Soeharso Orthopaedic Journal

Type Review Article
Published 02 November 2026
ISSN 3124-3495

Bio-Orthotics and Real-Time Monitoring in Conservative Musculoskeletal Pain Management: An Integrative Review

OPEN ACCESS

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Received 03 Mei 2026
Accepted 30 October 2026
Published 02 November 2026

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CITATION
Nugroho, A. P., Fathurrohman, M. ., & Suganda, T. (2026). Bio-Orthotics and Real-Time Monitoring in Conservative Musculoskeletal Pain Management: An Integrative Review. Soeharso Orthopaedic Journal, 1(2). 93-102
https://doi.org/10.65745/soj.v1.i2.21

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ABSTRACT

Conservative orthopedic care increasingly incorporates personalized bio-orthotics, including 3D-printed insoles, and real-time monitoring technologies using wearable sensors and artificial intelligence. However, these approaches have largely been investigated separately, and evidence regarding their combined benefits remains limited. This integrative review aimed to synthesize current evidence on bio-orthotics and real-time monitoring and examine their potential integration in musculoskeletal pain management. A structured literature search was conducted across PubMed, ScienceDirect, Google Scholar, and the Cochrane Library for studies published between January 2020 and February 2025, following PRISMA 2020 reporting guidelines. Of 671 records identified, 19 studies met the inclusion criteria. Methodological quality was assessed using RoB 2, the Newcastle–Ottawa Scale, and CASP checklists, as appropriate. Given the heterogeneity of study designs and outcomes, findings were synthesized narratively. Individual studies reported pain reductions of up to 40% and improvements in gait stability of 25–35% following bio-orthotic interventions, while real-time monitoring was associated with adherence improvements of approximately 40–60%. These findings represent individual study estimates rather than pooled effects. Evidence regarding combined interventions suggested potential improvements in rehabilitation outcomes and functional recovery, although direct comparative evidence remained limited. Overall, integrating personalized bio-orthotics with real-time monitoring may offer a promising approach to adaptive, patient-centered conservative orthopedic care. Further well-designed comparative studies are needed to establish clinical effectiveness, cost-effectiveness, and long-term outcomes, while clarifying the role of nursing professionals in patient education, monitoring, and interdisciplinary care coordination.

KEYWORDS

Conservative orthopedics; bio-orthotics; real-time monitoring; wearable sensors; musculoskeletal pain; integrative review

INTRODUCTION

Musculoskeletal pain remains one of the most prevalent and disabling health conditions worldwide, affecting individuals across all age groups and contributing substantially to outpatient consultations and rehabilitation caseloads in orthopedic settings (Budhiparama, 2025; Santos et al., 2025). This spectrum of disorders encompasses pathologies of muscles, tendons, ligaments, joints, and supporting structures, leading to functional impairment, reduced quality of life, and substantial economic burden through healthcare costs and productivity losses (Santos et al., 2025; Tueni et al., 2025). Conservative orthopedic management has emerged as the cornerstone initial approach for musculoskeletal pain, prioritizing non-invasive interventions that restore biomechanical function, alleviate pain, and improve functional capacity without surgical intervention (Chen et al., 2024). The evolution of conservative orthopedics has been marked by continuous integration of technological advancements aimed at enhancing the precision and personalization of care.

Bio-orthotics, particularly personalized devices such as 3D-printed orthopedic insoles and biocompatible braces, have demonstrated efficacy in correcting biomechanical abnormalities, optimizing pressure distribution, and reducing loads on affected tissues (Ho et al., 2022; Holubova & Mendricky, 2022; Kim & Kim, 2025). Concurrently, advances in digital health technologies have enabled real-time monitoring through wearable sensors and artificial intelligence algorithms, facilitating dynamic assessment of patient status during daily activities (Budhiparama et al., 2023; Viswanathan et al., 2023). Individual reviews and meta-analyses have described the benefits of bio-orthotics for conditions such as plantar fasciitis, flat foot, and knee osteoarthritis (Chen et al., 2024; Ho et al., 2022; Holubova & Mendricky, 2022), and the effectiveness of real-time monitoring and telehealth interventions in musculoskeletal rehabilitation has been reported in multiple studies (Alrowayeh et al., 2024; Jandova et al., 2024; Luo et al., 2023). However, existing literature has predominantly examined these two technologies in isolation, with limited synthesis of their complementary potential.

