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The Utility of Biomedical Physics in Health, with an Emphasis on Pediatrics

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Abstract

Biomedical physics is often perceived as a complex "black box," yet it constitutes the bridge between basic science and clinical practice, translating the universal principles of matter, energy, and their interactions into concrete tools for the diagnosis, prevention, and treatment of disease. This review outlines the role of biomedical physics from its origins in radiology—following Wilhelm Conrad Röntgen's discovery of X-rays in 1895 and the pioneering work of Marie and Pierre Curie—to its present status as a transversal pillar of modern medicine, encompassing medical imaging (computed tomography, magnetic resonance imaging, PET/CT, and SPECT), dosimetry and radiological protection, hemodynamics, biomechanics, computational modeling, and bioinformatics. Particular emphasis is placed on pediatrics, where patients are especially vulnerable and where accurate radiation dosing, motion-tolerant and radiation-sparing imaging, and precisely calibrated intensive-care and neonatal equipment are decisive for safe and timely care. The article argues that biomedical physics guarantees safety, precision, and quality in diagnosis and treatment, and considers its future along three axes: the personalization of medicine, the responsible integration of artificial intelligence, and the growth of portable, accessible biotechnologies.

Keywords

Biomedical physics; Medical physics; Pediatrics; Medical imaging; Radiological protection; Dosimetry.

Abbreviations

CT: Computed Tomography; MRI: Magnetic Resonance Imaging; PET: Positron Emission Tomography; SPECT: Single-Photon Emission Computed Tomography; AI: Artificial Intelligence; ALARA: As Low As

Reasonably Achievable; ICRP: International Commission on Radiological Protection.

Introduction

When people hear the term biomedical physics, they often think of something complicated—even a kind of technological "black box." This is not surprising: the human mind tends to organize knowledge into separate compartments, and here we encounter a discipline that unites two seemingly distant worlds. On one side stands physics, with its precision, its numbers, and its abstract character; on the other, medicine, deeply practical and focused on human life. Yet it is precisely in this apparent distance that its richness lies: biomedical physics translates the universal principles of matter, energy, and their interactions into concrete tools for the diagnosis, prevention, and treatment of disease.

In other words, biomedical physics is the bridge between basic science and clinical practice. It is the discipline that helps transform discoveries into concrete tools to diagnose, prevent, and treat diseases—or to verify existing conditions. And in fields such as pediatrics, where patients are more vulnerable and every detail counts, its role becomes even more indispensable.

Objective

This article seeks to make known the role of biomedical physics—from its origins in radiology to the present day, where it forms a transversal pillar of modern medicine—with special emphasis on pediatrics, where patients are more vulnerable and where every technical detail can mark the difference between a timely and a late diagnosis.

Origins and Evolution of Biomedical Physics

Biomedical physics is commonly associated solely with radiation and imaging, because that is where it arose as a field of knowledge. In 1895, the German physicist Wilhelm Conrad Röntgen discovered X-rays [1]; astonished by the ability this new technology offered—to see inside the body—he triggered an immediate revolution in medical diagnosis. Marie and Pierre Curie were at the forefront, working with radioactivity in medicine and even developing techniques for treating diseases such as cancer. This consolidated biomedical physics as an autonomous field, since radiotherapy and nuclear medicine demanded professionals capable of calculating doses with submillimeter precision and of protecting both patients and staff. From this arose the first radiological-protection units and the first steps toward more interdisciplinary research that integrated physical and mathematical approaches into the study of biological processes linked to the anatomical and physiological behavior of the human body and its diseases. Examples include the technological expansion of medical imaging—computed tomography (CT), magnetic resonance imaging (MRI), and nuclear medicine (PET/CT and SPECT)—dosimetry and radiological protection, pressures and fluid dynamics in medicine (hemodynamics, for example, and even the optimization of infusion pumps and dialysis systems), biomechanics (such as models of pulmonary ventilation), programming, computational modeling, and bioinformatics, among others—leading to today's medicine, which rests on a rigorous mathematical framework [2].

It is essential to conceive of knowledge as a living entity that evolves day by day and adapts to the evolution of human life, and that is, moreover, connected to a whole. Sectioning knowledge into areas allows us as humans to understand each area better, but each remains related to the whole.

Relevance in Pediatric Health

In life there are "invisible pillars"—elements that are neither easy nor immediate to detect, and that we may not even need to detect, yet that form part of the main structure. For instance, when we speak with another person, air is essential, for it is the medium in which the vibrations that give meaning to speech occur. In our biological organization, gravity is essential: it organizes everything—walking, blood circulation, and even how bones grow—so that, in the absence of gravity, an astronaut loses bone mass simply by being weightless. In the same way, biomedical physics acts as an invisible column that sustains technological and scientific confidence in modern medicine.

In pediatrics, differences in radiological dose are fundamental to avoiding harmful risks. As a historical problem, radiography and CT protocols were designed for adults, which led to the use of unnecessarily high doses in children and a greater risk of stochastic effects such as long-term cancer [3,4]. Today, MRI is optimized as the first choice in many pediatric cases in order to avoid radiation exposure [6]. Moreover, because young children rarely stay still, the difficulty of obtaining high-quality, motion-free images increases, causing repetitions that raise risks and costs; in response, several solutions have been offered, such as the development of fast MRI sequences to minimize the need for sedation, the optimization of ultrasound as a safe, high-resolution tool in pediatrics, and the development of digital processing methods that improve low-signal images [5,7].

In addition, in intensive care and neonatal monitoring, biomedical equipment—such as ventilators, incubators, and monitors—must be extremely precise, since any minimal deviation can have serious consequences. Finally, in pediatric research and biomarkers, the diagnosis of rare pediatric diseases used to be extremely difficult because diagnostic tools adapted to children were lacking; however, the development of physical models to interpret, for example, biomarkers in small blood volumes has effectively supported pediatric diagnosis, as has the design of specific equipment adapted to the pediatric population.

Thus, in its pediatric application, biomedical physics guarantees safety, precision, and quality in diagnosis and treatment—primarily in radiotherapy, imaging, and intensive care.

In this way, in specialized fields that must handle information with tenacity and meticulousness, such as pediatrics, the difference between an early and a late diagnosis, or between a safe treatment and one with adverse effects, may lie in the quality of an image, the accuracy of a dose, or the reliability of a piece of biomedical equipment. The biomedical physicist ensures that every medical value, every image obtained, and every guided intervention is supported by appropriate, objective, and reproducible parameters.

Conclusion and Future Perspectives

Biomedical physics is therefore not only the guardian of radiation but a bridge among physics, biology, programming, science, and medicine. Radiology was its historical cradle, but the discipline has expanded in parallel with other fields of knowledge, seeking to confront the challenges adjacent to the biological processes we experience every day. It provides safety and certainty in the face of risks and limitations, establishing both the scope of what is achievable and the risks incurred, with a scientific rigor based on numbers and formulations that make it possible to understand phenomena. It is the discipline that

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transforms numbers and formulas into reliable diagnoses and safe treatments.

In pediatrics, its relevance intensifies, seeking safe doses, precise images, and calibrated equipment capable of providing a foundation of medical confidence.

The future of this interdisciplinary, like that of medicine as a whole, is marked by three great axes: the personalization of medicine, through physical models capable of integrating diverse variables such as clinical, genomic, and even environmental data; the coupling of artificial intelligence with biotechnology, on a foundation of trust that complements—rather than replaces—medical decision-making [8]; and the growth of portable, accessible biotechnologies that enable continuous monitoring and early diagnosis in any setting, even outside hospitals [9].

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Conflict of interest

The author declares that she has no conflict of interest.

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