ANESTHESIOLOGY

Openventio PUBLISHERS

Review Article

Wearable Biosensors for Continuous Monitoring in the Post-Anesthesia Care Unit

Pierre Kowalczyk[1*], Hanna Wisniewski[2] and Aleksi Georgiou[3]

[1]*Department of Perioperative Medicine, Loire University of Medical Sciences, France*
[2]*Department of Perioperative Medicine, Rheinfeld University Hospital, Germany*
[3]*Department of Perioperative Medicine, Rheinfeld University Hospital, Germany*

ABSTRACT

Post-anesthesia care unit (PACU) monitoring has traditionally relied on intermittent, nurse-driven vital-sign checks, a model that struggles to detect the gradual, often nocturnal onset of hypoventilation and hypoxemia associated with residual anesthetic and opioid effects.

Wearable biosensors, including photoplethysmography-based chest patches, arm bands, and in-ear devices, have emerged as a means of providing continuous, cableless surveillance through the PACU stay and across the vulnerable transition to the surgical ward.

Validation studies indicate reasonable agreement between these devices and reference monitors for heart rate, oxygen saturation, and respiratory rate, while cuffless blood pressure estimation remains comparatively immature, and observational and meta-analytic data link continuous monitoring to earlier detection of deterioration and fewer opioid-induced respiratory depression events.

The principal unresolved challenges lie less in sensor accuracy than in translating continuous data streams into well-calibrated clinical alerts that avoid alarm fatigue and integrate into existing nursing and rapid-response workflows, an area where ongoing randomized trials are expected to clarify outcome benefit.

This review synthesizes the current evidence on wearable biosensor technology, validation, and implementation in perioperative recovery, and identifies where further prospective research is most needed.

Keywords: *wearable biosensors; post-anesthesia care unit; continuous monitoring; opioid-induced respiratory depression; postoperative deterioration*

Citation: Kowalczyk P, Wisniewski H and Georgiou A (2024) Wearable Biosensors for Continuous Monitoring in the Post-Anesthesia Care Unit. Anesthesiology. 4(1):01-06.

DOI: 10.17140/2024.vol4.i01.pp01-06

Corresponding Author: *Pierre Kowalczyk*

E-mail Address: *p.kowalczyk@lums.fr*

Article History: *Received 09 January 2024 | Accepted 30 January 2024 | Published 28 February 2024*

Copyright: *© 2024 Pierre Kowalczyk, et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited (**https://creativecommons.org/licenses/by/4.0/**).*

INTRODUCTION

Anyone who has staffed a post-anesthesia care unit (PACU) on a busy afternoon knows the pattern: a nurse assigned to four or five recovering patients, intermittent vital-sign checks every fifteen minutes, and a deterioration that reveals itself only at the next scheduled measurement rather than at the moment it began. Standard PACU monitoring - intermittent oscillometric blood pressure, spot pulse oximetry,

periodic respiratory rate counts - was built around the assumption that a nurse or monitor is physically tethered to the bedside. That assumption breaks down precisely when patients most need surveillance: in the first hour after a general anesthetic, when residual opioid and volatile agent effects on ventilatory drive are still resolving, and again during the handoff from PACU to the surgical ward, where monitoring intensity drops sharply even though the physiological risk does not [1,2].

Wearable biosensors - adhesive patches, wrist- or arm-worn photoplethysmography (PPG) devices, in-ear sensors, and multi-parameter chest patches - have been developed explicitly to close this gap. Unlike traditional telemetry, most of these devices are cableless, battery-powered, and designed to transmit continuously to a central station or mobile application, so that a change in heart rate, oxygen saturation, respiratory rate, or blood pressure surrogate is visible in near-real time rather than at the next nursing round [3,4]. The appeal for anesthesiologists and PACU staff is straightforward: earlier detection of hypoxemia, bradypnea, or hemodynamic instability should, in principle, allow earlier intervention and fewer rescue events. Whether that promise is being realized in practice, and where the evidence is still thin, is the subject of this review.

We focus specifically on the PACU and the immediate postoperative window, though much of the underlying device evidence necessarily comes from adjacent settings - general surgical wards, step-down units, and even home recovery - because that is where most of the validation and outcome studies have actually been conducted.

