Xiao, X.; Liu, H.; Wei, D, Xiong, L. (2023) Application prospect of bone substitute materials in orthopedic trauma repair under CT images. Revista Internacional de Medicina y Ciencias de la Actividad Física y el Deporte vol. 23 (89) pp. 199-211
DOI: https://doi.org/10.15366/rimcafd2022.89.014

ORIGINAL

APPLICATION PROSPECT OF BONE SUBSTITUTE MATERIALS IN ORTHOPEDIC TRAUMA REPAIR UNDER CT IMAGES FOR IMPROVED RECOVERY OF ATHLETE PLAYERS

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Spanish-English translators:

UNESCO Code / UNESCO Code:
Council of Europe classification / Council of Europe classification:

Recibido 30 de abril de 2020 **Received** April 30, 2020
Aceptado 26 de junio de 2020 **Accepted** June 26, 2020

ABSTRACT

The main content of this study is the important value and prospect of using bone substitute materials in orthopedic trauma repair in recovery of athlete players. Athlete-players are a population that frequently experiences orthopedic injuries, which can significantly impact their athletic performance and overall quality of life. Firstly, the biocompatibility of bone substitute materials is reviewed. The evaluation methods of biocompatibility of bone substitute materials mainly include in vivo and in vitro biological research. At the same time, it is also analyzed that bone substitute materials have important influence on the internal environment, including the influence on cell morphology and cell function. Combined with the above analysis, a personalized bone substitute was made based on the spiral CT image data, assisted by computer technology. It is found that the bone materials designed according to the above methods have good matching, and when implanted in the wound repair site, it will not cause great trauma during the operation, and it can also save the operation time. At the same time, after the follow-up of athletic patients, it is found that the artificial bone materials have very significant compatibility and high safety. Therefore, bone substitute materials made by combining CT imaging technology, computer technology and the actual clinical manifestations of athletic patients can play a significant therapeutic effect in wound repair, which is worthy of clinical application.

KEYWORDS: CT images; Bone substitute material; Orthopedics; repair in trauma, Athletic Patients

1 INTRODUCTION

With the rapid development of China's economy and society, people's life rhythm is accelerated, and the rapid development of sports, food service and entertainment, traffic accidents, clubbing, falling, boxing, kicking and explosion are gradually increasing (Salama, Farhoud, & Elbehairy, 2021). All these factors make the incidence of orthopedic trauma show a rising trend in recent years. For orthopedic trauma, patients with mild degree will lose their mobility, and patients with severe degree may even threaten their lives. According to the orthopedic trauma of patients, spiral CT images were examined, combined with clinical realization and computer technology, and bone substitute materials were designed for repair. Essentially, it refers to combining the actual situation of each patient, making use of high-tech forms to complete the manufacture of bone substitute materials suitable for different bones, so as to realize the repair of the injured parts of patients (Lu et al., 2021; Ma et al., 2021). Of course, this technique has been practiced repeatedly in clinical practice, and commonly used bone substitute materials include titanium and bioceramics. Combining CT images and computer technology to make bone substitute materials in orthopedic trauma repair can reduce postoperative adverse reactions, improve the overall repair effect and improve the prognosis of patients.

The development stages of bone substitute materials can be summarized as follows:

Stage 1: From 1960 to 1980, biologically inert materials, characterized by their relative stability in the human environment, difficulty in decomposition, and better matching of mechanical strength and physical and chemical properties with the human environment, such as polyethylene and carbon-based materials (Y. Li, Wang, Cui, Zhou, & Zhao, 2021).

Stage 2: From 1980 to 1990, bioactive or degradable absorbent materials, which have bioactivity, can interact with the environment when implanted in the body, such as active ceramics and bioglass.

Stage 3: Since 1990, tissue engineering materials with biological activity and degradability have combined biological activity with degradation and absorption, and they have good biological activity (Kumar, Hossain, & Osmani, 2018; ZHANG, WANG, & HE, 2020). They can be degraded by the internal environment in organisms, and finally participate in the metabolic reaction and be absorbed. In recent years, combining biomaterials with drugs to form drug-loaded biomaterials is one of the new research directions in this field (Choudhury et al., 2021).

