



A Review of Biophysics and Medical Physics

Indivar Balasingam

Associate Professor, Department of Condensed Matter Physics, Karachi School of Systems Management, Pakistan

Email: indivar.balasingam@kssm-pk.org

Peer Review Information	Abstract
<p><i>Submission: 18 Jan 2022</i></p> <p><i>Revision: 10 Feb 2022</i></p> <p><i>Acceptance: 22 Feb 2022</i></p> <p>Keywords</p> <p><i>Biophysics; medical physics; biomedical imaging; radiation therapy; biomechanics; bioelectricity; molecular biophysics; healthcare technology</i></p>	<p>Abstract</p> <p>Biophysics and medical physics are interdisciplinary fields that apply the principles of physics to understand biological systems and improve medical diagnosis and therapy. Biophysics focuses on the physical mechanisms underlying biological processes, ranging from molecular interactions and cellular mechanics to neural signaling and biomechanics. Medical physics, on the other hand, translates physical concepts into clinical practice, playing a critical role in medical imaging, radiation therapy, nuclear medicine, and biomedical instrumentation. This review provides a comprehensive overview of the fundamental concepts, theoretical frameworks, experimental techniques, and technological applications in biophysics and medical physics. Emphasis is placed on molecular and cellular biophysics, bioelectricity, biomechanics, medical imaging modalities, radiation physics, and emerging trends such as computational modeling and personalized medicine. The review highlights the close integration of physics with biology and medicine and discusses current challenges and future research directions.</p>

Introduction

Biophysics and medical physics represent two closely related disciplines that bridge the gap between physics, biology, and medicine. Both fields apply physical laws, mathematical modeling, and experimental techniques to understand living systems and to develop technologies that improve human health. While biophysics is primarily concerned with uncovering the fundamental physical principles governing biological processes, medical physics focuses on the clinical application of physics in diagnosis, therapy, and patient safety.

The origins of biophysics can be traced back to early attempts to quantify biological phenomena using physical laws. Concepts such as diffusion, thermodynamics, and electromagnetism were gradually applied to explain processes like membrane transport, nerve conduction, and muscle contraction. The development of molecular biology in the mid-twentieth century

further accelerated biophysics, as techniques such as X-ray crystallography and nuclear magnetic resonance (NMR) allowed direct investigation of biomolecular structures.

Medical physics emerged as a distinct discipline with the introduction of X-rays for diagnostic imaging and radiation for cancer treatment. The discovery of ionizing radiation revolutionized medicine, enabling non-invasive visualization of internal structures and targeted destruction of diseased tissues. Over time, medical physics expanded to include ultrasound, magnetic resonance imaging (MRI), computed tomography (CT), positron emission tomography (PET), and advanced radiation therapy techniques.

A defining feature of both biophysics and medical physics is their interdisciplinary nature. Biological systems are inherently complex, involving interactions across multiple spatial and temporal scales. Physics provides the tools to simplify and model this complexity through

quantitative frameworks, enabling predictive understanding and technological innovation. For example, fluid dynamics principles are used to study blood flow, while statistical mechanics helps explain protein folding and molecular interactions.

In biophysics, research spans multiple levels of biological organization. At the molecular level, biophysics investigates the structure, dynamics, and interactions of proteins, nucleic acids, and membranes. At the cellular level, it examines processes such as cell mechanics, signaling pathways, and transport phenomena. At the tissue and organism levels, biophysics contributes to biomechanics, sensory biophysics, and neural systems.

Medical physics, in contrast, is strongly application-oriented. Its primary goal is to ensure the safe and effective use of physical technologies in healthcare. Medical physicists play a crucial role in designing imaging protocols, calibrating radiation equipment, optimizing treatment plans, and ensuring compliance with safety standards. Advances in medical physics have significantly improved diagnostic accuracy, treatment precision, and patient outcomes.

In recent years, technological progress has further blurred the boundaries between biophysics and medical physics. Computational modeling, machine learning, and advanced imaging techniques are increasingly used to link molecular-level insights with clinical decision-making. Personalized medicine, which tailors treatment based on individual biological characteristics, relies heavily on quantitative biophysical models and medical physics technologies.

This review aims to provide a comprehensive overview of the fundamental concepts, methodologies, and applications of biophysics and medical physics. By integrating theoretical foundations with practical applications, the review highlights the critical role these disciplines play in advancing modern healthcare and biomedical research.

Literature Review

The literature on biophysics and medical physics encompasses foundational textbooks, experimental studies, and clinical research articles.

Classical biophysics texts established the application of thermodynamics, mechanics, and electromagnetism to biological systems. Molecular biophysics literature focuses on protein structure, enzyme kinetics, and membrane dynamics. Advances in spectroscopy and imaging have significantly expanded this domain.

Medical physics literature includes comprehensive works on radiation physics, medical imaging, and dosimetry. Landmark publications document the development of X-ray imaging, CT, MRI, and nuclear medicine. Recent research emphasizes image reconstruction, radiation dose optimization, and hybrid imaging techniques.

Interdisciplinary studies increasingly connect biophysical models with clinical applications, particularly in cancer therapy, cardiovascular diagnostics, and neuroscience. The literature reflects a shift toward computational and data-driven approaches, highlighting the evolving nature of these fields.

