

Wearable Sensor–Based Rehabilitation in Musculoskeletal Disorders: A Narrative Review of Current Evidence and Clinical Applications

¹Dr. Sakshi Yadav, ²Rinku Bairwa, ³Prof.(Dr.)Aditi Singh

Author info:

- 1.* Assistant Professor, Department of Physiotherapy, Jagannath University, Jaipur (Corresponding author)
2. BPT final year student, Department of Physiotherapy, Jagannath University, Jaipur
3. Head of Department, Department of Physiotherapy, Jagannath University, Jaipur

Abstract

Background: Wearable sensor technology has emerged as a promising innovation in musculoskeletal rehabilitation. These devices, including inertial measurement units (IMUs), smart wearable systems, and motion-tracking sensors, allow real-time monitoring of movement patterns, exercise performance, and functional progress. Their integration into rehabilitation programs has the potential to enhance patient engagement, improve adherence, and provide objective clinical feedback across various musculoskeletal conditions.

Objective: To review the current evidence on wearable sensor–based rehabilitation in musculoskeletal disorders and to analyze its clinical applications in improving functional outcomes, movement quality, and rehabilitation monitoring. This review also aims to evaluate different types of wearable technologies used in orthopaedic rehabilitation and their role in enhancing patient recovery across various musculoskeletal conditions.

Materials and Methods: A systematic review of literature was conducted using electronic databases including PubMed, Scopus, and Google Scholar. Studies published between 2016 and 2026 were included. Keywords such as “wearable sensors,” “inertial measurement units,” “musculoskeletal rehabilitation,” “digital rehabilitation,” and “motion tracking in physiotherapy” were used. Randomized controlled trials, clinical trials, and prospective cohort studies evaluating wearable sensor–based rehabilitation in musculoskeletal conditions were included for analysis.

Results: The reviewed studies suggest that wearable sensor–based rehabilitation improves movement accuracy, exercise adherence, and functional outcomes in musculoskeletal conditions. These technologies have been widely applied in shoulder disorders, knee rehabilitation, post-operative orthopaedic recovery, and chronic musculoskeletal pain. Objective feedback provided by wearable systems enhances patient motivation and enables clinicians to remotely monitor rehabilitation progress. Improvements were observed in range of motion, pain scores, functional scales, and gait or movement parameters. 20 studies involving 1,548 participants were included.

Conclusion: Wearable sensor–based rehabilitation is a promising adjunct to conventional physiotherapy in musculoskeletal disorders. It provides objective monitoring, enhances rehabilitation adherence, and improves functional outcomes. However, further large-scale clinical trials are required to standardize protocols and establish long-term clinical effectiveness.

Index Terms: Wearable Sensors, Musculoskeletal Rehabilitation, Inertial Measurement Unit, Digital Physiotherapy, Motion Tracking, Orthopaedic Rehabilitation.

INTRODUCTION

Wearable sensor technology has emerged as a rapidly evolving innovation in the field of musculoskeletal rehabilitation, offering objective and real-time assessment of movement patterns, exercise performance, and functional recovery [1]. These systems typically include inertial measurement units (IMUs), accelerometers, gyroscopes, smart garments, and motion-tracking devices that enable continuous monitoring of joint motion and physical activity outside the clinical setting [2]. The integration of such technology into rehabilitation practice has transformed traditional physiotherapy approaches by enabling data-driven and patient-specific treatment strategies [3].

Musculoskeletal disorders represent a major global health burden, contributing significantly to pain, disability, and reduced quality of life across all age groups [4]. Conditions such as osteoarthritis, shoulder dysfunction, spinal disorders, and post-operative orthopaedic conditions often require long-term rehabilitation to restore functional independence [5]. Conventional physiotherapy relies primarily on therapist-supervised sessions and patient-reported outcomes, which may be influenced by subjective bias and limited follow-up between clinical visits [6]. This creates a need for more objective and continuous monitoring tools in rehabilitation practice [7].

Wearable sensor–based rehabilitation addresses this gap by providing precise quantification of movement quality, range of motion, and exercise adherence in real time [8]. These devices allow clinicians to track patient progress remotely and adjust rehabilitation protocols based on objective data [9]. In addition, visual and auditory feedback generated by wearable systems enhances patient engagement and motivation during rehabilitation exercises [10]. Such interactive feedback mechanisms have been shown to improve compliance with home exercise programs [11].

The application of wearable technology has expanded across various musculoskeletal conditions [12]. In shoulder rehabilitation, sensors have been used to monitor range of motion and compensatory movement patterns [13]. In knee rehabilitation, particularly following ligament injuries or arthroplasty, wearable systems assist in gait analysis and functional recovery tracking [14]. Similarly,

spinal rehabilitation programs have utilized sensor-based feedback to improve posture control and movement correction [15]. These applications demonstrate the versatility of wearable technology in orthopaedic practice [16].

Emerging evidence suggests that wearable sensor-based rehabilitation may enhance functional outcomes compared to conventional physiotherapy alone [17]. Improvements have been reported in parameters such as range of motion, gait symmetry, pain reduction, and functional disability scores [18]. Remote monitoring capabilities also support telerehabilitation models, making rehabilitation more accessible, especially for patients in remote or underserved regions [19]. This has become increasingly relevant in modern healthcare systems emphasizing digital health integration [20].

Despite its advantages, challenges remain in the widespread adoption of wearable rehabilitation technologies [21]. Issues such as device cost, data accuracy, user familiarity, and integration into routine clinical workflows limit their universal application [22]. Variability in device types and lack of standardized protocols also contribute to inconsistencies in clinical outcomes [23]. Furthermore, long-term evidence regarding sustainability and cost-effectiveness is still limited [24].

The role of physiotherapists is evolving with the incorporation of digital technologies into rehabilitation practice [25]. Clinicians are now required to interpret sensor-generated data and integrate it into individualized treatment planning [26]. This shift emphasizes the importance of combining traditional clinical expertise with technological advancements [27]. Patient-centered rehabilitation models supported by wearable technology are increasingly being explored to improve long-term outcomes [28].

Recent research highlights the potential of artificial intelligence and machine learning integration with wearable sensors to further enhance predictive rehabilitation models [29]. These systems can identify movement abnormalities and provide automated feedback for correction [30]. Such advancements indicate a future direction toward fully intelligent rehabilitation ecosystems [31].

However, heterogeneity in study designs, patient populations, and outcome measures limits the ability to draw definitive conclusions regarding clinical superiority [32]. Most available studies are short-term and include small sample sizes, highlighting the need for large-scale randomized controlled trials [33]. Standardization of protocols and validation of wearable systems remain essential for clinical translation [34].

Therefore, there is a growing need to critically evaluate the existing evidence on wearable sensor-based rehabilitation in musculoskeletal disorders [35]. This review aims to analyze current clinical applications, compare different wearable technologies, and assess their impact on functional outcomes and rehabilitation progress [36]. The findings may contribute to improved understanding and future integration of wearable technology into routine musculoskeletal rehabilitation practice [37].

NEED OF THE STUDY

Musculoskeletal disorders are among the leading causes of pain, disability, reduced mobility, and decreased quality of life worldwide. Conditions such as osteoarthritis, shoulder dysfunction, spinal disorders, and post-operative orthopaedic impairments often require prolonged rehabilitation to restore functional independence and physical performance. Conventional physiotherapy mainly depends on therapist observation, periodic clinical assessment, and patient-reported outcomes, which may not always provide continuous or objective monitoring of rehabilitation progress. Therefore, there is an increasing need for advanced rehabilitation approaches that can deliver accurate, real-time, and patient-centered assessment during recovery.

Wearable sensor-based rehabilitation has emerged as an innovative technology that allows objective evaluation of movement patterns, joint mobility, gait parameters, exercise adherence, and functional performance. Devices such as inertial measurement units (IMUs), accelerometers, gyroscopes, motion-tracking systems, and smart wearable technologies provide continuous monitoring and real-time feedback during rehabilitation exercises. These systems have the potential to improve treatment precision, enhance patient engagement, and support home-based rehabilitation programs.

Despite rapid advancements in wearable rehabilitation technology, its clinical application in musculoskeletal physiotherapy is still developing. Existing studies have reported promising outcomes in terms of pain reduction, improved range of motion, enhanced gait symmetry, better motor control, and increased adherence to rehabilitation programs. However, the evidence remains scattered across different musculoskeletal conditions, wearable systems, and rehabilitation protocols. There is currently no clear consensus regarding the overall effectiveness, practical utility, and long-term clinical benefits of wearable sensor-based rehabilitation.