2 BONE STRUCTURE AND BONE SUBSTITUTE POLYMER COMPOSITES

2.1 Bone structure analysis

Bone is a kind of dense connective tissue, which is composed of different proportions of organic matter and inorganic matter (F. Li et al., 2020). From the perspective of materials science, bone can be understood as a composite material filled with collagen matrix by nano hydroxyapatite particles. The structure and comprehensive properties of bone are better than those of synthetic nano-hydroxyapatite-collagen composite, because bone is a multi-level and complex structural system. The multi-level structure of skeleton develops from low to high, including woven bone, primary bone and Haversian system. As shown in Figure 1.

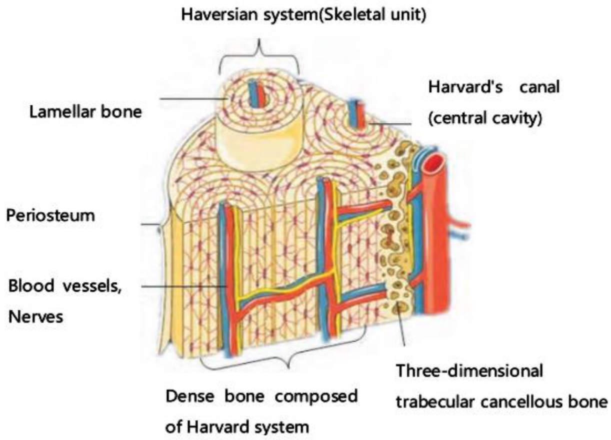

Figure 1 Bone structure

2.2 Bone substitute polymer composite material

The ideal artificial bone substitute repair material should have the following characteristics: 1)It has good biocompatibility, and the material is conducive to cell adhesion, proliferation or differentiation. 2)It has necessary mechanical properties, and its degradability is controllable. 3)It has a porous three-dimensional structure similar to bone tissue, which can provide support for the expansion and growth of new bone on the surface of the material (bone conductivity), and can induce pluripotent stem cells around the bone tissue to differentiate into osteoblasts (bone induction). 4)The material has sufficient sources and is easy to shape.

As a material for repairing and replacing hard tissues of human body, the modified polymer composite material will have the following advantages: the elastic modulus can reach the natural bone level through adjustment. Implants with various materials and varieties that can meet the needs of different parts of the human body; Easy molding, low density and high toughness. The disadvantage is that as a loading material, there are some limitations, such as poor strength and easy deformation. Meanwhile, the surface of polymer-carbon fiber composite has no biological activity (HE, LI, & XIE, 2018; Hou et al., 2021).

Polyetheretherketone(PEEK) is suitable to be used as the matrix of new bio-composites. It has high strength (tensile strength is 5 times higher than polyethylene), high toughness, high wear resistance, good fatigue resistance and impact resistance. It is a kind of semi-crystalline thermoplastic polymer, which can be molded without any additives, thus avoiding the harmful pollution to human body caused by the addition of other compounds. It has strong resistance to hydrolysis and radiation, so the mechanical properties of the material will not deteriorate after being sterilized by high temperature and high pressure or radiation, and the mechanical properties of this material are very stable in physiological environment (Silva, Queiroz, Ishikawa, Silvestre, & Xavier, 2017).