A number of previous reviews have focused on bio-orthotics or on real-time monitoring separately, but few have examined how mechanical support through personalized bio-orthotics might be complemented by continuous data acquisition through real-time monitoring systems. This gap is notable given the concurrent advancement of both technologies and their apparent compatibility in creating adaptive, patient-centered care pathways. Therefore, this review sought to bridge this gap by synthesizing evidence on the integrated use of bio-orthotics and real-time monitoring in conservative orthopedic management. The objectives of this review were to: (1) synthesize recent evidence (2020-2025) on the efficacy of bio-orthotics in improving biomechanical parameters and reducing pain; (2) evaluate the role of real-time monitoring technology in optimizing conservative orthopedic therapy processes and outcomes; and (3) explore the potential synergistic benefits, challenges, and future directions of integrating bio-orthotics with real-time monitoring systems. Given the heterogeneity of the study designs synthesized narratively rather than statistically pooled, this work is presented as an integrative review rather than a systematic review or umbrella review.

METHOD

This review is best characterized as an integrative review, since it synthesizes evidence from studies with substantially heterogeneous designs including systematic reviews, meta-analyses, experimental studies, biomechanical analyses, cross-sectional surveys, and narrative or perspective reviews using narrative synthesis rather than statistical pooling. The search and screening process was informed by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2020 reporting guidelines to enhance the transparency and reproducibility of study identification and selection, without claiming the more restrictive methodological standards of a formal systematic review or

umbrella review. The review focused on publications from January 2020 to February 2025, capturing the period of significant advancement in personalized orthotic devices and digital health monitoring.

A comprehensive literature search was performed across four electronic databases: PubMed, ScienceDirect, Google Scholar, and Cochrane Library, using a combination of keywords and Medical Subject Headings (MeSH) terms related to bio-orthotics, real-time monitoring, and musculoskeletal pain, combined with Boolean operators (AND, OR). Inclusion criteria encompassed original research articles, systematic reviews, and meta-analyses in English investigating bio-orthotics and/or real-time monitoring technology for musculoskeletal pain in conservative (non-surgical) settings, published between January 2020 and February 2025. Studies were excluded if they addressed only surgical interventions or pharmacotherapy without technology integration, were single case studies, editorials, or opinion pieces without empirical data, were non-peer-reviewed, or did not report outcomes relevant to pain or biomechanical parameters.

A total of 671 records were identified from the databases. The first reduction removed 183 duplicate articles. The second reduction, a title and abstract screening of 488 articles, excluded 423 for relevance. The final reduction assessed full-text eligibility for 65 articles, excluding 46, resulting in 19 articles included in the review. Because of the methodological heterogeneity among the included studies, a narrative synthesis approach was adopted rather than a meta-analysis. Methodological quality was assessed using tools appropriate to each study design: the Cochrane Risk of Bias tool (RoB 2.0) for randomized controlled trials, the Newcastle-Ottawa Scale for observational studies, and the Critical Appraisal Skills Programme (CASP) checklist for systematic reviews. Assessment was performed independently by two reviewers (inter-rater agreement: Cohen's $\kappa = 0.89$), with disagreements resolved through discussion and, when necessary, consultation with a third reviewer. Data extraction used a standardized form capturing study characteristics, participant demographics, intervention details, outcome measures, and main findings, and findings were organized thematically into: (1) efficacy of bio-orthotics; (2) benefits of real-time monitoring technology; and (3) potential synergistic benefits, challenges, and future directions of integration.

RESULTS

Table 1 summarizes the key characteristics of the 19 studies included in this review, including study design, population, intervention, and principal findings. Sample sizes across the included studies ranged from 30 to 520 participants (median = 128). Eight studies (42%) focused primarily on bio-orthotics, six studies (32%) on real-time monitoring technologies, and five studies (26%) explicitly examined integrated approaches. Geographically, studies were conducted across North America (n=7), Europe (n=6), Asia (n=5), and Oceania (n=1).

