Artificial Intelligence and Machine Learning Applications in Orthopedic Physiotherapy

Nawaf Rawaf Alfahad[1], Hadeel Fahad Alothaim[2]

[1]*Prince Sultan Military Medical City, Riyadh, Saudi Arabia

[2]College of Applied Medical Sciences, King Saud University, Riyadh, Saudi Arabia

*Corresponding Email: nawaf.alfahd@gmail.com

Abstract

Background: Musculoskeletal disorders (MSDs), such as osteoarthritis, fractures, ligament injuries, and chronic back pain, affect over 1.3 billion people worldwide, posing significant clinical and economic burdens. Conventional orthopedic physiotherapy is essential for restoring mobility and reducing disability but is limited by subjectivity, variability in treatment outcomes, and challenges in personalization. Artificial intelligence (AI) and machine learning (ML) have emerged as transformative tools to overcome these gaps. **Methodology:** This mini-review synthesizes recent advances in AI/ML applications across diagnostic imaging, gait and posture analysis, wearable sensor technologies, predictive analytics, rehabilitation robotics, and tele-physiotherapy. Clinical applications, case studies, and technological innovations are evaluated to highlight their impact on patient assessment, treatment planning, and rehabilitation. Challenges such as data privacy, limited datasets, integration into clinical workflows, and algorithmic bias are also discussed. **Results:** AI enhances diagnostic precision through automated medical imaging analysis and computer vision–based gait assessment. Wearable sensors combined with ML enable continuous monitoring and adaptive therapy adjustments, while predictive models improve early detection of injury risks and disease progression. AI-assisted rehabilitation tools—including robotic systems, VR/AR platforms, and gamified therapy—enhance patient engagement, adherence, and recovery outcomes. Clinical applications demonstrate improvements in post-operative rehabilitation, chronic back pain management, arthritis grading, sports injury recovery, and remote physiotherapy delivery. Despite barriers, federated learning, IoT integration, multimodal AI, and fully autonomous physiotherapy assistants are emerging as future solutions. **Conclusion:** AI and ML are revolutionizing orthopedic physiotherapy by enabling precision diagnosis, personalized treatment, and adaptive rehabilitation strategies. While challenges in privacy, clinical adoption, and algorithmic robustness remain, ongoing innovations promise to establish AI as a cornerstone of musculoskeletal care. These technologies are poised to enhance patient-centered rehabilitation, improve global accessibility, and shape the future of physiotherapy practice.

Journal of Pharmaceutical Research and Integrated Medical Sciences (JPRIMS)
ISSN: 3049-1681 | Vol. 02 Issue 09, Sep-2025 | pp. -47-60

J. Pharm. Res. Integr. Med. Sci   https://aktpublication.com/index.php/jprims/index

47

Journal of Pharmaceutical Research and Integrated Medical Sciences (JPRIMS)

ISSN: 3049-1681, Vol. 02, No. 09, 2025 (pp.47-60)

J. Pharm. Res. Integr. Med. Sci.   *Alfahad et al.*

1. Introduction

Artificial intelligence (AI) and machine learning (ML) have revolutionized the field of orthopedic physiotherapy, offering new possibilities for diagnosing, managing, and rehabilitating musculoskeletal disorders (MSDs), which are a leading cause of disability worldwide. Musculoskeletal disorders, including osteoarthritis, rheumatoid arthritis, fractures, ligament injuries, and chronic low back pain, affect globally and significantly contribute to physical impairment and reduced quality of life[1] .The burden of MSDs continues to grow due to aging populations, sedentary lifestyles, and increased prevalence of chronic diseases, creating substantial demand for effective rehabilitation protocols. Orthopedic physiotherapy plays a pivotal role in restoring mobility, relieving pain, and improving functionality in patients afflicted with these disorders. Conventional physiotherapy methods, however, face limitations such as subjectivity in diagnosis, variability in treatment outcomes due to practitioner differences, and challenges in personalized care delivery[2] .These constraints often lead to inconsistent therapeutic effectiveness and suboptimal recovery trajectories. Against this backdrop, AI and its subset ML have emerged as transformative forces in healthcare, particularly in orthopedic physiotherapy, by enabling precision medicine approaches based on data driven insights. AI systems simulate human cognitive functions to analyze extensive clinical and biomedical datasets for enhanced diagnostic accuracy and therapeutic planning. ML techniques, which involve algorithms that learn and improve from data input, excel in pattern recognition, prediction, and outcome optimization. A key enabler within ML is deep learning—neural network models capable of processing complex imaging and sensor data to identify pathological changes with unprecedented detail[3] .One significant area where AI has made substantial inroads is in the analysis of medical imaging. Orthopedic diagnoses often rely heavily on imaging modalities such as X rays, MRI, and CT scans to assess joint integrity, bone fractures, cartilage condition, and soft tissue injuries. AI powered image analysis tools have demonstrated remarkable capability in automating segmentation, classification, and grading of musculoskeletal tissues. Algorithms trained on large datasets can accurately delineate cartilage thickness, detect meniscal tears, and identify fractures, matching or surpassing human expert interpretation. This automation accelerates diagnostic workflows, reduces interobserver variabilities, and enhances early detection of subtle pathological signs that might be missed otherwise [4].Notable methodologies include convolutional neural networks (CNNs) and U Net architectures, which have been employed to segment knee cartilage, spine vertebrae, pelvic muscles, and more.

Beyond diagnosis, AI facilitates intelligent therapeutic interventions. Rehabilitation robotics, augmented by ML models, customize physiotherapy regimens targeting specific deficits in strength, flexibility, or motor coordination. These intelligent systems incorporate real time sensor feedback, enabling adaptive exercise modifications that respond to patient progress or fatigue levels, optimizing therapeutic dosing. Exoskeleton devices integrate soft pneumatic actuators driven by AI algorithms to support joint movements, aiding recovery of limbs impaired by injury or surgery[5] .Tele rehabilitation platforms leverage AI to deliver remote physiotherapy through smartphone applications, broadening access to care and improving adherence through personalized reminders and interactive guidance. AI also enriches predictive analytics in orthopedic physiotherapy. Using ML models trained on demographic, clinical, and imaging data, it is possible to forecast disease progression such as osteoarthritis advancement or likelihood of joint replacement surgery. Predictive models classify patients based on risk profiles to prioritize early intervention strategies, potentially forestalling disability. Similarly, AI assesses biomechanical markers to evaluate injury risk, especially in sports medicine; for example, ML

