© JUL 2026 | IRE Journals | Volume 10 Issue 1 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV10I1-1720117

Wearable Sensor-Based Remote Monitoring for Sports Injury Prevention and Rehabilitation Outcomes in Saudi Arabia

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Abstract- ***Background: Saudi Arabia is expanding organized sport, community fitness and specialist rehabilitation as part of Vision 2030, yet sports injury prevention still depends heavily on episodic screening, subjective symptom reporting and facility based follow up. Wearable sensors can transform this model by capturing movement, load, fatigue and recovery signals during ordinary training and home rehabilitation. Objective: This review synthesizes recent evidence on wearable sensor based remote monitoring for sports injury prevention and rehabilitation outcomes, and develops a Saudi oriented implementation framework. Methods: A structured review methodology was designed around Scopus, Web of Science, PubMed, IEEE Xplore and Google Scholar searches covering 2020 to 2025. Eligible sources addressed wearable inertial sensors, global positioning systems, surface electromyography, smart textiles, biofeedback, artificial intelligence, telerehabilitation, musculoskeletal injury risk or return to sport. Results: Evidence indicates that wearable systems are most valuable when they combine validated biomechanics, workload interpretation, individualized thresholds, clinician dashboards and privacy aware data governance. The strongest applications concern lower limb load monitoring, ankle and knee injury risk, rehabilitation adherence, asymmetry detection and return to play decision support. Conclusion: Wearable remote monitoring should be treated as a clinical service model rather than a device purchase. For Saudi Arabia, scalable adoption requires Arabic user experience, interoperable digital health infrastructure, sports federation participation, therapist training and ethical safeguards aligned with national health transformation goals.***

Keywords - Wearable Sensors, Remote Monitoring, Sports Injury Prevention, Rehabilitation Outcomes, Saudi Arabia, Vision 2030, Inertial Measurement Units, Telerehabilitation, Return to Play, Sports Medicine.

I. INTRODUCTION

Sports participation is increasing rapidly in Saudi Arabia as government policy, private sport investment and community health programs encourage more people to become physically active. This development is positive for population health, but it also increases demand for modern injury prevention and rehabilitation services that can operate beyond elite clubs and hospital-based sports medicine units. Lower limb injuries, overuse syndromes, recurrent ankle sprains, anterior cruciate ligament injuries, tendinopathy and return to play uncertainty remain common problems in athletic populations. Traditional assessment often relies on clinic appointments, coach observation and athlete self-reporting, which means subtle deterioration in workload tolerance, landing mechanics or rehabilitation adherence may remain invisible until pain, instability or re injury occurs (Rommers et al., 2020; Preatoni et al., 2022).

Wearable sensors provide a practical route to close this observation gap. Inertial measurement units measure acceleration, angular velocity and orientation; global positioning systems estimate distance, velocity and external load; pressure insoles describe foot loading; surface electromyography captures muscle activation; and heart rate or sleep sensors provide recovery context. When these data streams are combined with validated algorithms, clinicians can monitor movement quality and training exposure during real sport tasks rather than only during laboratory tests. Recent reviews show that wearables are increasingly used for biomechanical assessment, training load management, fatigue monitoring, rehabilitation feedback and injury risk

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analysis in sport (Rana and Mittal, 2021; Rebelo et al., 2023; De Fazio et al., 2023).

The relevance for Saudi Arabia is particularly strong. Vision 2030 emphasizes quality of life, preventive health, digital transformation and the growth of sports participation. The Health Sector Transformation Program also promotes access, e health, value based care and prevention, while the Quality of Life Program supports physical activity and sport sector development. Remote wearable monitoring sits at the intersection of these priorities because it enables continuous preventive care, data driven rehabilitation and distributed sports medicine access for athletes in schools, universities, clubs, military settings, community programs and rural regions (World Health Organization, 2020; Mani and Goniewicz, 2024; Vision 2030, 2025).

However, the adoption of wearable monitoring is not automatically beneficial. Many devices produce attractive dashboards but lack clinical validity, sport specific thresholds or transparent decision logic. Artificial intelligence can strengthen pattern recognition, yet biased datasets, black box predictions and inconsistent sensor placement can reduce trust. Remote rehabilitation can improve adherence, but it can also create safety risks if alerts are inaccurate or if athletes interpret feedback without professional oversight. Therefore, Saudi implementation must be evidence led, clinically governed and aligned with the realities of Arabic language interfaces, data privacy, interoperability, workforce capability and sports federation regulation (Ekerete et al., 2021; Zadeh et al., 2023; Eisenhart-Rothe et al., 2025).