Table 1. Synthesis of studies included in the review on bio-orthotics and real-time monitoring

No.	Author(s) & Year	Study Design	Population	Intervention	Main Findings
1	Chen et al., 2024	Systematic Review	Adults with flat foot	Customized orthopedic insoles	Reduced ankle eversion angle and plantar pressure; improved stability and function
2	Santos et al., 2025	Meta-Analysis	Workers with musculoskeletal pain	Ergonomic interventions and bio-orthotics	Significant pain reduction in lower back and other extremities

No.	Author(s) & Year	Study Design	Population	Intervention	Main Findings
3	Ho et al., 2022	Biomechanical Study	Healthy subjects and patients	3D-printed customized insoles	Biomechanical improvements and better plantar pressure distribution
4	Lin et al., 2023	Systematic Review	General population	Custom foot orthoses	Positive effects on biomechanics and pain reduction
5	Budhiparama, 2025	Perspective Review	Orthopedic patients	Real-time wearable sensor monitoring	Monitoring optimizes conservative therapy with continuous data
6	Viswanathan et al., 2023	Experimental	Postoperative orthopedic patients	SMART implants and sensor-based monitoring	Enhanced monitoring accuracy and clinical outcomes
7	Jandova et al., 2024	Systematic Review	Rehabilitation patients	Real-time biomechanical monitoring integration	Increased therapy effectiveness and patient compliance
8	Hohenschurz-Schmidt et al., 2020	Pragmatic Review	Musculoskeletal pain patients	Video and phone consultations	Effective pain reduction with remote consultations
9	Alrowayeh et al., 2024	Meta-Analysis	Telehealth physiotherapy patients	Telerehabilitation	Effectiveness comparable to in-person therapy with cost benefits
10	Zhang & Ye, 2025	Editorial/Review	General orthopedic field	New digital orthopedic technologies	Digitization increases therapy efficiency and personalization
11	Chen et al., 2025	Original Research	Musculoskeletal patients	Combination of orthotics and real-time monitoring	Improved therapy outcomes with integrated approach
12	Liang et al., 2024	Comprehensive Review	Rehabilitation patients	Wearable device with real-time feedback	Behavioral modifications improve compliance and outcomes
13	Scott W et al., 2025	Cross-sectional Survey	Orthopedic health professionals	Training on digital monitoring usage	Need for improved readiness among healthcare professionals
14	Nutz et al., 2024	Narrative Review	Wearable orthotics users	Cost and accessibility evaluation	Cost remains a major barrier to device adoption

No.	Author(s) & Year	Study Design	Population	Intervention	Main Findings
15	Ataabadi et al., 2024	Scoping Review	Orthopedic technology field	Data integration and device security	Need for interoperability standards and data security
16	Hsu et al., 2022	Experimental Study	Orthopedic patients	3D-printed insoles with biomechanical analysis	Improved biomechanical parameters in flatfoot conditions
17	Ra et al., 2025	Systematic Review	Pain patients	Remote therapeutic monitoring	Remote monitoring effective in pain management
18	Dami et al., 2024	Systematic Review	Bio-orthotic users	Smart orthotic interventions	Positive long-term effects on function improvement and pain reduction
19	Goulian et al., 2025	Comprehensive Review	Orthopedic patients	Smart personalized bio-orthotics	Great potential for adaptive and intelligent device development

(Source: Synthesized by the authors from the 19 studies included in this review)

Bio-orthotics are biocompatible devices used to support or correct impaired biomechanics without surgery. The use of personalized orthopedic insoles is widely applied in musculoskeletal pain management, particularly for lower-extremity conditions such as plantar fasciitis, flat feet, and knee osteoarthritis. 3D printing technology has enabled highly personalized devices tailored to the patient's anatomical needs (Holubova & Mendricky, 2022; Hsu et al., 2022; Kim & Kim, 2025). Clinical trials and biomechanical studies included in this review report reductions in ankle eversion angle, reductions in maximum pressure on the metatarsal area, and increased medial stability of the foot, which study authors associate with reduced pain intensity and improved motor function (Chen et al., 2024; Ho et al., 2022; Hsu et al., 2022). One meta-analysis included in this review reported that bio-orthotic use was associated with a significant reduction in pain among subjects with musculoskeletal disorders affecting the lower extremities (Santos et al., 2025).

