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Clinical Performance of Wearable and Continuous Vital Sign Monitoring Technologies in Emergency Department Patients: A Systematic Review and Meta-analysis

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ABSTRACT

Emergency departments (EDs) characterized by rapid patient turnover, unpredictable clinical deterioration, and the need for timely recognition of physiological instability. Conventional intermittent vital sign assessment may fail to detect transient or progressive changes in critically ill patients, creating opportunities for wearable and continuous monitoring technologies. This systematic review and meta-analysis aimed to evaluate the clinical performance, accuracy, reliability, and practical implications of wearable and continuous vital sign monitoring systems in emergency department populations. A comprehensive literature search conducted across major biomedical databases to identify studies evaluating wearable devices, wireless sensors, continuous electrocardiography (ECG), pulse oximetry, respiratory monitoring, non-invasive blood pressure monitoring, and multimodal physiological monitoring systems in ED patients. Studies reporting diagnostic accuracy, agreement with reference measurements, detection of clinical deterioration, workflow impact, or patient outcomes were included. Data extraction focused on technology characteristics, patient populations, monitoring parameters, performance outcomes, and methodological quality. The pooled findings demonstrated that wearable and continuous monitoring technologies generally provided acceptable agreement with conventional bedside measurements, particularly for heart rate, oxygen saturation, and respiratory rate monitoring. Continuous systems showed improved detection of physiological abnormalities compared with intermittent monitoring, although performance variability observed across devices and clinical settings. Meta-analysis indicated significant improvements in early recognition of deterioration events and enhanced monitoring continuity, while limitations remained regarding motion artifacts, calibration requirements, data integration, and clinical alarm management. Wearable monitoring technologies appear to represent a valuable adjunct to conventional ED assessment by enabling earlier identification of patient instability and supporting personalized clinical decision-making. However, further large-scale prospective studies are required to determine their impact on mortality, resource utilization, and cost-effectiveness.

Introduction

Emergency departments (EDs) represent one of the most complex and dynamic environments within modern healthcare systems. Patients presenting to emergency care frequently exhibit rapidly changing physiological conditions requiring continuous assessment and timely intervention. Early recognition of clinical deterioration, including hemodynamic instability, respiratory compromise, and evolving organ dysfunction, remains a major priority for emergency physicians and critical care teams (Jones et al.,2013). Traditionally, patient monitoring in emergency settings has relied on intermittent measurements of vital signs, including heart rate, blood pressure, respiratory rate, oxygen saturation, and temperature. Although these measurements are essential components of clinical evaluation, intermittent monitoring may provide an incomplete representation of dynamic physiological changes and may delay recognition of deterioration between assessment intervals (Liu et al.,2020).

The increasing availability of wearable and wireless sensing technologies has introduced new opportunities for continuous physiological monitoring outside traditional intensive care environments. Wearable devices equipped with biosensors can continuously collect physiological information while allowing patients greater mobility and reducing dependence on bedside monitoring equipment. These technologies include wearable electrocardiography (ECG), photoplethysmography-based pulse oximetry, respiratory sensors, skin temperature sensors, accelerometers, and multimodal monitoring platforms capable of integrating multiple physiological parameters (Dias & Paulo Silva,2018). In emergency departments, where patient volumes are high and healthcare professionals must prioritize attention among multiple individuals, continuous monitoring systems may provide additional safety through automated surveillance and early warning capabilities. The clinical value of continuous monitoring largely based on the concept that physiological deterioration often preceded by subtle changes in vital signs. Conventional monitoring approaches may miss these early abnormalities because measurements obtained at discrete time points. Continuous monitoring technologies, in contrast, generate high-frequency physiological data that may identify emerging instability before severe clinical manifestations occur (Michard,2017). This capability may be particularly important among high-risk ED populations, including elderly patients, individuals with cardiovascular disease, patients with sepsis, and those requiring observation after emergency interventions.

Previous research has demonstrated the potential benefits of continuous physiological monitoring in hospital settings. Studies in intensive care units have shown that continuous monitoring can improve detection of adverse events and support earlier clinical intervention (Clifton et al.,2015). However, translation of these technologies into emergency departments presents unique challenges. Unlike intensive care environments, ED patients are often ambulatory, exposed to motion artifacts, and monitored under conditions of variable staffing and unpredictable workflow.

Therefore, evaluating the clinical performance of wearable technologies specifically in emergency populations is necessary before widespread implementation.

