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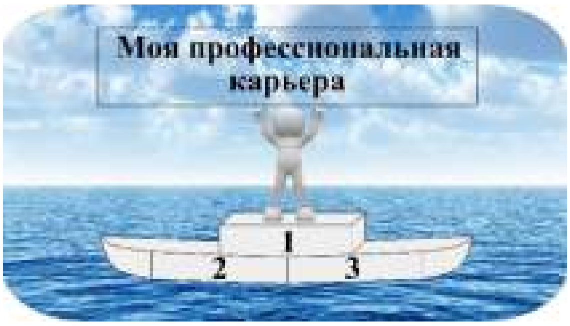

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Журнал объединяет авторов на территории стран СНГ и помогает обмениваться передовыми научно-образовательными исследованиями.

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

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Abstract

The bionic heart represents an interdisciplinary achievement in biomedical engineering, integrating mechanics, electronics, soft robotics, and tissue engineering to create artificial analogs of the human heart. This review article examines the evolution of bionic heart technologies, from historical developments to cutting-edge innovations such as soft robotic total artificial hearts (TAHs) and hybrid tissue-engineered systems. Based on bibliometric analysis and a review of key studies, it highlights trends in collaboration, technological breakthroughs, and challenges, including biocompatibility and long-term hemodynamics. The article draws on data from publications between 2010 and 2025, illustrating the transition from bridge-to-transplant devices to permanent implants. Keywords: bionic heart, total artificial heart, soft robotics, tissue engineering, electromagnetic actuators.

Introduction

Heart failure remains a leading cause of mortality worldwide, affecting millions of patients and necessitating innovative solutions in cardiology. The bionic heart, as a concept, combines biomimicry—mimicking biological structures and functions through engineering technologies—to create devices capable of fully or partially replacing myocardial function. Unlike traditional prostheses, bionic systems aim for integration with recipient tissues, minimizing complications such as thromboembolism and infections. Advances in materials, artificial intelligence (AI), and 3D bioprinting have accelerated this field, enabling a shift from temporary bridge-to-transplant solutions to permanent destination therapies.

This review systematizes key milestones in the evolution of the bionic heart, analyzes current technologies, and forecasts future directions based on bibliometric data and experimental research. The analysis covers over 6,300 publications from 2010 to 2024, showing a 13.9% annual growth in publications and a 260-fold increase in citations.

Historical Overview

The history of artificial hearts traces back to the 19th century when, in 1812, Julien Jean César Legallois proposed the concept of mechanical circulatory support. Experimental devices emerged in the 1920s: Charles Lindbergh and Alexis Carrel developed an in vitro system to sustain organ viability, while in 1937, Vladimir Demikhov implanted the first total artificial heart (TAH) in a dog, achieving survival for 5.5 hours.

A significant breakthrough occurred in the 1950s: in 1957, Tetsuzo Akutsu and Willem Kolff successfully implanted a TAH in a dog for 1.5 hours. The first human implantation took place in 1969 (Denton Cooley and Domingo Liotta), but the patient succumbed due to complications, including hemolysis and renal failure. In 1982, Robert Jarvik, under Kolff's guidance, introduced the Jarvik-7, a pulsatile pneumatic TAH, enabling patient survival for 112–620 days but requiring an external console, limiting mobility.

In the 2000s, self-contained devices emerged: AbioCor (2001) became the first fully implantable TAH, FDA-approved in 2006, despite complications like thromboembolism. Modern iterations, such as the SynCardia TAH (2010), incorporate portable drivers and have been used in over 1,700 cases as a bridge to transplantation. These developments laid the foundation for bionic systems, focusing on miniaturization and biocompatibility.

Current Technologies

Mechanical and Electromagnetic Systems

Modern bionic hearts are classified into pulsatile and continuous-flow (CF) systems. Rotary pumps, using screw-like blades for blood propulsion, outperform piston-based systems, with an 8-fold lower replacement rate and doubled two-year survival due to reduced infections and sepsis.

Electromagnetic technologies include transcutaneous energy transmission (TET) with up to 90% efficiency at 100 kHz, linear oscillating actuators (LOA) delivering peak forces of 71.2 N for the left ventricle, and magnetic bearings to reduce friction. Projects like BiVACOR and ReinHeart integrate axial motors with magnetic levitation, achieving compactness (volume <153 cm^3) and hemodynamic efficiency.

Soft Robotics and Hybrid Designs

Soft robotics is revolutionizing bionic hearts by offering biomimicry. The LIMO system (Less In, More Out) employs pneumatic "pouches" made of thermoplastic polyurethane (TPU) to transform low volumes of actuating fluid into larger blood volumes, with a transmission ratio up to 2.19 and an ejection fraction (EF) of 39–72%. In vitro tests demonstrate a cardiac output (CO) of 5.9 L/min at 70 bpm under 87 mmHg aortic pressure.

The Hybrid Heart combines soft nylon ventricles with TPU and a pneumatic septum mimicking the interventricular septum. A polycaprolactone-bisurea (PCL-BU) coating with heparin reduces thrombogenicity, ensuring laminar flow (via 4D-MRI). In an acute goat experiment, it achieved a CO of 2.275 L/min over 50 minutes at 65 bpm. These systems exhibit preload sensitivity (0.051–0.550 L/min/mmHg), akin to the Frank-Starling mechanism.

Tissue Engineering and 3D Bioprinting

Tissue engineering enables biohybrid hearts. 3D bioprinting of structural bionic hydrogels generates electromechanically coupled cardiac tissues, modeling organs in vitro. Conductive biomaterials, such as carbon nanotubes in hydrogels, enhance myocardial repair by improving conductivity and vascularization.

By 2025, AI integration in cardiac patch design and 4D bioprinting creates time-responsive biomaterials. Multicameral tissues derived from stem cells regenerate neural cells controlling the heart, paving the way for fully bionic organs.

Challenges and Future Directions

Despite progress, bionic hearts face challenges: biocompatibility (thrombosis, infections), power consumption (10–15 W), and size constraints for pediatric patients. Bibliometric analysis reveals a shift toward AI-driven control and regenerative medicine, with the USA (1,449 publications) and China (925) leading, but global collaboration remains limited (Europe's betweenness centrality 0.03).

Future directions include wireless TET, hydraulic actuation, and fully implantable hybrids with AI adaptation. Chronic animal studies and clinical trials (e.g., Realheart® TAH) will accelerate translation to practice, potentially reducing reliance on donor organs.

Conclusion

The bionic heart has evolved from experimental prototypes to promising devices integrating soft robotics and tissue engineering to mimic cardiac physiology. These innovations not only extend life for patients with end-stage heart failure but also usher in an era of personalized medicine. Further interdisciplinary efforts are needed to overcome remaining barriers and realize the full potential of bionic technologies.

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