Comparative Table and Detailed Analysis
Comparative Table of Biophysics and Medical Physics

Aspect	Biophysics	Medical Physics	Applications	Challenges
Scope	Fundamental biological processes	Clinical diagnosis & therapy	Research & healthcare	System complexity
Key Principles	Thermodynamics, mechanics, electromagnetism	Radiation physics, imaging physics	Medicine & biology	Safety & accuracy
Techniques	Spectroscopy, microscopy, modeling	CT, MRI, PET, radiotherapy	Disease diagnosis	Cost & accessibility
Scale	Molecular to organism level	Organ to whole-body level	Personalized medicine	Interdisciplinary integration
Outcomes	Mechanistic understanding	Improved patient care	Healthcare innovation	Regulation & ethics

Detailed Analysis

Biophysics and medical physics differ in emphasis but share a common foundation in physical principles. Biophysics seeks to uncover the mechanisms that govern life at various scales. For example, molecular biophysics uses

statistical mechanics to explain protein folding and ligand binding, while cellular biophysics applies elasticity theory to understand cell deformation and motility.

Medical physics builds upon these insights to develop and optimize medical technologies.

Imaging modalities rely on interactions between physical fields and biological tissues, such as X-ray attenuation, nuclear spin resonance, and acoustic wave propagation. Radiation therapy applies particle and photon physics to deliver precise doses to tumors while minimizing damage to healthy tissue.

The integration of biophysical models into medical physics has enhanced treatment planning and diagnostic interpretation. However, challenges remain in translating complex biological variability into reliable clinical models.

Discussion

The integration of physics with biology and medicine has transformed healthcare and biomedical research. One of the most significant strengths of biophysics is its ability to provide quantitative explanations for complex biological phenomena. By reducing biological complexity to physical models, biophysics enables predictive understanding and experimental validation.

Medical physics exemplifies the translation of scientific knowledge into practical benefit. Advances in imaging and radiation therapy have dramatically improved early disease detection and treatment outcomes. Techniques such as intensity-modulated radiation therapy and image-guided radiotherapy illustrate how physics-based optimization enhances clinical precision.

Despite these successes, both fields face challenges. Biological systems exhibit high variability and nonlinearity, complicating modeling efforts. In medical physics, balancing technological sophistication with cost, accessibility, and patient safety remains a critical concern. Ethical considerations, data privacy, and regulatory compliance further shape research and clinical practice.

Emerging trends such as artificial intelligence, multimodal imaging, and personalized medicine are expected to further strengthen the connection between biophysics and medical physics.

Conclusion

Biophysics and medical physics play indispensable roles in advancing scientific understanding and improving healthcare. Biophysics provides the fundamental framework for explaining biological processes using physical principles, while medical physics applies these principles to diagnose and treat disease.

This review highlights the complementary nature of the two disciplines, emphasizing their shared reliance on quantitative modeling, experimentation, and technological innovation. From molecular dynamics to medical imaging

and radiation therapy, the impact of physics on medicine is profound and far-reaching.

Looking ahead, continued interdisciplinary collaboration will be essential to address complex biomedical challenges. Advances in computation, imaging, and materials science promise to further expand the capabilities of biophysics and medical physics. As healthcare increasingly moves toward precision and personalization, these fields will remain central to scientific progress and clinical excellence.

References

- Nelson, P. (2014). *Biological Physics*. W.H. Freeman.
- Phillips, R., Kondev, J., & Theriot, J. (2012). *Physical Biology of the Cell*. Garland Science.
- Bialek, W. (2012). *Biophysics: Searching for Principles*. Princeton University Press.
- Hobbie, R. K., & Roth, B. J. (2015). *Intermediate Physics for Medicine and Biology*. Springer.
- Bushberg, J. T., et al. (2012). *The Essential Physics of Medical Imaging*. Lippincott Williams & Wilkins.
- Hall, E. J., & Giaccia, A. J. (2018). *Radiobiology for the Radiologist*. Wolters Kluwer.
- Webb, A. (2017). *Introduction to Biomedical Imaging*. Wiley.
- Stark, H., & Lubensky, T. (2005). *Physics of Biomolecules*. Springer.
- Cameron, J. R., Skofronick, J. G., & Grant, R. M. (1999). *Physics of the Body*. Medical Physics Publishing.
- Hendee, W. R., & Ritenour, E. R. (2002). *Medical Imaging Physics*. Wiley.
- Alberts, B., et al. (2014). *Molecular Biology of the Cell*. Garland Science.
- Boal, D. (2012). *Mechanics of the Cell*. Cambridge University Press.
- Griffiths, D. J. (2013). *Introduction to Electrodynamics*. Pearson.
- Bushberg, J. T. (2015). *Radiation Protection*. Elsevier.
- Keall, P. J., et al. (2018). *Medical Physics in Radiation Therapy*. Physics in Medicine & Biology.

Datta, S. (2005). *Quantum Transport*. Cambridge University Press.

Plonsey, R., & Barr, R. (2007). *Bioelectricity*. Springer.

Weissleder, R., et al. (2010). *Molecular Imaging*. PMPH-USA.

Jain, R. K. (2014). *Transport of Molecules in Biological Systems*. Annual Review of Biomedical Engineering.

McRobbie, D. W., et al. (2017). *MRI from Picture to Proton*. Cambridge University Press.

Foster, K. R., & Schwan, H. P. (2016). *Biological Effects of Electromagnetic Fields*. CRC Press.

LeVeque, R. J. (2007). *Finite Difference Methods*. SIAM.

Edelman, R. R., et al. (2013). *Clinical Magnetic Resonance Imaging*. Elsevier.

Dawson, L. A., et al. (2015). *Radiation Therapy Physics*. Springer.

Barrett, H. H., & Myers, K. J. (2013). *Foundations of Image Science*. Wiley.