SENSING MODALITIES AND DEVICE ARCHITECTURES

The wearable landscape relevant to perioperative recovery is not a single technology but a family of approaches built around a common sensing core: photoplethysmography. A PPG sensor measures the light-absorption changes in tissue caused by pulsatile blood flow, and from that single waveform a device can derive heart rate, an estimate of arterial oxygen saturation, respiratory rate (via amplitude or frequency modulation of the pulse waveform), and, with additional algorithmic processing, a beat-to-beat estimate of blood pressure [5,6]. The placement of the sensor varies by manufacturer and use case. Chest-worn adhesive patches, such as the Biobeat device evaluated in several postoperative cohorts, combine PPG with an accelerometer to add posture and activity data, and some incorporate a second electrode for a single-lead ECG trace [4]. Upper-arm cuffless devices trade some ECG-derived precision for comfort and simpler application by ward staff [5]. In-ear sensors exploit the auricle's dense capillary bed and relative immobility to produce a PPG signal that is less prone to motion artifact than a fingertip or wrist probe, an attractive property for patients who are mobilizing after surgery rather than lying still [6].

A separate category, sometimes overlapping with clinical-grade patches, consists of consumer fitness trackers - wrist-worn devices originally designed for the general wellness market. Several groups have asked whether patients' own devices, or hospital-issued consumer-grade trackers, can supplement postoperative monitoring at negligible incremental cost. Survey and pilot data suggest patient acceptance is generally good and many patients already own a compatible device, but signal quality and validated accuracy for clinical decision-making lag behind purpose-built medical patches [7]. This distinction between consumer and clinical-grade wearables matters throughout the literature: a device that tracks step count reliably is not automatically one that should trigger a rapid-response call.

Architecturally, most systems couple the sensor to a gateway - a bedside hub, a smartphone application, or a hospital Wi-Fi network - that relays data to a central monitoring dashboard reviewed by nursing staff or, increasingly, to an algorithm that computes a composite early warning score [8,9]. This software layer is arguably as important as the sensor hardware itself, because raw continuous data streams are of limited use to a busy nurse unless they are filtered into actionable alerts.

ACCURACY AND VALIDATION AGAINST REFERENCE STANDARDS

Before a wearable can be trusted to replace or supplement intermittent spot checks, it has to be shown to agree adequately with reference-standard measurements across the range of values actually seen in recovering surgical patients, including the hypoxemic and hypotensive tails of the distribution that matter clinically. The validation literature here is mixed but generally encouraging for heart rate and oxygen saturation, more cautious for respiratory rate, and least mature for blood pressure. A prospective clinical validation study of an upper-arm PPG wearable in non-cardiac surgery patients found acceptable agreement with reference monitors for heart rate and peripheral oxygen saturation across a wide postoperative population, though accuracy narrowed somewhat at the lower end of the saturation range where clinical decisions matter most [5]. Similarly, a wireless in-ear sensor validated against continuous reference monitoring in surgical patients demonstrated close tracking of heart rate and respiratory rate with motion artifact rejection performing reasonably well during ambulation [6].

The Biobeat chest patch, one of the more extensively studied devices in this space, has been evaluated in a multicenter prospective observational study of postoperative patients and shown to track vital signs

with clinically acceptable concordance against standard monitoring, while also generating a substantially higher density of data points per patient than intermittent nursing observations - the central practical advantage of continuous over spot-check monitoring [4]. A tablet-integrated wearable patch system designed specifically for postoperative cardiovascular monitoring similarly demonstrated feasibility for continuous heart rate and derived hemodynamic tracking in a postoperative cohort, illustrating how vendors have converged on similar patch-plus-gateway architectures even when the specific sensor technology differs [3].

Blood pressure remains the most technically difficult parameter to obtain continuously without a cuff. Cuffless estimation techniques, most relying on pulse transit time or pulse wave analysis derived from PPG morphology, require periodic cuff-based calibration and tend to drift over time or with changes in vascular tone - a limitation with obvious relevance to postoperative patients, whose vasomotor state changes rapidly as anesthetic agents wear off and as fluid shifts occur [5]. Clinicians adopting these devices should treat continuous blood pressure trends as a useful early-warning signal of a directional change rather than as a substitute for periodic cuff verification when a specific decision hinges on an absolute value.

