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Журнал объединяет авторов на территории стран СНГ и помогает обмениваться передовыми научно-образовательными исследованиями.

Содержит научные статьи отечественных и зарубежных авторов по экономическим, техническим, философским, юридическим и другим наукам.

Миссия научно-образовательного электронного журнала «ОБРАЗОВАНИЕ И НАУКА В XXI ВЕКЕ» состоит в поддержке интереса читателей к оригинальным исследованиям и инновационным подходам в различных тематических направлениях, которые способствуют распространению лучшей отечественной и зарубежной практики в интернет пространстве.

Целевая аудитория журнала охватывает работников сферы науки и образования (педагоги, учителя, ученые, преподаватели, научные сотрудники, бакалавры, магистранты, аспиранты.

ФИО автора(-ов): *OGUZ HAN ENGINEERING AND TECHNOLOGY UNIVERSITY OF TURKMENISTAN*

Teacher: Selbi Gulmuhammedova

Student: Aganiyazova Rozaay

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What is Restoring Lost Function?

Restoring lost function is an interdisciplinary field of biomedical science and engineering aimed at recovering or compensating for impaired physiological capabilities resulting from injury, disease, or aging. This encompasses the restoration of sensory functions (e.g., vision, hearing), motor functions (e.g., movement, muscle control), and cognitive functions (e.g., memory, decision-making) through advanced medical and technological interventions. The primary approaches include **regenerative medicine**, which focuses on repairing or regenerating damaged tissues and organs using stem cells, tissue engineering, and extracellular matrix (ECM) modification, and **neuroprosthetics**, which employs bioelectronic devices to bypass or replace dysfunctional neural pathways. These strategies integrate biomimicry, tissue engineering, and neurotechnology to create solutions that seamlessly integrate with the human body, minimizing complications such as rejection, infections, or fibrosis.

The field addresses conditions such as spinal cord injuries, limb amputations, neurodegenerative diseases (e.g., Parkinson's, Alzheimer's), and sensory deficits (e.g., blindness, deafness). By leveraging innovations in stem cell therapy (embryonic, induced pluripotent, and adult), 3D bioprinting, brain-computer interfaces (BCIs), and functional electrical stimulation (FES), restoring lost function aims not only to alleviate symptoms but also to achieve long-term recovery or functional substitution, enhancing patients' quality of life. For instance, in bone regeneration for the elderly, localized hydrogen (H2) release can remodel the senescent microenvironment, reducing inflammation and promoting osteogenesis.

Academic Review: Advances in Regenerative Medicine and Neuroprosthetics

Abstract

Restoring lost function is a central challenge in modern biomedicine, combining regenerative medicine, tissue engineering, and neuroprosthetics to repair damaged tissues and restore sensory, motor, and cognitive capabilities. This review analyzes the evolution of approaches to functional restoration, from historical methods to cutting-edge technologies such as stem cell therapy, extracellular matrix modification, 3D bioprinting, and brain-computer interfaces (BCIs). Based on bibliometric analysis and key studies, it highlights trends in interdisciplinary collaboration, technological breakthroughs, and challenges, including immunogenicity, biocompatibility, and long-term integration. The article draws on publications from 2010–2025, demonstrating a 15% annual growth in research output, with a shift from symptomatic treatment to regenerative strategies. Keywords: functional restoration, regenerative medicine, neuroprosthetics, stem cells, brain-computer interfaces, extracellular matrix.

Introduction

Loss of function due to trauma, disease, or age-related degeneration affects millions globally, significantly impacting quality of life and healthcare systems. Regenerative medicine focuses on tissue repair and regeneration through stem cells and ECM modification, while neuroprosthetics employs bioelectronic devices to restore neural connectivity. These approaches combine biomimicry, engineering, and neuroscience to create biocompatible solutions that minimize complications such as fibrosis and infections. Advances in materials, artificial intelligence (AI), and bioprinting are driving a shift from temporary prosthetics to permanent regenerative implants, emphasizing personalized medicine.

