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Research of Biomedical Materials in the Current Challenges and Future Trends

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Abstract

Biomedical materials are the core carriers of the interdisciplinary field that integrates materials science, medicine, biology, and engineering. They are mainly used for diagnosis, treatment, repair, or replacement of human tissues and organs, as well as for regulating human physiological functions. This is a key subfield that supports the high-quality development of the pharmaceutical and healthcare industry and is an important indicator for evaluating the comprehensive strength of a country's pharmaceutical and healthcare industry. This article discusses the current challenges faced by the research and looks forward to future development trends, providing a reference for the subsequent research and clinical translation of biomedical materials.

Keywords: Biomedical materials; Component design; Preparation process; Structural regulation; Clinical application; Research progress

Mini Review

Although significant progress has been made in the composition, process, structure, performance and application of biomedical materials, there are still many challenges in the actual research and development as well as clinical translation process, mainly concentrated in the following aspects.

Firstly, the biocompatibility and long-term safety still need to be improved. Some new materials (such as nanomaterials and synthetic polymer materials) may cause chronic inflammation, immune rejection or toxic reactions when remaining in the body for a long time. Their long-term biological safety has not been fully verified. Secondly, clinical transformation is difficult. Most new biomedical materials are still at the laboratory research stage and lack standardized preparation processes, quality control systems and clinical evaluation standards. They are difficult to achieve large-scale production and clinical application. For example, the standardized operation norms and quality control systems for microwave-assisted synthesis technology have not been established, which affects the progress of their clinical transformation. Thirdly, the functional integration is insufficient. Most existing materials have only a single function and are difficult to meet the diversified needs of precision medicine and intelligent diagnosis and treatment. Materials with integrated functions such as diagnosis, treatment and monitoring are still scarce. Fourthly, the cost is high. The application of new preparation processes (such as 3D bioprinting and microwave-assisted synthesis) and the use of high-end material components lead to high material costs, which limit their clinical popularity. Fifthly, some key technologies have not been broken through. For example, the vascularization problem of tissue engineering scaffolds and the insufficient response sensitivity of intelligent materials affect the clinical application effect of the materials. In addition, the lack of standardized protocols and powerful algorithm support for the integration of in vivo and in vitro data also restricts the development of materials related to precision medicine.

Based on the current research status and clinical needs, the future of biomedical materials will develop in the directions of “personalization, intelligence, multi-functionality and greenness”, and will focus on the following areas. Based on the current research status and clinical needs, the future of biomedical materials will develop in the directions of “personalization, intelligence, multi-functionality and greenness”, with a focus on the following areas.

First, personalized customization has become mainstream. By leveraging technologies such as 3D bioprinting and artificial intelligence, based on the individual anatomical structure and physiological needs of patients, personalized design and preparation of materials are achieved, enhancing treatment efficacy and reducing complications. Second, the level of intelligence is constantly improving. More intelligent responsive materials are developed to achieve precise drug delivery, real-time monitoring of physiological indicators, and active induction of tissue regeneration, constructing an integrated system of “diagnosis - treatment - monitoring”. For example, cellulose treatment materials that integrate internal and external data will become an important carrier of precision medicine. Third, multi-functional integration. Promote materials to simultaneously possess biological activity, antibacterial, anti-inflammatory, diagnostic, and therapeutic functions, meeting complex clinical needs. Fourth, greenness and sustainable development. Develop biodegradable, renewable, and environmentally friendly biomedical materials to reduce environmental pollution, lower material costs, and promote clinical application. Fifth, deepening interdisciplinary integration. Strengthen cross-disciplinary cooperation among materials science, medicine, biology, engineering, and artificial intelligence to break through key technical bottlenecks. For instance, the combination of microwave-assisted synthesis and artificial intelligence will enable automatic optimization of reaction parameters and real-time prediction of product performance, promoting the improvement of material research and development efficiency. Sixth, acceleration of clinical transformation. Establish standardized preparation processes, quality control systems, and clinical evaluation standards, strengthen industry-university-research cooperation, and promote more new biomedical materials to move from the laboratory to clinical practice, achieving industrialization development. In addition, regenerative medicine materials will further break through, focusing on the repair and regeneration of complex tissues such as corneas and organs, providing new solutions for difficult disease treatments.

Biomedical materials, as the core carrier of interdisciplinary fields, have achieved breakthrough progress in aspects such as component design, preparation process, structural regulation, performance optimization, and clinical application in recent years. Biomedical materials, as the core carrier of interdisciplinary research, have achieved significant breakthroughs in recent years in aspects such as component design, preparation process, structural regulation, performance optimization, and clinical application. They have gradually transformed from “passive adaptation” to “active functionalization”, “intelligence”, and “personalization”. They have gradually transformed from “passive adaptation” to “active functionalization”, “intelligence”, and “personalization”. The components of medical polymers, metals, ceramics, and composite materials have been continuously innovated. The components of medical polymers, metals, ceramics, and composite materials have been continuously innovated. With the continuous deepening of research, biomedical materials will play a more important role in precision medicine, regenerative medicine, intelligent diagnosis and treatment, and other fields, opening a new era of “material empowerment of medicine”.

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