The Potential Application in Medical Biomimetic Materials

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Abstract: The "biomimetic materials science" formed by the intersection of life science and material science has excellent theoretical and practical significance. Biomimetic materials science takes material formation and structure as the target, considers artificial material at the view of biomaterial, exploring the manufacture and design of material from the angle of biological function. With unique formation methods, structural characteristics, and biomechanical properties, biomimetic materials are becoming a new field of materials science. Based on a lot of research work, this article reviews and summarizes the work done by predecessors in medical bionic materials. The review focuses on the research progress of biomimetic materials science includes silk protein, nacre, bone, nanomaterials. Numerous studies have shown that these biomimetic materials have a potential application in medicine. Finally, the development prospects of medical biomimetic materials are forecasted.

1 INTRODUCTION

In recent years, with the development of related disciplines and the progress of modern technology, bionic materials have been developed rapidly. The results were widely used in aviation materials, biomedical materials, textile materials and so on. Biomimetic materials science aims to clarify biological materials' structure and formation process, with biological materials to consider the idea of artificial materials, from the perspective of biological function to consider the material design and production.

Biomimetic material science is an essential branch of bionics, which refers to study the structural characteristics, structure, and activity of biological materials from the molecular level. It aims to find the new science similar or better than the original biological materials, chemistry, material science, biology, physics, and other disciplines cross. Medical bionic materials are an important application field of bionic materials.

Bionic materials, such as artificial tooth enamel, artificial bone materials, and bionic artificial fibers, through the design of structures and materials, are expected to achieve high efficiency, low energy consumption, and environmental harmony (Arcidiacono, 2002). Imitation of natural animal and plant-specific function and intelligent response, the development of and biological similarity or beyond the existing biological function of artificial materials, such as lotus leaf self-cleaning materials, like the shark's self-lubricating material, in the gene transformation of the cells in the efficient synthesis of chiral molecules and macromolecules (Tabata, 2001). Imitate the structure and performance of biological tissues and organs, study the structure and properties of natural biological materials from the perspective of materials science, and develop bionic materials. This review will shed light on the research and development of high-performance biomedical materials. This review mainly introduces the biomimetic materials of silk protein, bone, nacre, and cells, summarizes the current development of biomimetic materials, and hopes to inspire other researchers.

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2 MECHANISM AND APPLICATION OF BIOMIMETIC MATERIALS

2.1 Biomimetic Materials of Silk Protein

Silk protein can be used to prepare excellent biomaterials due to its good biocompatibility, low immunogenicity, processability, and degradability.

In recent years, based on the basic principles of tissue engineering, through material processing technology, various forms of silk protein scaffolds (including three-dimensional porous scaffolds, nanofibers, hydrogels, two-dimensional membranes, etc.) (Applegate, 2016) and silk protein drug carriers (Microspheres, nanoparticles, etc.) have been used in the repair of hard bones, ligaments, skin, cardiovascular, cartilage, cornea, nerves and other organs and tissues and anti-cancer therapy (Melke, 2016).

According to different technologies for obtaining silk protein, the source of silk protein can be divided into natural silk protein, recombinant silk protein, and genetically modified silk protein. At present, natural silks that are used and studied more include spider silk protein and fibroin. In spider silk protein, major ampullate silk has the advantages of high strength, good tensile strength, and large breaking energy, so it is currently the most studied kind of spider silk (Hinman, 2000). The silk fibroin in the silkworm silk fiber is coated inside the sericin, with a diameter of about 10 μm. Studies have found that the secondary structure of silk protein includes four types: β-sheet, random coil, α-helix, and β-turn (Gray, 2016).

Silk protein biomaterials prepared by different processing technologies have different application forms in the field of biomedicine. Silk fibers were originally used as surgical sutures due to their biodegradability and good biocompatibility. Effective weaving of silk fibers can produce "artificial ligaments" that can be used to repair or replace broken ligaments (Altman, 2002). XU et al. combined silk fibroin and chitosan to prepare a composite membrane and obtained an excellent healing effect after covering the membrane on the wounded part of the rat (Xu,2015). YODMUANG et al. found that silk protein gel can effectively promote the growth of chondrocytes and the secretion of related collagen. The formation of the internal network of silk protein gel is conducive to the loading of drugs or foreign genes (Yodmuang, 2015). In addition, the most studied silk protein scaffold is used for bone tissue repair. A study showed that adding growth factors to the scaffold can better repair defective tissues (Meinel,2005). Recently, Shi et al. 3D printed silk protein and gelatin to obtain a composite scaffold that can repair damaged cartilage in rabbit knee joints (Shi, 2017).