This review paper addresses that need by synthesizing literature published between 2020 and 2025 and translating it into a Saudi oriented framework. It follows the attached Springer style model by combining background, structured methodology, thematic evidence synthesis, a practical framework, graphical representation, tables, implications, limitations and future research directions. The focus is not on promoting one device, but on clarifying how wearable sensors can become a remote monitoring pathway that improves prevention, rehabilitation outcomes and return to sport decisions.

II. AIM AND OBJECTIVES OF THE STUDY

The aim of this review is to evaluate how wearable sensor based remote monitoring can support sports injury prevention and rehabilitation outcomes in Saudi Arabia under Vision 2030. The review has five specific objectives. First, it identifies wearable sensor technologies most relevant to sports injury risk and rehabilitation monitoring. Second, it evaluates the clinical outcomes that can be measured remotely, including workload, movement asymmetry, pain related function, adherence, fatigue and return to play readiness. Third, it examines methodological and governance requirements for translating sensor data into safe clinical decisions. Fourth, it develops an implementation framework suited to Saudi sports medicine, physiotherapy and community sport settings. Fifth, it highlights research gaps that should guide future Saudi studies, including validation in local athletes, Arabic digital interfaces, data protection, health economic evaluation and federation level standardization.

III. REVIEW METHODOLOGY

A structured narrative review methodology was used because the topic spans sports science, rehabilitation, biomedical engineering, digital health, machine learning and Saudi policy. The search strategy was designed to approximate Scopus and Web of Science standards while allowing inclusion of high quality policy sources. Databases included PubMed, Scopus, Web of Science, IEEE Xplore, ScienceDirect, SpringerLink, MDPI, JMIR and Google Scholar. Search strings combined terms such as wearable sensors, inertial measurement unit, sports injury, rehabilitation monitoring, telerehabilitation, return to sport, athlete monitoring, machine learning, Saudi Arabia, Vision 2030, physiotherapy and remote care. Searches were limited to English language sources published from January 2020 to December 2025.

Inclusion criteria were peer reviewed articles, systematic reviews, scoping reviews, clinical studies, engineering studies and policy documents that addressed wearable monitoring for sports injury prevention, musculoskeletal rehabilitation or digital health implementation. Studies were included when they reported sensor type, clinical purpose, athlete or patient context, algorithmic approach, outcome measure, implementation barrier or rehabilitation relevance. Exclusion criteria were studies focused only on general consumer fitness without clinical relevance, pre 2020 publications unless needed for background definitions, opinion articles without evidence, and sources unrelated to sport or musculoskeletal rehabilitation. The final synthesis prioritized recent reviews and empirical studies because they provide stronger evidence for publication quality review writing.

Data extraction followed six categories: technology type, sport or rehabilitation setting, injury focus, monitored variables, analytic method and implementation implication. Evidence was then grouped into four themes: sensor capability, prevention logic, rehabilitation outcome monitoring and Saudi implementation readiness. Quality appraisal considered validity of measurements, ecological relevance, sample characteristics, transparency of algorithms, ethical safeguards and clinical actionability. Because wearable systems are heterogeneous, formal meta-analysis was not appropriate. Instead, the review uses integrative synthesis to identify patterns, contradictions and practical design principles for future Saudi research and service development.

IV. WEARABLE SENSOR TECHNOLOGIES FOR REMOTE SPORTS MONITORING

Inertial measurement units are the most widely applicable sensors for remote injury prevention because they are small, affordable and able to capture accelerations, rotations and segment orientation during sport specific movement. They can be placed on the ankle, tibia, thigh, pelvis, trunk or shoe to quantify landing impact, cutting mechanics, gait variability, jump asymmetry and movement volume. For injury prevention, IMUs are especially valuable when clinicians need repeated field measurements rather than occasional laboratory motion capture. Reviews of wearable inertial sensors emphasize their potential for real time kinematics analysis, but also warn that validity depends on sampling rate, filtering, calibration and consistent placement (Rana and Mittal, 2021; Preatoni et al., 2022).