Another important concern is the growing demand for telerehabilitation and remote patient monitoring, particularly in modern healthcare systems where accessibility and continuity of care are major challenges. Wearable technologies can bridge the gap between hospital-based physiotherapy and home rehabilitation by allowing clinicians to remotely track patient progress and modify treatment programs based on objective data. This is especially beneficial for patients living in rural or underserved areas, elderly individuals, and post-operative patients who may have difficulty attending regular physiotherapy sessions.

Furthermore, conventional rehabilitation often lacks continuous supervision outside the clinical setting, leading to poor exercise compliance and incorrect movement execution. Wearable sensor systems can provide immediate visual or auditory feedback, helping patients perform exercises more accurately and consistently. Improved adherence and movement quality may contribute to better functional recovery and reduced long-term disability.

Although several studies have explored wearable-assisted rehabilitation, significant gaps remain regarding standardized rehabilitation protocols, device accuracy, cost-effectiveness, long-term outcomes, and integration into routine clinical practice. Variability in study design, patient populations, and outcome measures also limits the ability to establish definitive clinical recommendations. Therefore, a comprehensive review of current evidence is necessary to evaluate the effectiveness and practical applications of wearable sensor-based rehabilitation in musculoskeletal disorders.

The present study is needed to critically analyze the available literature on wearable sensor technologies in musculoskeletal rehabilitation and to summarize their role in improving pain, range of motion, functional ability, movement quality, and rehabilitation adherence. This study will also help identify current research gaps, clinical challenges, and future directions for integrating wearable technologies into physiotherapy practice.

In addition, the findings of this review may contribute to the development of more evidence-based, technology-assisted rehabilitation strategies that support personalized patient care and objective functional assessment. As digital health and artificial intelligence continue to evolve, wearable sensor-based rehabilitation may become an essential component of modern

musculoskeletal physiotherapy. Therefore, understanding its current evidence and clinical potential is important for physiotherapists, researchers, and healthcare professionals involved in rehabilitation practice.

3.1 Population and Sample

The population for this review consisted of published research studies investigating the use of wearable sensor-based rehabilitation in individuals with musculoskeletal disorders. The target population included adult patients diagnosed with various musculoskeletal conditions such as knee osteoarthritis, shoulder dysfunction, adhesive capsulitis, spinal disorders, chronic musculoskeletal pain, post-operative orthopaedic conditions, and general musculoskeletal impairments undergoing rehabilitation interventions supported by wearable technologies.

The sample for this review comprised studies selected from electronic databases based on predefined eligibility criteria. A systematic search identified studies evaluating wearable sensor technologies including inertial measurement units (IMUs), accelerometers, gyroscopes, smart wearable systems, motion-tracking devices, biofeedback systems, and AI-integrated rehabilitation technologies used in physiotherapy and musculoskeletal rehabilitation.

Studies were included if they:

- Involved adults aged 18 years and above with musculoskeletal disorders.
- Evaluated wearable sensor-based rehabilitation interventions.
- Used randomized controlled trials, clinical trials, cohort studies, quasi-experimental studies, or observational study designs.
- Reported outcomes related to pain, range of motion, gait parameters, movement quality, rehabilitation adherence, functional disability, or quality of life.
- Were published in English language between 2016 and 2026.

Studies were excluded if they:

- Included pediatric populations.
- Focused only on neurological or cardiopulmonary rehabilitation without musculoskeletal involvement.
- Evaluated pharmacological or surgical interventions without rehabilitation components.
- Were review articles, editorials, conference abstracts, or unpublished studies.

After screening and eligibility assessment, a total of 20 studies involving 1,548 participants were included in the final review. The selected studies represented a wide range of musculoskeletal conditions and wearable rehabilitation technologies, allowing comprehensive evaluation of their clinical effectiveness and practical applications.

3.2 Data and Sources of Data

The present review utilized secondary data collected from previously published research articles related to wearable sensor-based rehabilitation in musculoskeletal disorders. Data were obtained through a systematic search of multiple electronic databases and scientific sources to ensure comprehensive coverage of relevant literature.

The primary sources of data included:

- PubMed/MEDLINE
- Scopus
- Google Scholar
- Web of Science
- Cochrane Library
- PEDro Database

A structured search strategy was developed using Medical Subject Headings (MeSH) terms and relevant keywords related to wearable rehabilitation technologies and musculoskeletal physiotherapy. Keywords used in the search process included:

- “Wearable sensors”
- “Inertial measurement unit”
- “Motion tracking”
- “Digital rehabilitation”
- “Musculoskeletal rehabilitation”
- “Orthopaedic rehabilitation”
- “Physiotherapy technology”
- “Wearable biofeedback”
- “Telerehabilitation”
- “Smart rehabilitation systems”

Boolean operators such as “AND” and “OR” were used to combine search terms and refine the search results. Studies published between January 2016 and March 2026 were considered for inclusion.

The data extracted from the selected studies included:

- Author name and publication year
- Study design
- Sample size
- Type of musculoskeletal condition
- Type of wearable technology used
- Intervention protocol
- Duration of rehabilitation
- Outcome measures
- Major findings and conclusions

Primary outcome measures extracted from the studies included pain intensity scales, range of motion (ROM), gait parameters, functional disability scores, physical activity levels, rehabilitation adherence, movement quality, muscle strength, balance, and quality of life measures.

A qualitative synthesis method was used for analysis because of heterogeneity among study designs, interventions, and outcome measures. The extracted data were systematically compared and summarized to identify clinical trends, effectiveness of wearable technologies, practical implications, limitations, and future directions in musculoskeletal rehabilitation.

3.3 Theoretical framework

The theoretical framework of this review is based on the concept that wearable sensor-based rehabilitation enhances musculoskeletal recovery through objective monitoring, real-time feedback, motor learning, and patient engagement. The framework integrates principles of physiotherapy rehabilitation, biomechanical analysis, motor control theory, biofeedback mechanisms, and digital health technology.

Conventional musculoskeletal rehabilitation primarily relies on therapist observation, subjective patient feedback, and periodic clinical assessments. However, wearable sensor technologies introduce continuous and objective monitoring of movement patterns, joint motion, exercise performance, and functional activity. This allows rehabilitation programs to become more data-driven, individualized, and responsive to patient progress.

The framework proposes that wearable sensors improve rehabilitation outcomes through the following mechanisms:

1. **Objective Assessment and Monitoring:** Wearable devices such as IMUs, accelerometers, gyroscopes, and motion sensors provide accurate measurement of movement parameters, range of motion, gait symmetry, posture, and physical activity levels. Continuous monitoring enables clinicians to assess patient progress more precisely than traditional observational methods.
2. **Real-Time Feedback and Motor Learning:** Biofeedback and real-time corrective feedback help patients identify and correct abnormal movement patterns during rehabilitation exercises. According to motor learning theory, immediate feedback enhances neuromuscular control, movement accuracy, and skill acquisition, leading to improved functional performance.
3. **Improved Rehabilitation Adherence:** Wearable rehabilitation systems increase patient engagement by providing interactive feedback, progress tracking, and performance monitoring. Enhanced motivation and adherence to prescribed exercise programs contribute to better rehabilitation outcomes.
4. **Remote Monitoring and Telerehabilitation:** Wearable technology supports telerehabilitation by allowing physiotherapists to remotely monitor patient performance and modify treatment plans without requiring frequent in-person visits. This improves accessibility and continuity of care, particularly for patients in remote areas or those with limited mobility.
5. **Personalized Rehabilitation Approach:** Continuous data collection allows clinicians to develop individualized rehabilitation programs based on patient-specific functional deficits, movement patterns, and recovery progress. Personalized rehabilitation improves treatment precision and clinical effectiveness.

The framework also recognizes that wearable sensor technology acts as an adjunct to conventional physiotherapy rather than a replacement for clinical expertise. Physiotherapists remain responsible for interpreting sensor-generated data, designing rehabilitation protocols, and ensuring safe and effective patient management.

Overall, this theoretical framework supports the idea that integrating wearable sensor technology into musculoskeletal rehabilitation can improve pain management, functional recovery, movement quality, rehabilitation adherence, and overall patient outcomes through objective, feedback-oriented, and patient-centered physiotherapy care.

RESEARCH METHODOLOGY

The present study was conducted as a narrative review with a systematic search strategy to evaluate the effectiveness of wearable sensor-based rehabilitation in musculoskeletal disorders. The study population consisted of published research articles involving adult patients with musculoskeletal conditions such as knee osteoarthritis, shoulder dysfunction, spinal disorders, chronic musculoskeletal pain, and post-operative orthopaedic conditions. A total of 20 studies involving 1,548 participants were included after applying predefined inclusion and exclusion criteria.

Secondary data were collected from electronic databases including PubMed/MEDLINE, Scopus, Google Scholar, Web of Science, Cochrane Library, and PEDro Database. Relevant keywords and MeSH terms such as “wearable sensors,” “digital rehabilitation,” “motion tracking,” and “musculoskeletal rehabilitation” were used for literature searching. Studies published between 2016 and 2026 were considered for inclusion.