Journal of Pharmaceutical Research and Integrated Medical Sciences (JPRIMS)
ISSN: 3049-1681 | Vol. 02 Issue 09, Sep.- 2025 | pp. 47-60

J. Pharm. Res. Integr. Med. Sci.   https://aktpublication.com/index.php/jprims/index

48

Journal of Pharmaceutical Research and Integrated Medical Sciences (JPRIMS)
ISSN: 3049-1681, Vol. 02, No. 09, 2025 (pp.47-60)

J. Pharm. Res. Integr. Med. Sci.   *Alfahad et al.*

algorithms analyze gait patterns and joint kinematics to determine anterior cruciate ligament (ACL) injury risks, supporting preventive training programs[6].Despite these advances, the incorporation of AI into routine orthopedic physiotherapy faces challenges. Data quality and variability hinder the generalizability of AI models across diverse populations and settings. Ethical considerations surrounding patient privacy and data security require robust governance frameworks. Integration into clinical workflows necessitates user friendly interfaces and clinician training to foster acceptance and trust. The role of AI and ML in Orthopaedic physiotherapy is shown below in **Figure-1**. Moreover, regulatory pathways for AI based medical devices remain evolving, necessitating clear validation standards to ensure patient safety.
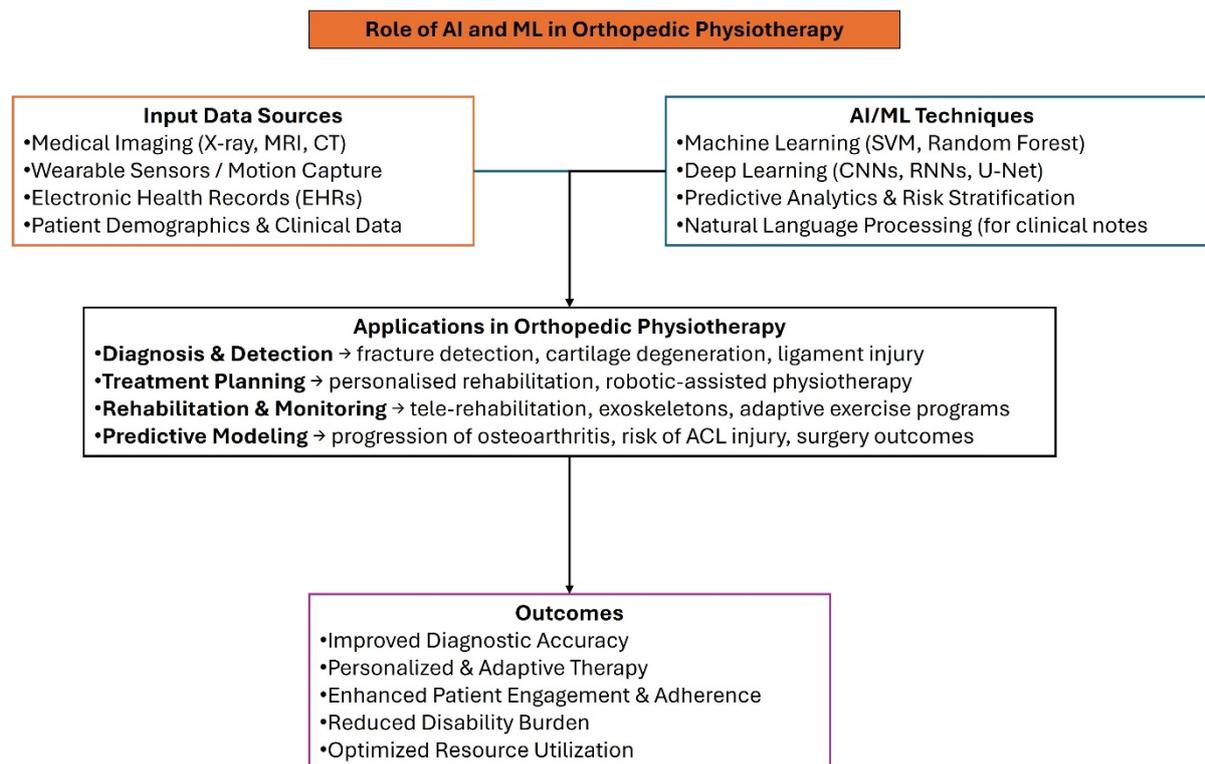
Role of AI and ML in Orthopedic Physiotherapy

Input Data Sources
- Medical Imaging (X-ray, MRI, CT)
- Wearable Sensors / Motion Capture
- Electronic Health Records (EHRs)
- Patient Demographics & Clinical Data

AI/ML Techniques
- Machine Learning (SVM, Random Forest)
- Deep Learning (CNNs, RNNs, U-Net)
- Predictive Analytics & Risk Stratification
- Natural Language Processing (for clinical notes)

Applications in Orthopedic Physiotherapy
- **Diagnosis & Detection** → fracture detection, cartilage degeneration, ligament injury
- **Treatment Planning** → personalised rehabilitation, robotic-assisted physiotherapy
- **Rehabilitation & Monitoring** → tele-rehabilitation, exoskeletons, adaptive exercise programs
- **Predictive Modeling** → progression of osteoarthritis, risk of ACL injury, surgery outcomes

Outcomes
- Improved Diagnostic Accuracy
- Personalized & Adaptive Therapy
- Enhanced Patient Engagement & Adherence
- Reduced Disability Burden
- Optimized Resource Utilization

Figure 1: Role of AI and ML in Orthopaedic Physiotherapy.

2. AI and ML in Patient Assessment

AI and machine learning (ML) have become pivotal technologies enhancing patient assessment in orthopedic physiotherapy, providing objective, precise, and scalable tools for evaluating musculoskeletal function. One of the most impactful applications is computer vision based posture and gait analysis. Traditional gait analysis often relies on subjective observational methods or expensive marker based motion capture systems that are time consuming and limited in accessibility. AI driven computer vision systems utilize ordinary cameras combined with advanced pose estimation algorithms to capture and analyze body posture and gait patterns in a non intrusive, cost effective manner. These systems can automatically extract spatiotemporal and kinematic parameters such as joint angles, step length, and gait velocity, delivering data with accuracy comparable to specialized motion capture labs. Machine learning classifiers then interpret this data to detect abnormal gait phenotypes associated with neurological or musculoskeletal disorders, enabling timely and personalized intervention decisions[7] .The integration of computer vision for gait assessment offers remote monitoring possibilities, supporting tele rehabilitation and continuous patient tracking outside clinical settings.

