MEDICAL ROBOTICS: DEFINITION AND CLASSIFICATION

Abduqodirov Nuriddin Faxriddin o'g'li

Assistant of the Department of "Information Technologies, Biophysics and Medical Physics" of Samarkand State Medical University.

Abstract: Medical robotics is one of the fastest-growing fields in modern healthcare, combining robotics, artificial intelligence, computer science, and biomedical engineering to improve the quality of medical services. Medical robots are widely used in surgery, rehabilitation, diagnostics, patient care, pharmacy, and hospital logistics. They provide higher precision, reduce human error, minimize invasive procedures, and improve patient safety and treatment outcomes. Depending on their functions and applications, medical robots can be classified into several categories, including surgical robots, rehabilitation robots, diagnostic robots, telepresence robots, assistive robots, and hospital service robots. This article presents the definition of medical robotics, its importance in healthcare, and the main classification of medical robotic systems.

Keywords: Medical robotics, healthcare technology, surgical robots, rehabilitation robots, diagnostic robots, telemedicine, assistive robots, artificial intelligence, biomedical engineering.

Introduction: Medical robotics is an interdisciplinary field that integrates robotics, medicine, computer science, and engineering to develop intelligent systems capable of assisting healthcare professionals in diagnosis, treatment, rehabilitation, and patient care. The rapid development of robotics technology has transformed healthcare by increasing the accuracy, efficiency, and safety of medical procedures.

Today, hospitals and healthcare institutions increasingly rely on robotic systems to perform minimally invasive surgeries, support rehabilitation, automate laboratory tasks, transport medical supplies, and assist elderly or disabled patients. As healthcare demands continue to rise, medical robotics plays an essential role in improving healthcare quality while reducing the workload of medical personnel. Understanding the definition and classification of medical robots is important for recognizing their capabilities and selecting appropriate technologies for different medical applications.

Main body: Medical robotics encompasses the development and use of robotic systems to perform or assist with medical tasks, including surgery, rehabilitation, diagnostics, and patient care. These systems combine sensors, actuators, and advanced software control to interact safely and precisely with the human body or the clinical environment. By integrating real-time sensing, imaging, and feedback, medical robots can enhance accuracy, repeatability, and consistency in complex medical procedures.

Robotic systems vary in their degree of autonomy: some operate with a high level of independence, relying on predefined algorithms and sensor input, while others are semi-autonomous or fully controlled by clinicians via teleoperation or assistive interfaces. In clinical practice, this flexibility enables robots to augment human skills rather than replace them, supporting surgeons, therapists, and healthcare staff in demanding or high-risk tasks. The field encompasses a wide range of platforms, including rigid robotic arms used in minimally invasive surgery, soft and wearable exosuits for rehabilitation and mobility assistance, mobile robots that transport supplies or guide patients within healthcare facilities, and robotic diagnostic instruments integrated into laboratory and imaging workflows.

Medical robotics has demonstrated benefits, including improved surgical precision, reduced invasiveness, enhanced clinician ergonomics, and more intensive, personalized rehabilitation for patients. However, successful deployment requires careful consideration of safety, usability, cost, and training, as well as integration with existing clinical systems and workflows. As technology advances, medical robots are increasingly paired with artificial intelligence and data-driven control strategies, expanding their capabilities and supporting more adaptive, patient-centered care models.

Classification schemes help organize the diversity of medical robots and clarify their functional scope within healthcare systems. A widely cited scoping review identified ten overarching roles: surgical, rehabilitation and mobility, radiotherapy, socially assistive, telepresence, pharmacy, disinfection, delivery and transport, and interventional and imaging assistance. This functional taxonomy highlights the breadth of clinical and operational applications and underscores that many robotic systems are multifunctional rather than confined to a single role. For example, an interventional robot used for tumor ablation may simultaneously support real-time ultrasound or fluoroscopic imaging, thereby combining therapeutic and diagnostic functions within a single platform.

