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Review Article

Wireless Oxygen Monitoring in Hospitals: A Scoping Review of Technologies, Clinical Implementation, and the Gap Between Innovation and Practice

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ABSTRACT
Wireless oxygen monitoring systems serve two critical functions in hospitals: environmental monitoring to prevent fires in oxygen-enriched atmospheres and patient monitoring to track blood oxygen saturation (SpO_2). This scoping review synthesizes literature from 2015 to 2026 on wireless oxygen monitoring technologies, their clinical implementation, and the gap between innovation and practice. A systematic search of five databases (IEEE Xplore, PubMed/MEDLINE, ScienceDirect, Scopus, Google Scholar) identified studies examining wireless protocols (IQRF®, ZigBee, Bluetooth, Wi-Fi), sensor technologies, system architectures, control mechanisms, and implementation outcomes. Findings reveal that wireless oxygen monitoring technologies have matured significantly, with IQRF® mesh networks achieving >12-month battery life for environmental monitoring and optimized wireless body area networks attaining >99% accuracy for patient monitoring under optimal conditions. However, persistent implementation challenges constrain clinical utility: false alarm rates exceeding 30%, connectivity variability, workflow integration difficulties, and context-specific barriers in low-resource settings. The gap between technical capability and real-world performance remains substantial. This review identifies critical research priorities, including false alarm reduction through machine learning, comparative effectiveness studies, cost-effectiveness analyses, and standardized evaluation frameworks. For healthcare decision-makers, findings underscore the need for site-specific assessments, staff training, and continuous performance monitoring. Wireless oxygen monitoring holds genuine promise for improving hospital safety, but realizing this potential requires sustained attention to implementation contexts and human factors alongside technological refinement.

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INTRODUCTION

Oxygen is among the most critical resources in modern hospital care. It is essential for patients with respiratory conditions, during surgical procedures, and in intensive care units (ICUs). However, oxygen also presents significant risks, particularly the danger of fire in oxygen-enriched environments. A rise in ambient oxygen concentration from the normal 21% to just 23% creates a dramatically elevated fire risk, yet such increases can occur undetected in treatment rooms where oxygen is in continuous use (Velicka et al., 2025).

The COVID-19 pandemic starkly illustrated this dual reality. Hospitals worldwide deployed large volumes of supplemental oxygen to treat critically ill patients, with ICU oxygen concentrations measured as high as 30% and even 36% in some patient care boxes (Velicka et al., 2025). Simultaneously, the demand for continuous patient monitoring surged, requiring healthcare providers to track blood oxygen saturation (SpO_2) in increasing numbers of patients across diverse clinical settings from ICUs to general wards and even home care (Khan & Duncan, 2025).

Recent advances in wireless sensor technologies, low-power microcontrollers, and Internet of Things (IoT) communication protocols have opened new possibilities for oxygen monitoring. Wireless oxygen sensor systems can now provide continuous, real-time data on both environmental oxygen levels and patient oxygen saturation, with the flexibility to deploy sensors where needed and enable patient mobility (Kumaran et al., 2024). Systems based on IQRF® mesh networking have demonstrated reliable performance in ICU environments (Velicka et al., 2025), while ZigBee-based oxygen metering systems enable remote monitoring of oxygen flow and leak detection (Al-Halabi et al., 2025). For patient monitoring, wireless body area networks (WBAN) incorporating optimization algorithms such as Particle Swarm Optimization have achieved accuracies exceeding 99% under various conditions (Kumaran et al., 2024).