3 SELECTION PRINCIPLE OF BONE SUBSTITUTE MATERIALS AND CELL ENVIRONMENT IN VIVO

3.1 Selection principle of bone substitute materials

3.1.1 Natural bone materials

This kind of bone material includes autogenous bone, allogeneic bone and xenogeneic bone. Autologous bone is mostly taken from the rib or ilium of the body, and its source is very limited. Its disadvantage is that it can't be obtained in large quantities, which will cause additional trauma to the patient when taking the bone. At the same time, a second operation is added, and the shaping effect is not ideal and the appearance is not good. Allogeneic bone is mostly taken from long-term frozen, freeze-dried or chemically treated bone in bone bank. Its disadvantage is that the cellular components have been destroyed, and it is easy to be contaminated in the process of transplantation. At the same time, there are many chances of immune rejection, which will eventually affect the therapeutic effect. Heterologous bone, which is taken from animal bones, is one of the earlier research and application bone substitute materials. Compared with the above two kinds of bone materials, it has abundant sources and can meet the increasing demand of patients clinically. As the main component of allogeneic bone is hydroxyapatite like human bone, it has good biocompatibility, but its immunogenicity and biomechanical properties are not as good as human bone, so it needs further research and improvement.

3.1.2 Artificial synthetic bone substitute materials

Artificial synthetic bone substitute materials made by different chemical synthesis methods include polymer materials, bioceramics materials, metal materials and other materials. Polymer materials include natural polymer and synthetic polymer. The former is a polymer containing collagen, fibrin, chitin and other natural polymers, which has the advantages of good biocompatibility and is conducive to cell adhesion and differentiation. However, bone entities made of this material lack mechanical strength, it is difficult to obtain a large number of them, and there are great differences in different production batches. Therefore, this material is difficult to be used as a matrix material for bone cell planting clinically (Zeng, Wu, Li, Wang, & Shang, 2021; Zhu, Wang, Yin, & Liu, 2021). The latter is a degradable polymer. This material can be used widely in bone tissue engineering by artificially controlling its tissue composition, mechanical properties, morphology and degradation speed. However, its disadvantage is that the material cells have poor adsorption capacity and lack of the ability of cells to recognize signals, which is not conducive to the activation of specific genes and cell-specific adhesion, resulting in a greater chance of aseptic inflammation. Bioceramic materials can be specifically classified according to their different activities in physiological environment. Their main components are calcium and phosphorus, which are also the main organic components of human bone tissues. Therefore, this kind of material shows its good biocompatibility, and it is easy to form osseointegration after implantation. However, its high rigidity and brittleness make it difficult to process or fix drilling holes, which is its obvious deficiency. Generally, the metal is made of stainless steel plate or stainless steel wire, which is convenient to shape and has a good appearance, so it is a good material for bone repair. However, due to the strong thermal conductivity of metal compared with other kinds of materials, patients should not work in the sun after surgery, and at the same time, it hinders X-ray penetration and affects patients' future check-up. At present, titanium metal is used instead of the former to make up for its deficiency (Tang et al., 2021).

3.1.3 Tissue engineered bone

In recent years, tissue-engineered bone has become a research hotspot. Because of the shortcomings of the above two kinds of materials, researchers have paid attention to the research of tissue-engineered bone. At present, this kind of bone substitute material is still in the stage of in-depth research and development, extensive screening and experiment. To sum up, through the analysis of the advantages and disadvantages of different types of bone substitute materials, when selecting bone substitute materials before surgery, firstly, it is necessary to select individual bone substitute materials according to the clinical application value of the materials themselves, and secondly, it is necessary to combine the characteristics of the patient's own trauma position to make individual bone entities (Adnan et al., 2020; Kang, Xu, Xiong, Xi, & Wu, 2020).

3.2 Cell environment of bone substitute materials in vivo

The sensitivity of cells from different tissues to materials is different, so only cells from soft tissues can be used to detect the cytotoxicity of materials, which can't fully reflect the compatibility of biomaterials. In patients with bone defects or diseases, bone substitute materials must match the original bones and be stably combined (Figure 2).

There are three forms of combination: the first is morphological combination. In the early stage, biomaterials were mechanically combined with the surface of bone tissue or cells, and the stress transmission was discontinuous in this way (Feng, 2015; Sasagawa, Takeuchi, & Aita, 2021). The second is biological combination. Materials and bone tissues or cells are embedded and cross-linked, and the stress transmission is discontinuous. The third is bone bonding or active bonding. Materials and bone tissues or cells form chemical bonds at molecular level (tight bonding, complete compatibility and continuous stress transmission), which is the best bonding method for long-term implantation of materials.