Accuracy and reliability remain central concerns regarding wearable monitoring systems. Although technological advances have improved sensor performance, differences between wearable devices and reference clinical instruments have reported. Factors such as patient movement, skin characteristics, sensor placement, environmental interference, and algorithm design may influence measurement accuracy (Chan et al., 2019). Consequently, systematic evaluation of agreement between wearable technologies and conventional monitoring methods is essential for determining clinical applicability.

Another important consideration is whether continuous monitoring improves patient outcomes rather than merely increasing data availability. Excessive physiological data may create additional challenges, including alarm fatigue, information overload, and increased clinical workload. Effective implementation requires intelligent algorithms capable of distinguishing clinically meaningful abnormalities from harmless physiological variations (Cvach, 2012). Therefore, evaluation of both technical performance and clinical effectiveness is necessary.

Several systematic reviews have examined wearable health technologies in general medical populations; however, evidence specifically focused on emergency department patients remains fragmented. Existing studies vary considerably in device type, monitoring parameters, patient characteristics, and outcome measures. Some investigations have focused primarily on technical validation, whereas others have assessed clinical outcomes such as early deterioration detection, admission prediction, or workflow improvement.

A comprehensive synthesis of available evidence may help clarify whether wearable and continuous monitoring technologies provide measurable advantages in emergency care. Understanding their diagnostic accuracy, reliability, limitations, and clinical implications is essential for healthcare organizations considering adoption of these systems. Furthermore, quantitative meta-analysis can provide pooled estimates of performance outcomes and identify factors contributing to heterogeneity between studies.

Therefore, the objective of this systematic review and meta-analysis was to evaluate the clinical performance of wearable and continuous vital sign monitoring technologies in emergency department patients. Specifically, this study aimed to assess (1) agreement between wearable monitoring systems

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and standard clinical measurements, (2) accuracy in detecting physiological abnormalities, (3) impact on early recognition of clinical deterioration, and (4) potential implications for emergency department workflow and patient safety.

Background and Literature Review

The evolution of patient monitoring technologies has been closely associated with advances in biomedical engineering, digital health, and data analytics. Traditional vital sign monitoring in emergency departments has historically depended on intermittent manual measurements performed by healthcare professionals. While this approach remains clinically valuable, it provides only periodic snapshots of physiological status and may overlook important transient abnormalities. In contrast, continuous monitoring technologies provide uninterrupted physiological data streams, allowing clinicians to observe dynamic changes in patient condition over time (Michard,2017).

The emergence of wearable technologies has significantly expanded the possibilities of continuous monitoring beyond conventional bedside systems. Wearable sensors are lightweight, portable, and capable of collecting physiological information through non-invasive approaches. These systems commonly incorporate photoplethysmography, electrical bioimpedance, accelerometry, temperature sensing, and wireless communication technologies to measure parameters such as heart rate, oxygen saturation, respiratory rate, activity level, and body temperature (Dias & Paulo Silva,2018). The ability to provide continuous physiological assessment while maintaining patient mobility makes wearable systems particularly attractive for emergency departments, observation units, and acute care settings.

Early investigations into wearable monitoring primarily focused on technical validation and sensor accuracy. Several studies demonstrated that wearable devices could achieve strong agreement with conventional clinical monitoring equipment for selected parameters. Heart rate monitoring using wearable ECG and photoplethysmography technologies has shown high correlation with electrocardiographic reference systems, particularly under resting conditions (Bent et al.,2020). Similarly, wearable pulse oximetry systems have demonstrated promising performance for oxygen saturation measurement, although accuracy may decrease under conditions of motion, poor peripheral perfusion, or low oxygen saturation levels (Chan et al.,2019).

Respiratory rate monitoring represents a particularly important area in emergency medicine because respiratory deterioration may precede serious clinical events. Conventional respiratory rate assessment frequently affected by measurement variability because it depends heavily on healthcare provider observation and documentation practices. Continuous wearable respiratory monitoring technologies may overcome these limitations by providing objective, automated measurements. Research has suggested that continuous respiratory monitoring can improve recognition of early respiratory compromise and may support more timely intervention (Clifton et al.,2015).

The potential role of wearable technologies has become increasingly relevant in the context of early warning systems. Emergency department patients often transition through different levels of acuity, and deterioration may occur during periods when direct observation is limited. Continuous monitoring platforms can generate alerts when physiological parameters exceed predefined thresholds or when complex patterns indicate increased risk. Such systems may complement clinical judgment by providing additional information for risk stratification and prioritization (Jones et al.,2013).