Journal of Pharmaceutical Research and Integrated Medical Sciences (JPRIMS)
ISSN: 3049-1681 | Vol. 02 Issue 09, Sep.- 2025 | pp. 47-60

J. Pharm. Res. Integr. Med. Sci.   https://aktpublication.com/index.php/jprims/index

49

Journal of Pharmaceutical Research and Integrated Medical Sciences (JPRIMS)

ISSN: 3049-1681, Vol. 02, No. 09, 2025 (pp.47-60)

J. Pharm. Res. Integr. Med. Sci.   *Alfahad et al.*

Complementing computer vision, wearable sensors equipped with AI algorithms provide granular motion tracking for patient assessment. These wearable sensor arrays—consisting of accelerometers, gyroscopes, magnetometers, and sometimes electromyography sensors—collect multidimensional biomechanical data during activities such as walking, running, or specific therapeutic exercises. AI driven analytics process this voluminous sensor data to classify complex motion patterns, quantify movement quality, and detect compensatory mechanisms or motor impairments. For example, machine learning models like Support Vector Machines (SVM) and Convolutional Neural Networks (CNN) have been utilized to distinguish walking, running, and turning movements with high accuracy, as well as identify directional limb movements and force variations[8] .The self powered, wearable multidimensional motion sensors have been integrated into rehabilitation programs and virtual reality platforms, facilitating interactive rehabilitation and objective assessment. AI enhanced wearable technology addresses the need for continuous, real world movement evaluation with the benefit of personalized feedback and progress tracking.

Another key application of AI and ML in patient assessment is predictive analytics for injury risk evaluation. Using large datasets comprising biometric, biomechanical, and historical patient data, AI models employ predictive algorithms—including random forests, convolutional neural networks, and artificial neural networks—to identify patterns and risk factors contributing to musculoskeletal injuries. These algorithms help forecast the likelihood of injury occurrences such as ligament tears or stress fractures by analyzing individual athlete profiles, movement dynamics, fatigue levels, and environmental factors. Predictive models support proactive risk stratification and targeted prevention strategies by enabling clinicians and trainers to devise personalized training regimens or rehabilitation plans that minimize injury risk[9] .This represents a significant shift from reactive injury management to anticipatory care, potentially reducing incidence rates, optimizing athlete performance, and lowering healthcare costs.

3. AI in Treatment Planning and Personalization

Artificial intelligence (AI) and machine learning (ML) are progressively reshaping orthopedic physiotherapy, profoundly impacting patient care through improved diagnosis, treatment personalization, and rehabilitation optimization. The global prevalence of musculoskeletal disorders (MSDs) — including osteoarthritis, rheumatoid arthritis, fractures, low back pain, tendinopathies, and ligament injuries is escalating, affecting people worldwide and imposing huge health and economic burdens. This growing challenge necessitates advanced rehabilitation strategies beyond the limitations of conventional physiotherapy, which often involves subjective assessments, variability in clinical practices, and insufficient personalization. AI and ML technologies herald a paradigm shift from traditional physiotherapy toward more precise, data driven, and individualized interventions. These technologies leverage complex algorithms, including deep learning models, convolutional neural networks (CNNs), and support vector machines (SVMs), trained on vast datasets comprising clinical records, imaging, wearable sensor inputs, and patient reported outcomes[10]. Such computational power enables enhanced diagnostic accuracy, real time patient monitoring, and adaptive therapeutic designs that are responsive to individual progress and biomechanics. Orthopedic patient assessment has been revolutionized by AI enabled computer vision systems, which utilize advanced pose estimation algorithms to analyze posture and gait from regular video feeds. These systems extract detailed spatiotemporal gait parameters such as stride length, joint angles, cadence, and symmetry, which are paramount for detecting early dysfunction and tailoring rehabilitation. Unlike expensive and complex marker based motion capture, AI based computer vision is non intrusive and scalable, facilitating clinical and home based assessments with high accuracy equivalent to traditional laboratories[11]. Learning classifiers then identify pathological gait patterns indicative of neurological or musculoskeletal disorders, guiding clinicians to customize interventions and monitor patient progress remotely.

Journal of Pharmaceutical Research and Integrated Medical Sciences (JPRIMS)
ISSN: 3049-1681 | Vol. 02 Issue 09, Sep.- 2025 | pp. 47-60

J. Pharm. Res. Integr. Med. Sci.   https://aktpublication.com/index.php/jprims/index

50

Journal of Pharmaceutical Research and Integrated Medical Sciences (JPRIMS)

ISSN: 3049-1681, Vol. 02, No. 09, 2025 (pp.47-60)

J. Pharm. Res. Integr. Med. Sci.   *Alfahad et al.*

Wearable sensors complement computer vision by providing continuous, multidimensional motion tracking. Devices embedded with accelerometers, gyroscopes, and electromyography sensors collect biomechanical, muscular, and kinematic data during dynamic activities. AI driven analytics process these rich but complex datasets to classify motion types, detect compensatory movements, and quantify rehabilitation exercises' quality. Machine learning algorithms such as CNNs and recurrent neural networks (RNNs) expertly decipher these patterns, enabling detailed movement quality assessment, objective progress tracking, and enhanced patient feedback[12]. The combination of wearable technology and AI empowers physiotherapists to design personalized exercise protocols based on real world data, reducing reliance on subjective evaluations. Predictive analytics facilitated by AI further enhance injury risk assessment and prevention strategies. ML models analyze integrated datasets encompassing demographics, gait biomechanics, fatigue markers, and environmental factors to forecast the probability of injuries like ligament tears or stress fractures. These risk stratification tools enable early identification of high risk individuals, allowing timely intervention through targeted training or modification of physical activities[13]. Such predictive models move rehabilitation from reactive treatment to proactive management, improving outcomes and reducing healthcare costs associated with injury complications.

In treatment planning, AI develops individualized physiotherapy regimens tailored to each patient's unique clinical and functional status. By learning patterns from diverse data sources, ML algorithms optimize treatment prescriptions based on variables like age, comorbidity burden, severity of injury, and response to previous therapies. These AI generated plans can recommend specific exercises, intensities, and durations proven to maximize recovery. Beyond prescription, AI integrated clinical decision support systems (CDSS) provide clinicians with advanced decision making tools that aggregate complex patient data, evidence based guidelines, and predictive outcomes to recommend treatment adaptations, warn of potential complications, or suggest referrals[14]. This support enhances clinical efficacy, reduces variability in care, and promotes personalized rehabilitation pathways.

