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Artificial Intelligence in Musculoskeletal Rehabilitation: A Review

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ABSTRACT

Artificial Intelligence (AI) is emerging as a transformative technology in musculoskeletal rehabilitation by improving diagnosis, treatment planning, patient monitoring, and rehabilitation outcomes. Musculoskeletal disorders such as osteoarthritis, low back pain, sports injuries, fractures, and post-operative conditions are major causes of pain and disability worldwide. Conventional rehabilitation methods often rely on subjective assessment and prolonged clinical supervision. AI-based technologies including machine learning, deep learning, computer vision, robotics, wearable sensors, and virtual reality are increasingly being integrated into musculoskeletal rehabilitation to provide personalized, accurate, and efficient care. These technologies assist clinicians in movement analysis, posture correction, gait assessment, exercise supervision, pain prediction, and functional recovery monitoring. AI-driven rehabilitation systems also support remote rehabilitation through telemedicine platforms and wearable devices, thereby improving accessibility and patient adherence. Robotic-assisted rehabilitation and intelligent exercise systems enhance treatment precision and reduce therapist workload. Despite significant advancements, challenges such as high implementation costs, data privacy concerns, limited technical expertise, and ethical issues remain barriers to widespread adoption. This review highlights the applications, benefits, limitations, and future prospects of AI in musculoskeletal rehabilitation. The integration of AI with conventional rehabilitation approaches has the potential to revolutionize musculoskeletal care by delivering more personalized, evidence-based, and patient-centered treatment.

Keywords: Artificial Intelligence; Musculoskeletal Rehabilitation; Physiotherapy

INTRODUCTION

Musculoskeletal disorders (MSDs) are among the leading causes of pain, disability, and reduced quality of life globally. Conditions such as osteoarthritis, low back pain, cervical pain, sports injuries, fractures, tendon injuries, and post-operative impairments significantly affect physical function and daily activities. Musculoskeletal rehabilitation aims to restore movement, reduce pain, improve strength and mobility, and enhance functional independence through therapeutic exercises, manual therapy, and physical modalities.1-3 In recent years, Artificial Intelligence (AI) has gained increasing attention in healthcare and rehabilitation sciences.4 AI refers to computer systems capable of mimicking human intelligence through learning, reasoning, and decision-making. AI technologies such as machine learning, deep learning, robotics, computer vision, wearable sensors, and virtual reality are now being utilized in musculoskeletal rehabilitation to improve assessment accuracy, personalize treatment plans, and monitor rehabilitation progress in real time.4-6 Traditional rehabilitation methods often depend on subjective clinical evaluations and periodic patient visits, which may limit treatment precision and continuity of care. AI-based rehabilitation systems provide objective analysis of movement patterns, posture, muscle activity, and functional performance. These technologies enable early detection of movement abnormalities, prediction of recovery outcomes, and automated feedback

during rehabilitation exercises.7,8 The integration of AI in musculoskeletal rehabilitation has also facilitated tele-rehabilitation and home-based therapy, improving access to care for patients in remote areas. This review discusses the major AI technologies used in musculoskeletal rehabilitation, their clinical applications, advantages, limitations, and future scope.