Global positioning systems and local positioning systems are commonly used in team sports to monitor external workload, high speed running, accelerations, decelerations and changes of direction. These variables are relevant because sudden spikes in workload or repeated high intensity actions may increase tissue stress, especially when recovery is inadequate. However, GPS data alone cannot explain joint mechanics or neuromuscular control. It should therefore be integrated with IMUs, heart rate, perceived exertion and wellness data to distinguish productive adaptation from risky overload. Machine learning models can help detect non linear relationships between load accumulation and injury, but model outputs must remain interpretable for coaches and clinicians (Rommers et al., 2020; Rebelo et al., 2023).

Surface electromyography, pressure sensors and smart textiles add physiological and mechanical detail. EMG can monitor delayed muscle activation, altered co contraction or fatigue related changes during rehabilitation exercises. Pressure insoles can identify loading asymmetry after ankle, knee or foot injury. Smart textiles may increase comfort and compliance by embedding sensors into garments or braces. These technologies are promising for remote rehabilitation because they allow therapists to verify whether prescribed exercises are performed with acceptable quality. Evidence from home based ankle rehabilitation and upper extremity monitoring shows that unobtrusive sensors can detect movement patterns and support remote feedback, although technical reliability and user burden remain important barriers (Ekerete et al., 2021; Zadeh et al., 2023).

The future is likely to involve sensor fusion rather than single device monitoring. A Saudi football academy, for example, could combine GPS workload, ankle IMUs, subjective wellness, sleep data and physiotherapist notes to generate individualized risk profiles. A hospital based rehabilitation service could combine knee IMUs, mobile video, pain scores and exercise adherence to identify patients who need earlier therapist contact. The technical challenge is not only to collect more data, but to convert multimodal data into clinically meaningful and ethically governed actions.

V. INJURY PREVENTION MECHANISMS

Wearable monitoring supports injury prevention through three connected mechanisms: exposure management, movement quality assessment and early warning feedback. Exposure management quantifies how much load an athlete experiences and how quickly it changes. Movement quality assessment identifies high risk patterns such as excessive knee valgus, poor landing symmetry, reduced ankle dorsiflexion, trunk instability or fatigue related variability. Early warning feedback provides alerts or coaching cues before accumulated stress becomes an injury event. This prevention logic aligns with recent biomechanical reviews showing that wearable technologies can inform training adaptation and injury prevention when data are interpreted in context (Preatoni et al., 2022; Rebelo et al., 2023).

Ankle sprains illustrate the clinical value of continuous monitoring. They often occur during rapid inversion, landing or cutting, but risk may increase earlier through fatigue, delayed peroneal response, instability and asymmetrical loading. Recent work on ankle biomechanics indicates that fatigue and chronic ankle instability can alter balance and proprioception during landing tasks (Fong et al., 2020; Liu et al., 2023; Dury et al., 2024). Wearable IMUs can detect changes in angular velocity, impact magnitude, stride variability and joint control that may indicate higher risk. Remote dashboards could then prompt workload reduction, bracing, neuromuscular training or physiotherapist review.

Knee injuries and overuse conditions require a broader monitoring strategy. Anterior cruciate ligament risk is influenced by landing mechanics, cutting technique, neuromuscular control, fatigue and previous injury. Wearable sensors cannot replace clinical screening, but they can extend screening into real training environments. For tendinopathy, stress fracture risk or patellofemoral pain, repeated measurement of load, asymmetry and recovery trends may be more useful than isolated tests. In Saudi settings with growing youth academies and women's sport participation, this continuous approach can protect athletes who may not yet have access to mature sports science support.

VI. REHABILITATION OUTCOMES AND RETURN TO SPORT

Rehabilitation outcomes are often measured through pain scores, range of motion, strength tests, functional scales and clinician observation. Wearable sensors add objective and continuous measures that can show whether recovery is progressing outside the clinic. For example, an athlete recovering from ankle sprain may appear stable during supervised balance testing but still show asymmetry during daily running. A post operative knee patient may report completing home exercises, while sensor data reveal reduced range, fewer repetitions or compensatory trunk motion. Wearable monitoring therefore improves outcome assessment by connecting prescribed rehabilitation with actual behavior (King et al., 2023; Seshadri et al., 2023).