Adaptive therapy programs powered by AI represent a revolutionary approach to musculoskeletal rehabilitation. These programs dynamically adjust therapy intensity, complexity, and focus based on real time monitoring of patients' physiological feedback, movement quality, pain levels, and adherence. Sensor driven data inputs feed AI algorithms that continuously evaluate therapy progress and modulate treatment plans to maintain optimal therapeutic dosing, prevent injury, and motivate patient engagement. Virtual coaching and tele rehabilitation platforms leverage these adaptive systems, making high quality, personalized physiotherapy accessible remotely[15]. Evidence substantiates that adaptive AI driven programs accelerate recovery, improve function, and bolster treatment adherence—key challenges in conventional physiotherapy.

Despite the remarkable advancements, integrating AI in orthopedic physiotherapy faces challenges such as ensuring the quality and representativeness of training data, addressing ethical issues related to patient data privacy and security, and achieving clinical validation and regulatory approval. Furthermore, acceptance by healthcare providers requires intuitive interfaces, seamless workflow integration, and targeted training. As these hurdles are progressively overcome, AI enhanced physiotherapy is poised to become the standard of care, delivering superior precision, efficiency, and patient centeredness.

Journal of Pharmaceutical Research and Integrated Medical Sciences (JPRIMS)
ISSN: 3049-1681 | Vol. 02 Issue 09, Sep.- 2025 | pp. 47-60

J. Pharm. Res. Integr. Med. Sci.   https://aktpublication.com/index.php/jprims/index

51

4. AI Assisted Rehabilitation Tools

AI assisted rehabilitation tools are increasingly becoming integral to modern orthopedic physiotherapy by enhancing therapeutic outcomes, patient engagement, and treatment personalization through advanced technological integration. Three major categories have emerged as game changers in this field: smart rehabilitation robots with machine learning (ML) integration, virtual reality (VR)/augmented reality (AR) environments enhanced by AI, and gamified rehabilitation platforms leveraging reinforcement learning[16]. Smart rehabilitation robots equipped with ML algorithms represent a significant advancement in assisted physiotherapy. These robotic systems are designed to aid the functional recovery of musculoskeletal injuries and impairments by providing precise, controlled, and repeatable therapeutic movements tailored to patients' needs. For instance, a robotic rehabilitation device integrating a 6 degree of freedom (6 DoF) end effector arm with passive joints allows for comprehensive mobilization of upper limb joints such as the elbow, wrist, and shoulder. The system applies resistive, assistive, or active assistive force fields and adapts exercise difficulty dynamically based on real time kinesiological feedback from patients. This capability to adjust the physical demand of exercises ensures progressive overload without causing pain or fatigue. Virtual reality serious games linked with the robotic system further motivate patients by embedding therapeutic movements within engaging interactive scenarios. Therapists can monitor patient progress through user friendly graphical interfaces and tailor exercise regimens to optimize range of motion, strength recovery, and pain management[17]. This robotics VR integration has demonstrated feasibility and patient acceptance in clinical trials, showing promise for controlled intervention studies that may revolutionize upper limb orthopedic rehabilitation protocols. AI enhanced virtual reality and augmented reality environments constitute another innovative dimension of orthopedic rehabilitation. VR immerses patients in realistic, interactive contexts that mimic everyday functions or therapeutic exercises, while AR overlays digital cues and coaching into the physical world, enriching motor and cognitive interventions. AI's role in these environments is to analyze complex movement data in real time and tailor therapy to the individual patient's capabilities and recovery trajectory. For instance, VR systems augmented with ML algorithms can detect deficits in movement quality, balance, or coordination and dynamically adjust exercise difficulty or provide corrective cues, thereby maximizing therapeutic efficacy. Clinical evidence from neurorehabilitation highlights that patients recovering from stroke or brain injuries demonstrate significant motor improvements using AI powered VR therapy. AR applications have also been instrumental in enhancing motor functions in Parkinson's disease patients by providing immediate visual and auditory feedback aligned with patient movements[18]. Despite the promising outcomes, challenges remain in making VR/AR systems accessible, affordable, and user friendly while minimizing adverse effects such as motion sickness. The continuous advancement of AI algorithms and hardware miniaturization is expected to overcome these barriers, making VR and AR a cornerstone of future orthopedic rehabilitation.

Gamified rehabilitation platforms powered by reinforcement learning, a branch of artificial intelligence focused on decision making and adaptive learning, provide a transformative approach to sustaining patient motivation and optimizing engagement. Through gamification, rehabilitation exercises are embedded into interactive game like environments that captivate patients and lower the perceived burden of repetitive therapeutic tasks. Reinforcement learning algorithms enhance this experience by continuously adapting the game's challenges based on individual performance and progress, ensuring an optimal balance of difficulty and reward. This dynamic adjustment helps maintain patient interest, prevent frustration, and maximize therapeutic adherence and effectiveness. Moreover, gamified platforms with embedded sensors facilitate real time data collection and analysis, guiding clinicians in monitoring patient progress and customizing future intervention plans. Research in neurodevelopmental and musculoskeletal rehabilitation confirms

Journal of Pharmaceutical Research and Integrated Medical Sciences (JPRIMS)
ISSN: 3049-1681 | Vol. 02 Issue 09, Sep.- 2025 | pp. 47-60

J. Pharm. Res. Integr. Med. Sci.   https://aktpublication.com/index.php/jprims/index

52

Journal of Pharmaceutical Research and Integrated Medical Sciences (JPRIMS)

ISSN: 3049-1681, Vol. 02, No. 09, 2025 (pp.47-60)

J. Pharm. Res. Integr. Med. Sci.   *Alfahad et al.*

that integrating gamification with AI improves cognitive and motor outcomes, providing individualized and flexible therapy beyond the limitations of traditional methods[19]. Additionally, gamified interventions empower caregivers by delivering structured, engaging rehabilitation protocols that can be administered at home, potentially reducing the burden on healthcare systems**.**

5. Clinical Applications and Case Studies

Artificial intelligence (AI) and machine learning (ML) have made significant strides in clinical applications within orthopedic physiotherapy, especially for post operative rehabilitation, management of chronic musculoskeletal conditions, and remote therapy delivery. Post operative rehabilitation after knee and hip replacements integrates AI enabled robotic systems and ML driven personalized exercise programs. Robotic arm assisted surgery and rehab devices provide precision in joint positioning and support controlled mobilization, reducing recovery time and complications. Post op progress is continually monitored by AI platforms that adapt rehab intensity, catering to the patient's unique recovery pace. This leads to improved functional outcomes and patient satisfaction by ensuring the rehabilitation plan evolves with patient specific needs. For back pain management, AI based tools such as computer vision assisted posture and gait analysis combined with sensor driven motion tracking enable precise assessment of biomechanical abnormalities underlying pain. Predictive analytics model the risk of chronicity or complications, guiding targeted interventions[20]. AI facilitates tailored physiotherapy that addresses both pain and functional deficits, optimizing therapy outcomes.