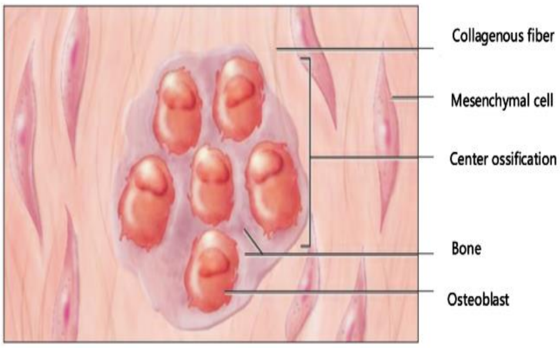

Figure 2 Cell environment of bone substitute materials in vivo

Biological methods are used to evaluate the environment of bone cells contacted by implants. Bone substitute materials should be cells from bone tissue, the most important of which is osteoblasts. The main function of osteoblasts is to secrete bone matrix and mineralize it to form new bone and maintain normal bone mass. When bone materials cause damage to osteoblasts, it will affect the normal function of osteoblasts, which will lead to the pathological changes of the original normal bones, resulting in weak bonding and inflammatory reaction and other rejection phenomena. It affects the normal function of bones. Therefore, selecting osteoblasts as experimental cells in vitro can better simulate the interaction between bone materials and bone tissues in vivo. MG-63 cells, derived from human osteoblast cell line, are commonly used cells in biocompatibility research of bone substitute materials. Bone substitute materials not only contact with osteoblasts in vivo, but also directly contact with soft tissue-derived cells. For example, some fibrous cells, etc. When bone substitute materials are implanted into human body, they must be connected and combined with the surrounding fibrous tissues (muscles), otherwise, muscle tissue atrophy, implant shedding, etc. will occur, resulting in the loss of bone motor function. Mouse fibroblast 3T3 is an important cellular material, which is usually used for in vitro toxicity research caused by carcinogens, etc (L. Li, Dong, He, Liu, & Tong, 2017; Wang, Xu, Chen, Zhao, & Quan, 2018; Yang et al., 2019).

4 EVALUATION METHODS OF BIOCOMPATIBILITY OF BONE SUBSTITUTE MATERIALS

Study and evaluate the effects of biomaterials on cells from different angles. According to the principle of biological function, cell compatibility should also include the evaluation of the effects of materials on the biological functions of cells. In vitro methods mainly focus on cell adhesion, cell cycle, apoptosis determination, differentiation, cell physiology, oxidative stress, signal pathway regulation and biosynthesis function. Through in vitro and in vivo research of biomaterials, the safety and effectiveness of biomaterials application can be ensured.

There are many ways to evaluate biocompatibility, which are mainly divided into in vivo biology and in vitro biology evaluation. When the material is implanted into the body and directly contacts with organs and tissues, the material will have various effects on human tissues; At the same time, the human body has an extremely complex physiological environment, which will also change the physical and chemical properties of materials, which in turn will produce new biological reactions. The dynamic interaction between materials and organisms will affect their respective properties and functions to varying degrees, as shown in Figure 3:

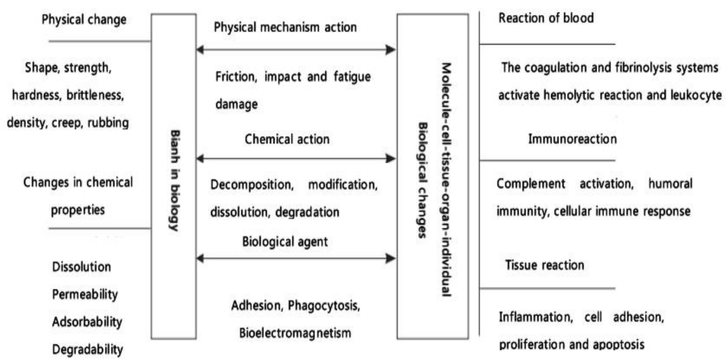

Figure 3 Interaction between materials and organisms

The biocompatibility of biological materials not only meets the principles and methods recommended by the International Organization for Stardardization (ISO) series standards, but also develops in vitro cytotoxicity tests in recent years. Many experimental methods are put forward from the perspectives of morphological methods to detect cell damage, cell growth measurement and cell metabolism measurement. From qualitative in vitro evaluation to quantitative measurement (Gui, Su, Lu, & He, 2020). Through these in vitro studies, we can comprehensively judge the effect and mechanism of materials on cells and evaluate the biocompatibility of materials. With the in-depth development of omics, some scholars think that the biocompatibility of materials needs to be evaluated from genome and protein group level, as shown in Figure 4. Biocompatibility of biomaterials can be evaluated from three levels of molecule, cell and whole biology to ensure that biomaterials can be safely and effectively applied to human body.

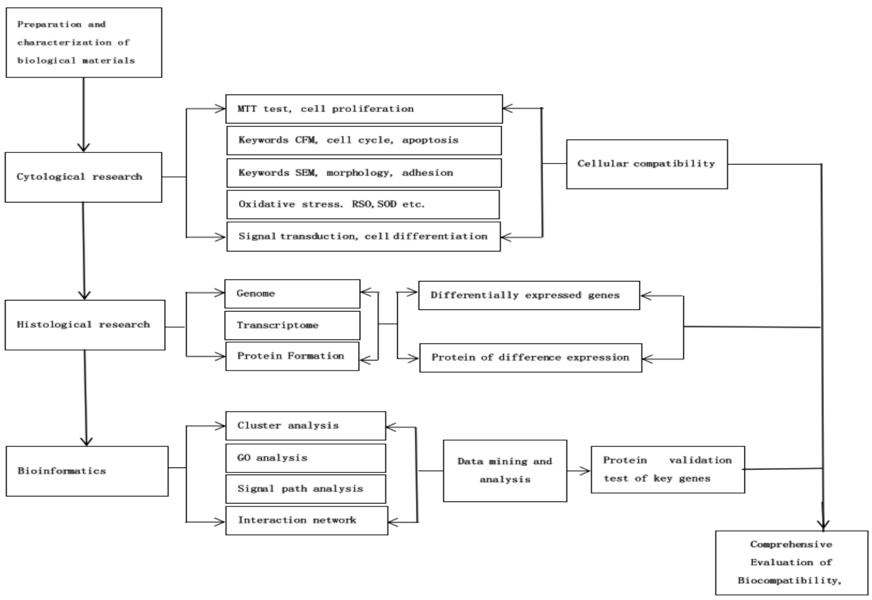

Figure 4 In vitro study of biological materials

5 EXPERIMENTAL METHODS

5.1 Material selection

The patients with bone injuries in different degrees and parts treated in hospitals were selected as the investigation objects, and 70 cases were selected. Among the research samples, there were 40 males and 30 females. The youngest is 28 years old and the oldest is 56 years old. Among the above-mentioned patients, there were 10 patients who repaired fractures and defects of distal femur, 10 patients with bone defects around elbow joint, 32 patients with bone defects around knee joint and 18 patients with bone defects around ankle joint.

5.2 Methods of using bone substitute materials

Perform spiral CT image examination on patients, count their clinical manifestations, and use computational design technology as an aid. Based on this, complete bone shaping for the injured parts of patients, and then make bone substitute materials suitable for patients, that is, get personalized bones. Only after you are ready can you implant them into the injured parts of patients for repair. The detailed steps are as follows:

Step 1: Data collection of patients before operation. Multi-row continuous scanning with slice thickness of 1.3mm was performed by spiral CT. On the basis of the above, the scanning data was saved by using the format of Digital Imaging and Communications in Medicine (DICOM).

Step 2: 3D reconstruction of damaged bones. The scanned data are input into Mimics software, which is developed by Materialise Company of Belgium. According to the above steps, three-dimensional reconstruction of the injured part of the bone can be carried out. After reconstruction, a digital bone model can be obtained. Through standard data registration, a series of simulated repair operations are completed by computer technology. Through rapid prototyping technology, a personalized three-dimensional simulated bone repair model can be obtained.

