Short Communication

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Biotechnology and Biomedical Engineering: A New Frontier for Medical University

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ABSTRACT

Background: Biotechnology and biomedical engineering are emerging transformative disciplines that intersect medicine, engineering, and life sciences. Their integration into medical universities is crucial for fostering innovation in diagnostics, therapeutics, and precision healthcare delivery.

Scope: Biotechnology provides molecular tools for diagnosis, pharmacogenomics, and regenerative medicine, while biomedical engineering applies principles to design medical devices, imaging modalities, digital health solutions, and rehabilitation technologies. Together, these disciplines enrich medical education, promote translational research, and drive industry-academic collaboration.

Relevance: In medical universities, incorporating biotechnology and biomedical engineering fosters future healthcare professionals with interdisciplinary skills to address clinical challenges and empower potential to bridge scientific innovation with clinical application. For resource-limited settings, locally adapted technologies and innovations can significantly improve cost-effective patient care.

Conclusion: Integration of biotechnology and biomedical engineering in medical universities holds a great promise to prepare a new generation of clinician scientists and engineer innovators who are equipped to design context appropriate solutions that contribute meaningfully to local healthcare needs and global health equity.

Keywords: Biotechnology; Biomedical Engineering; Medical University; Medical Education; Interdisciplinary Research; Healthcare Innovation

Introduction

The healthcare landscape is evolving quickly, propelled by technological innovations, scientific advancements, and paradigmatic shifts, reshaping traditional models, methodologies, and modalities of patient care, disease management, and therapeutic interventions [1]. Biotechnology and biomedical engineering are dynamic and multidisciplinary fields that have gained global significance in recent years. They represent the confluence of engineering principles and biomedical sciences to develop innovative healthcare solutions, advancing the understanding and treatment of human diseases [2]. Biotechnology and biomedical engineering have become integral to modern medical education and healthcare systems. With the rapid advancement of molecular biology, genetic engineering, regenerative medicine, and biomedical device development, medical universities in both developed and developing countries are embracing these fields to enhance research, innovation, and clinical practice. Their inclusion in academic programs aligns with the global movement toward precision medicine, cost-effective healthcare, and interdisciplinary collaboration [3]. In low and middle income countries (LMICs), medical universities face the dual challenge of strengthening human health capacity while addressing resource constraints [4]. Biotechnology and biomedical engineering offer a transformative potential to bridge these gaps, both in research and in healthcare delivery [5]. This short communication has delved into exploration of the scope, relevance, and strategic role of biotechnology and biomedical engineering within the academic environment of a medical university in a developing country setting.

Biotechnology

Technology that uses bioresources e.g., microorganisms, enzymes, and other biological products to make human life easier is defined as biotechnology. Biotechnology is no longer a futuristic concept; it's a transformative force reshaping modern healthcare. In medicine, biotechnology harnesses biological systems, living organisms, and molecular tools to develop innovative solutions for diagnosing, treating, and preventing diseases [6]. Over the past few decades, advances in genetic engineering, molecular biology, and bioinformatics have transformed the medical landscape from recombinant insulin production to personalized gene therapies [7]. Biotechnology at medical universities covers molecular diagnostics, vaccine development, genomics, biopharmaceuticals, targeted diagnostics, regenerative therapies and biosensor technologies among others that address both common and rare diseases [8]. In developing countries, its relevance is amplified as it offers cost-effective, locally adaptable interventions that improve patient care and public health outcomes.

Scope of Medical Biotechnology

Medical biotechnology is a rapidly advancing field that applies biological systems, cellular processes, and molecular technologies to improve human health and healthcare delivery. Its scope spans across diverse areas including the development of novel diagnostics, vaccines, and therapeutics, as well as regenerative medicine, genetic engineering, and personalized treatment strategies. Followings are some important areas of applications of biotechnology in medicine [9,10].