Real-time monitoring in conservative orthopedics involves wearable sensor technology and digital systems that continuously monitor a patient's biomechanical and biometric status during routine activities. Devices such as accelerometers, gyroscopes, pressure sensors, and bioelectrical sensors, combined with machine learning algorithms, were reported to enable dynamic data analysis and to provide feedback to patients and healthcare professionals (Budhiparama et al., 2023; Luo et al., 2023; Viswanathan et al., 2023). Several studies indicated that this approach allows for adaptive therapy adjustments based on the patient's actual condition, and that real-time monitoring can improve rehabilitation effectiveness by enabling therapy to be more responsive to patient progress (Jandova et al., 2024; Liang et al., 2024; Luo et al., 2023). Telehealth-based monitoring was also reported to expand access to conservative orthopedic services for patients in remote areas or with mobility limitations, with video consultations and remote monitoring achieving outcomes comparable to face-to-face consultations (Alrowayeh et al., 2024; Hohenschurz-Schmidt et al., 2020).

A smaller number of studies examined the combination of bio-orthotics with real-time monitoring technology directly. Patients using personalized orthopedic insoles equipped with real-time monitoring systems were reported to show improved biomechanical outcomes and therapeutic responses

relative to conventional interventions (Goulian et al., 2025; Liang et al., 2024; Luo et al., 2023), and monitoring data was reported to support the medical team in evaluating progress and educating patients on posture correction and activity modification (Jandova et al., 2024; Liang et al., 2024). This evidence remains limited in scope compared with the evidence available for either technology in isolation.

DISCUSSION

The findings of this review indicate that bio-orthotics, particularly insoles designed with digital technologies such as 3D printing, are associated with biomechanical and functional improvements across the studies synthesized, including reduced abnormal plantar pressure, improved joint kinematics, and a more physiological gait pattern (Chen et al., 2024; Ho et al., 2022; Hsu et al., 2022). This is potentially important because appropriate biomechanical improvements may reduce excessive pressure on soft tissues that contribute to musculoskeletal pain, particularly in conditions such as plantar fasciitis and knee osteoarthritis. Several included studies also note that the effectiveness of bio-orthotics depends heavily on personalized design and accurate biomechanical evaluation (Dami et al., 2024; Moisan et al., 2022), and that prefabricated insoles without individual adjustment tend to produce suboptimal outcomes.

Real-time monitoring may allow therapy to be adapted according to the patient's actual response and evolving condition, potentially resulting in more personalized and responsive care (Budhiparama, 2025; Luo et al., 2023; Viswanathan et al., 2023). Several studies suggest that continuous monitoring may improve patient adherence to rehabilitation programs through remote monitoring and guidance, aligning with the broader digital-health transformation of healthcare services, particularly for patients with limited mobility or those living in remote areas (Alrowayeh et al., 2024; Liang et al., 2024). The integration of wearable sensors and machine-learning algorithms was reported to support the collection of movement, muscle, and nerve data during rehabilitation, which several authors suggest could help clinicians evaluate patient recovery (Liang et al., 2024; Luo et al., 2023).

The integration of bio-orthotics and real-time monitoring may call for an expanded nursing role in conservative orthopedic management. Nurses can serve as intermediaries between technology and patients, with potential functions including patient education on device usage and data interpretation, monitoring and triage of real-time biomechanical data, coordination between orthotists, physiotherapists, and physicians, and psychosocial support during technology-assisted rehabilitation. As an illustration, consider a patient with plantar fasciitis using a 3D-printed insole equipped with pressure sensors: an orthopedic nurse monitoring real-time gait data through a dashboard could identify abnormal pressure patterns and proactively contact the patient for education or coordinate insole adjustment with the orthotist, rather than waiting for the next scheduled visit. This illustrates how such technology could support a shift in nursing practice toward more proactive, data-informed care, and points to a need for digital-health competencies within orthopedic nursing education and practice (Scott et al., 2025).

Several challenges persist in the wider adoption of these technologies. Variation in the type and quality of sensor devices leads to differences in data accuracy, indicating a need for more uniform calibration standards (Ataabadi et al., 2024; Nutz et al., 2023). Limited access to digital infrastructure, particularly in less developed regions, poses a significant obstacle, as do data-security and privacy concerns given the sensitivity of health data collected through mobile applications (Ataabadi et al., 2024). Training of medical personnel and patients is a critical factor for successful implementation (Scott et al., 2025), and cost remains a major barrier to device adoption in resource-limited settings (Nutz et al., 2024), although some evidence suggests potential long-term cost savings through reduced healthcare utilization (Alrowayeh et al., 2024; Gibbs & MacIntyre, 2023).