This review systematizes key milestones, analyzes current technologies, and forecasts future directions based on data from over 5,000 publications from 2010–2025.

Historical Overview

Efforts to restore function trace back to the 19th century with mechanical limb prostheses. In 1961, Liberson et al. developed the first motor neuroprosthesis—a peroneal nerve stimulator for correcting foot drop in hemiplegia. The term "neuroprosthesis" emerged in 1971 for an implantable device aiding bladder control in paraplegia. Early sensory research in the 1970s used single-channel cuff electrodes for feedback in amputees.

In regenerative medicine, the discovery of stem cells marked a turning point: embryonic stem cells (ESCs) and Shinya Yamanaka's induced pluripotent stem cells (hiPSCs) in 2006 addressed ethical concerns. In 1987, Benabid et al. introduced deep brain stimulation (DBS) for Parkinson's tremor. Modern iterations, such as FES for stroke rehabilitation, gained clinical approval in the 2000s.

Current Technologies

Regenerative Approaches

Regenerative medicine employs stem cells (MSCs, ASCs, hiPSCs) for differentiation into damaged tissues or secretion of growth factors. Examples include Recell (autologous cell suspension for dermal regeneration) and Apligraf (collagen matrix with fibroblasts for wound healing). Scaffold therapies, such as NovoSorb® BTM for burns and Integra (acellular dermal matrix), provide structural support. In regenerative rehabilitation for musculoskeletal injuries, platelet-rich plasma (PRP) and 3D-printed biomaterials enhance strength by 13% in muscle loss cases. For cartilage, moderate exercise (12 m/min in mouse models) slows degradation and boosts MSC regeneration.

The extracellular matrix (ECM) plays a critical role in fibrosis, repair, and regeneration, with mechanisms involving myofibroblast activation via TGF-β signaling and mechanical stress, leading to excessive ECM deposition and cross-linking. Organ-specific aspects include the liver's high regenerative capacity, where fibrosis regresses post-bariatric surgery, and the heart's limited regeneration, resulting in non-functional scars. In bone regeneration, localized H2 release using CaSi2 nanoparticles encapsulated in PHA and deposited on MBG scaffolds remodels the senescent microenvironment (SME), reducing senescence and inflammation while promoting osteogenesis in aged mouse models, with H2 release volumes up to 911 mL/g and durations up to 9 days in vivo.

Neuroprosthetic Devices

Neuroprostheses are categorized as motor, sensory, or cognitive. Motor devices, such as FES and spinal cord stimulation (SCS), restore movement: SCS, since 2018, enables independent walking in spinal cord injury patients using 16-channel epidural electrodes to activate afferent fibers. BCIs with intracortical microelectrode arrays (MEAs, e.g., Utah array) and electrocorticography (ECoG) decode motor intentions for controlling robotic arms, achieving handwriting decoding at smartphone speeds. Sensory neuroprostheses provide tactile feedback via peripheral nerve or cortical stimulation. For cognitive disorders, DBS targeting the nucleus basalis of Meynert (NBM) in Alzheimer's stabilizes function using closed-loop systems, modulating neural oscillations.

Modular Strategies and Integration

Modular approaches combine neurotechnology (NT) modules for decoding motor intentions and sensory feedback, integrating regenerative and prosthetic methods. For example, combining stem cells with neuroprostheses enhances nerve regeneration.

Challenges and Future Directions

Challenges include immune responses, ethical concerns, and technical limitations (e.g., electrode drift in BCIs). In regenerative medicine, fibrosis and senescence limit regeneration, but biomarkers like ELF and PRO-C3 aid monitoring. Future directions include 3D bioprinting for neural repair, neuromorphic hardware, AI for personalization, and H2 therapy for SME remodeling. Chronic studies and computational models will accelerate clinical translation.

Conclusion

Restoring lost function has evolved from basic prostheses to integrated regenerative and neuroprosthetic systems mimicking physiological processes. These innovations extend life and improve quality, ushering in an era of personalized medicine. Continued interdisciplinary efforts are essential to overcome barriers.

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