- **Development of Vaccines:** Recombinant, DNA, and mRNA-based vaccines for infectious and emerging diseases.
- **Production of Therapeutic Proteins:** Insulin, monoclonal antibodies, growth factors, and enzymes.
- **Molecular Diagnostics:** PCR, RT-PCR, microarrays, and next-generation sequencing for early and precise disease diagnosis.
- **Stem Cell Therapy & Regenerative Medicine:** Stem cells therapy for tissue repair and organ regeneration as an approach to regenerative medicine.
- **Biomarker Discovery:** Early diagnosis, disease monitoring, and prognosis.
- **Biopharmaceutical Production:** Large-scale manufacturing of biologics under GMP standards.
- **Immunotherapy:** CAR-T cells, immune checkpoint inhibitors, and engineered antibodies for cancer and autoimmune diseases.
- **Pharmacogenomics & Personalized Medicine:** Tailoring treatments based on an individual's genetic profile.
- **CRISPR & Genome Editing Applications:** Disease modeling, gene correction, and functional studies.
- **Gene Therapy:** For replacing defective genes to treat genetic disorders.

Biomedical Engineering

Biomedical engineering is a multidisciplinary field that sits at the crossroads of engineering, biology, and medicine, with the primary objective of developing innovative solutions to address complex challenges in healthcare [11]. Biomedical engineering integrates principles of engineering with those of biological and medical sciences for designing and development of devices, systems, and technologies applied to healthcare [12]. Within a medical university, biomedical engineering plays a vital role in bridging clinical practice with innovation, enabling the creation of diagnostic devices, therapeutic equipment, prosthetics, imaging systems, and health informatics solutions. From imaging diagnostic tools like MRI machines to life-saving devices such as the pacemaker, biomedical engineers contribute greatly to medical industries for the advancement of technological developments. Its inclusion in medical university fosters collaboration between engineers, clinicians, and researchers, advancing both medical education and patient care [13]. By integrating biomedical engineering into the academic and research framework, medical universities can become hubs for developing cost-effective, patient-centered technologies that address the needs of diverse healthcare settings, especially in resource-limited environments [2].

Scope of Biomedical Engineering

The scope of biomedical engineering spans medical device design, biomaterials, tissue engineering, biomedical imaging, and rehabilitation technologies. Followings are important applications where biomedical engineering plays a vital bridge between medicine and technology [11,13,14].

- **Imaging in Medicine:** Imaging systems like X-rays, MRI, and CT scans for the diagnostic medical imaging are already in practice and in the future, AI-aided imaging techniques will offer faster and more accurate diagnostic solutions.
- **Wearable Technology:** Wearables now under development by biomedical engineers will enable continuous monitoring of patients' vital signs, glucose levels, and more that can report data back to both physicians and patients for a real time management. Biosensors, smartwatches and wearable fitness trackers are some of the start-up wearables.
- **Regenerative Medicine:** Tissue engineering and stem cell therapy designed by biomed engineers are now contributing in the development of bio-artificial organs and tissues and with application of 3D printing it might replace human damaged organs as an effort of personalized medicine someday.

- **Biomaterials:** Innovative medical biomaterials like implants, prosthesis, and drug delivery systems developed by biomed engineers have wide applications in medical and surgical healthcare system.
- **Robotic Surgery:** Biomed engineers design highly precise robotic systems that assist surgeons during complex surgeries that allow faster patient's recovery with fewer complications.
- **Artificial Intelligence (AI) and Machine Learning:** Medical diagnostics and treatment planning in near future will largely be based on AI and machine learning and biomed engineers are in the forefront in developing smart medical devices that can predict health issues even before they occur.
- **Nanobiotechnology:** Nowadays, biomedical engineers use nanobiotechnology in target drug delivery system into specific cells, increasing the effectiveness of treatment with minimum side effects.
- **Telemedicine and Remote Monitoring:** With the advancement of telemedicine, biomedical engineers develop devices that remotely monitor patients to further access to health care, particularly in rural and underserved areas.

Relevance to Medical University

Biotechnology and biomedical engineering have emerged as transformative disciplines in modern healthcare, reshaping the way diseases are diagnosed, treated, and prevented. Their relevance to medical universities lies in their potential to bridge scientific innovation with clinical application, fostering an environment of interdisciplinary learning and translational research [8]. Biotechnology offers molecular tools for precision medicine, genetic engineering, and regenerative therapies, while biomedical engineering applies engineering principles to develop advanced diagnostic equipment, medical devices, and digital health solutions [10]. Incorporating these fields into medical universities not only enriches the curriculum but also equips future healthcare professionals with the skills to address evolving clinical challenges. These disciplines not only enhance education and research of the university but also contribute to the development of cost-effective, innovative solutions, especially relevant for developing nations [15]. Following areas of application of biotechnology and biomedical engineering are intimately relevant to medical university.