Remote rehabilitation is particularly important in Saudi Arabia because athletes and active citizens may live far from specialized sports medicine centers. Telerehabilitation supported by sensors can reduce travel burden, improve adherence and allow therapists to triage patients according to risk. Biofeedback systems can provide vibration, audio or app based cues when movement deviates from the target pattern. Evidence on asynchronous biofeedback assisted telerehabilitation suggests that remote exercise feedback can improve pain and function in musculoskeletal conditions when the intervention is structured and clinically supervised (Dario et al., 2023; Nairn et al., 2025).

Return to sport decisions should not depend on time alone. Wearables can contribute by tracking progressive exposure, limb symmetry, jump landing quality, running load, fatigue response and confidence related behavior. A dashboard could compare current capacity with pre injury baseline, team norms and sport specific demands.

Nevertheless, wearable data must remain one component of shared decision making. Clinical examination, strength testing, psychological readiness, imaging when needed and coach assessment remain essential. The safest model is a hybrid pathway where sensors provide continuous evidence while qualified clinicians interpret the evidence and approve progression.

VII. PROPOSED SAUDI IMPLEMENTATION FRAMEWORK

The proposed framework has five layers: athlete capture, edge processing, cloud analytics, clinical governance and outcome feedback. The athlete capture layer includes sensors selected for the sport and injury risk profile, such as ankle IMUs for sprain prevention, trunk IMUs for running mechanics, GPS for football load or pressure insoles for return to running. The edge processing layer filters signals, detects events and reduces data transfer. The cloud analytics layer converts validated features into risk scores, adherence summaries and rehabilitation progress indicators. The clinical governance layer defines who receives alerts, how thresholds are adjusted and when athletes must be reviewed. The outcome feedback layer delivers clear recommendations to athletes, coaches and therapists.
Saudi deployment should begin with targeted pathways rather than national scale device distribution. Early pilot programs could focus on high burden problems such as ankle sprain recurrence in football, ACL rehabilitation in women's sport, overuse injury in running clubs and return to play after knee surgery. Each pilot should include baseline testing, sensor placement protocols, Arabic and English app interfaces, clinician training, data privacy consent, adverse event reporting and cost evaluation. Integration with hospital electronic records and sports federation systems should be planned from the start to avoid isolated datasets.

The framework also requires governance. Wearable alerts should be classified by clinical risk: informational feedback, coach action, therapist review or medical escalation. Algorithms should be validated on Saudi athletes and diverse populations, including female athletes, youth, recreational participants and athletes with different body sizes. Data should be encrypted, stored according to Saudi health data rules and accessed only by authorized professionals. Procurement should prioritize interoperability, evidence, support, cybersecurity and the ability to export data for research.

VIII. ARTIFICIAL INTELLIGENCE AND DATA ANALYTICS

Artificial intelligence can improve wearable monitoring by recognizing complex patterns across time. Supervised learning can classify high risk movement, unsupervised learning can detect unusual deviations from an athlete's baseline, and time series models can forecast workload or fatigue trends. Deep learning models using IMU data are increasingly reported for gait analysis, motion classification, joint moment estimation and rehabilitation assessment (Liang et al., 2023; Ali et al., 2024; Eisenhart-Rothe et al., 2025). The attached Springer model demonstrates a technically advanced direction by combining lightweight temporal models, adaptive control and edge deployment for real time ankle injury detection, which is conceptually relevant for Saudi sports monitoring although the present review focuses on 2020 to 2025 evidence.

AI should be implemented with caution. Sports injury is a low frequency and multifactorial outcome, which makes prediction vulnerable to overfitting. A model trained on elite male footballers may not generalize to female athletes, school players, runners or post surgical patients. False positives may unnecessarily restrict participation, while false negatives may create unsafe confidence. For this reason, Saudi systems should use AI as decision support rather than autonomous diagnosis. Explainable outputs, uncertainty ranges, audit logs and clinician override functions should be mandatory. Model performance should be reported with sensitivity, specificity, false alarm rate, calibration, subgroup analysis and prospective validation rather than only accuracy.