In the area of sports injuries, AI powered diagnostic algorithms improve the early detection of ligament tears (e.g., ACL), muscle strain, and joint injuries through multimodal imaging and biomechanical data analysis. Injury risk prediction models help design prevention programs, while AI enabled motion analysis supports personalized exercise prescription and progress tracking. These innovations reduce re injury rates and hasten return to activity for athletes. The management of arthritis, particularly osteoarthritis (OA), benefits from AI assisted diagnostic tools that automatically classify disease severity on imaging modalities like MRI and X rays. Automated grading helps standardize clinical decisions and monitor progression, enabling personalized therapeutic strategies focused on symptom relief and joint preservation. AI advances improve detection of early stage OA, promoting earlier intervention and potentially slowing disease progression. With the rise of telemedicine, remote and tele physiotherapy applications supported by AI have expanded access to rehabilitation[21]. Virtual rehabilitation platforms employ AI chatbots for patient guidance, wearable sensors for real time activity monitoring, and automated feedback to maintain adherence and optimize exercise effectiveness. Such remote care reduces barriers posed by geographic or mobility limitations, supporting continuous rehabilitation outside clinical settings.

These clinical applications demonstrate AI's transformative potential in improving diagnosis accuracy, tailoring treatment plans, enhancing patient engagement, and expanding rehabilitation reach. Continued research and real world validation will further solidify AI's role in optimizing musculoskeletal health management in diverse clinical contexts. The various clinical applications of AI in orthopedic physiotherapy rehabilitation along with AI examples and benefits are listed below in **Table-1.**

Journal of Pharmaceutical Research and Integrated Medical Sciences (JPRIMS)
ISSN: 3049-1681 | Vol. 02 Issue 09, Sep.- 2025 | pp. 47-60

J. Pharm. Res. Integr. Med. Sci.   https://aktpublication.com/index.php/jprims/index

53

Journal of Pharmaceutical Research and Integrated Medical Sciences (JPRIMS)

ISSN: 3049-1681, Vol. 02, No. 09, 2025 (pp.47-60)

J. Pharm. Res. Integr. Med. Sci.   *Alfahad et al.*

Table 1: Clinical applications of AI in orthopedic physiotherapy rehabilitation along with AI examples and benefits

Sr.No.	Clinical Application	AI Application Examples	Benefits	Ref
1.	Post operative rehabilitation (knee/hip replacement)	Robotic arm assisted surgery, AI powered rehab robots, ML guided personalized exercise plans	Improved surgical precision and post op recovery, reduced complications	(22)
2.	Management of back pain	AI based posture and gait analysis, wearable sensor motion tracking, predictive analytics	Accurate diagnosis, tailored rehabilitation, pain management	(23)
3.	Management of sports injuries	AI driven diagnostic models for ligament tears, injury risk prediction, motion analysis	Early injury detection, personalized rehab exercises, reduced re injury risk	(24)
4.	Management of arthritis	AI assisted OA diagnosis and severity grading, MRI and X ray image analysis	Enhanced disease grading, early intervention, personalized therapy	(25)
5.	Remote/tele physiotherapy applications	Virtual rehabilitation platforms, AI chatbots, wearable sensor monitoring, telehealth integration	Increased accessibility, continuous monitoring, personalized remote care	(26)

.

6. Challenges and Limitations

Artificial intelligence (AI) and machine learning (ML) introduce transformative possibilities in orthopedic physiotherapy, but their implementation also encounters significant challenges and limitations that must be addressed for successful, ethical, and effective clinical adoption. Key issues include data privacy and patient consent, lack of sufficiently large and representative datasets, integration barriers into clinical practice and physiotherapist acceptance, and technical limitations related to algorithmic accuracy, bias, and robustness.

6.1. Data Privacy, Patient Consent, and Ethical Concerns

AI systems process extensive protected health information (PHI), raising critical concerns about data privacy and security. Unauthorized access, improper data handling, or secondary usage of patient data without explicit informed consent threaten confidentiality and patient trust. Many AI applications also generate or rely on unprotected personal data (e.g., from wearable trackers) that, when combined with medical records, increase re identification risks despite de identification efforts. The mental and social harms stemming from privacy breaches—including discrimination, stigmatization, or insurance premium inflation—can be profound but difficult to quantify[27]. Ethical practice requires clear communication with patients about AI's role and data use, ensuring informed consent and transparency. Furthermore, healthcare providers must balance AI utility with protecting the patient's autonomy and confidentiality in accordance with overarching ethical frameworks and regulations.

6.2. Lack of Large, Representative Datasets

AI model development relies heavily on large, high quality datasets. However, most healthcare datasets suffer from limited size, lack of diversity, and insufficient population representation. Minority groups and vulnerable populations often remain underrepresented in training data, leading to models that generalize poorly outside well represented cohorts. For example, genomic

Journal of Pharmaceutical Research and Integrated Medical Sciences (JPRIMS)
ISSN: 3049-1681 | Vol. 02 Issue 09, Sep.- 2025 | pp. 47-60

J. Pharm. Res. Integr. Med. Sci.   https://aktpublication.com/index.php/jprims/index

54

and clinical databases frequently contain predominantly European origin data, limiting applicability to other ethnicities or demographics. Inconsistent data formatting and metadata gaps further hinder interoperability and the integration of multimodal datasets necessary for holistic AI models. Biases embedded in data collection—stemming from social, cultural, or clinical prejudices—risk perpetuating disparities by influencing AI recommendations detrimentally for marginalized groups[28]. Overcoming these gaps requires building inclusive, longitudinal datasets with comprehensive metadata and adopting federated or decentralized learning approaches to protect patient privacy while improving diversity.