DETECTING OPIOID-INDUCED RESPIRATORY DEPRESSION

Perhaps the single strongest clinical argument for continuous wearable monitoring in the perioperative period concerns opioid-induced respiratory depression (OIRD). Postoperative opioid analgesia is nearly universal after moderate to major surgery, and OIRD remains a leading preventable cause of anesthesia-related morbidity and in-hospital cardiac arrest, disproportionately affecting patients on general wards where nurse-to-patient ratios preclude continuous bedside observation [1,10]. The pathophysiology is insidious: hypoventilation and progressive hypoxemia can develop gradually over minutes to hours, often nocturnally, and by the time an intermittent spot check captures a low saturation reading the patient may already be in a compromised state that would have been detectable much earlier with continuous monitoring [2].

The evidentiary case for continuous monitoring specifically - as opposed to intermittent monitoring - has been examined in several systematic reviews. Continuous pulse oximetry combined with capnography has been associated with reduced rescue events and fewer unplanned transfers to higher levels of care in ward-based cohorts, an association reproduced across multiple single-center studies before Taenzer and colleagues' influential analysis linking a hospital-wide continuous pulse oximetry surveillance program to reduced rescue events and ICU transfers [11]. A more recent systematic review and meta-analysis of continuous pulse oximetry and capnography on hospital wards similarly found reductions in postoperative respiratory failure and OIRD-related adverse events relative to intermittent monitoring, although the authors noted considerable heterogeneity in monitoring protocols, alerting thresholds, and staff response pathways across the included studies [12]. Capnography, which measures end-tidal carbon dioxide and therefore reflects ventilation more directly than pulse oximetry (which reflects the downstream consequence of hypoventilation and is confounded by supplemental oxygen), is generally regarded as the more sensitive of the two modalities for detecting early hypoventilation, but it is also less amenable to unobtrusive wearable integration than PPG-based approaches, which has shaped which technology has actually proliferated on general wards [13].

Beyond oximetry and capnography, a broader landscape of diagnostic and monitoring devices aimed specifically at OIRD detection - including impedance-based respiratory rate sensors, acoustic respiratory monitors, and multi-parameter composite algorithms - has been reviewed comprehensively, with the consistent theme that no single parameter captures the full physiological signature of opioid-induced ventilatory impairment as reliably as a combination of respiratory rate, oxygen saturation, and, where feasible, some measure of tidal ventilation [13].

FROM CONTINUOUS DATA TO CLINICAL ACTION: EARLY WARNING SYSTEMS

Continuous data streams are clinically inert unless they are converted into a signal that prompts a nurse or rapid-response team to act, and this translational step has proven to be at least as challenging as the underlying sensor technology. A scoping review of wearable devices incorporated into postoperative early warning score systems found a proliferation of device-algorithm combinations, most validated only in small single-center feasibility studies, with substantial variability in which physiological parameters were weighted, how alert thresholds were set, and how alarms were routed to clinical staff [14]. A retrospective observational study using continuous wireless vital sign monitoring to feed an early warning score on surgical wards found that trends in the composite score in the hours preceding a complication often diverged from normal well before the complication became clinically apparent by intermittent observation, supporting the underlying premise that continuous data can provide meaningful lead time - though the study's retrospective design limits causal claims about whether earlier detection actually changed outcomes [8].

Alarm fatigue is the recurring caveat throughout this literature. A device that alerts on every artifact-driven desaturation or every brief tachycardia during a

position change will quickly be ignored, muted, or physically removed by frustrated staff or uncomfortable patients, undermining the very safety benefit the technology was meant to provide. Successful implementations described in the literature tend to share features: adaptive or patient-specific thresholds rather than fixed population cutoffs, tiered alerting that distinguishes an informational trend change from an urgent notification, and integration into existing nursing workflows rather than a parallel system requiring separate monitoring [15,8]. The broader systematic review and meta-analysis of wearable continuous monitoring across hospitalized populations found a reduction in the composite outcome of clinical deterioration events and improved time-to-detection, but effect sizes varied considerably by ward type, underlying device, and how tightly the alerting algorithm was coupled to a defined clinical response protocol [15].