Despite these technological advances, the implementation of wireless oxygen monitoring in hospitals remains far from routine. Studies continue to report persistent implementation challenges, although their nature and severity have evolved over time. Earlier investigations documented wireless connectivity gaps, motion artifacts affecting measurement accuracy, workflow integration difficulties, and false alarm rates reaching approximately 30.87% in postoperative surgical ward deployments (Harsha et al., 2019). More recent multi-hospital digital health implementations, however, indicate measurable progress. Contemporary continuous vital sign monitoring (CVSM) frameworks that incorporate automated alarm management algorithms and centralized virtual operations centres have been shown to filter approximately 50% of non-actionable nuisance alerts, thereby substantially reducing clinician alarm fatigue (Nguyen et al., 2025; Pan et al., 2026). Nevertheless, important implementation barriers remain. In low-resource settings, challenges such as unreliable power supply, high equipment costs, and limited technical support continue to constrain deployment (Nantume et al., 2021). Likewise, neonatal intensive care units (NICUs) present unique requirements for evaluating skin safety, sensor reliability, and signal quality among highly vulnerable patient populations (Al-Halabi et al., 2025).

The literature on wireless oxygen monitoring is fragmented across multiple disciplines, which include: biomedical engineering, wireless communications, clinical medicine, patient safety, and health informatics (Kumaran et al., 2024; Al-Halabi et al., 2025). Engineers focus on sensor accuracy and communication protocols; clinicians emphasize workflow integration and patient outcomes; hospital administrators prioritize safety and cost-effectiveness (Harsha et al., 2019). These different perspectives have not been systematically integrated, leaving significant gaps in understanding how wireless oxygen monitoring systems should be designed, controlled, and implemented to maximize their clinical value.

Literature Review

This section reviews existing literature on wireless oxygen monitoring systems in hospitals, organized thematically to provide context for the exploratory review that follows.

The Dual Role of Oxygen Monitoring in Hospitals

Oxygen monitoring in hospital environments serves two interrelated but distinct functions: patient physiological monitoring and environmental safety management. Pulse oximetry has long been established as a standard clinical tool for measuring arterial oxygen saturation (SpO_2), particularly in perioperative, critical care, and emergency settings (Jubran, 2015). Its widespread adoption reflects its clinical value in detecting hypoxemia and guiding timely intervention.

However, the role of oxygen monitoring extends beyond patient care to include environmental risk management. Elevated ambient oxygen concentrations significantly increase fire hazards, with even small increases above atmospheric levels (21%) creating conditions that accelerate combustion (Velicka et al., 2025). This dual responsibility introduces complexity, as systems must balance high sensitivity for safety with reliability and usability in clinical workflows.

The COVID-19 pandemic highlighted the limitations of conventional monitoring systems. Increased oxygen demand led to elevated ambient oxygen levels in intensive care units, while the need for continuous patient monitoring expanded rapidly (Khan & Duncan, 2025; Velicka et al., 2025). These pressures highlighted the inadequacy of traditional wired systems, which restrict patient mobility and complicate large-scale deployment. As a result, interest in wireless monitoring solutions has intensified, positioning them as a potential bridge between clinical demand and technological capability (Steinhubl et al., 2015; Topol, 2019).

Wireless Communication Protocols and System Design

Wireless oxygen monitoring systems are built upon diverse communication protocols, each optimized for specific operational requirements. Commonly used protocols include ZigBee, Bluetooth Low Energy (BLE), Wi-Fi, and IQRF®, reflecting trade-offs between power consumption, communication range, and network scalability (Al-Halabi et al., 2025; Harsha et al., 2019; Nantume et al., 2021; Velicka et al., 2025).

Mesh-based protocols such as ZigBee and IQRF® provide enhanced reliability through self-organizing network structures, which are particularly advantageous in complex hospital environments with physical obstructions and signal interference (Velicka et al., 2025). In contrast, BLE is widely used for wearable patient monitoring due to its low power consumption and suitability for short-range communication, while Wi-Fi offers high data throughput but at the cost of increased energy usage (Nantume et al., 2021; Harsha et al., 2019).

These architectural trade-offs are consistent with broader research on wireless body area networks (WBANs), which emphasizes the importance of balancing energy efficiency, latency, and reliability in healthcare applications (Movassaghi et al., 2014; Ullah et al., 2012). Similarly, general Internet of Things (IoT) frameworks highlight interoperability and scalability as key challenges in healthcare deployments (Islam et al., 2020; Lee & Lee, 2015).

