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Metal Materials Research Progress of Bone Injuries Repair

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Abstract: Repairing large bone defects caused by trauma or disease poses a significant clinical challenge. Metallic materials with good mechanical properties, biocompatibility and manufacturing processes can be used to repair bone defects. Materials utilized for mending bone defects encompass autogenous bone, allograft bone, metallic substances, bioceramics, polymers, and diverse composites. Biodegradable metallic materials such as iron, magnesium and zinc alloys are considered ideal for bone repair. Emerging metallic materials such as porous tantalum and bismuth alloys are of interest due to their affinity and versatility with bone. Although these materials have shown strong reconstructive capabilities in bone repair, there are still many challenges to overcome. However, there are still many practical difficulties associated with these metallic materials that need to be improved.

Keywords: Metal Material; Bone.

1. Introduction

Bone is an important human tissue structure that has good stiffness and extreme flexibility to maintain the basic shape of the body and limbs, protect important internal organs, and ensure the normal performance of daily human activities. Bone defects are typical orthopaedic disorders which can be caused by severe trauma, viral infections, cancer or congenital musculoskeletal lesions. Studies have shown that 5-10% of patients with bone defects suffer from complications such as delayed healing of bone tissue and non-healing of bone tissue [1-3]. At present, the artificial tissue engineering bone repair materials commonly used in clinical practice are mainly divided into three categories: metal materials, non-metallic materials and polymer materials. Some bone repair materials, such as titanium and titanium alloys, are widely used in the repair of jaw defects due to their advantages of good biocompatibility and mechanical properties. However, the existing restorative materials generally have the problem of suboptimal osteogenic activity. Therefore, many studies have been devoted to the modification of existing bone repair materials in order to make the materials have better bone regeneration promotion properties [4]. Bone regeneration is a complex process, promoting osteogenesis at the cellular level is mainly manifested in the promotion of cell adhesion, proliferation and osteogenic differentiation, regulating the balance between osteogenesis and osteoblastogenesis, and improving the level of intercellular mineralisation. At the organismal level, the material repairs bone defects and promotes growth of trabeculae and new bone formation.[5]. By regulating osteogenesis-related signalling pathways, good bone repair materials can promote the proliferation and differentiation of bone marrow MSCs, thereby promoting bone formation and osseointegration, and thus improving the success rate of clinical bone repair. Past studies have found that different ions play a role in the cellular environment and bone healing process [6, 7]. In particular, certain metallic elements are gradually gaining attention for their contribution as bioactive components in material modification [8,9]. In this paper, we will summarise and discuss the metal materials commonly used in bone repair and their development in recent years.

2. Conventional Treatments for Bone Repair

Bone grafting is one of the most common treatments for bone defects. Autologous or allogeneic bone grafts are the most commonly used bone repair materials. Autologous bone graft has the advantages of good biocompatibility and rapid patient recovery, making it an ideal choice for bone filling, but the bone source is limited and requires a second surgery. Allogeneic bone grafts are easy to obtain, but can cause immune rejection and potential disease transmission. Factors such as the weak osteogenic activity of deproteinised bone and the lack of induced osteogenic activity of ceramic bone limit their widespread use in clinical practice [10-12]. With the advancement of medical technology, the search for safer and more effective bone substitutes has become a hot topic in orthopaedics. Artificial bone grafting composites have the same inorganic chemical composition as human bone tissue, which can effectively prevent and control bone defects, among which calcium phosphate composites are particularly prominent, which can be achieved by hydroxyapatite, tricalcium phosphate or a mixture of hydroxyapatite and tricalcium phosphate. These inorganic materials are sintered at high temperatures and are hard, porous and fracture-prone, allowing them to be used for artificial bone grafting without inducing spontaneous bone formation [13]. Although there are many different bone repair materials that can be used to repair bone defects, they all have their own limitations and drawbacks. For example, they are less biocompatible and less biodegradable; the rate of degradation differs from the creep replacement rate of new bone, which may affect the process of bone repair and healing; and they do not have sufficient mechanical strength to affect the biomechanics of the repaired bone defects. With the development of science and technology, the research, development and production of new bone substitute materials has become an important issue in the field of orthopaedics, which needs to be solved urgently.