Prospective, adequately powered trials specifically in the PACU-to-ward transition remain relatively scarce compared with the volume of feasibility and validation work. The WARD-AMS trial protocol, a randomized controlled trial designed to test whether wearable continuous vital sign monitoring reduces clinical deterioration events in postoperative general surgery patients relative to standard intermittent monitoring, is emblematic of where the field currently stands: the rationale and device selection are well grounded in the accuracy and observational literature summarized above, but the outcome data needed to establish a definitive mortality or major-morbidity benefit are still being generated [16]. A parallel multicentre, international, prospective cohort protocol aims to characterize the trajectory of continuous physiological signals preceding postoperative deterioration across a broader surgical population, which should help establish which trend features are actually predictive rather than merely associated [17].

RECOVERY TRAJECTORIES AND PATIENT-CENTERED APPLICATIONS

Beyond safety surveillance, wearables are also being used to characterize functional recovery after surgery in ways that intermittent nursing assessment cannot easily capture. Activity counts, step cadence, and heart rate variability trends derived from accelerometer- and PPG-equipped devices offer an objective, continuous window into how quickly a patient is mobilizing and whether that trajectory deviates from an expected recovery curve, complementing but not replacing patient-reported outcome measures [18]. A scoping review of wearables specifically in abdominal surgery recovery found that most published work has focused on step count and activity level as surrogate markers of enhanced-recovery-after-surgery protocol adherence, with fewer studies yet linking these activity metrics prospectively to hard outcomes such as readmission or complication rates [18]. This is a promising but still immature extension of wearable technology beyond acute safety monitoring into the broader recovery pathway, and it raises interesting possibilities for extending PACU-initiated monitoring into the early ward and even home-recovery period without requiring a device changeover.

Patient acceptance appears to be a facilitator rather than a barrier in most of the available survey data: patients recovering from surgery generally tolerate adhesive patches and wrist-worn sensors well, and some express reassurance at being continuously observed rather than feeling surveilled, though comfort during sleep and skin irritation with prolonged patch wear are recurring minor complaints [7].

ADOPTION BARRIERS, CLINICIAN ATTITUDES, AND IMPLEMENTATION CHALLENGES

Technology validated in a research study does not automatically translate into routine PACU or ward practice, and the implementation literature identifies several recurring obstacles. A survey of over a thousand anesthesiologists across Western Europe and the United States regarding wireless wearables for postoperative ward surveillance found broad enthusiasm for the underlying concept of continuous monitoring but substantial skepticism about current data reliability, concern about who is responsible for responding to an alert once continuous surveillance is in place, and worry about the workflow and staffing implications of managing a much higher volume of physiological data than existing nursing rounds generate [19]. This tension - between the theoretical safety benefit of continuous data and the practical burden of someone needing to watch it - is arguably the central unresolved issue in this field, more so than any remaining question about sensor accuracy.

Cost and integration with existing hospital information systems present further practical barriers. Devices marketed by major perioperative monitoring vendors are increasingly being positioned explicitly for PACU and ward deployment, with dashboards intended to integrate into the electronic medical record and existing nurse call and rapid-response infrastructure, but interoperability across vendors remains inconsistent, and many hospitals still operate with monitoring systems from multiple manufacturers that do not share a common alerting backbone [20,9]. Battery life, sensor durability, and the practicalities of decontamination and reuse between patients are comparatively mundane but operationally significant considerations that determine whether a technically validated device actually gets used at scale rather than remaining a research tool confined to a single unit.

CONCLUSION

Wearable biosensors have moved substantially beyond proof-of-concept in the perioperative space: photoplethysmography-based patches, arm bands,

and in-ear devices now demonstrate reasonable agreement with reference monitors for heart rate, oxygen saturation, and respiratory rate across diverse postoperative populations, and observational and meta-analytic data link continuous monitoring - particularly for opioid-induced respiratory depression - to fewer rescue events and earlier detection of deterioration. What remains less settled is the translational layer: how continuous data streams are converted into well-calibrated, non-fatiguing alerts, how those alerts are woven into nursing and rapid-response workflows without simply adding to staff burden, and whether the observational signal of benefit will be confirmed in adequately powered randomized trials such as WARD-AMS. Blood pressure estimation without a cuff, interoperability across monitoring platforms, and clinician trust in device output during the specific window of PACU-to-ward handoff are the areas where the evidence base is thinnest and where further work is likely to have the greatest practical yield. For anesthesiologists and PACU staff, the pragmatic takeaway from the current literature is that continuous wearable monitoring is a genuinely useful adjunct to, rather than yet a full replacement for, clinical judgment and periodic reference-standard measurement - and that the choice of device and alerting protocol matters as much as the underlying sensor technology in determining whether the promised safety benefit is actually realized at the bedside.