Step 3: Personality bone shaping. Before the operation, it is necessary to select the appropriate bone substitute materials, and then according to the results of the three-dimensional simulation repair model of bone, the personalized bone entity is made by embedding casting. It's also necessary to clean, edge-grind, rebound, passivate and decorate the bone entities, and wait for the follow-up treatment.

Step 4: Surgical repair. Individualized bone entities can be implanted into bone defects of different patients by standard surgical techniques and arthroscopic techniques if necessary.

5.3 Experimental result

All 70cases in this group were included in the analysis and statistics of postoperative results, with no omission. Among them, there were 2 cases of slight osteoarticular collapse, 3 cases of subcutaneous effusion, 1 case of absorption of bone substitute materials, 2 cases of local fever. The rest of the postoperative treatment results were satisfactory, the limb function recovered well, and the strength of repairing the surrounding muscle groups could reach grade IV or above. There is no rejection and infection, and the individual bone is in good agreement with the injured part of the bone. This method of bone repair using computer-aided design of prefabricated bone model is obviously superior to the traditional method.

6 APPLICATION OF COMPUTER AIDED DESIGN TECHNOLOGY IN BONE

MODEL RECONSTRUCTION

Interactive technology is essential in computer-aided design. Engineers use computer as an assistant design tool, and use interactive system to complete all links of a certain design process, such as drawing graphics, designing parts, designing equipment, analyzing engineering process, etc., so as to achieve the purpose of shortening the production cycle, reducing production costs and improving the quality of production design. This technology is not only widely used in industrial production, but also can be used as an advanced means of assistant medicine in basic and clinical medicine fields, especially in clinical medicine, to assist various medical substitute materials. This paper describes the application of computer-aided design of bone substitute materials in bone wound repair. In 70 cases of surgery requiring bone substitute materials to repair the wound site, after follow-up, it is found that there are 2 cases of slight bone joint collapse, 3 cases of subcutaneous effusion, 1 case of absorption of bone substitute materials, 2 cases of local fever, and the rest of the postoperative treatment results are satisfactory, without rejection and infection. Therefore, the computer-aided design of bone substitute molding technology has obvious advantages over the original traditional repair method, which is mainly manifested in the high consistency of the formed bone entities. The reason is that the bone model obtained by computer three-dimensional reconstruction has reached the anatomical accuracy, which can completely reach the appearance state before repair. At the same time, the personalized bone entities obtained by using this technology can obtain perfect geometric shapes without excessive treatment, so that the operation time will be greatly shortened.

7 CONCLUSION AND DEVELOPMENT PROSPECT

In the future, we should pay attention to the following aspects when using computer-aided design technology to repair bone wounds: 1)The selection of bone substitute materials should not only be based on the performance indexes of the materials themselves, but also be combined with the characteristics of the patients' own wounds, so as to tailor-made individual bone substitute materials for each patient, and use computer-aided technology to complete accurate three-dimensional bone model design, which can be used to make personalized bone entities later. 2)During the three-dimensional reconstruction of bones, the accurate data obtained by multi-row scanning should be based on spiral CT with high resolution and fast imaging speed, so as to ensure the complete reconstruction of the bones in the later trauma site. The thickness of the scanning layer should be controlled within 2 mm, and the scanning range should be more than 2 cm beyond the repaired edge. 3)The 3D bone reconstruction software Mimics is used to carry out 3D reconstruction based on the CT data of the patient's case (down to page

2060) to obtain the 3D bone digital model of the repaired part, which is simulated in the computer through standard data registration, and the personalized 3D bone simulation repair model is obtained through rapid prototyping technology. 4)After the individual bone entities in the repair site made of bone substitute materials are assembled and matched according to computer simulation, relevant follow-up treatments, such as cleaning, edging, springback, passivation and modification, are carried out.

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