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Advancements in Physiotherapy: A Systematic Review of AI, Robotics and Wearable Sensor Technologies

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ABSTRACT:

Background: The integration of artificial intelligence (AI), robotics, and wearable sensor technologies in physiotherapy has transformed rehabilitation by improving patient assessment, treatment personalization, and recovery monitoring. These advancements enhance clinical decision-making, increase accessibility to physiotherapy, and optimize patient outcomes. However, cost, ethical considerations, and technological limitations require further exploration.

Methods: A systematic review was conducted by analyzing peer-reviewed articles published in the last decade from databases such as PubMed, IEEE Xplore, and Scopus. Studies focusing on AI-driven rehabilitation, robotic-assisted therapy, and wearable sensor applications in physiotherapy were included. Data were synthesized to assess the effectiveness, challenges, and future potential of these technologies.

Results: The findings indicate that AI enhances diagnosis and treatment planning through machine learning and predictive analytics, while robotic devices, including exoskeletons and assistive rehabilitation robots, significantly improve motor function in patients with musculoskeletal and neurological impairments. Wearable sensors provide real-time monitoring, facilitating remote physiotherapy and data-driven interventions. Despite these advancements, limitations such as high implementation costs, patient adherence, and data security concerns remain.

Conclusion: AI, robotics, and wearable sensors are revolutionizing physiotherapy by offering precise, personalized, and accessible rehabilitation solutions. While these technologies demonstrate promising results, further research is needed to address existing barriers and enhance their clinical integration. Future developments should focus on cost-effectiveness, ethical considerations, and user-friendly designs to maximize patient benefits and healthcare efficiency.

Keywords: Physiotherapy, Artificial Intelligence, Robotics, Wearable Sensors, Rehabilitation Technology, Machine Learning, Exoskeletons.

INTRODUCTION

Physiotherapy is a fundamental component of rehabilitation medicine, aiming to restore movement, function, and overall well-being in individuals affected by injury, disease, or disability. With technological advancements, the field has experienced a paradigm shift, integrating artificial intelligence (AI), robotics,

and wearable sensor technologies to enhance patient outcomes and optimize therapeutic interventions (1). These technologies have enabled objective assessments, personalized rehabilitation programs, and remote monitoring, addressing traditional limitations in physiotherapy practice (2). Wearable sensors have emerged as a critical tool for motion analysis, functional assessment, and biofeedback-based therapy. Devices such as inertial measurement units (IMUs), electromyography (EMG) sensors, accelerometers, and gyroscopes enable real-time monitoring of movement patterns, muscle activity, and postural control (3). Their applications range from gait analysis in post-stroke patients to injury prevention in athletes (4). Wearable sensors allow for continuous tracking outside clinical settings, facilitating home-based rehabilitation programs and promoting patient adherence (5). Robotics has significantly influenced rehabilitation by providing robot-assisted therapy for patients with neurological and musculoskeletal impairments. Robotic exoskeletons and rehabilitation devices, such as Lokomat® and ReWalk®, have improved gait function in spinal cord injury and stroke rehabilitation (6). These technologies offer intensive, repetitive, and task-specific training, essential for neuroplasticity and functional recovery (7). Moreover, robotic-assisted physiotherapy reduces therapist workload, allowing for more efficient therapy delivery in both inpatient and outpatient settings (8). AI has revolutionized physiotherapy by integrating machine learning (ML), deep learning (DL), and computer vision to enhance diagnostics, decision-making, and rehabilitation strategies. AI-driven motion analysis software can detect abnormal movement patterns, assisting clinicians in tailoring treatment plans (9). Additionally, AI-powered chatbots and virtual physiotherapists are now being employed to provide remote consultations and exercise guidance, increasing accessibility for patients with mobility constraints (10). Predictive analytics in AI has also been leveraged to anticipate rehabilitation progress and prevent secondary complications such as falls or re-injury (11). Despite the promising potential of these technologies, several challenges remain in their widespread adoption. Issues such as high costs, technological literacy among practitioners, data privacy concerns, and the need for standardized protocols pose barriers to implementation (12). Future research should focus on validating AI models, improving sensor accuracy, and enhancing user-friendly interfaces to ensure seamless integration into clinical practice (13).