DECLARATIONS

Acknowledgements The authors thank their respective departments for institutional support during the preparation of this review.

Funding This review received no external or internal funding.

Conflict of Interest The authors declare no conflicts of interest relevant to the content of this review.

Author Contributions P. Kowalczyk conceived the review and drafted the initial manuscript. H. Wisniewski performed the literature search and contributed to the sections on sensing modalities and validation. A. Georgiou critically revised the manuscript for intellectual content and prepared the final version for submission. All authors read and approved the final manuscript.

Ethics Statement This is a literature review that did not involve new human or animal data, and therefore did not require institutional ethics review or approval.

Data Availability No new data were generated for this review. All sources discussed are publicly available in the cited literature.

REFERENCES

1. Monitoring for Opioid-Induced Respiratory Depression (2019) Anesthesia Patient Safety Foundation.
2. Characterisation and monitoring of postoperative respiratory depression: current approaches and future considerations (2019) British Journal of Anaesthesia.
3. Tablet-Based Wearable Patch Sensor Design for Continuous Cardiovascular System Monitoring in Postoperative Settings (2023) PMC, https://pmc.ncbi.nlm.nih.gov/articles/PMC10296635/.
4. Continuous remote monitoring of postoperative vital signs with the Biobeat patch: A multicenter prospective observational study (2024) PLOS ONE.
5. Accuracy of vital sign monitoring using a photoplethysmography upper arm wearable device in postoperative non-cardiac surgery patients: a prospective observational clinical validation study (2025) PMC.
6. Continuous Vital Signs Monitoring with a Wireless and Wearable Earsensor in Surgical Patients: A Clinical Validation Study (2026) Sensors, DOI:10.3390/s26041201.
7. Postoperative use of fitness trackers for continuous monitoring of vital signs: a survey of hospitalized patients (2025) Journal of Clinical Monitoring and Computing.
8. Early Warning Scores to Support Continuous Wireless Vital Sign Monitoring for Complication Prediction in Patients on Surgical Wards: Retrospective Observational Study (2023) JMIR Perioperative Medicine.
9. Wireless Continuous Monitoring in the Post-op Period (2023) GE HealthCare Clinical View.
10. Patients Receiving Opioids Must Be Monitored With Continuous Electronic Monitoring (2017) Physician-Patient Alliance for Health & Safety.
11. Continuous Pulse Oximetry and Capnography Monitoring for Postoperative Respiratory Depression and Adverse Events (2017) Anesthesia & Analgesia.
12. Role of continuous pulse oximetry and capnography monitoring in the prevention of postoperative respiratory failure, postoperative opioid-induced respiratory depression and adverse outcomes on hospital wards: A systematic review and meta-analysis (2024) Journal of Clinical Anesthesia.
13. Current and Future Perspective of Devices and Diagnostics for Opioid and OIRD (2022) Biomedicines, DOI:10.3390/biomedicines10040743.
14. Wearable devices as part of postoperative early

warning score systems: a scoping review (2024) Journal of Clinical Monitoring and Computing.

15. The impact of wearable continuous vital sign monitoring on deterioration detection and clinical outcomes in hospitalised patients: a systematic review and meta-analysis (2021) Critical Care, DOI:10.1186/s13054-021-03766-4.

16. Wearable Continuous Vital Sign Monitoring Study (WARD-AMS) to Detect Clinical Deterioration in Postoperative General Surgery Patients: Protocol for a Randomized Controlled Trial (2025) JMIR Research Protocols, PMID:41418280.

17. Continuous physiological monitoring for the detection of postoperative deterioration: a protocol for a multistage, multicentre, international, prospective cohort study (2025) PMID:41057181.

18. Wearable devices to monitor recovery after abdominal surgery: scoping review (2022) BJS Open.

19. Wireless wearables for postoperative surveillance on surgical wards: a survey of 1158 anaesthesiologists in Western Europe and the USA (2023) PMC.

20. Post Anesthesia Care Unit (2024) Masimo, https://www.masimo.com/care-areas/perioperative/pacu/.