IX. TABLES AND GRAPHICAL SYNTHESIS

Table 1 summarizes core wearable technologies and their clinical use in remote sports injury prevention and rehabilitation. Table 2 translates the evidence into a Saudi implementation roadmap. Figure 1 presents the remote monitoring ecosystem in an Apple inspired design language, while Figure 2 illustrates the evidence to outcome pathway. Together, these visuals show that the value of wearables depends on the connection between sensors, analytics, clinicians, athletes and policy infrastructure. A technically impressive device has limited value if it lacks validated thresholds, if coaches do not understand alerts, or if athletes stop wearing it because it is uncomfortable.

X. ETHICAL, PRIVACY AND EQUITY CONSIDERATIONS

Continuous athlete monitoring creates ethical responsibilities. Motion, location, workload and physiological data can reveal health status, performance limitations and personal routines. Athletes should know what data are collected, who can access them, how long they are stored and whether they influence selection or contracts. Consent should be meaningful rather than hidden inside app terms. Youth athletes require additional safeguards because parents, schools, clubs and federations may all have interests in the data. Saudi implementation should therefore establish transparent data sharing agreements and clear boundaries between medical care, coaching and performance management.

Equity is also important. Wearable monitoring should not become available only to elite clubs or wealthy users. Vision 2030 goals include broad health and quality of life improvements, so remote monitoring pilots should consider public schools, community sport programs, women's sport, para sport and rural areas. Low cost IMU based systems may be preferable to expensive proprietary platforms when the clinical question is simple. Arabic language interfaces, culturally appropriate health education and accessible telehealth channels will improve adoption.

XI. DISCUSSION

The reviewed evidence supports wearable sensor based remote monitoring as a promising approach for sports injury prevention and rehabilitation, but the field is still maturing. The most convincing evidence concerns measurement capability and rehabilitation feedback rather than definitive injury reduction. Wearables can measure training load, movement symmetry, fatigue indicators and exercise completion with increasing accuracy. They can help therapists observe patients remotely and help coaches identify changes that require load adjustment. However, proving that wearables reduce injury incidence requires prospective trials with adequate sample sizes, standardized definitions and careful control of confounders (Preatoni et al., 2022; Rebelo et al., 2023).

For Saudi Arabia, the strategic opportunity is to build a connected sports medicine ecosystem before fragmented device use becomes entrenched. Hospitals, physiotherapy clinics, universities, sports clubs, federations and technology firms could collaborate around shared protocols. Local research should validate algorithms in Saudi climate, surfaces, sports calendars and athlete populations. Heat, prayer schedules, travel between cities, tournament formats and differences between elite and recreational sport may all influence workload and recovery patterns. Wearables can capture these local realities if studies are designed properly.

Another important discussion point is professional adoption. Physiotherapists and sports physicians may resist dashboards that increase workload or produce unclear alerts. Coaches may prefer simple traffic light outputs, while researchers need raw data and model transparency. The implementation framework must therefore provide role specific views. Athletes need understandable feedback; coaches need actionable training guidance; clinicians need clinical detail; administrators need outcome and cost indicators; researchers need anonymized datasets. Successful adoption will depend on workflow design as much as sensor accuracy.

XII. LIMITATIONS OF THE REVIEW

This review has limitations. It synthesizes a broad and fast moving field, and the heterogeneity of devices, sports, algorithms and outcomes prevents

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DOI: https://doi.org/10.64388/IREV10I1-1720117

quantitative pooling. Some wearable studies use small samples, laboratory tasks or healthy participants, which limits generalization to real injuries. Many commercial systems do not disclose algorithms, making independent validation difficult. Saudi specific empirical evidence remains limited, so several recommendations are based on international literature interpreted through Vision 2030 priorities. The review also focuses on publications from 2020 to 2025 and does not include every older foundational study.

XIII. FUTURE RESEARCH AGENDA

Future Saudi research should move from feasibility toward outcome evaluation. Priority studies include prospective injury surveillance in football and running, randomized trials of sensor augmented rehabilitation after ankle and knee injury, validation of Arabic mobile feedback, cost effectiveness analysis and clinician usability studies. Researchers should report sensor placement, sampling frequency, preprocessing, missing data handling, algorithm performance and adverse events. Multicenter collaboration would improve sample size and population diversity. A national anonymized sports rehabilitation dataset could support responsible AI development while protecting privacy.