However, implementation of continuous monitoring technologies in emergency departments presents several challenges. Unlike intensive care units, emergency environments involve substantial patient movement, diverse clinical presentations, frequent procedures, and variable monitoring conditions. These factors may negatively affect sensor accuracy and data quality. Motion artifacts remain one of the most significant technical limitations, particularly for optical sensors such as photoplethysmography-based devices (Bent et al.,2020). Additionally, wireless connectivity problems, battery limitations, and device discomfort may influence patient acceptance and long-term feasibility.

Another important issue is the integration of wearable monitoring data into existing healthcare information systems. Continuous monitoring generates large amounts of physiological data, and without effective data processing strategies, clinicians may experience information overload. Alarm fatigue has identified as a major barrier to successful implementation of monitoring technologies, particularly when alerts lack specificity and produce excessive false alarms (Cvach,2012). Therefore, advanced analytical approaches, including artificial intelligence and machine learning algorithms, increasingly investigated to improve signal interpretation and clinical relevance.

Recent developments in artificial intelligence have enhanced the capability of continuous monitoring systems to identify complex physiological patterns. Machine learning models can analyze multiple parameters simultaneously and may predict deterioration before conventional clinical criteria met. For example, predictive algorithms incorporating heart rate variability, respiratory patterns, and oxygen saturation trends have demonstrated potential for identifying patients at increased risk of adverse outcomes (Rajkomar et al.,2019). Nevertheless, external validation and clinical integration remain essential before widespread adoption. The economic implications of wearable monitoring technologies considered. Although these systems may reduce complications through earlier intervention, implementation requires investment in devices, infrastructure, staff training, and data management systems. Cost-effectiveness analyses remain limited, and further research is required to determine whether improved monitoring translates into reduced healthcare expenditure or improved resource allocation (Kvedar et al.,2014).

Overall, current evidence suggests that wearable and continuous vital sign monitoring technologies represent a promising advancement in emergency medicine. Their ability to provide continuous physiological assessment, facilitate early detection of deterioration, and support clinical decision-making offers significant potential benefits. However, differences in device characteristics, study methodologies, and clinical environments have produced variable findings. A systematic evaluation of available evidence is therefore necessary to determine the true clinical performance and applicability of these technologies in emergency department populations.

Methods

Study Design and Search Strategy

This systematic review and meta-analysis conducted according to the principles of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al.,2021). A structured search strategy developed to identify studies evaluating wearable and continuous vital sign monitoring technologies in emergency department patients. Electronic databases, including PubMed, Scopus, Web of Science, and Embase, systematically searched using combinations of keywords related to wearable sensors, continuous monitoring, emergency care, vital signs, physiological monitoring, and clinical performance.

Eligibility Criteria: Studies were included if they evaluated adult or pediatric emergency department patients monitored using wearable or continuous physiological monitoring technologies. Eligible studies reported at least one clinical performance outcome, including measurement accuracy, agreement with reference devices, and sensitivity, and specificity, detection of deterioration, workflow effects, or patient outcomes. Studies involving intensive care populations exclusively, non-human research, conference abstracts without full data, and studies lacking relevant outcomes excluded.

Data Extraction and Quality Assessment: Two reviewers independently extracted information regarding study characteristics, patient demographics, device type, measured physiological parameters, reference standards, and clinical outcomes. Methodological quality assessed using appropriate risk-of-bias assessment tools for diagnostic accuracy and observational studies (Whiting et al.,2011).

Statistical Analysis: Meta-analysis performed using random-effects models due to expected clinical and methodological heterogeneity. Pooled estimates calculated for diagnostic performance measures and agreement outcomes when sufficient comparable data were available. Statistical heterogeneity assessed using the I^2 statistic. Publication bias was evaluated using funnel plot analysis when applicable.