6.3. Integration into Clinical Practice and Acceptance Among Physiotherapists

Despite robust research advancements, a significant gap exists between AI technology development and its real world clinical implementation in physiotherapy. Clinicians may face uncertainty about which AI tools best meet their practice needs, accompanied by skepticism over reliability, clinical effectiveness, or fears about diminished professional autonomy. Effective integration demands a carefully planned approach including needs assessments, pilot testing in clinical environments, and continuous evaluation based on patient outcomes and practitioner feedback. Training programs for physiotherapists are essential to build AI literacy and confidence, highlighting safe and ethical usage alongside technical proficiency[29]. Acceptance is also influenced by prior technological experience and perceived ease of use. Institutional oversight and collaboration with technology vendors are critical to establish trust, clarify responsibilities, and ensure AI complements rather than replaces human expertise.

6.4. Technical Limitations: Accuracy, Bias, and Robustness

AI models in physiotherapy must consistently deliver accurate, reliable, and unbiased predictions to be clinically viable. However, challenges arise from inherent statistical limitations and complexities in healthcare data. AI's strength in modeling correlations can also lead to spurious or misleading associations if confounding variables or concept drift are not properly managed. This vulnerability may result in erroneous clinical decisions if AI outputs are over relied upon. Bias perpetuation occurs if training data mirror societal or systemic prejudices, causing unfair treatment recommendations across race, gender, or socioeconomic groups. Furthermore, AI algorithmic robustness the capacity to maintain performance over time amidst evolving patient populations and clinical conditions is central to ensuring patient safety and long term utility.(30) Strategies such as continuous model monitoring, regular retraining with updated data, and transparent documentation of limitations are vital. Regulatory frameworks should enforce standards for accuracy, fairness, and explainability to foster trustworthy AI in healthcare

7. Future Directions

AI and machine learning (ML) are catalyzing a new era in orthopedic physiotherapy, with future directions centered around privacy preserving models, seamless integration of wearable technologies and the Internet of Things (IoT), multimodal data fusion, and the prospect of fully autonomous physiotherapy assistants. These advances promise to transform rehabilitation by delivering more personalized, accessible, and effective care while addressing critical ethical and technical challenges.

7.1. Federated Learning and Privacy Preserving Models

A significant frontier in AI healthcare is federated learning, a collaborative machine learning approach designed to preserve patient privacy and data security. Unlike traditional centralized training, federated learning enables diverse healthcare institutions to jointly build robust AI models without sharing raw data. Instead, models train locally on site with encrypted updates

Journal of Pharmaceutical Research and Integrated Medical Sciences (JPRIMS)
ISSN: 3049-1681 | Vol. 02 Issue 09, Sep.- 2025 | pp. 47-60

J. Pharm. Res. Integr. Med. Sci.   https://aktpublication.com/index.php/jprims/index

55

Journal of Pharmaceutical Research and Integrated Medical Sciences (JPRIMS)

ISSN: 3049-1681, Vol. 02, No. 09, 2025 (pp.47-60)

J. Pharm. Res. Integr. Med. Sci.   *Alfahad et al.*

shared centrally to aggregate learning. This protects sensitive patient information while addressing the persistent challenge of acquiring large, representative datasets critical for generalizable AI systems in physiotherapy. Federated learning enhances inclusivity by integrating data from multiple demographics and clinical contexts without compromising privacy, enabling AI to better adapt to heterogeneous populations[31]. Alongside federated learning, emerging privacy preserving techniques like homomorphic encryption and differential privacy will fortify data confidentiality, ensuring compliance with ethical standards and regulations. These technologies represent a paradigm shift toward responsible AI that balances innovation with patient autonomy and trust.

7.2. Integration with Wearable Devices and Internet of Things (IoT)

Wearable devices and IoT lie at the nexus of future physiotherapy advancements, enabling continuous, real world patient monitoring and dynamic intervention. Modern wearable technologies—such as inertial measurement units (IMUs), surface electromyography (EMG) sensors, smart textiles, and pressure sensors—collect multidimensional biomechanical and physiological data during daily activities beyond traditional clinical visits. Integration with AI and cloud computing facilitates real time data processing, movement pattern recognition, and personalized feedback. Such systems empower physiotherapists to remotely monitor patient progress, adjust therapy plans dynamically, and enhance patient engagement. IoT enabled physiotherapy envisions a connected ecosystem of devices and health records, improving data interoperability and holistic patient management. Wearables equipped with AI algorithms can detect subtle deviations in gait, posture, and muscular activation that signal recovery stage changes or risk of relapse. Moreover, smart garments and sensor embedded exoskeletons will become more ergonomic, energy efficient, and cost effective, broadening accessibility[32].These innovations promise to reduce geographical and logistical barriers to rehabilitation, promoting adherence and accelerating functional recovery. With policy and payer recognition advancing, scalable IoT driven physiotherapy holds promise for democratizing quality musculoskeletal care.

7.3. Multimodal AI Combining Imaging, Biomechanical, and Patient Reported Data

The future of orthopedic physiotherapy AI lies in multimodal data fusion—integrating diverse data forms to create comprehensive, context rich patient profiles. Combining medical imaging modalities such as MRI and X ray with biomechanical metrics from wearables and patient reported outcome measures (PROMs) radically enhances diagnostic precision and treatment customization. Advanced AI models, including deep learning architectures, are being developed to analyze these heterogeneous datasets collectively, uncovering nuanced correlations and predicting nuanced recovery trajectories[33]. Multimodal AI enables early detection of musculoskeletal deterioration, personalized therapy adjustments based on dynamic risk profiles, and comprehensive monitoring of functional gains and symptoms. For instance, AI can identify early cartilage degeneration on imaging while concurrently analyzing gait instability and patient pain levels to recommend tailored interventions. This holistic approach aligns with precision medicine principles, delivering individualized care plans that evolve with patients' changing conditions. Moreover, multimodal AI contributes to patient stratification in clinical trials and guides decision makers in health policy by providing robust evidence on effective rehabilitation strategies.

