

Smart Watches to Monitor Depth of Anesthesia: A Feasibility Study Using Wearable Technology

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Abstract

Background: Accurate monitoring of the depth of anesthesia (DoA) is essential for ensuring patient safety, optimizing drug titration, and preventing intraoperative awareness or excessive anesthetic administration. While the Bispectral Index (BIS) remains the established standard for DoA monitoring, its high cost and limited availability restrict its use in resource-constrained healthcare settings. In recent years, wearable consumer technologies such as smartwatches—equipped with physiological sensors—have emerged as potential low-cost adjuncts for perioperative monitoring. This study investigates the feasibility of leveraging smartwatch-derived physiological parameters to correlate with BIS-based DoA assessment.

Methods: A prospective observational study was carried out on 60 American Society of Anesthesiologists (ASA) physical status I–II patients scheduled for elective surgical procedures under general anesthesia. Each patient wore a commercially available smartwatch capable of tracking heart rate variability (HRV), peripheral oxygen saturation (SpO₂), and movement through accelerometry. These parameters were continuously recorded and analyzed in parallel with intraoperative BIS readings. Correlation analysis was performed, and a machine learning–based integration model was applied to evaluate predictive accuracy.

Results: HRV data obtained from smartwatches demonstrated a strong inverse correlation with BIS values ($r = -0.68$, $p < 0.001$), suggesting that decreases in HRV reliably reflected deeper levels of anesthesia. SpO₂ fluctuations, particularly during induction and emergence, showed temporal alignment with transitions in anesthetic depth. When HRV and SpO₂ data were processed through a simple artificial intelligence (AI) algorithm, the model achieved 78% accuracy in distinguishing between light and deep anesthesia states.

Conclusion: Commercially available smartwatches show promising potential as supplementary tools for DoA monitoring. While they cannot yet replace BIS, their accessibility, affordability, and capacity for continuous data collection position them as valuable alternatives in low-resource environments. With advancements in algorithmic integration and refinement of sensor technology, wearable devices may contribute to the future of personalized, cost-effective perioperative monitoring and broaden access to safe anesthesia care globally.

Keywords: Anesthesia, Smartwatch, Depth of Anesthesia, Wearable Technology, BIS, Heart Rate Variability, Artificial Intelligence

Introduction

Monitoring the depth of anesthesia (DoA) represents a fundamental aspect of modern anesthetic care, directly impacting both patient safety and clinical outcomes. Precise titration of anesthetic agents is essential: inadequate dosing may result in intraoperative awareness with psychological sequelae, whereas excessive dosing can contribute to hemodynamic instability, delayed emergence, or postoperative cognitive

dysfunction. Thus, reliable DoA monitoring is indispensable for balancing efficacy with safety in perioperative management.(1)

Conventional modalities such as the Bispectral Index (BIS) have established themselves as robust tools for assessing anesthetic depth through electroencephalographic (EEG) analysis. BIS monitoring has been widely validated and is routinely employed in advanced healthcare environments. However, the relatively high cost of BIS monitors and their consumables, coupled with the need for specialized hardware, often restricts their availability to tertiary-care centers.(2) Consequently, patients in low- and middle-income regions, or in resource-limited hospitals, may be deprived of access to such advanced monitoring, potentially compromising anesthetic precision.(3)

Concurrently, the past decade has witnessed remarkable advancements in wearable technologies. Smartwatches, once regarded primarily as consumer lifestyle accessories, now incorporate sophisticated biosensors capable of continuously tracking heart rate variability (HRV), peripheral oxygen saturation (SpO₂), and physical activity through accelerometry.(4) These physiological signals are intimately linked with the autonomic nervous system, which itself is profoundly modulated by anesthetic administration. For instance, HRV tends to decline with deeper levels of anesthesia as parasympathetic and sympathetic influences are altered, while SpO₂ fluctuations and motion indices may provide additional indirect markers of anesthetic transitions.(5)

Given their affordability, portability, and wide commercial availability, smartwatches represent a potentially transformative adjunct for perioperative monitoring. If validated, such devices could offer an accessible means of estimating DoA in operating rooms worldwide, particularly in settings where conventional EEG-based monitoring is not feasible.(6)

The present study was therefore designed to investigate the feasibility of repurposing commercially available smartwatches for intraoperative DoA monitoring. Specifically, it aimed to assess the correlation between smartwatch-derived physiological parameters and BIS values, while exploring the preliminary application of algorithmic integration to predict anesthetic states(7)

Aims and Objectives

Primary Objective:

- To evaluate the correlation between smartwatch-derived HRV and BIS index during general anesthesia.

Secondary Objectives:

- To assess the reliability of SpO₂ and motion detection in predicting emergence.
- To determine the feasibility of using AI-based interpretation of smartwatch data to predict anesthetic depth.

Materials and Methods

Study Design

Prospective observational study conducted over 6 months at a tertiary-care academic hospital.

Sample Size

60 patients, aged 18–60, ASA grade I–II, undergoing elective surgeries under general anesthesia.

Inclusion Criteria

- Consent for smartwatch and BIS monitoring.
- No known arrhythmias or neurological disorders.

Exclusion Criteria

- Emergency surgeries.
- Patients with implanted cardiac devices or motion disorders.

Methodology

Each participant wore a Fitbit Sense 2 smartwatch synced to a data collection device via Bluetooth. Parameters monitored:

- HRV (using RMSSD metric)
- SpO₂
- Accelerometer motion

Simultaneously, a BIS monitor (Covidien) recorded DoA at 1-minute intervals.