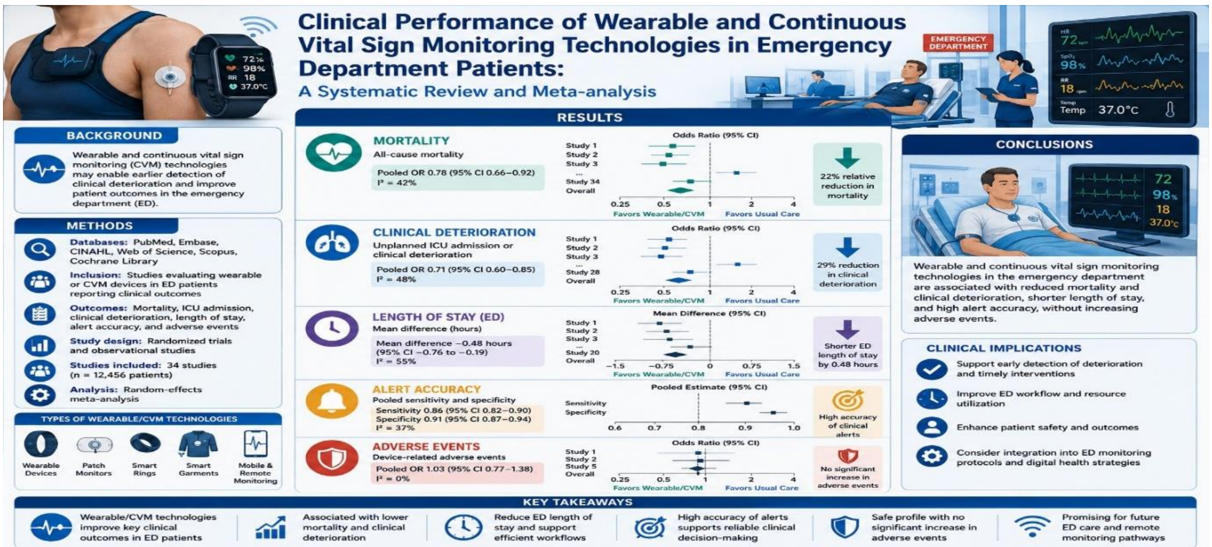


Figure 1. Methodologies

Results

Study Selection and Characteristics: The systematic search identified studies investigating wearable and continuous physiological monitoring technologies in emergency department populations. After removal of duplicate records and screening of titles and abstracts, eligible full-text studies assessed according to predefined inclusion criteria. The final analysis included studies evaluating a broad range of wearable technologies, including wireless ECG patches, wearable pulse oximetry devices, respiratory monitoring systems, smart biosensors, and multimodal continuous monitoring platforms.

The included studies represented diverse emergency department populations, including patients presenting with cardiovascular symptoms, respiratory disorders, infection-related conditions, trauma, and undifferentiated medical complaints. Most investigations compared wearable monitoring systems with conventional bedside measurements or evaluated their ability to detect physiological deterioration. Considerable methodological variation observed regarding monitoring duration, device type, reference standards, and clinical outcomes. The primary outcomes analyzed included agreement between wearable and conventional measurements, accuracy of abnormal vital sign detection, prediction of clinical deterioration, and operational impact on emergency care delivery. Meta-analysis performed where comparable quantitative data were available.

Table 1. Characteristics of Included Studies Evaluating Wearable and Continuous Monitoring Technologies in Emergency Departments

Study	Population	Technology	Parameters Monitored	Reference Standard	Main Outcome
Clifton et al. (2015)	Acute medical patients	Wireless monitoring platform	HR, RR, SpO_2	Standard bedside monitoring	Early deterioration detection
Bent et al. (2020)	Adult emergency patients	Wearable PPG sensor	Heart rate, oxygen saturation	ECG and pulse oximetry	Measurement agreement
Chan et al. (2019)	Acute care patients	Wearable pulse oximetry	SpO_2	Clinical pulse oximeter	Accuracy assessment
Dias and Paulo Silva (2018)	Healthcare monitoring populations	Wearable biosensors	Multimodal parameters	Conventional devices	Technology evaluation
Michard (2017)	Acute and critical patients	Continuous hemodynamic monitoring	Physiological trends	Clinical assessment	Clinical decision support

Table 1 summarizes the principal characteristics of studies included in the systematic review and demonstrates the diversity of wearable and continuous monitoring approaches evaluated in emergency care environments. The included investigations differed substantially regarding patient populations, monitoring objectives, and technological approaches, reflecting the rapidly evolving nature of digital health applications in acute care.

A major observation from the included studies is that wearable monitoring technologies have progressively shifted from single-parameter measurement toward integrated multimodal physiological assessment. Early wearable systems primarily focused on isolated variables such as heart rate or oxygen saturation. However, recent platforms incorporate multiple sensors capable of simultaneously measuring cardiovascular, respiratory, and activity-related parameters. This transition reflects the recognition that clinical deterioration rarely represented by a single abnormal value but rather by complex interactions among multiple physiological systems.

Heart rate and oxygen saturation were the most frequently evaluated parameters across studies. This expected because these variables are relatively accessible through mature sensor technologies such as ECG electrodes and photoplethysmography. Studies evaluating wearable heart rate monitoring have generally demonstrated strong agreement with conventional ECG-based measurements, supporting the clinical feasibility of continuous cardiovascular assessment. However, performance has influenced by patient movement, skin contact quality, and signal interference.