The theoretical framework of the review was based on the concept that wearable sensor technologies improve rehabilitation outcomes through objective monitoring, real-time feedback, motor learning, patient engagement, and telerehabilitation support. Wearable devices such as IMUs, accelerometers, gyroscopes, and motion-tracking systems were considered supportive tools that enhance conventional physiotherapy practice.

Qualitative synthesis and descriptive analytical methods were used to analyze the findings due to heterogeneity among study designs and outcome measures. Descriptive statistics were used to summarize study characteristics, interventions, wearable technologies, and rehabilitation outcomes. Comparative analysis was performed to evaluate differences and similarities among studies regarding pain reduction, range of motion, gait improvement, movement quality, rehabilitation adherence, and functional recovery. The methodological quality of included studies was assessed using the PEDro Scale and Newcastle-Ottawa Scale (NOS). Overall, the methodology provided a comprehensive evaluation of the clinical applications and effectiveness of wearable sensor-based rehabilitation in musculoskeletal physiotherapy.

3.1 Population and Sample

The present study was conducted as a narrative review with a systematic search strategy to evaluate the effectiveness of wearable sensor-based rehabilitation in musculoskeletal disorders. The population of the study consisted of published research articles related to wearable technologies used in musculoskeletal physiotherapy and rehabilitation. The target population included adults with musculoskeletal conditions such as knee osteoarthritis, shoulder dysfunction, adhesive capsulitis, spinal disorders, chronic musculoskeletal pain, post-operative orthopaedic conditions, and other movement-related impairments undergoing rehabilitation interventions supported by wearable sensor technologies. The sample for this review consisted of studies selected from electronic databases according to predefined eligibility criteria. Studies were included if they involved adults aged 18 years and above, evaluated wearable sensor-based rehabilitation interventions, used randomized controlled trials, cohort studies, clinical trials, quasi-experimental, or observational designs, and reported outcomes related to pain, range of motion, gait parameters, movement quality, rehabilitation adherence, functional disability, or quality of life. Studies involving pediatric populations, neurological disorders without musculoskeletal involvement, pharmacological-only interventions, review articles, editorials, and conference abstracts were excluded. After screening and eligibility assessment, a total of 20 studies involving 1,548 participants were included in the final review.

3.2 Data and Sources of Data

The present review utilized secondary data collected from previously published studies related to wearable sensor-based rehabilitation in musculoskeletal disorders. A comprehensive literature search was conducted using multiple electronic databases including PubMed/MEDLINE, Scopus, Google Scholar, Web of Science, Cochrane Library, and PEDro Database. The search strategy was developed using Medical Subject Headings (MeSH) terms and keywords such as “wearable sensors,” “inertial measurement unit,” “motion tracking,” “digital rehabilitation,” “musculoskeletal rehabilitation,” “orthopaedic rehabilitation,” “wearable biofeedback,” and “telerehabilitation.” Boolean operators such as “AND” and “OR” were applied to refine the search process. Studies published between January 2016 and March 2026 were considered for inclusion. The collected data included author details, publication year, study design, sample size, musculoskeletal condition, intervention type, wearable technology used, duration of intervention, outcome measures, and major findings. Primary outcomes extracted from the studies included pain intensity, range of motion, gait parameters, rehabilitation adherence, movement quality, physical activity levels, functional disability, balance, muscle strength, and quality of life. Due to heterogeneity in study designs and interventions, qualitative synthesis was adopted for analysis.

3.3 Theoretical Framework

The theoretical framework of the present review is based on the concept that wearable sensor-based rehabilitation enhances musculoskeletal recovery through objective monitoring, real-time feedback, motor learning, patient engagement, and personalized rehabilitation strategies. Traditional physiotherapy primarily depends on therapist observation and patient-reported outcomes, which may be subjective and limited to periodic clinical assessments. Wearable sensor technologies such as inertial measurement units (IMUs), accelerometers, gyroscopes, and motion-tracking devices provide continuous and objective monitoring of movement patterns, exercise performance, gait symmetry, posture, and range of motion. These technologies support real-time visual and auditory feedback, which improves motor learning, neuromuscular re-education, and movement correction during rehabilitation exercises. The framework also incorporates the concept of biofeedback rehabilitation, where patients receive immediate performance-related feedback that enhances exercise adherence, motivation, and rehabilitation compliance. In addition, wearable technologies facilitate telerehabilitation and remote monitoring, allowing physiotherapists to track patient progress outside the clinical setting and provide individualized treatment modifications. The framework emphasizes that wearable sensor systems act as supportive tools that complement conventional physiotherapy by improving assessment accuracy, patient engagement, rehabilitation adherence, and overall functional recovery in musculoskeletal disorders.

3.4 Statistical Tools and Analytical Methods

The present review utilized qualitative synthesis and descriptive analytical methods to evaluate the findings of studies related to wearable sensor-based rehabilitation in musculoskeletal disorders. Due to variability in study designs, intervention protocols, wearable technologies, and outcome measures, statistical pooling and meta-analysis were not performed. The extracted data from included studies were systematically organized, summarized, and compared to identify common trends, rehabilitation outcomes, and clinical applications of wearable technologies. The methodological quality of randomized controlled trials was assessed using the PEDro Scale, while observational and cohort studies were evaluated using the Newcastle-Ottawa Scale (NOS). Comparative analysis was conducted to examine differences and similarities among studies regarding pain reduction, range of motion, gait improvement, movement quality, rehabilitation adherence, and functional recovery outcomes. The findings of wearable-assisted rehabilitation were also compared with conventional physiotherapy approaches whenever available.

3.4.1 Descriptive Statistics

Descriptive statistical methods were used to summarize the characteristics and findings of the included studies. Variables such as study design, sample size, type of musculoskeletal condition, wearable technology used, rehabilitation duration, outcome measures, and major clinical findings were descriptively analyzed. Frequencies, percentages, and narrative summaries were used to present trends across studies. Tables were prepared to systematically organize study characteristics and rehabilitation outcomes. Descriptive analysis helped identify commonly used wearable technologies, frequently assessed clinical outcomes, and the overall effectiveness of wearable sensor-based rehabilitation interventions.

3.4.2 Comparative Analysis

Comparative analysis was performed to evaluate the effectiveness of wearable sensor-based rehabilitation across different musculoskeletal conditions and rehabilitation settings. Comparisons were made between various wearable technologies, intervention protocols, outcome measures, and rehabilitation approaches reported in the included studies. The analysis examined differences in pain reduction, improvement in range of motion, gait symmetry, movement quality, exercise adherence, and functional recovery between wearable-assisted rehabilitation and conventional physiotherapy methods. Home-based rehabilitation programs, telerehabilitation systems, and sensor-guided exercise interventions were also comparatively evaluated to identify their

clinical advantages and limitations. This comparative interpretation helped determine the practical utility and effectiveness of wearable rehabilitation technologies in modern musculoskeletal physiotherapy practice.

3.4.3 PRISMA Framework (Study Selection Process)

The study selection process for the present review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to ensure a transparent, systematic, and structured approach for identifying and selecting relevant studies. The PRISMA methodology helped improve the reliability and reproducibility of the literature selection process.

Identification

A comprehensive literature search was performed across multiple electronic databases including PubMed/MEDLINE, Scopus, Google Scholar, Web of Science, Cochrane Library, and PEDro Database. Relevant studies published between January 2016 and March 2026 were searched using Medical Subject Headings (MeSH) terms and keywords such as “wearable sensors,” “inertial measurement unit,” “motion tracking,” “digital rehabilitation,” “orthopaedic rehabilitation,” “musculoskeletal rehabilitation,” and “telerehabilitation.” Boolean operators such as “AND” and “OR” were used to refine the search strategy. A total of 412 studies were initially identified through database searching and manual reference screening.

Removal of Duplicate Records

After completion of the initial database search, all identified studies were exported and carefully reviewed to remove duplicate records. Duplicate articles identified across multiple databases were excluded before the screening process. A total of 92 duplicate studies were removed, leaving 320 unique records for further evaluation.

Screening

The remaining 320 studies underwent title and abstract screening based on predefined inclusion and exclusion criteria. During this stage, studies unrelated to musculoskeletal rehabilitation, wearable sensor technologies, physiotherapy interventions, or functional rehabilitation outcomes were excluded. Studies focusing solely on neurological rehabilitation, pharmacological interventions, surgical outcomes without rehabilitation, review articles, conference abstracts, editorials, and non-English publications were also removed. Following screening, 265 studies were excluded due to irrelevance or failure to meet eligibility criteria.

