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Biomedical Engineering Applications for Affordable and Accessible Healthcare



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Abstract

Escalating healthcare costs, uneven resource distribution, and persistent service gaps continue to hinder the achievement of equitable health outcomes across low- and middle-income regions. Technological innovation rooted in biomedical engineering offers a strategic pathway toward affordable and accessible healthcare delivery. This book chapter critically examines emerging advancements in frugal medical device design, point-of-care diagnostics, artificial intelligence-driven screening systems, telemedicine infrastructures, wearable monitoring technologies, additive manufacturing, and open-source biomedical innovation. Emphasis was placed on clinical validation frameworks, regulatory alignment, economic evaluation, and scalable implementation models that enable translation from prototype development to system-level integration. The convergence of data-driven analytics, decentralized diagnostic platforms, and sustainable manufacturing approaches demonstrates measurable potential to reduce diagnostic delays, enhance preventive care, and optimize public health expenditure. Environmental sustainability and circular economy principles within biomedical engineering are also explored to address long-term ecological impact alongside financial feasibility. By synthesizing technological, economic, and policy dimensions, this chapter establishes a comprehensive framework for advancing equitable healthcare transformation through context-aware and cost-effective biomedical solutions suitable for diverse healthcare ecosystems.

Keywords: Affordable Healthcare, Biomedical Engineering, Point-of-Care Diagnostics, Artificial Intelligence in Healthcare, Telemedicine, Sustainable Medical Technologies.

Introduction

Escalating global healthcare expenditure, widening disparities in service availability, and uneven distribution of medical infrastructure continue to challenge the realization of equitable health systems [1]. Rapid population growth, urbanization, aging demographics, and the increasing prevalence of chronic diseases have intensified demand for diagnostic, therapeutic, and monitoring services [2]. In many regions, particularly low- and middle-income economies, limited healthcare budgets constrain acquisition of advanced medical technologies, resulting in delayed diagnosis and fragmented care delivery [3]. Centralized hospital-centric models dominate traditional systems, often creating geographic and financial barriers for rural and underserved communities [4]. Sustainable healthcare transformation requires technological solutions that balance clinical effectiveness with affordability and contextual adaptability [5]. Biomedical engineering has emerged as a strategic enabler in this transformation by integrating engineering design, biological

sciences, and computational intelligence to develop cost-efficient healthcare innovations [6]. The discipline emphasizes optimization of performance-to-cost ratios, miniaturization of complex equipment, and development of decentralized platforms capable of operating in infrastructure-limited environments [7]. Such an approach aligns with global objectives focused on universal health coverage, preventive care expansion, and reduction of catastrophic out-of-pocket expenditure [8]. Advancements in electronics, materials science, data analytics, and digital connectivity have collectively expanded the potential for accessible healthcare delivery models that transcend conventional institutional boundaries [9].

Frugal and context-aware biomedical device design represents a foundational pillar in achieving affordability without compromising safety or functionality [10]. Conventional high-end medical equipment typically requires stable electricity supply, climate-controlled facilities, specialized operators, and continuous maintenance support [11]. Resource-constrained healthcare environments frequently lack such conditions, leading to underutilization or abandonment of imported technologies [12]. Context-responsive engineering frameworks prioritize simplicity, durability, low power consumption, and ease of repair using locally available resources [13]. Additive manufacturing, modular architecture, and standardized component integration enable flexible customization of devices tailored to community-specific epidemiological needs [14]. Cost reduction strategies extend beyond material substitution to encompass streamlined manufacturing processes, optimized supply chains, and lifecycle cost minimization [15]. Clinical validation and regulatory harmonization remain essential to ensure reliability and patient safety while maintaining affordability targets [16]. Structured evaluation protocols measuring diagnostic accuracy, mechanical stability, and operational robustness across diverse environmental conditions strengthen adoption confidence among clinicians and policymakers [17]. Integration of these devices into existing public health programs enhances primary care capacity and reduces reliance on tertiary referral networks [18]. Such alignment between technological innovation and contextual healthcare realities supports sustainable system-level impact rather than isolated pilot success [19].