly includes three-point bending test and four-point bending test. Three-point bending test can quickly determine the maximum load, obtain stress-strain curve and stress-displacement curve, and preliminarily determine the stiffness of the material. The mandible is mainly composed of cortical bone, cancellous bone, teeth, periodontal ligament, and internal neurovascular bundles . In general we believe that mechanical properties of bone depend on microcomposition: porosity , mineralization degree and microstructure: aligned collagen fibers, cortical, cancellous and trabecular bone[10],while the mechanical properties of these microcompositions and structures are mainly reflected in macromechanical properties of bone tissue (that is, they can be achieved by three-point bending tests)[11] . In the research process, because the design and usage are simple, three-point bending test is often widely used in the detection of biomechanical properties of various animal experiments, which greatly increases the test homogeneity, reduces the experimental error and avoids data confusion. Although the three-point bending test is easy to operate and has high applicability, it still has some disadvantages. The compressive stress in the middle region of the sample comes from the upper part and the tensile stress from the lower part of the sample as well as the shear stress existing in the loading direction. Some scholars think that the length-to-height ratio of the test sample is 10: 1, which has great influence on the mechanical properties. Therefore, in order to reduce the error of the test[9], Li Yanfeng et al. believed that the stable elastic modulus of the sample depended on its length-height ratio, that is, when the length-height ratio was greater than 1/25 , the obtained elastic modulus was the most stable[12] . Therefore, the difference in the size of each sample during the three-point bending test would also have an impact on the final experimental data. Four-point bending test refers to that the sample is placed on a four-point bending fixture to form a simple beam form, the distance between the two lower support points of the support sample is adjustable depending on the length of the sample, and two activation points above the four-point bending fixture are symmetrically pressurized on both sides of the bone tissue callus. Because there are two activation points and stress points each, there is no shear force and stress concentration in the sample, which can avoid the destruction of the callus area, and well avoid the drawbacks caused by the three-point bending test. Therefore, from the experimental design, the three-point bending test is less accurate than the four-point bending test, but easy to operate, while the four-point bending test can protect the callus area because there are two activation points and stress points, respectively, so the requirements for the bone tissue sample are higher.

2.2 Tensile test, compression test and torsion test

These three mechanical tests are mainly used to test the biomechanically relevant properties of bone tissue, such as compressive properties, tensile properties and torsional properties. Although Young 's modulus, yield strength and ultimate strength of bone tissue can be obtained by tensile test as biomechanical properties of related bone materials, and structural properties of bone tissue (such as stiffness and maximum load) can also be obtained, because human bone is not in a tensile state for a long time, tensile test is not in line with the physiological state of the human body, so it is difficult to obtain the original mechanical properties of bone by tensile test. Therefore, tensile testing is performed when assessing relative differences in biomechanical properties, whereas compressive testing can be performed when assessing elastic modulus and mechanical properties of cancellous and cortical bone[13][14]. Elastic modulus testing of bone tissue by compression testing is essential to describe its physiological state, and compression testing is easier to perform than tensile testing. Of course, the compression test methods for different tissues are also different[15][16], and the compression test results for different experimental equipment will also be different[17][18] . Therefore, the mechanical test method should be determined by

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the properties of the sample and the physical characteristics of the experimental material. Torsion test is mainly applicable to measure the shear force of bone tissue samples[19]. One of the basic test methods for mechanical property test of materials is the test for determining the torsional action of materials. Torsion test is to apply torsion T to the test sample, measure torsion T and corresponding torsion angle φ value, draw torsion curve diagram, generally twist to break, so as to determine various torsion mechanical performance indicators of materials. It can be used as an effective means to analyze the fracture related mechanism of bone, evaluate the quality and strength of reduction after internal fixation of fracture as well as the mechanical properties after prosthesis fixation. Torsion testing may be performed to supplement samples with poor tensile and compression test results.

3. Mandibular microarchitecture Biomechanics

The regular arrangement of trabeculae in the mandible can effectively disperse the force from the teeth, while the density, number and arrangement of mandibular microarchitecture are closely related to the biomechanical properties of the mandible[20].It has been studied to observe the changes of mandibular microarchitecture with age in mouse mandibles using Micro CT after OPG deletion , and the results indicate that the mandible will be affected by force as well as various factors in vivo throughout the life cycle, With increasing age , bone destruction is also more pronounced[21], and it can be seen that mandibular microstructural changes are closely related to overall biomechanics. In addition, in the biomechanical measurement of bone trabecula, the quality of fixation effect will inevitably affect the biomechanical measurement results. In order to firmly fix and protect the structure of bone trabecula, some scholars have filled polymethyl methacrylate (PMMA) on both sides of sample bone trabecula and made the bone trabecula become hard after it solidifies. It can be seen that the use of PMMA in the fixation of bone trabecula can play a good effect[22], which can more quickly obtain the biomechanical related results of bone trabecula and reduce the deviation.