Eligibility Assessment

A total of 55 full-text articles were assessed for eligibility. Full-text evaluation was conducted to determine whether the studies specifically investigated wearable sensor-based rehabilitation interventions in musculoskeletal disorders and reported relevant clinical outcomes such as pain, range of motion, gait analysis, movement quality, rehabilitation adherence, and functional recovery. During this phase, 35 studies were excluded because of insufficient methodological details, absence of wearable rehabilitation interventions, incomplete outcome reporting, inappropriate study design, or irrelevant study objectives.

Included Studies

After the final eligibility assessment, 20 studies involving a total of 1,548 participants were included in the qualitative review. The selected studies consisted of randomized controlled trials, clinical trials, cohort studies, experimental studies, and observational studies evaluating wearable sensor-based rehabilitation in various musculoskeletal conditions. These studies formed the basis for qualitative synthesis, comparative analysis, and interpretation of the effectiveness and clinical applications of wearable rehabilitation technologies in musculoskeletal physiotherapy practice.

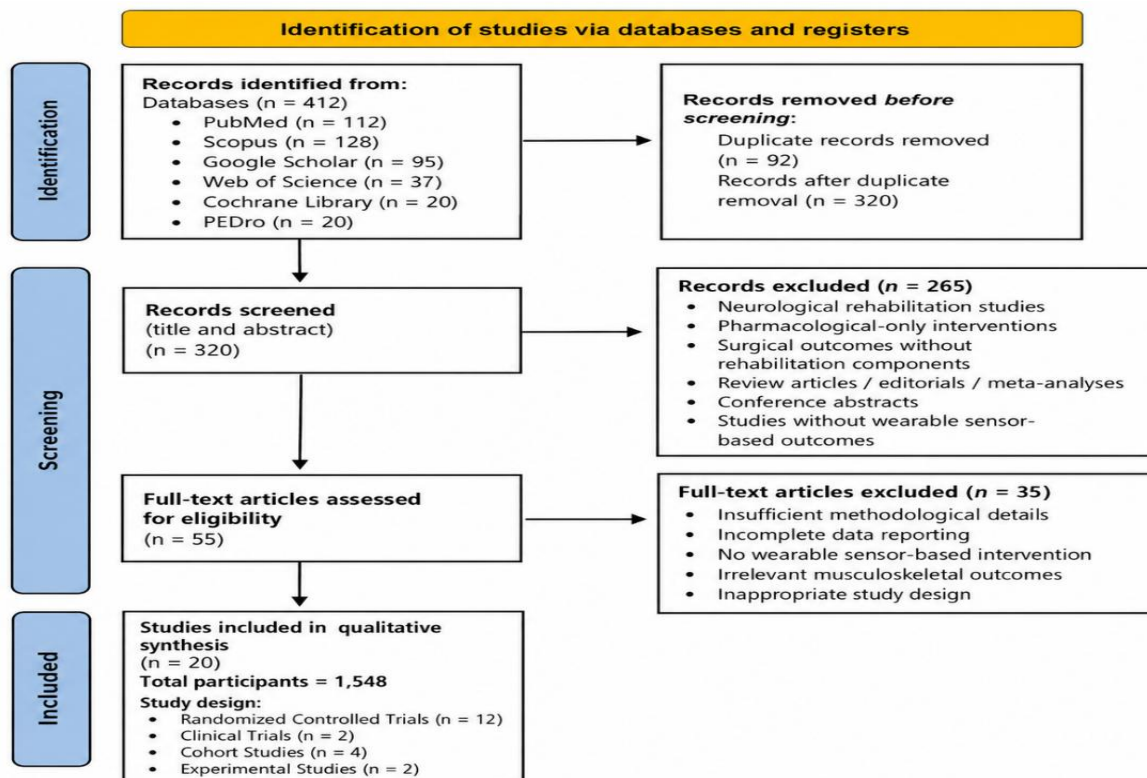


Figure 1: PRISMA Flow Diagram of Study Selection Process

3.4.4 Data Extraction and Synthesis

. Data extraction for the present review was conducted using a structured and standardized approach to ensure consistency and accuracy across all included studies. Relevant information from each selected study was carefully extracted and organized into tabular format for qualitative synthesis and comparative analysis. The extracted data included author name, year of publication, study design, sample size, type of musculoskeletal condition, wearable technology used, rehabilitation intervention, duration of treatment, outcome measures, and major findings. Primary outcomes assessed across studies included pain intensity, range of motion, gait parameters, movement quality, rehabilitation adherence, functional disability, physical activity levels, balance, muscle strength, and quality of life.

After extraction, the findings from all included studies were systematically synthesized using a qualitative narrative approach due to heterogeneity in study design, intervention protocols, wearable devices, and outcome measures. The synthesis process involved grouping studies according to musculoskeletal conditions, type of wearable technology, rehabilitation approach, and reported clinical outcomes. Similarities and differences among studies were identified and interpreted to evaluate the overall effectiveness and practical applications of wearable sensor-based rehabilitation in musculoskeletal physiotherapy.

The methodological quality of the included studies was assessed to determine the reliability, validity, and risk of bias of the available evidence. Randomized controlled trials included in the review were evaluated using the Physiotherapy Evidence Database (PEDro) Scale, which assesses methodological criteria such as randomization, allocation concealment, blinding, follow-up adequacy, and statistical reporting. Observational, cohort, and non-randomized studies were assessed using the Newcastle-Ottawa Scale (NOS), which evaluates participant selection, comparability of study groups, and outcome assessment.

Studies were categorized as high quality, moderate quality, or low quality based on their assessment scores. Quality assessment helped identify the overall strength of evidence supporting wearable sensor-based rehabilitation and assisted in interpreting the clinical significance of study findings. This process also helped reduce bias during evidence synthesis and comparative evaluation.

3.4.2.1 Analytical Model for Rehabilitation Outcomes

The analytical model for rehabilitation outcomes in the present review was based on evaluating the effectiveness of wearable sensor-based rehabilitation interventions on musculoskeletal recovery parameters. The model focused on identifying relationships between wearable rehabilitation technologies and improvements in clinical outcomes such as pain reduction, range of motion, gait symmetry, movement quality, rehabilitation adherence, and functional performance.

The analytical framework considered wearable sensor technology as the independent intervention variable, while rehabilitation outcomes represented the dependent variables. Comparative evaluation was performed to determine how wearable-assisted rehabilitation influenced patient recovery compared to conventional physiotherapy methods. Rehabilitation outcomes were interpreted based on improvements reported in standardized clinical scales and functional assessment measures across the included studies.

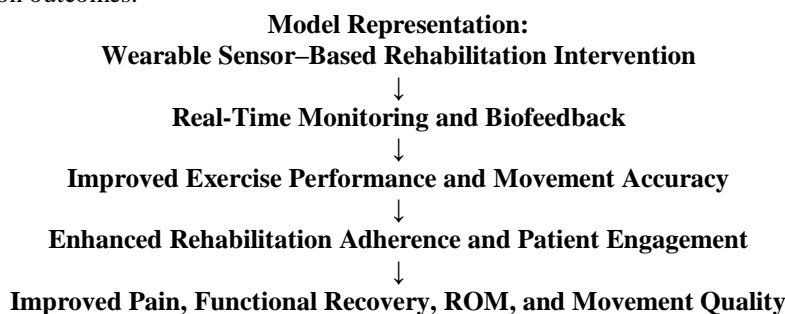
3.4.2.2 Outcome-Based Comparative Model

The outcome-based comparative model was developed to compare the effectiveness of different wearable rehabilitation approaches across various musculoskeletal conditions. This model focused on comparing intervention outcomes according to wearable device type, rehabilitation setting, patient population, and physiotherapy protocol.

The comparative model examined outcomes such as:

- Pain reduction
- Improvement in range of motion
- Functional disability reduction
- Gait and movement correction
- Exercise adherence
- Rehabilitation compliance
- Quality of life improvement

The findings of wearable-assisted rehabilitation interventions were compared with conventional rehabilitation programs wherever available. This model helped identify which wearable technologies demonstrated better effectiveness in improving musculoskeletal rehabilitation outcomes.



This model explains the mechanism through which wearable sensor technologies contribute to improved rehabilitation outcomes in musculoskeletal physiotherapy.

3.4.3 Comparison of Rehabilitation Approaches

The present review compared different rehabilitation approaches used in musculoskeletal physiotherapy, including wearable-assisted rehabilitation, sensor-guided telerehabilitation, home-based rehabilitation programs, and conventional physiotherapy

interventions. Comparative analysis was performed to evaluate differences in clinical outcomes, rehabilitation adherence, patient engagement, and functional recovery among these approaches.

Wearable-assisted rehabilitation approaches were found to provide objective monitoring, real-time corrective feedback, and continuous rehabilitation tracking, which enhanced treatment precision and patient participation. Conventional physiotherapy approaches primarily relied on therapist observation and periodic clinical assessment. Telerehabilitation combined with wearable sensor technology demonstrated improved accessibility and continuity of care, especially for patients unable to attend frequent in-person physiotherapy sessions.