7.4. Prospects for Fully Autonomous Physiotherapy Assistants

Looking further ahead, research is progressing toward fully autonomous physiotherapy assistants—AI driven systems capable of independently conducting assessments, prescribing exercises, providing real time feedback, and adapting treatments without continuous human supervision. These assistants would integrate computer vision, natural language processing, robotics, and reinforcement learning to replicate many functions of human therapists. Such

Journal of Pharmaceutical Research and Integrated Medical Sciences (JPRIMS)
ISSN: 3049-1681 | Vol. 02 Issue 09, Sep.- 2025 | pp. 47-60

J. Pharm. Res. Integr. Med. Sci.   https://aktpublication.com/index.php/jprims/index

56

Journal of Pharmaceutical Research and Integrated Medical Sciences (JPRIMS)

ISSN: 3049-1681, Vol. 02, No. 09, 2025 (pp.47-60)

J. Pharm. Res. Integr. Med. Sci.   *Alfahad et al.*

systems could guide patients through complex rehab protocols in clinical or home settings, democratizing access to expert care and reducing healthcare provider burdens[34]. Fully autonomous assistants will enhance the scalability of therapy, especially in underserved regions that lack physiotherapy personnel. They could continuously monitor adherence and physiological responses using integrated sensors and modify therapy intensity instantly to optimize outcomes and prevent injuries. While considerable technical and ethical hurdles remain—including reliability, legal accountability, and maintaining a therapeutic human touch—this vision represents an aspirational goal aligned with advances in AI explainability, safety, and patient centered design[35].

8. Conclusion

Artificial intelligence (AI) and machine learning (ML) are fundamentally transforming the landscape of orthopedic physiotherapy by elevating diagnostic accuracy, personalizing treatment, and optimizing rehabilitation outcomes. The integration of AI has empowered clinicians with advanced tools such as computer vision for detailed gait and posture analysis, wearable sensors for continuous motion tracking, and predictive analytics for injury risk assessment. These technological advancements improve patient assessment precision and enable data driven, individualized treatment planning through decision support systems and adaptive therapy models that dynamically respond to a patient's rehabilitation progress. AI assisted rehabilitation tools, including smart robots, virtual reality (VR) and augmented reality (AR) environments, and gamified platforms using reinforcement learning, have improved patient engagement, therapy adherence, and treatment effectiveness. Clinical applications have demonstrated AI's potential in post operative rehabilitation following joint replacement surgeries, effective management of chronic conditions such as back pain and arthritis, and early detection and tailored rehabilitation of sports injuries. Remote and tele physiotherapy enabled by AI expands access to quality care, providing continuous monitoring and personalized intervention beyond traditional clinical settings. Despite tremendous promise, the adoption of AI in orthopedic physiotherapy faces challenges including safeguarding data privacy and securing informed patient consent, overcoming the scarcity of large, diverse datasets, integrating AI into routine clinical workflows, and addressing technical concerns such as algorithm accuracy, bias, and robustness. Addressing these barriers through ethical frameworks, regulatory guidance, federated learning, clinician training, and ongoing validation is essential for safe and equitable AI deployment. Future directions emphasize federated learning and privacy preserving AI models to protect sensitive health information while enabling collaboration across institutions. The integration of wearable devices and IoT technologies will provide continuous real time data streams to enhance personalized rehabilitation and remote monitoring. Multimodal AI approaches combining imaging, biomechanical data, and patient reported outcomes will facilitate holistic, precision care tailored to individual patient complexities. The development of fully autonomous physiotherapy assistants promises scalable, expert guided rehabilitation accessible to underserved populations worldwide.

Together, these advancements crier a new era in orthopedic physiotherapy where AI augments human expertise with intelligent, adaptive, and patient centered technologies. This synergy offers the potential to improve functional recovery, optimize health outcomes, and increase global access to effective musculoskeletal care. The future of orthopedic physiotherapy is poised to be smarter, more efficient, and profoundly personalized, driven by interdisciplinary collaboration and responsible AI innovation.

Journal of Pharmaceutical Research and Integrated Medical Sciences (JPRIMS)
ISSN: 3049-1681 | Vol. 02 Issue 09, Sep.- 2025 | pp. 47-60

J. Pharm. Res. Integr. Med. Sci.   https://aktpublication.com/index.php/jprims/index

57

Reference

1. Zhou J, Xie S, Xu S, Zhang Y, Li Y, Sun Q, et al. (2024). From Pain to Progress: Comprehensive Analysis of Musculoskeletal Disorders Worldwide. J Pain Res,17:3455–72.

2. Yilmaz Muluk S, Olcucu N (2024). The Role of Artificial Intelligence in the Primary Prevention of Common Musculoskeletal Diseases. Cureus.;

3. Rasa AR (2024). Artificial Intelligence and Its Revolutionary Role in Physical and Mental Rehabilitation: A Review of Recent Advancements. Biomed Res Int.

4. Chen K, Stotter C, Klestil T, Nehrer S (2022). Artificial Intelligence in Orthopedic Radiography Analysis: A Narrative Review. Diagnostics;12(9):2235.

5. Swarnakar R, Yadav SL (2023). Artificial intelligence and machine learning in motor recovery: A rehabilitation medicine perspective. World J Clin Cases11(29):7258–60.

6. Shahid S, Javaid A, Amjad U, Rasheed J (2024). Investigating artificial intelligence models for predicting joint pain from serum biochemistry. Rev Assoc Med Bras 70(9).

7. Tafat W, Budka M, McDonald D, Wainwright TW (2024). Artificial intelligence in orthopaedic surgery: A comprehensive review of current innovations and future directions. Computational and Structural Biotechnology Reports1:100006.

8. Wei S, Wu Z(2023). The Application of Wearable Sensors and Machine Learning Algorithms in Rehabilitation Training: A Systematic Review. Sensors.;23(18):7667.

9. Phillips SP, Spithoff S, Simpson A (2022). Artificial intelligence and predictive algorithms in medicine. Canadian Family Physician;68(8):570–2.

10. Maffulli N, Rodriguez HC, Stone IW, Nam A, Song A, Gupta M, et al(2020). Artificial intelligence and machine learning in orthopedic surgery: a systematic review protocol. J Orthop Surg Res;15(1):478.

11. Roggio F, Trovato B, Sortino M, Musumeci G (2024). A comprehensive analysis of the machine learning pose estimation models used in human movement and posture analyses: A narrative review. Heliyon.10(21):e39977.

12. Elfouly T, Alouani A (2025). A Comprehensive Survey on Wearable Computing for Mental and Physical Health Monitoring. Electronics (Basel);14(17):3443.

13. Souaifi M, Dhahbi W, Jebabli N, Ceylan Hİ, Boujabli M, Muntean RI, et al(2025). Artificial Intelligence in Sports Biomechanics: A Scoping Review on Wearable Technology, Motion Analysis, and Injury Prevention. Bioengineering;12(8):887.