Advancement of Medical Education [16]

- **Curriculum Enrichment:** Integration of biotechnology and biomedical engineering exposes medical students to molecular diagnostics, bioinformatics, tissue engineering, and medical device design. It must be aligned to address diseases of local relevance, tropical infectious diseases, neglected tropical diseases, non communicable diseases endemic to the region.
- **Interdisciplinary/multidisciplinary learning:** Encourages collaboration between clinicians, engineers, and scientists.
- **Research-oriented approach:** Provides opportunities for translational research and medical innovation.

Enhancement of Clinical Care [13,17]

- **Diagnostic innovations:** Development of advanced diagnostic kits, point-of-care testing, and biomarker-based tests.
- **Therapeutic applications:** Use of biotechnological approaches in gene therapy, stem cell therapy, targeted drug delivery.
- **Medical devices:** Designing of cost-effective, durable devices for diagnostics, therapy, monitoring, and rehabilitation.

Contribution to Research and Innovation [18]

- **Biomedical research platforms:** Cell culture, genomics, proteomics, synthetic biology.
- **Innovation in treatment modalities:** Personalized medicine, regenerative therapies, targeted therapy and nanotechnology-based treatments.
- **Capacity building:** Training future healthcare professionals in cutting-edge technologies.
- **Collaboration opportunities:** University can incubate start-ups and drive medical device innovation through academia industry partnerships. Partnerships with industry, start-ups, research institutions and foster internationalization through graduate programs.

Challenges and Limitations

The incorporation of biotechnology and biomedical engineering into a medical university faces multifaceted challenges ranging from infrastructure and funding to regulatory, cultural, and curriculum integration issues. Theoretical knowledge may not always be aligned with practical hospital-based applications. Establishing state-of-the-art biotechnology labs and biomedical engineering facilities requires expensive equipments and all these advanced instruments require regular maintanance that costs high too [19]. Medical universities traditionally focus on clinical training and may lack adequate space for engineering workshops or wet labs. Moreover, limited number of expert faculty bridging medicine, biotechnology, and engineering could be a practical shortcoming. Further, there may be difficulty in attracting highly qualified faculty due to competitive job markets in industry and research institutions. Funding in medical universities often prioritizes clinical research over technological innovation. The application of specific innovations, such as cloning, whole-genome sequencing or CRISPR-Cas9 gene editing raises significant ethical, legal, and societal issues about the safety and potential impact of genetical-

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ly modified organisms and possible misuse [20]. Handling of genetically modified organisms, biohazardous materials, or nanomaterials requires strict safety compliance. Additionally, stem cell research, genetic modification, and AI-driven devices raise bioethical issues that must be addressed in policy frameworks [21]. Issues like understanding of patent filing, technology transfer, and commercialization processes in academic settings may suffer from lack of experience and expertise. There may be difficulty in converting academic research into market-ready products due to lack of technology incubation support [10,22].

Conclusion

Biotechnology and biomedical engineering are no longer auxiliary fields; they are integral to the transformation of medical education, research, and patient care. For medical universities, their scope extends beyond academic enrichment to driving innovation, developing affordable technologies, and shaping precision healthcare. The relevance of these disciplines lies in their ability to bridge basic science, engineering, and clinical practice, creating a dynamic platform for translational medicine. Integrating biotechnology and biomedical engineering into medical university curricula especially in developing countries offers a powerful mechanism and capacity building to address local health challenges, sustainable innovation systems, and enhance academic scope. Through strategic curriculum design, hands on pedagogy, collaborations, and policy support, medical universities can prepare a new generation of clinician scientists and engineer innovators who are equipped to design context appropriate solutions and contribute meaningfully to local healthcare needs and global health equity. Embracing these fields today will ensure that medical universities are prepared to lead healthcare innovation for tomorrow.

Conflict of Interest

None.

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Data Availability

All data are within the manuscript.

Author Contribution

Md. Abdus Salam (MAS) was responsible for conceptualization, acquisition of information, drafting and final editing; Sakib Imtiaz (SI) was involved in acquisition and compilation of scientific information and drafting of the manuscript. All authors have read and agreed to the published version of the manuscript.

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