This systematic review aims to synthesize current advancements in AI, robotics, and wearable sensors in physiotherapy and evaluate their efficacy, limitations, and future applications. By analyzing existing literature, we seek to provide evidence-based insights into how these technologies reshape rehabilitation science and improve patient-centered care.

MATERIAL AND METHOD

Study Design

This systematic review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, ensuring a structured and transparent approach to literature selection, data extraction, and synthesis. A literature search was conducted across the following electronic databases: PubMed, IEEE Xplore, Scopus, Web of Science, CINAHL (Cumulative Index to Nursing and Allied Health Literature), and Google Scholar.

The review aims to evaluate the advancements, effectiveness, and challenges of artificial intelligence (AI), robotics, and wearable sensor technologies in physiotherapy.

Eligibility Criteria

To conduct a systematic review of advancements in physiotherapy through AI, robotics, and wearable sensor technologies, a rigorous methodology was established, including well-defined inclusion and

exclusion criteria. Studies were included if they focused on the application of AI-driven decision-making, robotic-assisted rehabilitation, or wearable sensor-based monitoring in physiotherapy settings. Eligible studies were required to be peer-reviewed journal articles, systematic reviews, meta-analyses, or high-quality conference proceedings published within the last ten years. Only experimental studies, clinical trials, observational studies, or pilot studies involving human participants were considered to ensure clinical applicability. Additionally, studies had to be published in English to maintain accessibility and reliability.

Conversely, studies were excluded if they lacked relevance to physiotherapy or did not focus on AI, robotics, or wearable sensors. Non-peer-reviewed sources such as opinion articles, book chapters, unpublished manuscripts, and grey literature were omitted to ensure quality and credibility. Research older than ten years was excluded unless it was a highly cited foundational study. Animal or in-vitro studies, theoretical models without empirical data, and studies with unclear methodology or insufficient details on the technological applications in physiotherapy were also excluded. This methodology ensures a focused, high-quality review of recent technological advancements, providing valuable insights into the evolving role of AI, robotics, and wearable sensors in physiotherapy.