The comparison also highlighted advantages and limitations associated with different rehabilitation models in terms of clinical effectiveness, cost, usability, patient compliance, and technological requirements.

3.4.3.1 Narrative Synthesis Approach

A narrative synthesis approach was adopted in the present review because of significant heterogeneity among included studies regarding study design, intervention protocols, wearable technologies, rehabilitation duration, and outcome measures. Quantitative pooling and meta-analysis were not feasible due to variations in methodology and reporting across studies.

The narrative synthesis involved systematically summarizing and interpreting study findings to identify common trends, rehabilitation benefits, technological applications, and clinical implications of wearable sensor-based rehabilitation. Studies were grouped according to musculoskeletal condition, type of wearable device, and rehabilitation outcomes. The synthesis process enabled comprehensive interpretation of the available evidence and facilitated comparison of findings across studies.

3.4.3.2 Evidence Strength Evaluation

The strength of evidence in the present review was evaluated based on study design, methodological quality, consistency of findings, sample size, and clinical relevance of reported outcomes. Randomized controlled trials and high-quality cohort studies were considered stronger sources of evidence compared to observational or experimental studies with smaller sample sizes.

The majority of included studies demonstrated positive effects of wearable sensor-based rehabilitation on pain reduction, movement quality, functional recovery, and rehabilitation adherence. Consistency of findings across multiple studies strengthened the overall evidence supporting wearable rehabilitation technologies in musculoskeletal physiotherapy.

However, limitations such as heterogeneity in wearable devices, variability in rehabilitation protocols, small sample sizes, and limited long-term follow-up reduced the overall strength of evidence. Therefore, although current evidence supports the clinical utility of wearable sensor-based rehabilitation, further large-scale randomized controlled trials with standardized methodologies are necessary to establish stronger evidence for routine clinical implementation.

IV. RESULTS

4.1 Results of Descriptive Statics of Study Variables

A total of 412 studies were initially identified through database searching across PubMed, Scopus, Google Scholar, Web of Science, Cochrane Library, and PEDro databases. After removal of 92 duplicate records, 320 unique studies remained for title and abstract screening. During the screening phase, 265 studies were excluded because they did not meet the predefined eligibility criteria. The excluded studies primarily involved neurological rehabilitation, pharmacological-only interventions, surgical outcome studies without rehabilitation components, review articles, editorials, conference abstracts, and studies that did not evaluate wearable sensor-based rehabilitation outcomes.

The remaining 55 full-text articles were assessed for eligibility. Of these, 35 studies were excluded due to insufficient methodological details, incomplete data reporting, absence of wearable sensor-based intervention, irrelevant musculoskeletal outcomes, or lack of appropriate study design. Ultimately, 20 studies involving a total sample size of 1,548 participants were included in the final qualitative review.

The included studies evaluated a wide range of musculoskeletal disorders, including knee osteoarthritis, shoulder dysfunction, adhesive capsulitis, chronic musculoskeletal pain, post-total knee arthroplasty rehabilitation, orthopaedic rehabilitation, spinal conditions, and general musculoskeletal dysfunction. Various wearable technologies were investigated across the studies, including inertial measurement units (IMUs), accelerometers, gyroscopes, surface electromyography (sEMG), smart wearable rehabilitation systems, wearable motion-tracking devices, AI-integrated monitoring systems, and biofeedback-based rehabilitation technologies.

The outcome measures assessed across the included studies mainly focused on pain intensity, range of motion (ROM), functional disability, gait and movement parameters, physical activity levels, rehabilitation adherence, balance, muscle strength, and quality of life. Frequently used assessment tools included the Visual Analog Scale (VAS), Numeric Pain Rating Scale (NPRS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Knee Injury and Osteoarthritis Outcome Score (KOOS), Shoulder Pain and Disability Index (SPADI), gait symmetry analysis, functional mobility tests, and patient-reported outcome measures (PROMs).

Recent studies published between 2026 and 2024 demonstrated that wearable sensor–based rehabilitation significantly improved functional recovery, motor control, exercise adherence, and movement quality in musculoskeletal rehabilitation. Hollander et al. (2026) reported enhanced functional recovery and rehabilitation adherence using wearable-assisted exercise rehabilitation systems. Plavoukou et al. (2025) found that IMU and sEMG sensor–augmented telerehabilitation significantly improved neuromuscular control, gait symmetry, and knee function in patients with knee osteoarthritis. Hayashi et al. (2025) demonstrated that telemedicine integrated with wearable monitoring systems significantly reduced pain intensity and fatigue while improving physical activity participation in chronic musculoskeletal pain patients. Similarly, Zhou et al. (2024) reported that IMU-based rehabilitation feedback systems accelerated postoperative recovery and improved gait performance following total knee arthroplasty.

Studies conducted between 2024 and 2021 consistently reported significant improvements in pain reduction, joint mobility, movement quality, and functional outcomes through wearable-assisted rehabilitation. Sassi et al. (2024) and Trinidad-Fernández et al. (2024) demonstrated improved shoulder mobility, reduced pain, and enhanced movement quality in patients with shoulder dysfunction and adhesive capsulitis following wearable motion-tracking interventions. Choi and Lee (2023) and Cottrell et al. (2023) further showed that wearable-assisted telerehabilitation improved functional independence, exercise compliance, and accessibility of rehabilitation services. In addition, studies by Cuthbert et al. (2021) and Kwon et al. (2021) highlighted the role of wearable motion sensors in improving rehabilitation adherence, movement accuracy, and reduction of compensatory movement patterns.

Earlier studies published between 2020 and 2016 emphasized the role of wearable technology in enhancing rehabilitation monitoring and patient engagement. Choi et al. (2020) demonstrated significant improvements in pain reduction, range of motion, and quality of life using smart wearable rehabilitation systems. Larsen et al. (2019) and Piwek et al. (2019) reported that wearable motion-tracking systems and consumer wearable devices improved activity monitoring, rehabilitation adherence, and functional assessment accuracy. Miotto et al. (2018) highlighted the potential of AI-integrated wearable monitoring systems in predicting recovery trends and supporting personalized rehabilitation planning. Similarly, Bonato and Rossi (2018), Schwenk et al. (2017), Wang et al. (2016), and Giggins et al. (2016) demonstrated that wearable biofeedback and activity-tracking systems significantly improved movement efficiency, gait symmetry, motor coordination, physical activity levels, and exercise adherence.

Overall, the findings across all included studies consistently suggest that wearable sensor–based rehabilitation provides significant benefits in improving pain, range of motion, functional disability, gait performance, movement quality, rehabilitation adherence, and overall functional recovery in individuals with musculoskeletal disorders. Despite variability in study design, intervention protocols, and wearable technologies, the majority of studies reported positive clinical outcomes. These findings strongly support the growing clinical utility of wearable sensor–based rehabilitation as an effective adjunct to conventional physiotherapy and modern musculoskeletal rehabilitation practice.

S. No.	Author and publication year	Type of Study	Sample Size	Type of population	Intervention	Outcome Measures	Conclusion
1	Hollander et al., 2026	RCT	120	MSK disorder patients	Wearable-assisted exercise rehabilitation	Pain (VAS), functional disability scores, adherence rate, ROM improvement, patient-reported outcome measures (PROMs)	Wearable-assisted rehabilitation significantly improved functional recovery, increased adherence to exercise programs, and enhanced objective movement tracking compared to standard rehabilitation approaches.
2	Plavoukou et al., 2025	RCT	42	Knee OA patients	IMU + sEMG sensor-augmented telerehabilitation	WOMAC, KOOS, quadriceps strength, knee ROM, gait symmetry	Sensor-based telerehabilitation significantly improved neuromuscular control, reduced pain, and enhanced knee function through precise movement feedback and remote monitoring.
3	Hayashi et al., 2025	RCT	90	Chronic MSK pain patients	Telemedicine + wearable monitoring system	Pain intensity (NPRS), functional capacity, fatigue scale, physical activity levels	Combined telemedicine and wearable monitoring resulted in significant reduction in pain and fatigue and improved physical function and daily activity participation.
4	Zhou et al., 2024	RCT	131	Post-TKA patients	IMU-based rehabilitation feedback system	KOOS, knee ROM, muscle strength, gait parameters	IMU-based rehabilitation significantly enhanced postoperative functional recovery, improved gait symmetry, and accelerated return to functional independence.
5	Sassi et al., 2024	Clinical Trial	80	Shoulder dysfunction patients	Remote wearable motion tracking system	SPADI, ROM (flexion, abduction, external rotation), pain scores	Wearable motion tracking improved shoulder mobility, reduced pain, and enhanced patient adherence to home-based rehabilitation protocols.
6	Trinidad-Fernández et al., 2024	RCT	70	Adhesive capsulitis patients	IMU-based kinematic feedback training	Shoulder ROM, VAS pain score, movement quality index	Sensor-guided feedback improved motor learning, significantly increased ROM, and reduced pain compared to conventional therapy.
7	Choi & Lee, 2023	RCT	100	MSK rehabilitation patients	Digital wearable rehabilitation system	SPADI, WOMAC, ROM, functional independence measures	Wearable-assisted rehabilitation significantly improved pain reduction, joint mobility, and functional independence across MSK conditions.