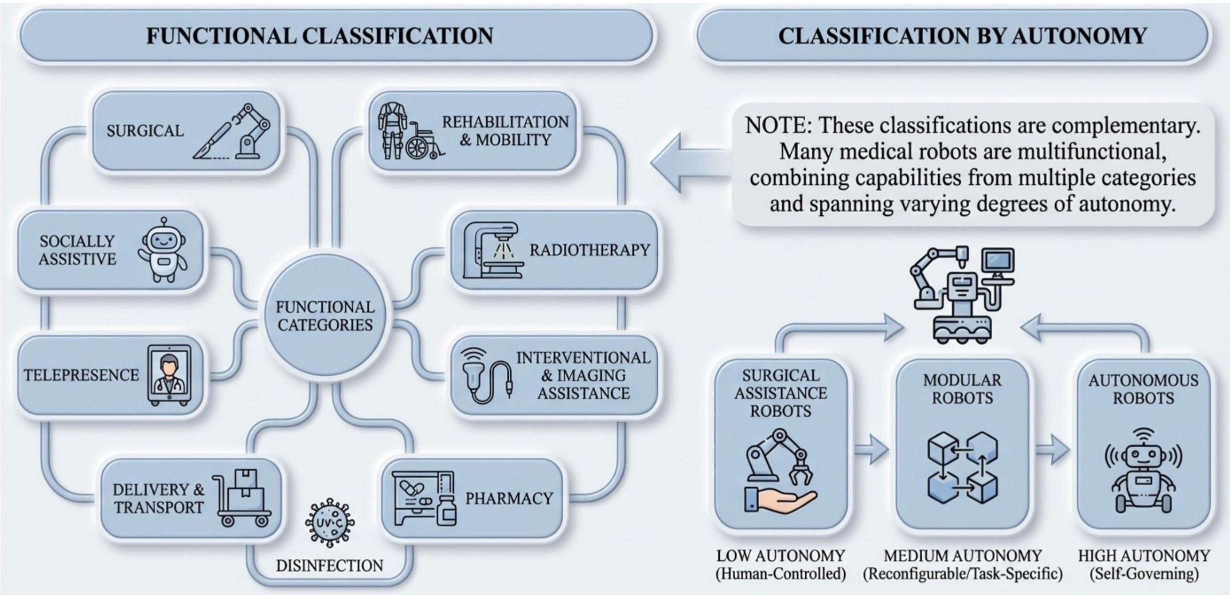

Figure 1. Classification of medical robotic systems

Another commonly used classification groups medical robots by technological level and degree of autonomy, distinguishing between surgical assistance, modular, and autonomous systems. Surgical assistance robots are primarily designed to enhance clinician performance through precision, stability, and ergonomics, while remaining under direct human control. Modular robots consist of interchangeable components that can be reconfigured for different procedures or clinical environments, increasing flexibility and cost-effectiveness across multiple use cases. Autonomous robots constitute the most advanced category, capable of navigating complex environments, perceiving their surroundings, and executing tasks with minimal, continuous human oversight.

Together, these classification frameworks offer complementary perspectives: functional taxonomies focus on what robots do in clinical practice, while technological classifications describe how they operate and the extent of their autonomy. Such structured categorization supports more transparent communication among clinicians, engineers, and policymakers, facilitates comparative evaluation of robotic systems, and informs regulatory, ethical, and training considerations as medical robotics continues to evolve.

Historically, surgical robots were among the earliest developments in medical robotics, driven by demand for enhanced precision, dexterity, and minimally invasive techniques in operative care. The first commercial systems, such as ROBODOC® for orthopedic procedures and ZEUS® for laparoscopic surgery, demonstrated the feasibility of robot-assisted interventions and paved the way for broader clinical acceptance. This progression culminated in the da Vinci Surgical System, which remains widely used across multiple surgical specialties, including urology, gynecology, and general surgery, because of its advanced visualization, articulated instruments, and ergonomic benefits for surgeons.

As the field matured, development expanded beyond the operating room to include service robots that support hospital logistics and operations. These systems now guide patients within healthcare facilities, transport medications and supplies, and perform cleaning and disinfection tasks, thereby reducing staff workload and supporting infection control. In parallel, home care and socially assistive robots have emerged to provide physical assistance, monitoring, and companionship to older adults and individuals with disabilities, addressing demographic pressures associated with aging populations and long-term care needs.

Classifying medical robots by clinical setting, functional role, or level of autonomy provides a structured framework for understanding the scope and impact of medical robotics. Such classification supports more precise evaluation of benefits and risks, informs regulatory approval processes, and helps address ethical considerations related to safety, accountability, and human-robot interaction. By situating robotic systems within well-defined categories, stakeholders can better align technological capabilities with clinical requirements, policy development, and responsible adoption in healthcare settings.

Conclusion: Medical robotics has become an essential component of modern healthcare, offering innovative solutions that enhance medical diagnosis, treatment, rehabilitation, and patient support. The classification of medical robots into surgical, rehabilitation, diagnostic, assistive, telepresence, and hospital service robots demonstrates the wide range of applications available in healthcare.

As robotics technology continues to evolve, future medical robots will become more intelligent, autonomous, and integrated with artificial intelligence and digital healthcare systems. Although challenges such as high costs, technical complexity, and ethical considerations remain, the benefits of medical robotics significantly outweigh its limitations. Therefore, understanding the definition and classification of medical robotics is fundamental for healthcare professionals, engineers, and students preparing for the future of digital medicine.

References.

1. Hu, J., Song, Q., & Zhang, M. (2024). Revolutionizing healthcare and medicine: The impact of modern technologies. *International Journal of Medical Informatics*, 178, 104444.
2. Weed, L. (1968). *Medical Records, Medical Education, and Patient Care.* Cleveland: Case Western Reserve University Press.
3. Parekh, N., & Bate, A. (2022). *Precision Medicine and Genomic Profiling. New England Journal of Medicine*, 386 (14), 1290-1302.
4. Frist, W., & Daschle, T. (2012). *The HITECH Act and Electronic Health Records. Health Affairs Blog*.
5. Topol, E. (2019). *Deep Medicine: How Artificial Intelligence Can Make Healthcare Human Again.* New York: Basic Books.
6. Alibekova, N., Rizayeva, M., Kimsanbaeva, S., Nazarov, T., Akilov, F., Abduqodirov, N., & Qurbonov, T. (2026). Artificial Intelligence-Powered Discovery of Regulatory Variants Across Human and Model Organism Genomes. *Genetics and Molecular Research*, *25*(1).
7. *F.O. Toxirova, O.R. Yalg'ashev, N.F. Abduqodirov, D.A. Ibragimova. Handbook on information technology in medicine*. – Samarkand: 2026. – 194 p