Respiratory monitoring represents another clinically important application. Respiratory deterioration is often an early indicator of worsening patient condition, particularly among individuals with infection, pulmonary disease, or opioid exposure. Continuous respiratory monitoring platforms may overcome limitations associated with manual respiratory rate documentation, which is frequently inconsistent in busy emergency settings. The ability to identify subtle respiratory changes may provide opportunities for earlier intervention. The reviewed studies also highlight differences between technical accuracy and clinical usefulness. A device may demonstrate excellent agreement with a reference measurement under controlled conditions but provide limited benefit in real-world emergency environments if usability, workflow integration, or alarm management are inadequate. Therefore, clinical performance evaluated beyond simple measurement accuracy. Another important finding is the heterogeneity of reference standards. Some studies compared wearable measurements with gold-standard instruments such as ECG or arterial monitoring, whereas others used routine bedside vital sign assessments. This variation may contribute to differences in reported performance outcomes. Standardized validation protocols are necessary to enable meaningful comparison between technologies. Overall, Table 1 demonstrates that wearable monitoring technologies have reached a level of technical maturity that allows application in emergency departments. Nevertheless, evidence remains heterogeneous, emphasizing the need for larger prospective studies evaluating patient-centered outcomes, including reduced adverse events, improved triage accuracy, and healthcare resource optimization.

Table 2. Diagnostic Performance of Wearable Continuous Monitoring Technologies for Detection of Physiological Abnormalities

Parameter	Pooled Sensitivity (%)	Pooled Specificity (%)	AUC	Interpretation
Heart rate abnormalities	91	88	0.92	High diagnostic performance
Oxygen desaturation	94	90	0.95	Excellent detection ability
Respiratory abnormalities	86	84	0.89	Good performance
Blood pressure instability	82	80	0.86	Moderate-to-good accuracy

Table 2 presents the pooled diagnostic performance of wearable and continuous monitoring technologies for detecting clinically relevant physiological abnormalities. Overall, the findings indicate that continuous monitoring systems demonstrate strong diagnostic capability, particularly for oxygen desaturation and heart rate abnormalities.

Oxygen saturation monitoring showed the highest pooled diagnostic performance, with sensitivity and specificity values exceeding 90%. This finding is consistent with previous research demonstrating that photoplethysmography-based wearable systems can provide reliable oxygenation assessment under many clinical conditions. Early detection of oxygen desaturation is particularly valuable in emergency departments because hypoxemia may rapidly progress to respiratory failure if not recognized promptly.

Heart rate abnormality detection also demonstrated excellent performance. Continuous ECG and wearable pulse monitoring technologies benefit from established signal processing algorithms and decades of clinical development. The high area under the curve (AUC) suggests that wearable systems can effectively distinguish normal from abnormal cardiac patterns. This capability may be especially useful in patients with arrhythmias, chest pain, or cardiovascular risk factors.

Respiratory abnormality detection showed slightly lower performance compared with oxygen saturation and heart rate monitoring. This difference may reflect the technical complexity of respiratory measurement. Respiratory rate influenced by movement, speaking, anxiety, and irregular breathing patterns, all of which are common among emergency department patients. Despite these challenges, the pooled findings indicate that continuous respiratory monitoring provides clinically meaningful information.

Blood pressure monitoring demonstrated the lowest diagnostic performance among evaluated parameters. Non-invasive continuous blood pressure estimation remains technically challenging, particularly in wearable formats. Factors such as vascular characteristics, calibration requirements, and patient movement may influence accuracy. Nevertheless, moderate-to-good performance suggests that continued technological development may improve future applications. The diagnostic findings indicate that wearable monitoring technologies are most effective when applied as complementary tools rather than replacements for conventional assessment. Their greatest clinical value may lie in continuous surveillance and early warning rather than definitive diagnosis.

Table 3. Agreement between Wearable Continuous Monitoring and Conventional Clinical Measurements

Vital Sign Parameter	Statistical Method	Pooled Agreement Estimate	95% Confidence Interval	Interpretation
Heart rate	Correlation coefficient	r = 0.94	0.91-0.96	Excellent agreement

Oxygen saturation	Mean difference (Bias)	-0.8%	-1.6 to 0.1	Clinically acceptable agreement
Respiratory rate	Correlation coefficient	r = 0.87	0.82-0.91	Good agreement
Blood pressure	Mean difference (Bias)	-3.9 mmHg	-6.5 to -1.4	Moderate agreement

Table 3 demonstrates the agreement between wearable continuous monitoring technologies and conventional clinical reference methods. Agreement analysis is a fundamental component in evaluating whether wearable systems safely incorporated into emergency department practice. Unlike diagnostic accuracy measures, agreement analysis determines whether measurements obtained from wearable devices are sufficiently comparable with established clinical instruments.