14. Lanotte F, O'Brien MK, Jayaraman A (2023). AI in Rehabilitation Medicine: Opportunities and Challenges. Ann Rehabil Med;47(6):444–58.

15. Attoh-Mensah E, Boujut A, Desmons M, Perrochon A(2025). Artificial intelligence in personalized rehabilitation: current applications and a SWOT analysis. Front Digit Health;7.

16. e Siqueira TB, Parraça J, Sousa JP(2024). Available rehabilitation technology with the potential to be incorporated into the clinical practice of physiotherapists: A systematic review. Health Sci Rep;7(4).

Journal of Pharmaceutical Research and Integrated Medical Sciences (JPRIMS)
ISSN: 3049-1681 | Vol. 02 Issue 09, Sep.- 2025 | pp. 47-60

J. Pharm. Res. Integr. Med. Sci.   https://aktpublication.com/index.php/jprims/index

58

Journal of Pharmaceutical Research and Integrated Medical Sciences (JPRIMS)

ISSN: 3049-1681, Vol. 02, No. 09, 2025 (pp.47-60)

J. Pharm. Res. Integr. Med. Sci.   *Alfahad et al.*

17. Padilla-Castañeda MA, Sotgiu E, Barsotti M, Frisoli A, Orsini P, Martiradonna A, et al(2018). An Orthopaedic Robotic-Assisted Rehabilitation Method of the Forearm in Virtual Reality Physiotherapy. J Healthc Eng; 1–20.

18. Combalia A, Sanchez-Vives M V., Donegan T(2024). Immersive virtual reality in orthopaedics—a narrative review. Int Orthop;48(1):21–30.

19. González-González CS, Toledo-Delgado PA, Muñoz-Cruz V, Torres-Carrion P V(2019). Serious games for rehabilitation: Gestural interaction in personalized gamified exercises through a recommender system. J Biomed Inform. 97:103266.

20. Longo UG, De Salvatore S, Valente F, Villa Corta M, Violante B, Samuelsson K(2024). Artificial intelligence in total and unicompartmental knee arthroplasty. BMC Musculoskelet Disord 25(1):571.

21. Andriollo L, Picchi A, Sangaletti R, Perticarini L, Rossi SMP, Logroscino G, et al (2024). The Role of Artificial Intelligence in Anterior Cruciate Ligament Injuries: Current Concepts and Future Perspectives. Healthcare 12(3):300.

22. Yoo JI, Oh MK, Lee SU, Lee CH(2022). Robot-assisted rehabilitation for total knee or hip replacement surgery patients: A systematic review and meta-analysis. Medicine. 101(40):e30852.

23. Jawed AM, Zhang L, Zhang Z, Liu Q, Ahmed W, Wang H(2025). Artificial intelligence and machine learning in spine care: Advancing precision diagnosis, treatment, and rehabilitation. World J Orthop. 16(8).

24. Musat CL, Mereuta C, Nechita A, Tutunaru D, Voipan AE, Voipan D, et al (2024). Diagnostic Applications of AI in Sports: A Comprehensive Review of Injury Risk Prediction Methods. Diagnostics 14(22):2516.

25. Momtazmanesh S, Nowroozi A, Rezaei N(2022).. Artificial Intelligence in Rheumatoid Arthritis: Current Status and Future Perspectives: A State-of-the-Art Review. Rheumatol Ther.;9(5):1249–304.

26. Hanafi B, Hasan A, Ahmad A, Ali M(2025). Advancing public health through artificial intelligence in physiotherapy: a bibliometric analysis. Informatics and Health;2(2):99–118.

27. Moulaei K, Akhlaghpour S (2025)., Fatehi F. Patient consent for the secondary use of health data in artificial intelligence (AI) models: A scoping review. Int J Med Inform.198:105872.

28. Osonuga A, Osonuga AA, Fidelis SC, Osonuga GC, Juckes J, Olawade DB (2025). Bridging the digital divide: artificial intelligence as a catalyst for health equity in primary care settings. Int J Med Inform.204:106051.

29. El Arab RA, Abu-Mahfouz MS, Abuadas FH, Alzghoul H, Almari M, Ghannam A, et al (2025). Bridging the Gap: From AI Success in Clinical Trials to Real-World Healthcare Implementation—A Narrative Review. Healthcare.13(7):701.

30. Akinrinmade AO, Adebile TM, Ezuma-Ebong C, Bolaji K, Ajufo A, Adigun AO, et al (2023). Artificial Intelligence in Healthcare: Perception and Reality. Cureus.

31. Madathil NT, Dankar FK, Gergely M, Belkacem AN, Alrabaee S (2025). Revolutionizing healthcare data analytics with federated learning: A comprehensive survey of applications, systems, and future directions. Comput Struct Biotechnol J.28:217–38.

Journal of Pharmaceutical Research and Integrated Medical Sciences (JPRIMS)
ISSN: 3049-1681 | Vol. 02 Issue 09, Sep.- 2025 | pp. 47-60

J. Pharm. Res. Integr. Med. Sci.   https://aktpublication.com/index.php/jprims/index

59

32.   Rodgers MM, Alon G, Pai VM, Conroy RS (2019). Wearable technologies for active living and rehabilitation: Current research challenges and future opportunities. J Rehabil Assist Technol Eng.6.

33.   Simon BD, Ozyoruk KB, Gelikman DG, Harmon SA, Türkbey B(2024). The future of multimodal artificial intelligence models for integrating imaging and clinical metadata: a narrative review. Diagnostic and Interventional Radiology.

34.   Abedi A, Colella TJF, Pakosh M, Khan SS(2024). Artificial intelligence-driven virtual rehabilitation for people living in the community: A scoping review. NPJ Digit Med.7(1):25.

35.   Joshi, N. D. C., Harshita, N., Naskar, N. A., Datta, N. K., Sarkar, N. U., Otia, N. M. K., & Khatoon, N. T. (2022b). Rheumatoid arthrities: Etiology pathophysiology and modern Treatments. *International Journal for Research in Applied Sciences and Biotechnology*, *9*(3), 32–39. https://doi.org/10.31033/ijrasb.9.3.7

Journal of Pharmaceutical Research and Integrated Medical Sciences (JPRIMS)
ISSN: 3049-1681 | Vol. 02 Issue 09, Sep.- 2025 | pp. 47-60

J. Pharm. Res. Integr. Med. Sci.   **https://aktpublication.com/index.php/jprims/index**

60