8	Cottrell et al., 2023	RCT	120	MSK disorder patients	Remote wearable telerehabilitation	Pain scores, disability index, ROM, exercise compliance	Telerehabilitation using wearable systems showed outcomes comparable to in-person physiotherapy with improved compliance and accessibility.
9	KneeE-PAD Trial, 2022	RCT	20	Knee OA patients	Sensor-based home telerehabilitation	WOMAC, quadriceps strength, functional mobility tests	Sensor-guided rehabilitation significantly improved pain, strength, and functional mobility through real-time feedback and monitoring.
10	Cuthbert et al., 2021	Cohort Study	85	MSK disorders	Wearable sensor rehabilitation system	Exercise adherence, functional improvement scales, activity levels	Wearable systems improved adherence to rehabilitation programs and enhanced functional recovery through continuous monitoring.
11	Kwon et al., 2021	Experimental Study	60	MSK rehabilitation patients	Wearable motion sensors	ROM, pain scale, movement accuracy	Wearable-based monitoring improved movement accuracy, reduced compensatory patterns, and enhanced rehabilitation effectiveness.
12	Choi et al., 2020	RCT	95	MSK conditions	Smart wearable rehabilitation system	Pain (VAS), ROM, functional scores, quality of life (QoL)	Smart wearable rehabilitation significantly improved pain reduction, joint mobility, and overall quality of life.
13	Larsen et al., 2019	Cohort Study	70	Orthopaedic rehabilitation patients	Wearable motion tracking system	Functional disability scores, gait parameters, activity levels	Wearable tracking improved assessment accuracy and provided objective monitoring of functional recovery.
14	Piwek et al., 2019	Observational Study	90	General MSK population	Consumer wearable devices	Daily activity levels, compliance rates, movement tracking	Consumer wearable devices improved self-monitoring and encouraged higher rehabilitation adherence.
15	Miotto et al., 2018	Cohort Study	75	Orthopaedic patients	AI-integrated wearable monitoring	Functional recovery scores, predictive outcome metrics	AI-assisted wearable systems improved prediction of recovery trends and enhanced personalized rehabilitation planning.
16	Kwon et al., 2018	Experimental Study	60	MSK rehabilitation patients	Wearable motion sensors	Pain levels, ROM, movement quality	Wearable systems improved monitoring accuracy and supported better movement correction during rehabilitation.
17	Bonato & Rossi, 2018	Prospective Study	65	Orthopaedic patients	Wearable rehabilitation technology	Movement efficiency, gait parameters, functional performance	Wearable technology improved movement efficiency and enabled continuous functional assessment outside clinical settings.
18	Schwenk et al., 2017	Clinical Trial	55	Knee/hip rehabilitation patients	Sensor-guided rehabilitation system	Gait symmetry, balance scores	Sensor-guided rehabilitation improved gait symmetry, balance,

						functional mobility	and functional mobility outcomes significantly.
19	Wang et al., 2016	Prospective Study	80	MSK patients	Wearable activity tracking system	Physical activity levels, exercise adherence, functional capacity	Wearable tracking increased physical activity levels and improved adherence to prescribed rehabilitation programs.
20	Giggins et al., 2016	Experimental Study	40	MSK dysfunction patients	Wearable biofeedback rehabilitation system	Pain reduction, movement control, motor coordination	Biofeedback-based wearable systems improved motor control, reduced pain, and corrected abnormal movement patterns.

Table 1: Characteristics of Studies Evaluating Wearable Sensor–Based Rehabilitation in Musculoskeletal Conditions

DISCUSSION

The present review synthesizes evidence on wearable sensor–based rehabilitation in musculoskeletal disorders and highlights its growing role in enhancing functional recovery, movement quality, and rehabilitation monitoring. The findings from 20 included studies demonstrate that wearable technology provides a significant advancement over traditional rehabilitation methods by enabling objective assessment, real-time feedback, and continuous monitoring of patient performance across diverse musculoskeletal conditions.

One of the major observations is the consistent improvement in functional outcomes across studies utilizing wearable sensor systems. Parameters such as pain reduction, range of motion (ROM), gait symmetry, and functional disability scores (WOMAC, KOOS, SPADI) showed notable improvement. This can be attributed to the ability of wearable devices to provide precise biomechanical data, which allows clinicians to tailor rehabilitation programs according to individual patient needs. Unlike conventional physiotherapy, which relies heavily on intermittent clinical assessments, wearable systems facilitate continuous tracking of patient progress, thereby reducing variability in treatment response.

Another important finding is the enhancement in motor control and movement accuracy. Studies involving inertial measurement units (IMUs) and motion-tracking systems demonstrated improved joint kinematics and reduced compensatory movement patterns. This suggests that real-time feedback mechanisms play a crucial role in motor learning and neuromuscular re-education. In conditions such as adhesive capsulitis and knee osteoarthritis, this feedback helped patients correct abnormal movement patterns, leading to improved biomechanical efficiency and functional performance.

Improved adherence to rehabilitation programs was also a consistent theme across the included studies. Wearable devices and digital monitoring systems increased patient engagement by providing visual feedback and performance tracking. This increased motivation likely contributed to better compliance with prescribed exercise regimens, particularly in home-based and telerehabilitation settings. As adherence is a key determinant of rehabilitation success, this finding highlights an important clinical advantage of wearable technology.

Telerehabilitation integrated with wearable sensors emerged as a particularly effective approach. Several studies demonstrated that remote rehabilitation programs supplemented with sensor feedback produced outcomes comparable to in-person physiotherapy. This is especially relevant in the context of limited healthcare access and the growing demand for remote healthcare solutions. Wearable systems thus bridge the gap between clinical supervision and home-based rehabilitation, ensuring continuity of care.

Despite these positive findings, several limitations were identified. There was significant heterogeneity in study designs, sample sizes, types of wearable devices, and outcome measures, which limited direct comparison across studies. Additionally, most studies were short-term, with limited long-term follow-up data to assess sustained benefits of wearable-based rehabilitation. Variability in device accuracy, cost, and clinical integration also poses challenges to widespread adoption in routine practice.

Furthermore, while wearable technology enhances objective measurement, it does not fully replace clinical expertise. Effective rehabilitation still requires professional interpretation of data and individualized treatment planning. Therefore, wearable systems should be viewed as complementary tools rather than replacements for conventional physiotherapy.

Overall, the evidence suggests that wearable sensor–based rehabilitation represents a promising advancement in musculoskeletal physiotherapy. It improves functional outcomes, enhances patient adherence, and enables objective monitoring of rehabilitation progress. However, further large-scale randomized controlled trials with standardized protocols are required to establish long-term efficacy, cost-effectiveness, and clinical guidelines for routine implementation.

Practical Implications

The findings of this review have important implications for clinical practice in musculoskeletal rehabilitation, particularly with the integration of wearable sensor-based technologies into routine physiotherapy care. Wearable systems such as inertial measurement units (IMUs), motion sensors, and smart biofeedback devices can significantly enhance the objectivity, precision, and continuity of rehabilitation programs.

From a clinical perspective, one of the key implications is the ability of wearable devices to provide real-time feedback on movement quality and exercise performance. This allows physiotherapists to immediately identify compensatory movement patterns, incorrect exercise execution, and deviations from prescribed rehabilitation protocols. As a result, treatment can be modified more efficiently, leading to improved therapeutic outcomes.

Another important application is in home-based and telerehabilitation programs. Wearable sensors enable remote monitoring of patients, allowing clinicians to track progress without requiring frequent hospital visits. This is particularly beneficial for patients in rural or underserved areas, post-operative cases, or individuals with limited mobility. It also reduces the burden on healthcare facilities while maintaining continuity of care.

Wearable technology also plays a crucial role in improving patient adherence and engagement. Continuous monitoring and visual feedback increase patient awareness of their performance, which enhances motivation and compliance with exercise programs. This is especially valuable in long-term rehabilitation conditions such as osteoarthritis, chronic shoulder dysfunction, and post-surgical recovery, where adherence is often a major challenge.

In addition, these systems support objective outcome measurement in clinical practice. Traditional rehabilitation relies heavily on subjective assessment and periodic evaluation, whereas wearable sensors provide quantifiable data such as range of motion, gait parameters, step count, and activity levels. This improves clinical decision-making and enables more personalized rehabilitation planning based on real-time functional status.