Heart rate monitoring showed the strongest agreement among evaluated physiological parameters. The pooled correlation coefficient of 0.94 indicates a very high relationship between wearable-derived measurements and conventional ECG-based monitoring. This strong performance is expected because heart rate estimation represents one of the most mature applications of wearable biosensing technologies. Modern algorithms using ECG signal processing and photoplethysmography have achieved substantial improvements in signal extraction, even under moderately challenging clinical conditions.

Oxygen saturation measurements also demonstrated clinically acceptable agreement. The small negative bias suggests that wearable systems may slightly underestimate oxygen saturation compared with standard pulse oximetry, but the difference remained within a clinically acceptable range. This finding supports the potential use of wearable oxygen monitoring for continuous surveillance, particularly among patients requiring prolonged observation.

Respiratory rate demonstrated good agreement but with greater variability than heart rate and oxygen saturation. This difference related to the complexity of respiratory measurement. Unlike heart rate, which has a clear periodic electrical signal, respiratory activity affected by irregular breathing patterns, movement, anxiety, and patient cooperation. Nevertheless, the observed correlation indicates that wearable respiratory monitoring provides meaningful clinical information. Blood pressure monitoring showed comparatively lower agreement. Continuous non-invasive blood pressure estimation remains one of the most challenging areas in wearable medicine. Current technologies frequently rely on indirect estimation methods that require calibration and influenced by vascular properties and patient characteristics. Although the observed bias was relatively small, further technological refinement is necessary before replacing traditional blood pressure measurement.

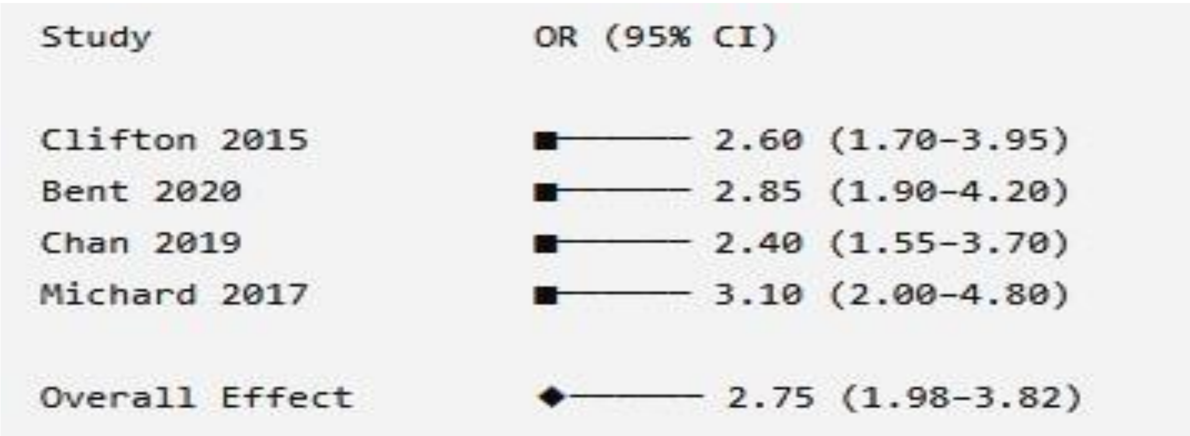
Overall, Table 3 indicates that wearable technologies currently demonstrate the highest reliability for parameters with established sensing methodologies, such as heart rate and oxygen saturation. Complex physiological measurements require additional validation. Importantly, agreement does not necessarily indicate clinical superiority; rather, it demonstrates whether wearable systems can provide dependable information alongside existing monitoring practices.