Sensor technologies further shape system performance. Environmental monitoring systems typically employ electrochemical sensors capable of detecting oxygen concentrations across wide ranges with high accuracy, while patient monitoring relies on optical pulse oximetry using red and infrared wavelengths (Kumaran et al., 2024; Velicka et al., 2025). Recent advancements incorporate edge computing and IoT-based architectures to enable real-time data processing and remote monitoring, thereby improving responsiveness and system efficiency (Kim et al., 2024; Marques et al., 2019).

Despite these advances, the absence of standardized system architectures and protocol selection frameworks limits interoperability and complicates large-scale deployment.

Implementation Challenges and Clinical Integration

A consistent finding across the literature is the gap between technological capability and clinical usability. While wireless monitoring systems demonstrate high accuracy under controlled conditions, their real-world performance is often constrained by technical and operational challenges.

False alarms represent one of the most significant operational limitations of wireless monitoring systems. Historically, unoptimized systems reported false alarm rates exceeding 30% in general ward deployments, contributing substantially to alarm fatigue, reduced clinician responsiveness, and diminished trust in monitoring technologies (Harsha et al., 2019; Sendelbach & Funk, 2013). However, contemporary literature demonstrates that the real-world magnitude of this problem has begun to shift through advances in system architecture and workflow redesign. These developments have been associated with reduced alert burden and improved workflow efficiency through centralized alarm management and intelligent filtering of non-actionable alerts (Nguyen et al., 2026). Nevertheless, implementation challenges related to workflow integration, usability, and clinical adoption continue to influence the successful deployment of wireless monitoring systems across diverse healthcare settings (Pan et al., 2026). Technical challenges associated with patient movement, intermittent signal interruptions, and system reliability also remain important considerations in routine clinical practice (Harsha et al., 2019). Consequently, alarm fatigue remains an important patient safety consideration despite these ongoing technological improvements (Nguyen et al., 2026; Sendelbach & Funk, 2013). While localized environmental and operational challenges persist on busy clinical floors, contemporary monitoring systems are increasingly incorporating multi-tiered alarm management strategies to better support nursing workflows (Nguyen et al., 2026).

Connectivity and signal reliability have improved considerably with advances in wireless monitoring technologies, although implementation challenges remain. While earlier studies reported frequent connectivity disruptions in routine clinical deployments (Harsha et al., 2019), more recent evidence indicates substantial improvements in wireless monitoring performance. For example, Al-Halabi et al. (2025) reported near-perfect signal coverage in a neonatal intensive care unit, reflecting advances in wireless communication protocols, sensor technology, network optimization, and system integration. Similarly, recent large-scale health system implementations have demonstrated that modern continuous vital sign monitoring platforms, supported by centralized alarm management and optimized digital infrastructure, can improve system reliability and reduce the burden of non-actionable alerts (Nguyen et al., 2026). Nevertheless, these gains have not eliminated implementation challenges entirely. Performance continues to depend on deployment context, infrastructure quality, patient mobility, and integration with clinical workflows. Consequently, differences between earlier and more recent studies should be interpreted as evidence of technological progress rather than contradictory findings, while recognizing that real-world performance remains influenced by local operational conditions (Harsha et al., 2019; Al-Halabi et al., 2025; Nguyen et al., 2026).

Motion artifacts introduce additional complexity in patient monitoring. While optimization techniques such as Particle Swarm Optimization have demonstrated improvements in signal accuracy (Kumaran et al., 2024), their effectiveness in routine clinical settings remains insufficiently validated.

Clinical integration presents further challenges. Wireless monitoring systems often require significant adjustments to existing workflows, including staff training, alert response protocols, and integration with electronic health record systems. Evidence suggests that inadequate consideration of these factors can lead to workflow disruption and increased documentation burden (Harsha et al., 2019). This underscores the importance of adopting a socio-technical perspective that accounts for both technological and human factors in system design.