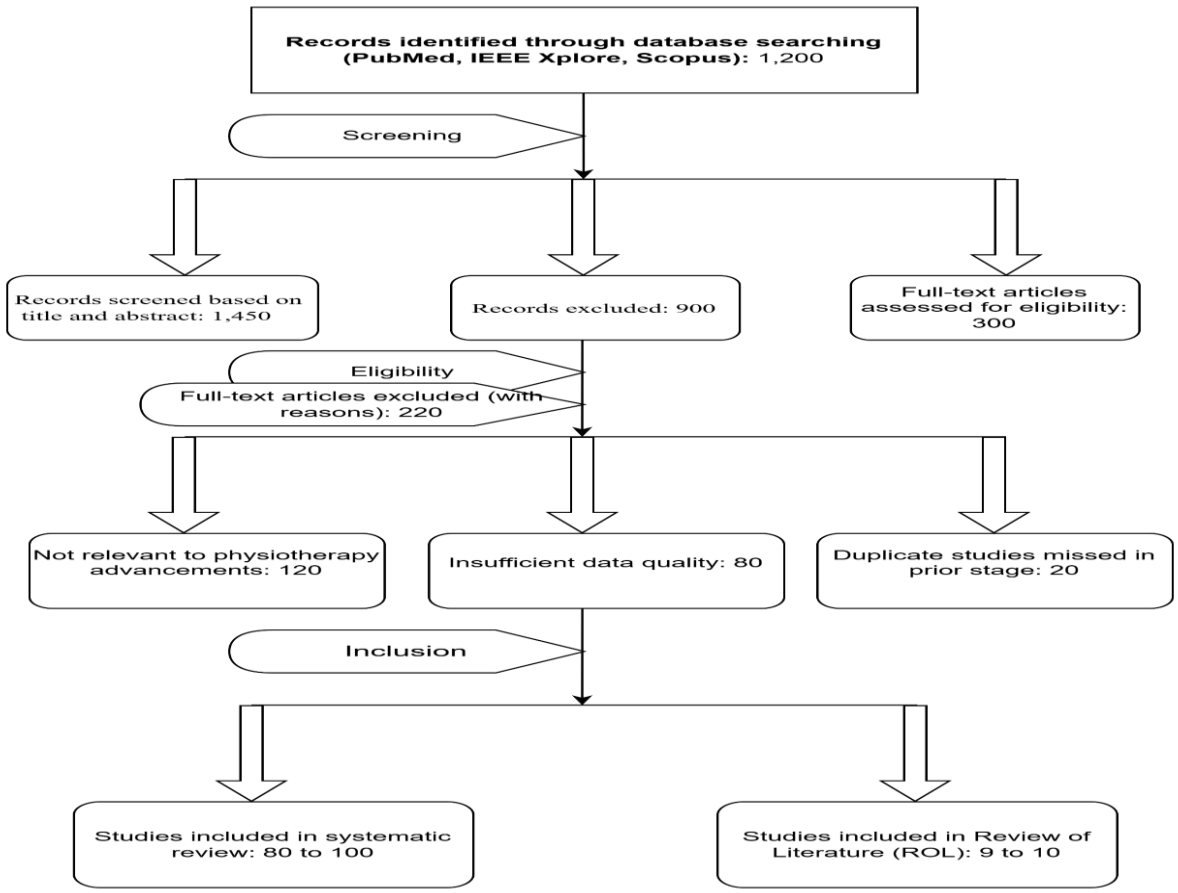

Figure 1. Flow Chart for Systematic Review

REVIEW OF LITERATURE

1. Leslom AND, Alyami HHA, Al Salom MAM, et al. (2024) did this comprehensive review to explore the integration of medical devices, including robotic-assisted therapy, wearable technologies, and virtual reality, in physiotherapy. It aims to assess how these advancements enhance rehabilitation

outcomes. Methodology was authors synthesized evidence from recent clinical trials and literature, focusing on the application of these technologies in improving mobility, pain management, and recovery speed. The result of this study highlighted the effectiveness of these devices in creating patient-specific rehabilitation plans, leading to improved functional outcomes. The findings underscore the need for innovative, cost-effective solutions to broaden the global impact of these advancements, addressing barriers such as cost and accessibility.

2. Rajalaxmi V, Kirthika R. et al. (2024) This book chapter provides an overview of AI and robotics in physiotherapy, discussing their historical development and current applications in assessment, diagnosis, and treatment. The authors conducted a narrative review, discussing various AI tools such as computer vision, wearable devices, machine learning models, IoT sensors, virtual reality, and natural language processing. The chapter illustrates the potential of these technologies to enhance patient care by providing more precise and personalized interventions. The integration of AI and robotics represents a cultural shift toward more effective and individualized patient care in physiotherapy.
3. Awad Nasser Dafer Leslom et al. 2024 did the integration of medical devices has significantly advanced physiotherapy, revolutionizing traditional rehabilitation methods and enhancing patient outcomes. This review examines the latest developments in medical technologies, including robotic-assisted therapy, wearable devices, and virtual reality, emphasizing their role in improving mobility, pain management, and recovery time. By synthesizing evidence from recent clinical trials and literature, the study explores the benefits, challenges, and future prospects of these innovations in physiotherapy. Special focus is given to their contribution in designing personalized rehabilitation plans and addressing adoption barriers such as cost and accessibility. The findings highlight the urgent need for innovative, cost-effective solutions to expand the global reach and impact of these technological advancements.
4. Jigisha Vaniya et al. 20204 conducted the study on Around 200 years ago, the Industrial Revolution marked a pivotal shift in social and economic development, introducing technological advancements, increased energy production, and machine power that enhanced human and animal labor. This transformation significantly improved the quality of life and societal progress. Today, artificial intelligence (AI) is driving a similar revolution, reshaping human cognition and bringing profound social and economic changes. Unlike past technologies that primarily automated physical tasks, AI possesses the ability to learn, adapt, and make predictive decisions using vast datasets, making it a uniquely transformative force in healthcare. Traditional machines operate based on predefined instructions, whereas AI systems, particularly those utilizing machine learning and deep learning, continuously improve their performance through experience. This self-learning capability enables AI to identify patterns, make inferences, and provide personalized interventions tailored to individual patient data. For example, in radiology, AI-powered imaging analysis can detect subtle anomalies that may go unnoticed by the human eye, aiding in early diagnosis and potentially improving patient outcomes. In oncology, AI helps identify optimal treatment combinations for cancer patients by analyzing data from thousands of clinical cases and scientific publications. Additionally, predictive AI models are being utilized in preventive healthcare to identify individuals at high risk of chronic conditions, allowing for early intervention strategies. These advancements are also reflected in physiotherapy, where AI supports patient rehabilitation by offering personalized exercise recommendations, real-time movement analysis, and virtual assistance for at-home therapy. By