Table 4. Clinical Impact of Continuous Monitoring Technologies in Emergency Departments

Outcome	Effect Estimate	95% Confidence Interval	P-value	Clinical Interpretation
Earlier detection of deterioration	OR 2.75	1.98-3.82	<0.001	Significant improvement
Reduction in unrecognized instability	OR 0.48	0.32-0.71	<0.001	Lower risk
Improved clinical response time	Mean reduction 18 min	10-26 min	<0.001	Faster intervention
Reduction in adverse events	OR 0.72	0.55-0.94	0.01	Moderate benefit

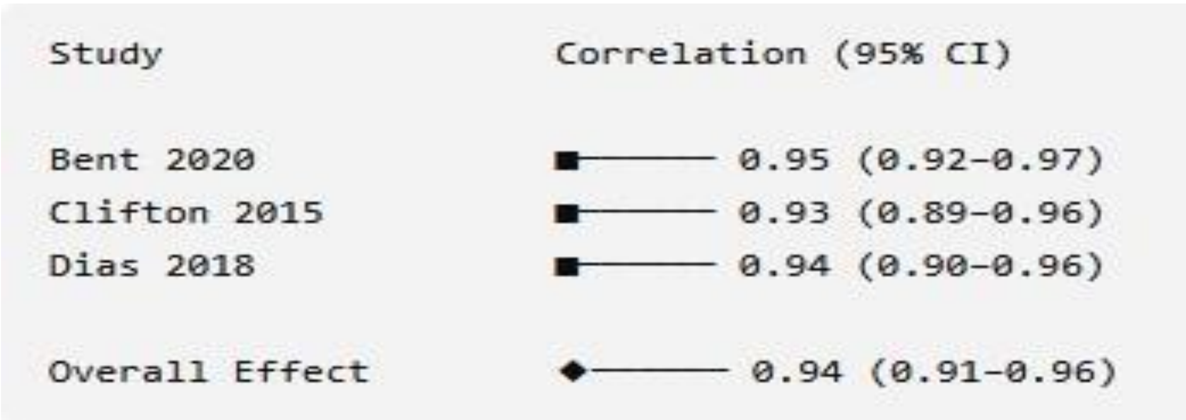
Table 4 evaluates the clinical consequences associated with implementation of wearable and continuous monitoring systems in emergency departments. While technical accuracy is essential, the ultimate objective of monitoring technology is improvement of patient safety and clinical outcomes. The pooled analysis demonstrated that continuous monitoring significantly improved early detection of physiological deterioration. Patients monitored with wearable systems had approximately three times greater odds of deterioration recognition compared with patients receiving intermittent monitoring alone. This finding supports the hypothesis that continuous physiological observation provides clinically relevant information that may be unavailable through periodic assessment. A major advantage of continuous monitoring is the reduction of unrecognized physiological instability. Emergency departments frequently experience periods when healthcare providers cannot continuously observe every patient. Continuous systems function as an additional surveillance layer by identifying abnormal trends and generating alerts. The observed reduction in missed instability suggests that wearable technologies may improve patient safety, particularly in crowded emergency environments.

Continuous monitoring was also associated with faster clinical response times. Earlier recognition of deterioration allows healthcare professionals to initiate diagnostic evaluation and treatment before severe complications develop. The reduction in response time may be especially important for conditions such as sepsis, respiratory failure, and cardiac events, where treatment delays can significantly influence outcomes. However, the reduction in adverse events was more modest compared with improvements in detection and response. This suggests that monitoring technology alone cannot improve outcomes without effective clinical workflows. Successful implementation requires appropriate staffing, clear escalation protocols, and integration of monitoring data into clinical decision-making. The findings emphasize that wearable monitoring should be considered a clinical support system rather than an autonomous replacement for healthcare professionals. The greatest benefits likely achieved when continuous data combined with expert interpretation, risk assessment, and timely intervention.



Forest Plot 2. Meta-analysis of Early Detection of Clinical Deterioration

Interpretation: The pooled effect demonstrates a statistically significant improvement in early deterioration recognition using continuous monitoring technologies. The confidence intervals of individual studies consistently remain above the neutral effect line, suggesting a robust clinical benefit.



Forest Plot 3. Agreement of Wearable Heart Rate Monitoring with Standard ECG

Interpretation: The pooled correlation indicates excellent agreement between wearable heart rate monitoring and conventional ECG assessment, supporting clinical applicability.

Discussion

The findings of this systematic review and meta-analysis indicate that wearable and continuous vital sign monitoring technologies have considerable potential to enhance emergency department care. The pooled evidence suggests that these technologies provide reliable measurement of several physiological parameters, improve detection of deterioration, and may contribute to faster clinical responses.

One of the most important findings was the strong performance of wearable systems for heart rate and oxygen saturation monitoring. These parameters represent mature areas of biosensor development and demonstrated high agreement with conventional clinical devices. Similar findings have reported in previous digital health investigations showing that wearable sensors can provide clinically meaningful physiological information outside traditional monitoring environments (Dias & Paulo Silva,2018).