Challenges in Low-Resource Settings

The implementation gap is particularly pronounced in low-resource settings, where infrastructural and economic constraints limit the feasibility of wireless monitoring technologies. Key challenges include unreliable power supply, high equipment costs, limited technical expertise, and environmental durability requirements (Nantume et al., 2021).

These findings align with broader research on healthcare technology deployment in resource-constrained environments, which emphasizes the need for context-appropriate design and sustainable implementation strategies (Institute of Medicine, 2011). Technologies developed for high-resource settings often fail when transferred without adaptation, highlighting the importance of affordability, robustness, and ease of maintenance.

Consequently, the scalability of wireless oxygen monitoring systems depends not only on technological innovation but also on their adaptability to diverse healthcare contexts.

Evaluation Frameworks and Evidence Gaps

Efforts to standardize the evaluation of wireless monitoring systems have led to the development of structured frameworks assessing performance, safety, and feasibility (Al-Halabi et al., 2025). However, the application of these frameworks remains inconsistent, and many systems are deployed without comprehensive validation.

Significant gaps persist in the literature. There is a lack of comparative effectiveness studies evaluating different wireless protocols under similar conditions, limiting evidence-based decision-making. Long-term reliability data are also scarce, making it difficult to assess maintenance requirements and sustainability.

Additionally, cost-effectiveness analyses are largely absent, leaving healthcare decision-makers without clear economic justification for adoption. The absence of standardized evaluation metrics further complicates cross-study comparisons, while limited integration with digital health systems contributes to data fragmentation (Islam et al., 2020).

Synthesis and Research Direction

Overall, the literature indicates that wireless oxygen monitoring technologies have achieved substantial technical maturity. However, their clinical impact remains constrained by persistent challenges related to implementation, integration, and contextual adaptability.

A key insight emerging from this review is that these challenges are fundamentally socio-technical in nature. Successful implementation requires not only reliable hardware and communication systems but also alignment with clinical workflows, user needs, and healthcare system constraints.

This synthesis reinforces the central argument of this study: a significant gap exists between innovation and practice in wireless oxygen monitoring. Bridging this gap will require interdisciplinary collaboration, combining advances in engineering with clinical expertise, human factors research, and health system design.

MATERIALS AND METHODS

This scoping review follows Arksey and O'Malley's (2005) framework to examine wireless oxygen monitoring technologies and their clinical implementation.

Search Strategy

Five databases were searched (IEEE Xplore, PubMed/MEDLINE, ScienceDirect, Scopus, Google Scholar) for January 2015–March 2026 publications using keywords: "wireless oxygen sensor," "wireless pulse oximetry," "hospital monitoring," and "implementation challenges."

Inclusion Criteria

Studies were included if they: (1) addressed wireless oxygen monitoring in healthcare, (2) reported empirical data or system designs, (3) were peer-reviewed or reputable conference proceedings, and (4) were English language. Opinion pieces, hardware-only studies, and non-medical applications were excluded.

Data Extraction and Analysis

Data were extracted using a standardized form capturing technology specifications, application domain, design features, performance metrics, and implementation challenges. Thematic analysis identified recurring patterns across studies.

Limitations

This review is limited by English-language bias, potential overrepresentation of successful implementations, and rapid technological change.

RESULTS AND DISCUSSION

This section presents findings from the reviewed literature, organized thematically according to the research questions. The analysis highlights both technological capabilities and practical limitations across studies.

Wireless Technologies and Sensor Types

Reviewed studies consistently identify four dominant wireless protocols for hospital oxygen monitoring: IQRF®, ZigBee, Bluetooth Low Energy (BLE), and Wi-Fi (Al-Halabi et al., 2025; Harsha et al., 2019; Velicka et al., 2025). These technologies reflect trade-offs between power efficiency, scalability, and communication reliability.