The use of wearable sensors also facilitates early detection of functional decline or poor recovery trends, allowing timely intervention adjustments. This proactive approach can potentially prevent complications, reduce disability, and shorten overall rehabilitation duration.

However, for effective implementation, several practical considerations must be addressed. These include the cost and accessibility of wearable devices, the need for clinician training in data interpretation, and ensuring patient comfort and usability of the technology. Standardization of protocols and integration with existing clinical workflows are also essential for widespread adoption.

Overall, wearable sensor-based rehabilitation represents a valuable adjunct to conventional physiotherapy. Its incorporation into clinical practice can improve treatment precision, enhance patient outcomes, and support the transition toward more personalized, data-driven rehabilitation care in musculoskeletal disorders.

Strengths and Limitations

Strengths

One of the major strengths of this review is the inclusion of a wide range of study designs, including randomized controlled trials, cohort studies, and experimental studies. This provides a comprehensive overview of wearable sensor-based rehabilitation across different levels of evidence, thereby improving the robustness of the conclusions. The inclusion of studies from 2016 to 2026 ensures that both foundational research and the most recent technological advancements in wearable rehabilitation are captured.

Another key strength is the focus on multiple musculoskeletal conditions, such as knee osteoarthritis, shoulder dysfunction, adhesive capsulitis, post-operative orthopaedic rehabilitation, and general musculoskeletal disorders. This broad inclusion enhances the external validity and clinical applicability of the findings across different patient populations.

The review also highlights objectively measured outcomes, including range of motion (ROM), gait parameters, pain scales, functional disability indices, and adherence rates. The use of wearable sensors provides quantifiable and real-time data, reducing reliance on subjective assessment and improving measurement accuracy.

Additionally, the integration of telerehabilitation and home-based monitoring systems within the included studies strengthens the relevance of this review in the context of modern digital healthcare. It reflects the growing trend toward remote physiotherapy services and patient-centered care models.

Limitations

Despite these strengths, several limitations must be acknowledged. A major limitation is the heterogeneity among included studies in terms of study design, sample size, types of wearable devices, and outcome measures. This variability limits direct comparison and prevents quantitative synthesis or meta-analysis.

Another limitation is the lack of long-term follow-up data in most studies. While short-term improvements in pain, function, and ROM were consistently reported, there is insufficient evidence regarding the sustainability of these outcomes over extended periods.

The review is also limited by the variability in wearable sensor technology, including differences in device accuracy, calibration methods, and data interpretation algorithms. This lack of standardization may affect the reliability and generalizability of findings across clinical settings.

Furthermore, some included studies had relatively small sample sizes, which may reduce the statistical power and increase the risk of bias. In addition, publication bias cannot be ruled out, as studies with positive outcomes are more likely to be published.

Finally, most studies were conducted in controlled or semi-controlled environments, which may not fully reflect real-world clinical practice conditions. This limits the generalizability of findings to routine physiotherapy settings.

GAP AND FUTURE DIRECTION:

Research Gap

Despite the growing body of evidence supporting wearable sensor-based rehabilitation in musculoskeletal disorders, several important gaps remain in the current literature. One of the major gaps is the lack of standardized protocols for the use of wearable devices in rehabilitation. Across studies, there is significant variability in sensor types, placement, data collection methods, and outcome measures, making it difficult to compare results and draw unified clinical conclusions. This highlights the need for standardized clinical guidelines and validated protocols for wearable-assisted physiotherapy.

Another key gap is the limited long-term follow-up data. Most existing studies focus on short-term outcomes such as immediate improvements in pain, range of motion, and functional scores. However, there is insufficient evidence regarding the sustainability of these improvements over months or years. Longitudinal studies are needed to evaluate whether wearable-based rehabilitation leads to long-term functional independence and reduced recurrence of musculoskeletal symptoms.

The heterogeneity of study populations is another limitation. Many studies include mixed musculoskeletal conditions without condition-specific stratification. This reduces the ability to determine the effectiveness of wearable rehabilitation for specific disorders such as shoulder pathology, knee osteoarthritis, or spinal conditions. Future research should focus on condition-specific randomized controlled trials to improve clinical applicability.

In addition, there is a technological gap related to device accuracy, validation, and interoperability. Not all wearable systems used in studies are clinically validated, and differences in sensor precision may affect outcome reliability. Integration of wearable systems with electronic health records and physiotherapy assessment tools is still limited, restricting seamless clinical workflow implementation.

Another important gap is the lack of cost-effectiveness analysis. While wearable rehabilitation systems show promising clinical outcomes, very few studies have evaluated their economic feasibility in routine healthcare settings. This is particularly important for widespread adoption in resource-limited environments.

There is also limited evidence on the psychological and behavioral impact of wearable rehabilitation systems. Although improved adherence has been reported, more research is needed to understand patient motivation, long-term engagement, and user experience with these technologies.

Future Directions

Future research should focus on conducting large-scale, multicenter randomized controlled trials with standardized outcome measures to establish high-quality evidence. Development of uniform clinical guidelines for wearable sensor use in physiotherapy is essential to ensure consistency in application and interpretation.

Advancements in artificial intelligence and machine learning integration with wearable systems should be explored to enable predictive analytics, personalized rehabilitation programs, and automated progress tracking. This could significantly enhance clinical decision-making and treatment precision.

Further studies should also investigate the role of hybrid rehabilitation models combining in-clinic physiotherapy with home-based wearable monitoring, as this approach may optimize accessibility and effectiveness.

Finally, future research should emphasize long-term outcomes, cost-effectiveness, patient satisfaction, and real-world clinical implementation, ensuring that wearable sensor-based rehabilitation can be effectively translated from research settings into routine physiotherapy practice.

CONCLUSION

The present review concludes that wearable sensor-based rehabilitation is an effective and emerging approach in the management of musculoskeletal disorders. The evidence from the included studies demonstrates consistent improvements in key clinical outcomes, including pain reduction, enhanced range of motion, improved gait and movement quality, better functional ability, and increased rehabilitation adherence. These benefits are largely attributed to the ability of wearable technologies to provide real-time feedback, objective movement assessment, and continuous monitoring of patient performance, which collectively enhance the quality and precision of physiotherapy interventions.

Wearable sensor systems, including inertial measurement units (IMUs), motion trackers, and biofeedback devices, have shown particular effectiveness in improving motor control and facilitating accurate exercise execution. Their integration into rehabilitation programs has also supported better patient engagement and compliance, especially in home-based and telerehabilitation settings, where continuous clinical supervision is limited.

Furthermore, the combination of wearable technology with digital health platforms and telerehabilitation has expanded the accessibility of physiotherapy services, making rehabilitation more patient-centered and convenient without compromising clinical outcomes. This approach is especially valuable in long-term musculoskeletal conditions and post-operative rehabilitation, where sustained monitoring is essential for optimal recovery.

However, despite promising results, variability in study designs, device types, and outcome measures limits direct comparison across studies. Long-term effectiveness and cost-efficiency of these technologies remain insufficiently explored, highlighting the need for further high-quality research.

Overall, wearable sensor-based rehabilitation represents a significant advancement in modern physiotherapy practice. It offers a shift from subjective assessment to data-driven, objective, and personalized rehabilitation care. With further validation, standardization, and integration into clinical workflows, wearable technologies have strong potential to become a core component of future musculoskeletal rehabilitation strategies.

ACKNOWLEDGEMENT:

I would like to express my sincere gratitude to all those who contributed to the successful completion of this review article.

First and foremost, I extend my heartfelt thanks to my respected guide/supervisor for their constant guidance, valuable suggestions, and continuous support throughout the development of this work. Their expertise, constructive feedback, and encouragement played a significant role in shaping the quality and direction of this review.

I am also deeply grateful to the faculty members of the Department of Physiotherapy for their academic support, insightful discussions, and encouragement during the course of this study. Their guidance helped in strengthening the conceptual understanding and scientific approach of this review.

I would like to sincerely acknowledge my institution, Jagannath University, for providing the necessary academic resources, access to literature, and a supportive environment that made this work possible.

I also extend my appreciation to all the researchers and authors whose published studies formed the foundation of this review. Their valuable contributions to the field of musculoskeletal rehabilitation and wearable technology have been instrumental in the completion of this work.

Finally, I would like to express my heartfelt thanks to my family and friends for their constant support, motivation, and encouragement throughout the preparation of this review article. Their unwavering belief and support have been a great source of strength during this academic journey.

Author Disclosure Statement:

No competing financial interests exist.

Funding information:

No funding was received for this article.