AI TECHNOLOGIES USED IN MUSCULOSKELETAL REHABILITATION9-11

Machine Learning: Machine learning algorithms are widely used in musculoskeletal rehabilitation to analyze patient data, identify hidden patterns, and predict rehabilitation outcomes. These systems learn from clinical records, movement data, and patient responses to therapy in order to support evidence-based rehabilitation planning. Machine learning can assist clinicians in predicting injury risk, evaluating pain severity, and designing personalized rehabilitation protocols according to individual patient needs. It is also useful in forecasting functional recovery and identifying patients who may require early intervention. The use of machine learning improves clinical decision-making, enhances treatment personalization, and allows more efficient rehabilitation planning, ultimately leading to improved patient outcomes. Deep Learning: Deep learning is an advanced branch of artificial intelligence that utilizes artificial neural networks to process complex healthcare data such as medical imaging, biomechanical signals, and movement analysis. In musculoskeletal rehabilitation, deep learning models are increasingly used for automated posture analysis, detection of movement dysfunctions, gait assessment, and interpretation of MRI and radiographic images. These systems can accurately recognize abnormal movement patterns and assist clinicians in diagnosing musculoskeletal disorders at an early stage. Deep learning also supports rehabilitation monitoring by continuously analyzing patient performance and providing objective assessments of functional improvement. Computer Vision: Computer vision technology enables computers to analyze videos and images for the assessment of body movements, posture, and physical function. In musculoskeletal rehabilitation, computer vision systems are used for range of motion analysis, gait assessment, balance evaluation, and exercise performance monitoring. These systems provide real-time feedback to patients during rehabilitation exercises, helping them maintain proper posture and movement patterns. Computer vision offers several advantages, including non-invasive assessment, accurate movement tracking, and automated analysis without the need for complex physical markers or equipment. This technology improves rehabilitation precision and supports home-based therapy programs. Robotic-Assisted Rehabilitation: Robotic-assisted rehabilitation involves the use of robotic devices to help patients perform repetitive therapeutic movements with high precision and consistency. These systems are particularly beneficial in post-operative rehabilitation and mobility training for musculoskeletal conditions. Robotic devices can assist with joint mobilization exercises, strength training, gait retraining, and assisted walking therapy. The repetitive and controlled movements provided by robotic systems enhance motor recovery and improve functional outcomes. In addition, robotic rehabilitation increases therapy intensity while reducing physical strain and fatigue experienced by physiotherapists during manual rehabilitation sessions. Wearable Sensors and Smart Devices: Wearable sensors and smart devices play a major role in modern musculoskeletal rehabilitation by continuously monitoring patient activity, movement patterns, muscle function, and rehabilitation progress. These technologies include smart bands, motion sensors, and electromyography (EMG) sensors that collect real-time biomechanical data during rehabilitation exercises and daily activities. Wearable devices support home-based rehabilitation by providing instant feedback to patients and clinicians regarding exercise accuracy and performance. They are also useful in monitoring physical activity levels, detecting falls, and evaluating functional recovery. Continuous monitoring through wearable technology improves patient compliance and enables more personalized rehabilitation programs. Virtual Reality (VR) and Augmented Reality (AR): Virtual Reality (VR) and Augmented Reality (AR) technologies create interactive and immersive rehabilitation environments that improve patient participation and motivation during therapy sessions. In musculoskeletal rehabilitation, VR and AR are used for balance training, coordination exercises, pain management, and functional movement retraining. These technologies allow patients to perform rehabilitation exercises in engaging virtual environments while receiving real-time visual and sensory feedback. VR and AR systems increase exercise adherence, enhance patient motivation, and provide a more enjoyable rehabilitation experience. Their immersive nature also helps reduce pain perception and anxiety during rehabilitation procedures.

CLINICAL APPLICATIONS OF AI IN MUSCULOSKELETAL REHABILITATION12-16

Low Back Pain Rehabilitation: Artificial Intelligence plays an important role in the rehabilitation of patients with low back pain by analyzing posture, spinal alignment, movement patterns, and muscle activity. AI-based systems help physiotherapists identify movement dysfunctions and

biomechanical abnormalities that contribute to pain and disability. These technologies guide patients during rehabilitation exercises by providing real-time corrective feedback and monitoring recovery progress. AI applications in low back pain rehabilitation include postural correction, core strengthening guidance, and movement tracking. Continuous monitoring improves exercise accuracy and helps clinicians modify treatment plans according to patient progress, thereby enhancing rehabilitation outcomes. Osteoarthritis Rehabilitation: AI-assisted rehabilitation programs are increasingly used in the management of osteoarthritis to improve mobility, reduce pain, and enhance joint function. Intelligent systems monitor joint movements, gait patterns, pain levels, and functional performance during rehabilitation sessions. These technologies help patients perform exercises with proper technique while providing personalized rehabilitation recommendations. AI-based monitoring improves exercise accuracy and supports better pain management strategies. In addition, continuous assessment of functional mobility allows clinicians to track rehabilitation progress and optimize treatment protocols, leading to improved mobility outcomes and enhanced quality of life for osteoarthritis patients. Sports Injury Rehabilitation: AI technologies have become highly valuable in sports physiotherapy for injury prevention, rehabilitation monitoring, and performance enhancement. Advanced AI systems analyze biomechanical movements, muscle function, and athletic performance data to identify injury risks and guide rehabilitation programs. AI applications in sports injury rehabilitation include biomechanical analysis, return-to-play assessment, performance optimization, and injury risk prediction. These systems assist clinicians and sports physiotherapists in developing individualized rehabilitation strategies and monitoring athlete recovery more accurately. AI-based analysis also helps prevent re-injury by identifying abnormal movement patterns and muscular imbalances before athletes resume sports activities. Post-Operative Rehabilitation: AI-assisted rehabilitation systems play a significant role in recovery following orthopedic surgeries such as total knee replacement, hip replacement, anterior cruciate ligament (ACL) reconstruction, and other musculoskeletal procedures. These systems continuously monitor patient progress, joint mobility, muscle strength, and functional performance during rehabilitation. AI enables personalized exercise progression based on patient recovery status and provides real-time feedback during therapeutic exercises. Continuous monitoring helps clinicians detect complications or delayed recovery at an early stage. As a result, AI-supported post-operative rehabilitation improves functional recovery, enhances patient engagement, and promotes faster return to daily activities. Fracture Rehabilitation: Artificial Intelligence is increasingly being utilized in fracture rehabilitation to assist patients in regaining strength, mobility, and functional independence after bone injuries. Wearable sensors and AI-guided rehabilitation systems monitor limb movement, exercise performance, and weight-bearing activities throughout the recovery process. These technologies provide real-time feedback to ensure proper exercise execution and safe progression of rehabilitation. AI-based monitoring also helps clinicians evaluate healing progress and modify rehabilitation programs according to patient needs. The integration of wearable devices and intelligent rehabilitation systems enhances patient compliance, improves functional recovery, and supports efficient fracture management.