3. Current Status of Metallic Materials for Bone Repair

The first materials for hard tissue repair and replacement are metals and alloys, followed by bioceramics, polymers, composites and human or animal bone derivatives. The earliest application of bone repair materials is in metallic materials. Metals and alloys are clinically important because of their high strength, fatigue resistance and ease of fabrication. They are still considered the preferred implant material for highly loaded bones and teeth. The main applications are: fracture plates, screws, artificial joints and dental implants [14]. The most commonly used bone repair materials are stainless steel (iron-based alloys), cobalt-based alloys and titanium-based alloys [15]. However, the structure and properties of medical metallic materials are very different from those of bone tissue, and they usually do not chemically bond with bone tissue like bioactive materials. In addition, metallic materials can release metal ions under the action of physiological body fluids and various corrosion and abrasion, and these releases have no affinity by themselves and cannot participate in the normal metabolism of biological tissues, and the biological tissues will have a rejection reaction to them, and fibrous inclusions will be formed around the materials, and with the prolongation of time, the released ions or monomers will increase, and the fibrous inclusion layer will be gradually thickened, and it will gradually densify, calcify, and even lead to fibrous tumour formation, also accompanied by effusion, inflammation and necrosis and other rejection phenomena, etc. And the vast majority of medical metal elastic modulus is too high compared to the bone, and the biomechanical compatibility with the bone is not good, easy to cause bone stress resorption, caused by the loosening of the implant [16,17].

(1) Medical Stainless Steel

Medical stainless steel is an iron-based corrosion-resistant alloy, one of the earliest medical alloys to be developed and used, and is widely used because of its ease of processing and low cost. The biocompatibility of medical stainless steel and its corrosion behaviour in the body and the tissue reaction caused by corrosion products. Because corrosion can cause metal ions or other compounds to enter surrounding tissues or the whole organism, causing certain histological reactions such as oedema, infection, tissue necrosis, etc. Medical stainless steel corrosion caused by its long-term implantation of poor stability, coupled with its density and modulus of elasticity and the human body hard tissues differ greatly, resulting in poor mechanical compatibility, difficult and biological tissues to form a strong bond and other reasons, the proportion of its application is a declining trend. Medical stainless steel is widely used in orthopaedic surgery and dentistry. It is mainly used for artificial joints and internal fixation devices for bone fractures, dental veneers, orthopaedic and auxiliary devices. It is also used in the cardiovascular system as implanted electrodes, sensor housings, artificial heart valves and intravascular dilation stents for interventional therapy [18,19].

(2) Medical cobalt alloys

Medical cobalt alloys are widely used for their excellent mechanical properties and good biocompatibility, especially excellent corrosion resistance, wear resistance and casting properties. Cobalt alloys in the human body to maintain a passivated state, rarely seen corrosion phenomenon, from the point of view of wear resistance is the best of all medical metal materials, implanted in the human body after no obvious histological reaction. Compared to stainless steel, more suitable for the manufacture of the body bearing harsh, wear-resistant requirements of the higher long-term implant parts. The main applications are artificial joints and orthopaedic implants used in cardiac surgery, dentistry, etc. [20,21].