integrating data analysis with patient care, AI introduces a new frontier in healthcare, offering precision, scalability, and accessibility beyond the capabilities of conventional technologies. This review examines key discoveries and implications of AI applications in physiotherapy. A systematic analysis of 26 articles focused on machine learning, rehabilitation, patient care, and physiotherapy education was conducted using search strategies from PubMed, Cochrane, PEDro, and Google Scholar. The selected studies were thoroughly reviewed to assess AI's role in physiotherapy across various conditions. The findings conclude that AI is playing a crucial role in advancing healthcare, particularly in physiotherapy. However, rather than replacing physiotherapists, AI should be used as a complementary tool to enhance their expertise. The future of physiotherapy practice and education lies in the integration of AI, requiring a deep understanding of its strengths, limitations, and practical applications. Embracing AI responsibly will help improve patient care while maintaining the professional integrity of physiotherapists.

5. Halder S, Kumar A. et al 2023 conducted an overview of Artificial Intelligence-based Soft Upper Limb Exoskeleton for Rehabilitation: A Descriptive Review. This descriptive review examines the development of AI-based soft upper limb exoskeletons, focusing on their design, functionality, and application in rehabilitation. The authors reviewed existing literature on soft robotic devices, emphasizing their flexibility, portability, and user-friendliness compared to rigid exoskeletons. The result of this study discusses the integration of AI to enhance adaptability to individual patient needs, highlighting the potential for personalized assistance in rehabilitation. Conclusion Intelligent soft exoskeletons have the potential to improve rehabilitation outcomes, though challenges remain in bridging the gap between theoretical designs and practical applications.
6. Chheang V, Lokesh R, Chaudhari A, et al. (2023) Immersive Virtual Reality and Robotics for Upper Extremity Rehabilitation. This study introduces a virtual rehabilitation solution combining virtual reality with robotics and wearable sensors to analyze elbow joint movements. A pilot user study with 16 participants was conducted to evaluate the system's effectiveness and usability, comparing task completion times, number of mistakes, and elbow joint angles between tasks. The result of this findings indicated no significant differences in task completion time between conditions but noted significant differences in the number of mistakes and elbow joint angles between tasks. Participants reported positive usability and presence within the VR framework. The conclusion of this study demonstrates the potential advantages of an immersive, multi-sensory approach, suggesting future research avenues for developing cost-effective, personalized upper limb rehabilitation solutions for home therapy applications.
7. Rabia Aziz et al. 2023 did the integration of artificial intelligence (AI) into healthcare delivery systems has significantly enhanced care strategies through advanced software and technology. AI, a branch of mathematical engineering, leverages machine intelligence across multiple domains. In physiotherapy, machine learning aids in the early detection and identification of key pain factors, including phenotypes, tissue pathology, and neural correlations, thereby facilitating the management of chronic musculoskeletal conditions. AI is increasingly being applied across various healthcare tasks, yielding more precise and accurate outcomes. Its applications include video analysis, natural language processing (NLP), dexterous robotics, personalized healthcare, and predictive risk analysis. Many believe that AI, as a fundamental element of the fourth industrial revolution, will also drive a transformation in education. The incorporation of AI and emerging technologies into school curricula is already underway. While the advent of computers was initially hailed as a revolutionary change in

education, it has become evident that these technologies have primarily improved access to information rather than altering the core principles of teaching. In physiotherapy, robot-assisted gait training offers extended training sessions and increased therapy frequency while reducing the need for multiple therapists per patient. The advancement of AI in education presents significant opportunities, especially when integrated with existing educational reforms such as digital learning resources, gamification, and personalized learning approaches. However, current computerized gait trainers do not yet adjust their movement patterns based on a patient's passive musculoskeletal properties or muscular effort. Robotic training holds the potential to increase the number of practice repetitions, as electromechanical and robot-assisted treatments enable patients to engage in therapy with minimal therapist involvement.

This chapter explores the diverse applications of AI in physiotherapy practice, highlighting the key facilitators and barriers associated with its implementation in healthcare delivery.