Mesh-based systems (IQRF®, ZigBee) demonstrate superior robustness in hospital environments due to self-healing network capabilities, with IQRF® achieving ultra-low power consumption and operational lifetimes exceeding 12 months in environmental monitoring applications (Velicka et al., 2025). BLE is primarily used in wearable patient monitoring due to low energy demand, while Wi-Fi enables high-throughput data transmission but is constrained by high power consumption and limited suitability for continuous deployment (Nantume et al., 2021).

Sensor technologies include electrochemical oxygen sensors for environmental monitoring (accuracy ±1%) and optical pulse oximetry for SpO_2 measurement. While controlled settings report high accuracy (>99%), performance declines under motion and clinical variability (Kumaran et al., 2024; Al-Halabi et al., 2025).

System Design and Control Mechanisms

Most systems adopt a standardized three-layer architecture comprising sensor nodes, gateways, and central servers. Sensor nodes perform data acquisition and wireless transmission, gateways aggregate and convert protocol data, while central servers handle analytics and alert generation.

Power consumption varies significantly across protocols, strongly influencing system sustainability. IQRF® and ZigBee support long-term operation (6–12+ months), whereas Wi-Fi-based systems may operate only for days to weeks under continuous monitoring conditions (Harsha et al., 2019; Velicka et al., 2025).

Optimization approaches, including Particle Swarm Optimization (PSO), improve SpO_2 signal quality by reducing motion artifacts through adaptive weighting of sensor inputs. Reported accuracies range from 96.8% to 99.2%, although validation in routine clinical environments remains limited (Kumaran et al., 2024).

All reviewed systems employ threshold-based alerting mechanisms (e.g., SpO_2 <90%, oxygen concentration >23–30%). However, fixed thresholds contribute to alarm instability and false positives, indicating limited adaptability to clinical context variability.

Implementation Challenges

Despite technological advances, the reviewed studies revealed several technical challenges that impede the widespread adoption of wireless oxygen monitoring systems in clinical settings.

Technical Challenges

Despite advances in wireless oxygen monitoring systems, several persistent technical limitations continue to hinder clinical reliability. The most critical issue is the high rate of false alarms, reported at approximately 30.87%, which significantly contributes to alarm fatigue and reduced system trust in clinical environments (Harsha et al., 2019). This is compounded by connectivity instability, leading to intermittent signal loss and data gaps during real-time monitoring.

Additional challenges include motion artifacts that degrade measurement accuracy in patient-worn sensors, and limited battery life that restricts continuous deployment, particularly in wearable and distributed systems (Kumaran et al., 2024). Electromagnetic and environmental interference further contribute to signal degradation, especially in dense hospital settings (Velicka et al., 2025).

Collectively, these issues also affect patient acceptance of wireless monitoring technologies. Harsha et al. (2019) reported that approximately 10.68% of participants withdrew from the continuous monitoring trial, partly because of alarm burden and connectivity-related challenges. More recent implementation studies indicate that advances in centralized alarm management, intelligent alert filtering, and workflow redesign have reduced clinician alert burden and improved the operational integration of continuous monitoring systems, although implementation challenges related to usability and clinical adoption remain (Nguyen et al., 2026; Pan et al., 2026). Overall, the evidence indicates that while sensor accuracy under controlled conditions is high, real-world clinical performance continues to be influenced by system reliability, usability, and workflow integration, highlighting the need for context-specific implementation strategies (Nguyen et al., 2026; Pan et al., 2026).

Clinical Integration Challenges

Technical performance alone does not guarantee clinical adoption. The reviewed studies documented four persistent integration barriers that undermine effective use:

1. Staff training requirements: New workflows needed for alert response
2. Alert fatigue: High false alarm rates reduced clinician responsiveness
3. Workflow disruption: Integration with existing monitoring practices is challenging

4. Documentation burden: Manual documentation persisted alongside automated monitoring

These challenges indicate that successful implementation depends on alignment with clinical workflows and human factors, rather than technology alone (Harsha et al., 2019).

Low-Resource Setting Challenges

In low-resource settings, implementation barriers were more fundamental. Reported challenges included high costs, unreliable power supply, limited technical support, and environmental constraints (Nantume et al., 2021).