The synthesized evidence offers preliminary, cautious support for the potential value of integrating bio-orthotics with real-time monitoring; given the narrative, non-meta-analytic nature of this synthesis, these observations should not be read as established overall effects. Individual studies reported

pain intensity reductions of up to approximately 40% and gait stability improvements of 25–35% in flat foot conditions with bio-orthotic use, and adherence improvements in the range of 40–60% with real-time monitoring; these figures reflect findings from individual reports rather than pooled estimates, and the included studies did not consistently document a standardized calculation method or a direct head-to-head comparison against conventional interventions within the same sample. Combined interventions were associated with accelerated rehabilitation and potential long-term cost reduction in several studies, offering preliminary support for a possible synergy between the two technologies, though robust, adequately powered comparative trials are needed before these effects can be considered established.

Several limitations warrant acknowledgment. This integrative review synthesizes diverse study designs with varying methodological rigor, which limits direct comparability and precludes quantitative (meta-analytic) synthesis. The rapid pace of technological advancement means that specific devices and algorithms discussed may evolve quickly. The focus on English-language publications may have excluded relevant research published in other languages, and publication bias may favor positive findings, potentially inflating apparent effectiveness. Finally, robust large-scale comparative trials directly testing integrated versus isolated approaches remain limited, necessitating cautious interpretation of any synergy-related claims, including the percentage figures reported above.

CONCLUSION

This integrative review suggests that the integration of bio-orthotics and real-time monitoring technology may represent an emerging direction in the conservative orthopedic management of musculoskeletal pain, potentially moving practice from static, reactive interventions toward more dynamic, adaptive, and precision-based care. Contemporary bio-orthotics, particularly those produced using 3D printing and personalized biomechanical assessment, showed promising results across the reviewed studies in correcting biomechanical abnormalities and reducing pain relative to traditional approaches, while real-time monitoring via wearable sensors was reported to support continuous assessment, enhance adherence, and facilitate timely therapeutic adjustments. Preliminary evidence suggests possible synergistic benefits when these modalities are combined, though these observations require confirmation through larger, controlled comparative research; for nursing practice and education, the findings point to a need for digital-health competencies and interdisciplinary coordination skills as conservative orthopedic care becomes more technology-integrated.

This review is limited by its reliance on narrative rather than statistical synthesis, the heterogeneity of included study designs, and the scarcity of robust trials directly comparing integrated versus isolated use of these technologies; the numerical findings reported here should therefore be treated as illustrative of individual studies rather than as pooled or confirmed effects. Future research should prioritize adequately powered, standardized comparative trials, long-term effectiveness and cost-effectiveness analyses, and development of interoperability and calibration standards for wearable and monitoring devices, so that the preliminary synergy suggested here can be tested more rigorously before being adopted into routine clinical protocols.

CONFLICT OF INTEREST

The author(s) declare no conflict of interest.

ACKNOWLEDGMENTS

The authors thank the nursing staff at RSUP Dr. Kariadi, Semarang, for their valuable clinical insights into the implementation challenges and nursing-care aspects of bio-orthotics and real-time

monitoring technology in conservative orthopedic management, and acknowledge RSUP Dr. Kariadi and Universitas Sultan Ageng Tirtayasa for providing access to research resources and databases.

PATIENT CONSENT STATEMENT

Not applicable. This is a literature-based integrative review and did not involve the enrolment of patients or the collection of primary clinical data.

DATA AVAILABILITY STATEMENT

All data supporting this review are derived from the publicly available published literature cited in the reference list.

GENERATIVE AI STATEMENT

The author(s) declare that no Generative AI was used in the creation of this manuscript

LIST OF ABBREVIATIONS

AI : Artificial Intelligence
CASP : Critical Appraisal Skills Programme
MeSH : Medical Subject Headings
PRISMA : Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RoB 2.0 : Cochrane Risk of Bias tool, version 2.0

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