4. Three-dimensional finite element analysis

Finite Element Analysis (FEA) is an important research tool in biomechanical analysis in biological research. Von Mises stress, also known as equivalent stress, is an important parameter for ductile materials (such as metals) and is used to define the yield point. Once the yield point is reached, the material will not be elastic and produce permanent deformation[23].It analyzes the stress by dividing the sample into a number of finite elements by considering it as a geometry formed by the connection of each finite element. Mechanical testing has long been regarded as a standard tool to investigate the extrinsic properties of bone: stiffness, yield force, and intrinsic properties: Young 's modulus, elastic modulus[24]. With the development of science and technology and the progress of medicine, some scholars have proposed the use of three-dimensional finite element analysis model for the analysis of relevant data, in which the type, arrangement and total number of elements will affect the accuracy of the results. By constructing a finite element model, appropriate material properties, loading and boundary conditions are then specified so that some disease states in the clinic can be accurately simulated[25]. FEA was first applied in engineering related fields, and its application in the medical field shows that engineering is closely related to clinical medicine. Three-dimensional reconstruction of body structure can be performed through the model, and stress changes occurring with external conditions can be analyzed[26]. Some specific experiments and conditions can certainly also be simulated, and there is high repeatability, which greatly avoids ethical problems in animal medicine and heavy animal experiments and can save costs. Mechanical analysis function cannot be less studied[27]. Now FEA mechanical analysis is widely used in oral surgery, oral implant prosthodontics and other fields[28], which mainly includes finite element analysis before jaw cyst block resection to evaluate and simulate the stress concentration of mandibular fracture reduction and internal fixation as well as dentition defect repair and implant repair[29][30], KAVANAGH[31]et al. use 3D reconstruction technology to reconstruct the mandible of healthy patients, finite element method analysis of unilateral mandibular angle fracture, with one to two titanium plates for external oblique fixation, mandibular angle fixation and other different methods, the advantages and disadvantages of different analysis, such as unilateral mandibular angle fracture that the effect of different fixation methods of mandibular angle fracture in vitro finite element analysis, the accurate analysis of preoperative surgeons is beneficial.

5. Prospect

In recent years, biomechanical research is still a research hotspot in stomatology. Different research purposes can be achieved through the above-mentioned detection methods, and corresponding mechanical results can be obtained from different dimensions and analyzed. Macromechanical results can be obtained through three-point bending test, four-point bending test, compression test and tensile test. Micromechanical results can be obtained by observing trabecular bone through Micro CT and detecting its elastic modulus by nano-indentation test, which enables us to have a more full and comprehensive understanding of the mechanical properties of bone tissue. It can model complex geometrical objects, obtain the stress and displacement values and their distribution laws of integrity and locality, and compare and analyze the stress magnitude and distribution changes of the original model under the condition of maintaining the original model geometry unchanged, such as loading and boundary conditions, and can change according to needs. This method has become a practical, effective and convenient method for structural optimisation and design, material non-linearity and geometric non-linearity analysis, which is efficient, accurate and low cost. Because FEM has the advantage of other experimental stress analysis methods, it promotes the rapid development of medical science in surgical simulation, medical education and training, surgical planning and intraoperative assistance in combination with computer technology and numerical stress analysis. The stress distribution and stress concentration of the mandible can be approximately simulated by finite element analysis, but the internal stress system of the jaw is very complex under functional loading, and the interruption of the continuity of the jaw after the occurrence of the fracture means that the stress trajectory in the jaw is interrupted, and then the resistance structure and bearing function are lost. The aim of internal fixation of jaw fractures is to temporarily reconstruct the alternative structure of stress conduction and create conditions for fracture healing while restoring oral function. U It is difficult to avoid relative misalignment of the fracture section in a functional state with unstable fracture fixation, which can lead to poor fracture healing and even infection. Although there is a good correlation between FEA results and in vitro results. However, the FEA model has some errors in simulating clinical situations as the raw data is not available and most studies score the results differently, making it difficult to compare the findings, so further research is needed to address the challenges of accurately modelling stress distribution in clinical lesions of the mandible and accurately detecting biomechanical properties.

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