Phases Observed:

- Induction
- Maintenance
- Emergence

Data was analyzed using Pearson correlation and regression models. A basic AI model (logistic regression classifier) was used to assess predictive power of wearable data for anesthetic depth.

Results

Demographics

- Mean age: 38.2 ± 11.5 years
- M:F ratio = 1:1.3
- Types of surgery: Laparoscopic (40%), ENT (30%), Orthopedic (30%)

Correlation of HRV with BIS

- Strong inverse correlation: $r = -0.68$, $p < 0.001$
(Higher HRV associated with lighter anesthesia)

SpO₂ and Motion Detection

- SpO₂ desaturation corresponded with anesthetic induction in 84% cases.

- Movement detection via accelerometer increased during light planes of anesthesia and pre-awakening phases.

AI Prediction Model

- Using smartwatch data alone, the model predicted DoA zones (light/moderate/deep) with:
 - Sensitivity: 81%
 - Specificity: 76%
 - Overall accuracy: 78%

Discussion

The present study demonstrates that commercially available smartwatches are capable of capturing meaningful physiological signals that parallel established indices of anesthetic depth.(8) While the Bispectral Index (BIS) continues to serve as the gold standard due to its EEG-based validation and clinical reliability, its single-purpose design, high acquisition cost, and limited availability constrain its universal use, particularly in low-resource or rural healthcare systems. Our findings suggest that wearable technologies, though originally intended for consumer fitness and wellness applications, may hold promise as cost-effective adjuncts in anesthetic monitoring.(9)

A key observation of this study was the robust inverse correlation between smartwatch-derived heart rate variability (HRV) and BIS values.(10) HRV is a well-recognized surrogate of autonomic nervous system balance, and its sensitivity to commonly used anesthetic agents such as propofol and sevoflurane aligns with existing neurophysiological evidence. Suppression of sympathetic activity and modulation of parasympathetic tone under anesthesia explain the observed decline in HRV as patients transitioned to deeper anesthetic states.(11) Thus, the ability of smartwatches to continuously and non-invasively track HRV provides anesthesiologists with a valuable proxy measure of DoA without requiring additional invasive instrumentation.(12)

Another noteworthy finding was the contribution of motion sensing. Subtle wrist micro-movements detected during the emergence phase were observed to precede measurable increases in BIS values.(13) This suggests that accelerometry data may serve as an early clinical signal of arousal, potentially offering anesthesiologists additional lead time to anticipate patient movement, awareness, or recovery.(14) Although such signals require further validation, their presence highlights the potential for multiparametric monitoring—where HRV, SpO₂, and motion data are integrated—to provide a richer understanding of anesthetic depth dynamics than any single parameter alone.(15)

Nevertheless, the present work also underscores practical limitations. Motion artifacts, environmental interference, and occasional Bluetooth connectivity disruptions may compromise data reliability, particularly in high-dependency or crowded operating room environments.(16) Furthermore, smartwatches are not designed to meet the stringent standards of medical-grade monitoring devices, raising questions regarding calibration, accuracy, and regulatory compliance.(17) Despite these limitations, their ubiquity, affordability, and capacity for continuous wireless data acquisition make them attractive candidates for integration into anesthesia dashboards. With advancements in artificial intelligence and signal processing, smartwatch-derived parameters could be harmonized with conventional monitors, thereby creating hybrid systems that extend monitoring capabilities even in resource-constrained settings.(18)

Taken together, these findings support the concept that wearable consumer devices may serve as scalable adjuncts to traditional anesthetic monitoring. While not intended to replace BIS or other EEG-based tools in high-resource settings, their deployment in rural hospitals, mobile surgical camps, or emergency environments could democratize access to DoA monitoring. Future research should focus on validating sensor accuracy, refining predictive algorithms, and establishing interoperability with clinical monitoring systems to realize the full potential of wearable technology in perioperative care.(19)

Limitations

- Single-center, small sample size.
- Limited to one smartwatch brand and one anesthetic protocol.
- No EEG data from smartwatch — limits direct comparison with BIS algorithm.

Conclusion

This study highlights the potential of commercially available smartwatches as adjunctive tools for monitoring the depth of anesthesia. By leveraging embedded sensors that capture heart rate variability (HRV) and peripheral oxygen saturation (SpO₂), smartwatches demonstrated a meaningful correlation with BIS-derived anesthetic depth indices.(20) Such findings underscore the capacity of wearable consumer technologies to provide clinically relevant physiologic insights, despite their original design for non-medical applications.(21)

As wearable devices continue to advance in sensor accuracy, data fidelity, and connectivity, their integration into anesthetic practice appears increasingly feasible.(22) The combination of smartwatch-derived physiologic signals with artificial intelligence–driven algorithms could enable real-time, multiparametric monitoring that is not only cost-effective but also accessible in environments where conventional BIS monitoring is impractical or unavailable.(23)

While these devices are not yet positioned to replace established EEG-based modalities, their affordability, portability, and widespread availability render them attractive as supplementary tools in perioperative care.(24) Particularly in rural, resource-limited, and emergency settings, smartwatches could help democratize access to advanced monitoring, thereby improving patient safety and anesthetic precision. Continued research, validation through larger clinical trials, and refinement of algorithmic integration will be essential to transform this proof-of-concept into a reliable, scalable solution for the future of anesthesia monitoring.(25)

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