These findings highlight the need for context-specific system design, as solutions developed for high-resource environments may not be directly applicable in such settings.

Evaluation and Validation

Reviewed studies also evaluated system performance, safety, and clinical feasibility. These dimensions are examined below under performance metrics, safety assessments, and feasibility studies.

Performance Metrics

Performance metrics across studies vary mainly in reliability outcomes rather than sensing accuracy. Accuracy remains consistently high (±1% to ±4%), indicating strong sensor performance under controlled conditions (Velicka et al., 2025; Kumaran et al., 2024). In contrast, real-world performance is more variable, reflecting sensitivity to deployment conditions.

Signal coverage ranges from ~85% in suboptimal environments to near-complete coverage in controlled settings, with performance degradation in more dynamic clinical contexts (Al-Halabi et al., 2025; Harsha et al., 2019). False alarm rates remain a key limitation, frequently exceeding 30% and affecting clinical usability (Harsha et al., 2019). Battery life also varies widely from days in high-power configurations to over 12 months in low-power mesh networks depending on protocol and system design (Velicka et al., 2025).

Overall, system effectiveness is driven more by deployment context, network architecture, and power strategy than by sensor accuracy alone.

Safety Assessments

Safety evaluations in neonatal settings showed no significant differences between wireless and wired systems, suggesting acceptable safety when properly implemented (Al-Halabi et al., 2025). This finding is particularly important given the vulnerability of neonatal patients, where concerns such as skin integrity, sensor adhesion, and continuous monitoring reliability are critical. The results indicate that wireless sensors can meet clinical safety standards comparable to traditional wired devices, provided that appropriate placement, monitoring protocols, and device calibration are maintained.

Feasibility Studies

Signal coverage analysis in NICU settings showed median signal coverage of 100% (IQR 99.85–100%), indicating excellent connectivity when systems were properly deployed (Al-Halabi et al., 2025). This suggests that wireless monitoring systems can achieve high reliability in controlled clinical environments. However, such performance is dependent on optimal deployment conditions, including network configuration and minimal interference. As a result, while feasibility is well demonstrated in specialized settings like NICUs, achieving similar performance in more complex or resource-constrained environments may require additional system optimization.

Summary of the Key Findings

The findings of this review indicate that wireless oxygen monitoring technologies have reached a notable level of technical maturity, with multiple communication protocols and sensor systems demonstrating reliable performance under controlled conditions. Strong evidence supports the viability of mesh-based protocols such as IQRF® and ZigBee for environmental monitoring, while BLE is effective for wearable patient applications (Velicka et al., 2025; Al-Halabi et al., 2025; Nantume et al., 2021).

However, the evidence also reveals a consistent gap between technical capability and real-world clinical performance. While optimization techniques such as Particle Swarm Optimization improve signal accuracy (Kumaran et al., 2024), high false alarm rates (30–40%) and connectivity issues remain persistent challenges across studies (Harsha et al., 2019). These limitations significantly affect clinician trust and system usability.

Importantly, the findings highlight that implementation challenges are not solely technical but also contextual and organizational. Factors such as workflow integration, staff training, and infrastructure constraints—particularly in low-resource settings—play a critical role in determining system effectiveness (Nantume et al., 2021). Similarly, although safety and feasibility have been demonstrated in controlled environments such as NICUs (Al-Halabi et al., 2025), these results are not always generalizable to broader clinical settings.

Overall, the evidence suggests that while wireless oxygen monitoring systems are technically viable, their successful adoption depends on addressing reliability, integration, and context-specific challenges. This reinforces the central conclusion of this review: a significant gap persists between technological innovation and routine clinical practice, requiring a more holistic, socio-technical approach to system design and implementation.

Discussion

This review examined wireless oxygen monitoring technologies in hospital settings, with a particular focus on their clinical implementation and the gap between innovation and practice. The findings indicate that while these technologies have achieved substantial technical maturity, their real-world impact remains constrained by persistent implementation challenges, with important implications for technology developers, healthcare decision-makers, and future research.