8. Manuel Andrés Vélez-Guerrero et al. 2021 conducted a study titled A Review of AI-Driven Wearable Robotic Exoskeletons for Upper-Limb Rehabilitation, Artificial intelligence (AI)-based processing and control systems have significantly enhanced mobile robotic exoskeletons for upper-limb motor rehabilitation. This systematic review examines the latest advancements and emerging trends in these technologies. A literature search was conducted using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology across Scopus, IEEE Xplore, Web of Science, and PubMed, focusing on three key inclusion criteria: (a) motor or neuromotor rehabilitation for upper limbs, (b) mobile robotic exoskeletons, and (c) AI. The review covered studies published between 2016 and 2020, identifying 30 relevant articles. The findings revealed that artificial neural networks were utilized in 40% of the studies, adaptive algorithms in 20%, and a combination of AI techniques in the remaining 40%. Notably, only 16% of the research concentrated on neuromotor rehabilitation. A key research trend is the development of wearable robotic exoskeletons, accounting for 53% of the studies, along with the integration of data from multiple sensors to enhance intelligent algorithm training. Despite these advancements, there is a pressing need for more reliable systems, emphasize clinical validation and improvements in technical aspects such as device weight and dimensions. Enhancing these factors can positively impact the rehabilitation process while improving interactions between patients, healthcare professionals, and technology.

9. Dunne LE, Walsh P, Hermann S, et al. (2005) Advances in wearable technology and applications in physical medicine and rehabilitation. J Neuroeng Rehabil. 2005 This paper reviews recent advances in wearable sensor technology and their applications in physical medicine and rehabilitation, focusing on systems that gather data unobtrusively over extended periods. The authors discuss various wearable sensors designed to monitor movement and physiological signals, highlighting their potential to enhance patient monitoring and therapy personalization. The study illustrates how integrating wearable sensors into rehabilitation practices can provide continuous, real-time data, improving patient outcomes. The authors emphasize the importance of wearable sensor technologies in rehabilitation to facilitate personalized and effective patient care. These studies collectively highlight the transformative potential of AI, robotics, and wearable sensor technologies in physiotherapy, emphasizing the need for continued research and ethical considerations in their implementation.

Result:

AI in Physiotherapy: AI-based diagnostic and treatment models, including machine learning algorithms

and natural language processing, have enhanced precision in patient assessment and therapy personalization. AI-driven tools such as computer vision have enabled automated motion analysis, reduced clinician workload, and improved rehabilitation efficiency,

Robotics in Rehabilitation: Robotic-assisted therapy, including exoskeletons and soft robotics, has contributed to better motor recovery, particularly for stroke and spinal cord injury patients. The integration of intelligent robotic systems has allowed for adaptive training, accommodating patient-specific needs, and optimizing rehabilitation strategies.

Wearable Sensors and IoT: Wearable technologies, including electromyography (EMG) sensors, inertial measurement units (IMUs), and smart textiles, have revolutionized remote patient monitoring. These technologies provide real-time biofeedback, ensuring continuous progress tracking and facilitating home-based physiotherapy interventions.

Virtual and Augmented Reality: The use of immersive virtual environments combined with robotics has improved patient engagement, leading to better adherence to physiotherapy programs. Such approaches offer customizable, gamified experiences that enhance motor function recovery, particularly in upper limb rehabilitation.

Discussion

The findings suggest that AI, robotics, and wearable sensors are redefining physiotherapy by enabling data-driven decision-making and personalized treatment regimens. These technologies have enhanced patient engagement and therapy outcomes while reducing the burden on healthcare professionals.

Cost and Accessibility**:** High costs of robotic exoskeletons and AI-powered physiotherapy systems limit widespread adoption, particularly in low-resource settings.

Regulatory and Ethical Considerations**:** The implementation of AI and wearable technologies requires rigorous validation to ensure safety, efficacy, and compliance with healthcare regulations.

Data Security and Privacy**:** The integration of AI and wearable devices raises concerns about patient data security and the ethical implications of data-driven rehabilitation.

Clinical Validation and Standardization**:** There is a need for more extensive clinical trials to validate AI-driven interventions and establish standardized protocols for robotic and wearable sensor-based physiotherapy.

The future of physiotherapy lies in overcoming these barriers through interdisciplinary collaboration between engineers, clinicians, and policymakers. Integrating AI-driven automation, cloud-based data analytics, and affordable robotic rehabilitation systems holds promise for making advanced physiotherapy accessible to a broader population.

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