2.2 Biomimetic Materials of Nacre

In order to protect molluscs from water-carried debris and predators, the shells of organisms like abalone have evolved into a stiff and impact-resistant material named shell. Shells are composite materials made by mollusks that combine inorganic minerals (CaCO3) in the surrounding environment with organic matter generated by themselves under ambient temperature and pressure. The formation process of shells is a biological mineralization process.

The shell structure is divided into 3 layers, from the outside to inside are stratum corneum, prismatic layer, and nacre layer. The organic layer and the mineral layer in the nacre are arranged alternately under appropriate magnification. The so-called "brick and mortar" structure can be easily observed. Its comprehensive mechanical properties, especially fracture toughness can be rasied by 2 to 3 orders of magnitude than that of single-phase calcium carbonate ceramics. The alternate laminated arrangement of nacre aragonite crystals and an organic matrix is the key to its high toughness. Based on this principle, material scientists have developed the development of imitation pearl laminated composite materials. Based on this principle of biomineralization, Yoo et al. prepared a boron nitride nanosheet (BNNS)/gelatin nanocomposite. In this study, hyperbranched polyglycerol was used to functionalize BNNS to enhance the bonding strength between entities. By changing the composition and arrangement degree of BNNSs and gelatin in the nanocomposite, the mechanical properties of the nanocomposite can be controlled. This adjustment of mechanical properties can produce a material with properties similar to human cortical bone. In vitro cell experiments show that this artificial nacre can support the adhesion and proliferation of adipose-derived stem cells, indicating that it can be used in biomedicine (Yoo, 2018).

Fabrication techniques such as hot-press assisted slip casting, freeze casting, extrusion and roll compaction, paper-making method, and layer-by-layer self-assembly have successfully yielded materials that mimic the mechanical properties of nacre. Yongli Zhang made SiC/AL toughening composites with AL as soft phase and SiC as the ceramic base (Heuer,1992). And his fracture toughness is 2 - 5 times compared to the original one. Yang hui made A1203 toughening composites with carbon fiber as soft phase and A1202 as a ceramic base, increasing its fracture toughness by 1.5 -2 times (Qian,2004).

2.3 Biomimetic Materials of Bone

The mimicking of the porous and branched structure of bone is general in the work of some architects, originating structures that are tough and lightweight. Bone has evolved to protect their vital organs and provide efficient structural support to vertebrates. Bone structure is ideal for optimal solid structure (Almqvist, 1999)—the shape of the long bones of the animals at both ends of the thick, elongated intermediate. The dumbbell head in the ends of the long bone can increase the tensile strength and fracture toughness. Inspired by this, people design short fiber into a "dumbbell", improving the composite strength and elongation. It is conducive to the coordinated movement of the material in the fiber and the bonding materials, greatly improving the service life.

Hu et al. developed the absorbable chitosan/hydroxyapatite composite bionic bone structure of fracture fixation material by situ precipitation method and shaping not only is a dumbbell-shaped structure but easy degradation and absorption, with releasing orthophosphate and calcium ion. At the same time, mechanical properties of the biomimetic composites, such as bending strength, bending modulus, shear strength, compression strength, are 2 to 3 times higher than the natural bone. It is expected to replace the metal and become the internal fixation of bone fracture, avoiding suffering second surgery for patients (Qiao,2003).

2.4 Nano Biomimetic Materials

After the advent of nanomaterials, biomimetic materials research has begun to shift to nano biomimetic materials. This is because the nature of the animal's tendons, teeth, cartilage, skin, bones, insects, etc., are nanocomposite materials (Lazaris, 2002). Mimic is the design of nature's biological structure and the development of artificial bone, joints, and blood vessels. Many nanomaterials such as nanoparticles, nanotubes, nucleic acids, and nanomaterials have great potential in clinical applications. The main problem is that these materials can be accepted by the host immune system. As more and more nanodevices are manufactured, it is reported that the biological membranes with 18 nm diameter holes can protect the encapsulated cells or tissues to avoid the immune response (Wang,2020).

Biological cells have always been considered to be a complex microenvironment. In order to be able to develop more biochemical drugs, biodiagnostic technologies, and bio-smart materials, many investigators have shown strong interest in using biomimetic nanotechnology to simulate and study the regulation mechanism of enzymes separated in cells. Balasubramanian et al. used undecylenic acid-modified thermally hydrocarbonized porous silicon (UnPSi) nanoparticles to "capture" horseradish peroxidase (HRP) enzyme as a model and demonstrated a design as a biomimetic cell nanoreactor (Balasubramanian, 2017). Yuan Jinying et al. used block copolymers containing amidine groups to construct CO_2-responsive macromolecular vesicles and developed a new type of biomimetic macromolecular nanodevices. The permeability of vesicles can be controlled by adjusting the concentration of CO_2 gas. It can be used as a nano-separator to selectively distinguish functional molecules of different scales to achieve the directional control of vesicles to different reactions in the space and time range and achieve the function of cell regionalized reaction (Yan, 2013).