Future systems should also integrate environmental and contextual data. Heat stress, sleep, travel, playing surface, footwear and training schedule may modify injury risk. Combining wearable biomechanics with contextual variables could produce more individualized recommendations. However, more data should not mean more surveillance. The guiding principle should be clinical usefulness: collect the minimum data needed to improve safety, recovery and participation.

13.1 Operational metrics for Saudi pilots

A Saudi pilot should evaluate success with measures that matter to clinicians, coaches, athletes and policy makers. At athlete level, the minimum dataset should include exposure minutes, completed rehabilitation sessions, pain response, perceived exertion, sleep or wellness score, movement asymmetry, alert frequency and return-to-sport stage. At service level, teams should monitor therapist response time, missed sessions, re injury episodes, unplanned clinic visits, athlete satisfaction and device adherence. At system level, decision makers should track cost per monitored athlete, avoidable referral, reduction in travel, data completeness and the number of clinicians trained. These indicators translate wearable monitoring from a technology demonstration into a measurable health service.

The operational pathway should start when an athlete enters a prevention program or receives a rehabilitation prescription. The clinician selects the pathway, explains data use, places sensors, performs baseline movement tests and sets individual thresholds. During training or home exercise, the device records relevant movement and sends summarized indicators to the dashboard. Low-risk results generate encouragement and progression guidance. Moderate-risk deviations trigger coaching advice, exercise modification or a message to repeat the task. High-risk alerts notify the therapist or sports physician and may pause progression until review. This stepped response prevents unnecessary alarm fatigue while preserving safety.

Interoperability is critical because Saudi sports medicine will involve hospitals, private physiotherapy providers, universities, clubs and federations. Systems should use common data dictionaries for sport, injury type, exercise, sensor placement, event definition and outcome scale. Dashboards should export clinician-readable summaries and machine-readable files for approved research. Integration with electronic health records should be gradual, beginning with summary reports rather than raw sensor streams. This approach reduces cybersecurity burden and protects privacy while allowing clinicians to document objective rehabilitation progress.

Workforce capability will determine whether remote monitoring becomes useful. Physiotherapists need training in sensor placement, signal interpretation, false alert management and athlete coaching. Sports physicians need guidance on how wearable trends fit with imaging, clinical examination and return-to-play criteria. Strength and conditioning coaches need clear boundaries so that risk information supports training decisions without becoming unauthorized medical advice. Athletes need simple education explaining that a sensor does not judge them; it helps them recognize movement patterns that may otherwise be missed. Saudi universities and professional societies can support this capability through short courses, certification modules and supervised clinical pilots.

Procurement should also be evidence based. Purchasers should ask whether the device has peer reviewed validation, whether algorithms can be audited, whether data can be exported, whether Arabic language support is available, how battery and comfort perform during hot weather training, and whether the supplier provides clinical implementation support. Buying devices without these requirements may produce impressive dashboards but weak outcomes. A staged procurement model is safer: test usability in a small group, validate metrics against clinical assessment, evaluate workflow impact, then scale only if the pathway improves adherence, decision quality or injury-related outcomes.

Finally, Saudi research groups should use wearable monitoring to build publishable evidence rather than only internal reports. Prospective cohort studies can identify local risk profiles. Randomized trials can test sensor-augmented rehabilitation against usual care. Implementation studies can explore adoption barriers among athletes, families and clinicians. Economic evaluations can show whether remote monitoring reduces unnecessary appointments and improves recovery efficiency. By linking clinical service development with rigorous research, Saudi Arabia can contribute original evidence to international sports medicine while advancing Vision 2030 objectives for prevention, digital health, participation and quality of life.

The monitoring model should also consider the Saudi sport calendar. Many athletes train in hot environments, travel between regions for competitions and combine club duties with school, university or employment commitments. These factors influence fatigue and adherence, so dashboards should allow contextual notes rather than presenting risk as a purely mechanical score. For example, an elevated running-load alert after congested fixtures should be interpreted differently from the same alert after an isolated training session. Similarly, reduced exercise completion during Ramadan, examinations or travel may require supportive scheduling rather than non-compliance labeling. Context-aware interpretation is essential for respectful and clinically accurate remote care.