ADVANTAGES OF AI IN MUSCULOSKELETAL REHABILITATION17-19

Personalized Rehabilitation: One of the major advantages of Artificial Intelligence in musculoskeletal rehabilitation is its ability to provide personalized treatment programs. AI systems analyze patient-specific data such as age, functional limitations, movement patterns, pain levels, and recovery progress to design individualized rehabilitation plans. These customized exercise programs improve treatment effectiveness and ensure that rehabilitation protocols are adapted according to the patient's specific needs and response to therapy. Objective Assessment: AI technologies provide objective and accurate assessment of movement, posture, gait, and functional performance. Unlike traditional clinical evaluations that may depend on subjective observation, AI-based systems use sensors, cameras, and analytical algorithms to generate measurable data regarding patient movement and rehabilitation progress. Real-Time Feedback: AI-assisted rehabilitation systems provide immediate corrective feedback during therapeutic exercises. Through wearable sensors, motion analysis systems, and computer vision technologies, patients receive real-time guidance regarding posture, joint movement, and exercise accuracy. Improved Patient Engagement: Interactive AI-based rehabilitation technologies such as virtual reality, augmented reality, and gamified exercise systems significantly improve patient engagement and motivation. Increased patient motivation leads to better adherence to rehabilitation programs and improved long-term outcomes. Remote Rehabilitation Support: AI has greatly expanded the possibilities of tele-rehabilitation and home-based rehabilitation services. Intelligent rehabilitation systems and wearable devices allow clinicians to remotely monitor patient progress and provide guidance outside hospital settings. Reduced

Healthcare Burden: Automation and AI-assisted technologies reduce the workload of physiotherapists and healthcare professionals by performing repetitive monitoring and assessment tasks. AI systems streamline rehabilitation planning, progress tracking, and exercise supervision.

LIMITATIONS AND CHALLENGES17-19

High Cost of Technology: One of the major barriers to the implementation of AI in musculoskeletal rehabilitation is the high cost associated with advanced technologies such as robotic rehabilitation systems, wearable devices, and AI software platforms. Data Privacy Concerns: AI systems rely heavily on large-scale patient data collection and digital health records for analysis and decision-making. This raises concerns regarding patient confidentiality, data privacy, and cybersecurity. Technical Limitations: The successful implementation of AI technologies requires reliable internet connectivity, advanced hardware, and technical infrastructure. Limited technological resources may restrict the use of AI-assisted rehabilitation systems. Limited Clinical Validation: Although many AI-based rehabilitation systems show promising results, some technologies still lack sufficient long-term clinical evidence and validation. Lack of Professional Training: Healthcare professionals may require additional training and technical knowledge to effectively use AI technologies in rehabilitation practice. Ethical Concerns: The increasing dependence on AI technologies may reduce direct human interaction between patients and healthcare providers. Ethical concerns also arise regarding decision-making responsibilities and algorithm bias.

Future Scope: The future of Artificial Intelligence in musculoskeletal rehabilitation is highly promising due to rapid advancements in digital healthcare technologies. The integration of AI with wearable devices, robotics, Internet of Things (IoT), cloud computing, and telemedicine is expected to further improve rehabilitation efficiency, accessibility, and patient outcomes. Future developments may include: • AI-powered virtual physiotherapists • Smart rehabilitation clinics • Fully automated exercise monitoring systems • Brain-computer interface-assisted rehabilitation • Advanced biomechanical modeling The combination of AI with telemedicine and mobile health applications is expected to expand home-based rehabilitation services, particularly in rural and underserved areas where access to rehabilitation specialists is limited.

CONCLUSION

Artificial Intelligence is revolutionizing musculoskeletal rehabilitation by enhancing assessment accuracy, treatment personalization, and patient monitoring. Technologies such as machine learning, robotics, wearable sensors, computer vision, and virtual reality are improving rehabilitation outcomes and increasing patient engagement. AI-assisted rehabilitation offers significant benefits in managing musculoskeletal conditions including low back pain, osteoarthritis, sports injuries, fractures, and post-operative recovery. Despite challenges related to cost, ethics, and technical limitations, AI has immense potential to transform musculoskeletal rehabilitation into a more efficient, accessible, and patient-centered discipline. Continued research and clinical integration are essential to maximize the benefits of AI in rehabilitation practice.

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