3 DEVELOPMENT PROSPECTS OF BIOMIMETIC MATERIALS

Bionic technology has been applied to military, medical, industrial manufacturing, construction, and other popular industries and fields. In the medical field, bionic technology has just emerged. It is still in the preliminary exploration and development stage. Development of biomimetic materials is growing exponentially, they can be well applies in tissue engineering and regenera-tive medicine, biosensors, drug/protein delivery, stem cell research, 3D bioprinting and soon (Das,2018). These biological materials are inspired and manufactured from existing designs and procedures in nature, as well as understanding the chemistry and mechanisms of cell biology, the nature of diseases, modes of action, and biomolecular mechanisms. Still, it has played an important role in medical rehabilitation and the reconstruction of human organs and tissues. It has been widely used in diagnosing, preventing, and treating major human diseases and rehabilitation. Biomedical materials science has demonstrated the potential of the future. The ultimate goal of this field is to produce natural functional biomaterials, which can better understand the basic principle of the cross-field of life science and materials science.

Biomimetic technology is used for human bionic materials. The difference in essence in biomimetic materials and industrial materials is whether to use in the physiological environment and conditions. Bionic materials can be applied to human medical research at the medical level by transplanting some recognizable characteristics in the body and being compatible with human organs, such as human skin materials, blood, heart, etc (figure 1).

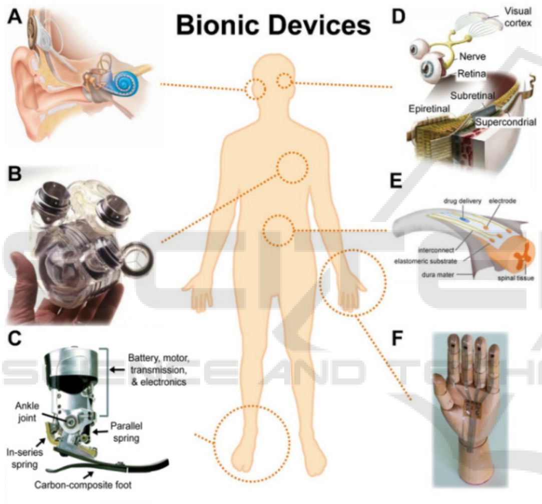

Figure 1: Bionic technologies for restorative medicine.

(A) Cochlear implant. (B) AbioCor self-contained replacement heart. (C) Powered ankle-foot prosthetic controlled by a neuromuscular model. (D) Epiretinal, subretinal, and suprachoroidal implants. (E) Electronic dura mater, "e-dura," tailored for the spinal cord. (F) A skin-inspired digital mechanoreceptor, where the image shows a model hand with DiTact sensors on the fingertips connected with stretchable interconnects (Kong, 2016).

The development trend of materials is complex, intelligent, dynamic, environmental, and bionic materials have these aspects. The development and achievements of bionic materials will affect all aspects of society. It will bring about changes to the human organs and biological systems and make the materials and applications.

In short, the biomimetic medical materials developed should have biocompatibility and flexibility. They should contain cellular and molecular induction and adhesion sites, sufficient mechanical strength, and biodegradable and tissue remodeling properties. To become a suitable material for model biomedicine, the first requirement is the ideal effect that is effective in the body. The combination of biomaterials, technology, software and equipment and interdisciplinary can provide a systematic approach for medical applications.

4 CONCLUSIONS

Four types of biomimetic medical materials with different research have been discussed such as 1) biomimetic materials of silk protein, 2) biomimetic materials of nacre, 3) biomimetic materials of bone, and 4) nano biomimetic materials. And these materials can be applied to human medical research at the medical level by transplanting some recognizable characteristics in the body such as cochlear implant, mechanical heart and so forth, which is a boon for the disabled or the patient.

The development of this material involves many cutting-edge disciplines and high-tech fields, such as material science, medicine, cytology, engineering, bionics, biotechnology, etc. If biomimetic medical materials can get substantial and stable development, they will have significant application prospects and social effects. In the future, better biocompatibility, biodegradability, good mechanical strength and biological stability, and clinical applicability will still require extensive and in-depth research.

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