A further practical priority is communication. Alerts should be short, ranked and connected to a recommended next step. An athlete might receive a simple cue such as reduce intensity today, repeat balance exercise with slower control, or contact the physiotherapist. The clinician dashboard can show richer evidence, including trend graphs, thresholds and raw event examples. Coaches should see only information relevant to training modification unless the athlete consents to broader sharing. This tiered communication protects confidentiality while ensuring that each stakeholder receives usable information. It also supports trust, which is the foundation of sustained wearable adoption.

Pilot reports should therefore publish both positive and negative findings. Reporting discomfort, missing data, false alerts, abandoned sensors and workflow delays is not a weakness; it helps future programs avoid repeated mistakes and strengthens the credibility of Saudi digital sports medicine research. Transparent learning cycles will make scale-up safer, faster and more defensible for funders and clinicians.

XIV. CONCLUSION

Wearable sensor based remote monitoring offers Saudi Arabia a practical opportunity to modernize sports injury prevention and rehabilitation outcomes under Vision 2030. The evidence from 2020 to 2025 shows that IMUs, GPS, EMG, pressure sensors, smart textiles and AI enabled dashboards can quantify load, movement quality, adherence and recovery outside the clinic. The strongest value arises when wearable data are linked to clinician oversight, validated thresholds and individualized rehabilitation goals. For Saudi Arabia, implementation should begin with targeted pilot pathways, local validation, Arabic interfaces, privacy governance and integration with sports medicine services. Wearables should not replace clinical judgment, but they can make prevention and rehabilitation more continuous, objective and accessible. If deployed responsibly, they can help athletes return safely, reduce recurrent injury and strengthen the Kingdom's emerging sports health infrastructure.

Figure 1. Remote sports injury monitoring ecosystem

Figure 1. Apple website inspired graphical representation of the Saudi remote monitoring ecosystem connecting wearable capture, edge filtering, clinical analytics, care dashboards and athlete feedback.

Figure 2. Evidence-to-outcome pathway for wearable rehabilitation

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DOI: https://doi.org/10.64388/IREV10I1-1720117

Figure 2. Apple website inspired pathway showing how evidence mapping, data quality appraisal, clinical interpretation and Saudi implementation convert wearable data into injury prevention and rehabilitation outcomes.

Table 1. Wearable sensor applications for sports injury prevention and rehabilitation

Technology	Primary variables	Best use case	Saudi implementation note
IMU sensors	Acceleration, angular velocity, orientation, impact, jump and gait events	Ankle sprain risk, landing control, running mechanics and exercise quality	Low-cost entry point for clubs, schools and physiotherapy clinics
GPS/LPS trackers	Distance, speed, accelerations, decelerations, high speed running and player load	Team sport workload management and return-to-running progression	Useful in football academies and federated team sport programs
Surface EMG	Muscle activation timing, co-contraction, fatigue patterns and neuromuscular response	Post-injury activation retraining and fatigue monitoring	Requires clinician training and careful electrode placement
Pressure insoles	Foot pressure, symmetry, stance time, loading rate and center of pressure	Foot, ankle and knee rehabilitation plus return to running	Can support objective progression after lower limb injury
Smart textiles	Embedded motion, stretch, pressure or physiological sensing	Longer-duration monitoring with improved comfort and compliance	Arabic app support and washable durable design are important

Table 2. Saudi implementation roadmap for wearable remote monitoring

Phase	Core actions	Governance controls	Expected outcome
Pilot design	Select injury pathway, sensor set, clinical dashboard and athlete cohort	Ethics approval, consent, cybersecurity and role-based access	Feasible pathway with measurable baseline
Clinical validation	Compare wearable outputs with clinical tests, video and therapist assessment	Report accuracy, false alarms, subgroup performance and limitations	Trusted thresholds for Saudi athletes
Service integration	Link alerts with physiotherapy, coaching and return-to-play workflows	Escalation rules, documentation and clinician override	Actionable remote monitoring
Scale-up	Extend to clubs, universities, community sport and rural services	Interoperability, procurement standards and quality audits	Nationally scalable sports medicine capability
Research learning	Create anonymized datasets and publish outcomes	Data minimization, de-identification and responsible AI review	Saudi evidence base for Q1/Scopus research

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