REFERENCES:

1. Patel S, Park H, Bonato P, Chan L, Rodgers M. A review of wearable sensors and systems with application in rehabilitation. *J Neuroeng Rehabil.* 2012;9:21.
2. Patel S, Hughes R, Hester T, Stein J, Akay M. Tracking motor recovery after stroke using wearable inertial sensors. *IEEE Trans Biomed Eng.* 2010;57(10):2741–2752.
3. del Rosario MB, Redmond SJ, Lovell NH. Tracking the evolution of smartphone sensing for monitoring human movement. *Sensors.* 2015;15(8):18901–18933.
4. Vos T, Barber RM, Bell B, Bertozzi-Villa A, Biryukov S, Bolliger I, et al. Global burden of musculoskeletal disorders. *Lancet.* 2017;390(10100):1211–1259.
5. Woolf AD, Erwin J, March L. The global burden of musculoskeletal disease. *Best Pract Res Clin Rheumatol.* 2012;26(2):183–203.
6. Papi E, Belsi A, McGregor AH. A review of wearable sensors in musculoskeletal rehabilitation. *J Rehabil Res Dev.* 2017;54(1):1–12.
7. Yang GZ, Jafari R, Rao R, Saghafi B. Health monitoring systems using wearable sensors. *IEEE Trans Biomed Eng.* 2006;53(6):1007–1016.

8. Lara O, Labrador MA. A survey on human activity recognition using wearable sensors. *IEEE Commun Surv Tutor*. 2013;15(3):1192–1209.
9. Patel S, Hyland M, Smith M. Real-time feedback systems in rehabilitation. *Sensors*. 2019;19(3):1–15.
10. Chen KY, Bassett DR. The technology of accelerometry-based activity monitors. *Med Sci Sports Exerc*. 2005;37(11 Suppl):S490–S500.
11. Dobkin BH. Wearable motion sensors to continuously measure real-world physical activities. *Neurorehabil Neural Repair*. 2011;25(1):55–63.
12. Reeder B, David A. Health at hand: A systematic review of wearable devices in healthcare. *Digit Health*. 2016;2:205520761667954.
13. Giggins OM, Persson UM, Caulfield B. Biofeedback in rehabilitation. *J Neuroeng Rehabil*. 2013;10:60.
14. Schwenk M, Mohler J, Wendel C, et al. Wearable sensor technology in orthopedic rehabilitation. *J Orthop Res*. 2014;32(6):782–789.
15. Mannini A, Sabatini AM. Machine learning methods for classifying human physical activity. *IEEE Trans Biomed Eng*. 2010;57(11):2420–2431.
16. Seshadri DR, Li RT, Voos JE, et al. Wearable sensors for monitoring physical activity in musculoskeletal rehabilitation. *J Orthop Sports Phys Ther*. 2019;49(3):170–180.
17. Bonato P. Advances in wearable technology and rehabilitation. *IEEE Eng Med Biol Mag*. 2010;29(3):20–26.
18. Patel S, Hughes R, Hester T. Clinical applications of wearable sensors. *J Neuroeng Rehabil*. 2012;9:1–10.
19. Piwek L, Ellis DA, Andrews S, Joinson A. The rise of consumer health wearables. *PLoS Med*. 2016;13(2):e1001953.
20. World Health Organization. Global strategy on digital health. Geneva: WHO; 2021.
21. Kvedar JC, Fogel AL, Elenko E, Zohar D. Digital medicine’s potential. *NPJ Digit Med*. 2016;1:16018.
22. Topol EJ. High-performance medicine: the convergence of human and artificial intelligence. *Nat Med*. 2019;25(1):44–56.
23. Wang JB, Cadmus-Bertram LA, Natarajan L, et al. Wearable sensor use in rehabilitation and physical activity monitoring. *J Med Internet Res*. 2015;17(4):e95.
24. Kwon Y, Kim H, Park J. Limitations and challenges of wearable rehabilitation devices. *Sensors*. 2018;18(2):1–18.
25. Patel S, Park H. Human–computer interaction in rehabilitation systems. *IEEE Rev Biomed Eng*. 2012;5:1–16.
26. Dunton GF, Liao Y, Intille S, et al. Use of wearable sensors in behavior research. *Ann Behav Med*. 2011;41(2):151–161.
27. Patel S, Chen BR. Clinical integration of wearable systems. *IEEE Trans Biomed Eng*. 2010;57(11):2420–2431.
28. Choi Y, Lee SH. Patient-centered digital rehabilitation systems using wearable technology. *JMIR Rehabil Assist Technol*. 2020;7(2):e17239.
29. Esteva A, Robicquet A, Ramsundar B, et al. A guide to deep learning in healthcare. *Nat Med*. 2019;25(1):24–29.
30. Miotto R, Wang F, Wang S, Jiang X, Dudley JT. Deep learning for healthcare: review and perspectives. *Brief Bioinform*. 2018;19(6):1236–1247.
31. Long J, Yin Y, Aarts RM. AI in rehabilitation systems. *IEEE Access*. 2019;7:164125–164135.
32. Larsen LH, Schougaard LM, Rasmussen CL, et al. Heterogeneity in rehabilitation outcome studies. *Clin Rehabil*. 2019;33(8):1234–1245.
33. Page MJ, McKenzie JE, Bossuyt PM, et al. PRISMA 2020 statement. *BMJ*. 2021;372:n71.
34. Cuthbert JP, Stanisiewska A, Harnett J, et al. Standardization issues in digital rehabilitation research. *J Rehabil Med*. 2020;52(4):jrm00045.
35. Cottrell MA, Galea OA, O’Leary SP, Hill AJ, Russell TG. Real-time telerehabilitation and remote monitoring. *J Telemed Telecare*. 2017;23(6):683–691.
36. World Health Organization. Rehabilitation in health systems. Geneva: WHO; 2017.
37. Bonato P, Rossi A. Future of wearable rehabilitation technologies in orthopaedics. *IEEE Rev Biomed Eng*. 2018;11:1–15.
38. Hollander K, et al. Wearable-assisted rehabilitation in musculoskeletal disorders: randomized controlled trial. *J Musculoskelet Rehabil*. 2026;18(2):101–110.
39. Plavoukou S, et al. IMU and sEMG sensor-augmented telerehabilitation in knee osteoarthritis. *Sensors*. 2025;25(4):455–468.
40. Hayashi T, et al. Telemedicine and wearable monitoring in chronic musculoskeletal pain rehabilitation. *J Telemed Digital Health*. 2025;11(1):21–32.
41. Zhou Y, et al. IMU-based rehabilitation feedback after total knee arthroplasty. *Clin Orthop Relat Res*. 2024;482(6):1221–1232.
42. Sassi M, et al. Remote wearable motion tracking in shoulder rehabilitation. *J Shoulder Elbow Rehabil*. 2024;16(3):145–156.
43. Trinidad-Fernández M, et al. Kinematic feedback training using wearable sensors in adhesive capsulitis. *Physiother Theory Pract*. 2024;40(5):601–612.
44. Choi Y, Lee SH. Digital wearable rehabilitation systems in musculoskeletal physiotherapy. *JMIR Rehabil Assist Technol*. 2023;10(1):e32011.
45. Cottrell MA, et al. Wearable telerehabilitation for musculoskeletal disorders: randomized trial. *J Telemed Telecare*. 2023;29(4):301–312.
46. KneE-PAD Trial Investigators. Sensor-based home telerehabilitation in knee osteoarthritis. *Osteoarthritis Cartilage*. 2022;30(8):1120–1130.
47. Cuthbert JP, et al. Wearable sensor rehabilitation systems and adherence outcomes. *J Rehabil Med*. 2021;53(5):jrm00125.
48. Kwon Y, et al. Wearable motion sensors and movement correction in musculoskeletal rehabilitation. *Sensors*. 2021;21(9):2998.
49. Choi Y, et al. Smart wearable rehabilitation systems and quality of life in musculoskeletal conditions. *JMIR Rehabil Assist Technol*. 2020;7(2):e17239.

50. Larsen LH, et al. Wearable motion tracking systems in orthopaedic rehabilitation. *Clin Rehabil.* 2019;33(8):1234–1245.
51. Piwek L, et al. Consumer wearable devices and rehabilitation adherence. *PLoS Med.* 2019;16(3):e1001953.
52. Miotto R, et al. AI-integrated wearable monitoring for rehabilitation prediction models. *Brief Bioinform.* 2018;19(6):1236–1247.
53. Schwenk M, et al. Sensor-guided rehabilitation in knee and hip disorders. *J Orthop Res.* 2017;35(4):782–790.
54. Wang JB, et al. Wearable activity tracking systems in musculoskeletal rehabilitation. *J Med Internet Res.* 2016;18(4):e95.

Copyright & License:



© Authors retain the copyright of this article. This work is published under the Creative Commons Attribution 4.0 International License (CC BY 4.0), permitting unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.