Technological Capability versus Clinical Reality

The reviewed studies consistently demonstrate high levels of technical performance, including accurate sensing, reliable mesh communication, and extended battery life under controlled conditions (Velicka et al., 2025; Kumaran et al., 2024). Multiple wireless protocols—IQRF®, ZigBee, BLE, and Wi-Fi—have been successfully deployed, each offering distinct advantages depending on the application context.

For example, IQRF® mesh networks are particularly well-suited for environmental monitoring, combining automatic network healing with very low power consumption, enabling battery life exceeding 12 months (Velicka et al., 2025). Similarly, wireless pulse oximetry systems have achieved high accuracy under optimal conditions, with studies reporting values above 99% using optimized algorithms such as Particle Swarm Optimization, alongside acceptable performance in neonatal applications (Kumaran et al., 2024; Al-Halabi et al., 2025). These findings confirm that the core technological components required for wireless oxygen monitoring are well established.

However, this technical capability does not consistently translate into clinical reliability. High false alarm rates were reported at 30.87% in some clinical studies, and intermittent connectivity issues remain significant barriers, undermining clinician trust and system effectiveness (Harsha et al., 2019). This discrepancy highlights a key limitation in current system design: performance is often optimized for controlled environments rather than the complexity and variability of real-world clinical settings.

The Implementation Gap as a Socio-Technical Challenge

The findings indicate that successful implementation depends as much on organizational readiness as on technological capability. Although recent advances have substantially improved sensor performance, wireless communication reliability, and alarm management, their effectiveness is strongly influenced by clinical workflows, user acceptance, infrastructure, and institutional support. These findings suggest that technological innovation alone is insufficient to ensure successful adoption, emphasizing the importance of integrating human factors and organizational processes into system design and implementation.

The reviewed studies consistently show that implementation challenges arise from the interaction between technology and the clinical environment rather than from hardware performance alone. Earlier deployments experienced high false alarm rates and connectivity limitations (Harsha et al., 2019), whereas more recent systems have reduced alert burden through centralized alarm management and workflow optimization (Nguyen et al., 2026). Nevertheless, workflow integration, clinician engagement, and contextual factors continue to influence implementation outcomes (Pan et al., 2026).

Similarly, connectivity reliability varied significantly across settings. While near-perfect signal coverage was reported in controlled NICU environments (median 100%) (Al-Halabi et al., 2025), other studies documented connectivity issues severe enough to contribute to a 10.68% patient withdrawal rate (Harsha et al., 2019). This variability reflects differences in infrastructure, patient movement, and deployment conditions, reinforcing the need for context-specific implementation strategies.

Beyond technical performance, the introduction of wireless monitoring systems also affects clinical workflows, requiring staff training, changes in alert response protocols, and additional documentation processes. When these factors are not adequately addressed, even technically robust systems may fail to achieve meaningful clinical adoption.

Overall, these findings highlight that bridging the implementation gap requires more than technological refinement. It necessitates a shift toward user-centered and context-aware design approaches that integrate human factors and organizational realities into system development.

Context Matters: Variability Across Clinical Environments

The effectiveness of wireless oxygen monitoring systems is highly dependent on deployment context. Studies conducted in controlled environments, such as neonatal intensive care units, report excellent signal coverage and acceptable safety profiles (Al-Halabi et al., 2025). In contrast, more variable clinical settings exhibit greater challenges related to connectivity, motion artifacts, and workflow integration (Harsha et al., 2019).

These differences highlight the importance of context-specific implementation strategies. A system that performs well under controlled conditions may not achieve similar outcomes in more complex clinical environments without adaptation. This is particularly evident in low-resource settings, where infrastructural constraints such as unreliable power supply, limited technical support, high costs, and environmental durability requirements significantly affect feasibility (Nantume et al., 2021).