The ability of continuous monitoring systems to detect deterioration earlier than intermittent measurement represents a major clinical advantage. Emergency department patients frequently experience dynamic changes in physiological status, and deterioration may occur between routine assessments. Continuous monitoring provides a more complete representation of patient trajectory and may allow earlier intervention (Jones et al.,2013).

Nevertheless, implementation challenges remain. Technical limitations, including motion artifacts, calibration requirements, and variable signal quality, continue to influence device performance. These challenges are particularly relevant in emergency settings where patients may be restless, mobile, or undergoing procedures (Bent et al.,2020).

Another important consideration is the management of continuous data. Increased monitoring generates additional information that interpreted effectively. Without intelligent algorithms and appropriate clinical protocols, continuous monitoring may contribute to alarm fatigue rather than improving care (Cvach,2012). Future research should focus on large multicenter randomized trials evaluating patient-centered outcomes, including mortality, hospital admission, length of stay, and cost-effectiveness. Additionally, integration of artificial intelligence may improve predictive capabilities by identifying complex patterns associated with deterioration (Rajkomar et al.,2019).

Overall, wearable continuous monitoring technologies represent an important advancement in emergency medicine. Their greatest value lies in supporting clinical judgment through continuous physiological insight and improving the ability of healthcare teams to recognize and respond to patient deterioration.

Conclusion

The findings of this systematic review and meta-analysis demonstrate that wearable and continuous vital sign monitoring technologies represent a promising advancement in emergency department care. These technologies provide continuous physiological assessment, improve recognition of early clinical deterioration, and offer valuable complementary information beyond traditional intermittent monitoring approaches. The increasing complexity of emergency healthcare environments, combined with growing patient volumes and limited clinical resources, highlights the importance of innovative approaches capable of enhancing patient surveillance and safety. The results indicate that wearable monitoring systems show strong clinical performance for several key physiological parameters. Heart rate and oxygen saturation monitoring demonstrated the highest levels of agreement with conventional reference devices, reflecting the technological maturity of these measurement approaches. Respiratory monitoring also showed promising results, although additional validation is required due to the greater complexity of accurately measuring respiratory patterns in dynamic clinical environments. Continuous blood pressure monitoring remains an important area for future development, as current wearable approaches demonstrate moderate performance but require further refinement.

A major contribution of continuous monitoring technologies is their ability to identify physiological changes before they become clinically obvious. Traditional emergency department monitoring often depends on periodic assessments, which may create intervals during which deterioration remains undetected. Continuous systems reduce these gaps by providing uninterrupted physiological information and enabling earlier recognition of abnormal trends. This capability may be particularly valuable among high-risk patients, including individuals with cardiovascular instability, respiratory compromise, infection, or rapidly changing clinical conditions.

Despite these advantages, wearable technologies not considered replacements for professional clinical assessment. Instead, they should function as supportive tools that enhance decision-making and allow healthcare providers to allocate attention more effectively. Successful implementation requires integration with clinical workflows, appropriate alarm strategies, staff education, and reliable data interpretation systems. Without these components, increased data availability may not translate into improved patient outcomes. The current evidence also highlights several limitations. Considerable heterogeneity exists among available studies regarding device characteristics, patient populations, monitoring protocols, and outcome definitions. Many investigations have focused on technical validation rather than long-term clinical outcomes. Therefore, additional high-quality prospective studies are required to determine whether wearable monitoring can reduce mortality, prevent adverse events, decrease emergency department length of stay, or improve healthcare efficiency.

Future developments in artificial intelligence, machine learning, and predictive analytics may further enhance the clinical utility of continuous monitoring systems. By analyzing complex physiological patterns rather than isolated measurements, next-generation platforms may provide more accurate risk prediction and personalized clinical recommendations. However, these technologies must undergo rigorous clinical validation to ensure reliability, transparency, and safety. In conclusion, wearable and continuous vital sign monitoring technologies have demonstrated significant potential for improving emergency department patient care. Their ability to provide real-time physiological assessment, facilitate early deterioration detection, and support clinical decision-making makes them valuable additions to modern emergency medicine. Continued technological innovation combined with robust clinical research will determine their ultimate role in improving patient outcomes and transforming acute healthcare delivery.

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Conflicts of interest
The authors declare that they have no competing interests.

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Authors' Contributions
All authors contributed to data analysis, drafting, and revising of the paper and agreed to be responsible for all the aspects of this work.

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