(3) Titanium and titanium alloys The use of titanium as a biomedical implant material dates back to the 1930s, with pure titanium being used for bone splints and bone screws in 1951. Today, titanium is widely used as a hard tissue repair, replacement and fixation material. Titanium has high strength, low modulus of elasticity and good biomechanical compatibility; it has excellent biocompatibility, corrosion resistance and fatigue resistance and can be implanted in the human body to achieve osseointegration; titanium can also be biologically active through certain surface activation treatment techniques. Titanium has been widely used in medicine since the mid-1970s and has become the most promising medical metal material. Titanium is one of the most biophilic metals known. Titanium reacts readily with oxygen to form a dense, passivated film of titanium oxide (TiO2) that causes little tissue reaction after implantation. The gel state of the titanium oxide film even has the ability to induce calcium and phosphorus ions in body fluids to form apatite, which shows a certain degree of bioactivity and osseointegration ability, particularly suitable for intraosseous implantation. However, as its biological activity is not very strong, surface modification is often used to improve its biological activity and osseointegration ability. Titanium and titanium alloys are mainly used in orthopaedic surgery, especially for limb and cranial bone repair, and are currently the most widely used medical metal materials. In orthopaedic surgery, they are used to make all types of internal fixation devices for fractures and artificial joints.

It is characterised by a modulus of elasticity closer to that of natural bone than other metallic materials, low density and low weight. In craniofacial surgery, microporous titanium mesh can be used to repair damaged skulls and effectively protect the spinal cord, and it can also be used to make cranial plates for skull repair. In oral and maxillofacial surgery, pure titanium mesh is used as a bone support in jaw reconstructive surgery, to make dentures, dental beds, brackets, bridges and crowns, and also has good clinical results in orthodontics and oral implantology. In cardiovascular applications, pure titanium can be used to make artificial heart valves and frames [22,23]. Other metal alloys, including zirconium and molybdenum, are used in various metal alloys for orthopaedic and dental applications [24, 25]. The latter metals are mainly used to achieve specific material properties.

Other metals, such as titanium, are utilized as implant materials, forming a highly stable oxide layer and can be regarded as nearly inert under physiological conditions. Porous metallic materials can be categorized into two types of pores: open pores that are connected to the outside, and closed pores that are isolated from the ouside. [26]. However, in the case of titanium and its alloys, released titanium has been shown to enhance the release of bone-resorbing cytokines from LPS-stimulated monocyte cultures [27]. Long-term in vivo studies in baboons have shown increased urinary concentrations of titanium ions and increased tissue concentrations of titanium ions [28].

4. Biomedical Porous Metallic Materials

With the advancement of technology, metallic materials are being developed for biomedical use, porous metallic materials are multiphase composites consisting of metal with pores (pores). The pores in porous metallic materials can be divided into two types: open pores, which are connected to the outside, and closed pores, which are isolated from the outside [58]. This special structure gives porous metallic materials both the characteristics of metals and excellent properties that other metallic materials do not have. Considering the preparation process and performance of biomedical materials, porous titanium with a certain porosity, pore size distribution in a certain range, pore interconnection, a certain degree of strength and toughness, biocompatibility, and to meet the requirements of tissue engineering scaffold material is prepared, and then take the subsequent surface treatment process, so that the titanium matrix surface has a certain degree of bioactivity, and finally the formation of titanium as a substrate, coating to enhance the activity of biomedical composite porous materials, as a biological and medical materials. Medical porous composite materials, such as a certain bearing capacity of bone repair materials (mainly as a filler) applications. At present, research on porous metallic materials mainly focuses on manufacturing methods. With the development of science and technology and the deepening of scientific interactions, it has been recognised that porous metallic materials are not only structural materials, but also have unique structures and properties that make them versatile and functional materials with excellent performance and a wider range of applications. Porous metallic materials for biomedical applications are being developed based on the principle that biological tissues can grow into them, thereby improving mechanical fixation. Porous titanium, porous magnesium, porous NiTi memory alloys, etc. can be used as human implants due to their good corrosion resistance, biocompatibility and mechanical properties similar to those of human bone, as well as their structure containing a large number of penetrating pores, which can promote the transfer of body fluids and the ingrowth of new bone tissue. Among these, porous titanium materials are widely used in applications such as orthopaedic joint replacement, dental defect repair and bone graft substitutes [62]. Through appropriate geometric design, alloying, machining and surface treatment, additively manufactured biodegradable porous metals can represent a new generation of functional biomaterials that are particularly useful as bone substitutes and can greatly facilitate the treatment of large bone defects.

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