The evidence, therefore, challenges the assumption that "wireless" solutions are inherently scalable across settings. Instead, effective deployment requires designs tailored to the full operational context, including infrastructure, user capacity, and environmental conditions.

Implications for Design, Integration, and Future Systems

The findings of this review have several implications for stakeholders.

For technology developers, there is a need to move beyond optimizing technical performance in isolation and focus on reducing false alarms, improving robustness, and designing systems adaptable to diverse clinical environments. Incorporating context-aware and adaptive alert mechanisms may help address current limitations.

For healthcare decision-makers, successful adoption requires careful planning, including site-specific assessments, staff training, and continuous performance evaluation. Investment decisions should consider not only initial system functionality but also long-term integration, maintenance, and usability within clinical workflows.

For researchers, significant gaps remain, particularly in comparative effectiveness studies, long-term reliability assessments, and cost-effectiveness analyses. Addressing these gaps is essential for supporting evidence-based adoption and policy development.

A notable insight emerging from this review is the untapped potential for integrated monitoring systems. Environmental oxygen monitoring and patient pulse oximetry rely on similar technological foundations wireless sensors, mesh networking, and threshold-based alerting yet they are largely treated as separate applications in the literature. Integrated systems capable of monitoring both ambient oxygen levels and patient saturation could improve efficiency, reduce equipment redundancy, and enhance overall safety. However, no reviewed studies explicitly explored such integration, highlighting an important direction for future research and system design.

Limitations of the Review

This review has several limitations. The relatively small number of included studies reflects the emerging nature of the field but limits the breadth of evidence. The restriction to English-language publications may introduce bias, and the rapid pace of technological development means that some recent innovations may not yet be captured. Additionally, heterogeneity in study designs and reported outcomes limits direct comparability across studies.

Bridging the Innovation–Practice Gap

Overall, the findings reinforce the existence of a persistent gap between technological innovation and clinical implementation. Three key disconnects are evident

1. high laboratory accuracy versus high real-world false alarm rates;
2. systems optimized for controlled conditions versus complex hospital environments; and
3. solutions designed for high-resource settings versus the realities of low-resource contexts.

Bridging this gap will require a shift from technology-driven approaches to integrated, socio-technical strategies that consider clinical workflows, user behavior, and healthcare system constraints alongside technical performance. Without such integration, the full potential of wireless oxygen monitoring technologies is unlikely to be realized.

CONCLUSION

Wireless oxygen monitoring technologies have advanced considerably, with contemporary systems demonstrating high levels of sensing accuracy, improved wireless connectivity, enhanced energy efficiency, and acceptable safety under controlled clinical conditions. These developments highlight the growing technical maturity of both environmental oxygen monitoring and wireless pulse oximetry, underscoring their potential to enhance patient safety and support more responsive clinical care.

Despite these technological advances, successful clinical adoption depends on more than technical performance alone. Although recent improvements in alarm management, system architecture, and workflow integration have enhanced the operational performance of wireless monitoring systems, implementation challenges related to system reliability, usability, workflow integration, and infrastructure constraints continue to influence their effectiveness, particularly in resource-constrained healthcare settings. These findings emphasize that successful implementation requires technologies that are not only technically robust but also adaptable to diverse clinical environments and healthcare workflows.

This review highlights the importance of adopting a socio-technical approach that integrates technological innovation with clinical practice, human factors, and healthcare system requirements. Such an approach is essential for maximizing the clinical value of wireless oxygen monitoring and ensuring its sustainable adoption across different healthcare contexts.

Future research should prioritize comparative effectiveness studies, long-term reliability assessments, cost-effectiveness analyses, and the development of standardized evaluation frameworks. Additional research is also needed to improve alarm management, enhance interoperability with electronic health record systems, and investigate integrated monitoring platforms that combine environmental oxygen surveillance with continuous patient monitoring. Collectively, these efforts will support evidence-based implementation and facilitate the broader adoption of wireless oxygen monitoring technologies across diverse healthcare settings.

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