

Wearable-Derived Data for Patient Frailty: Extending Hospital Frailty Risk Score While Confronting Bias and Inequities



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ABSTRACT

Objective, continuous measurements from wearable devices present a unique opportunity to enhance traditional, episodic clinical assessments of frailty by passively capturing real-world data on mobility, activity, and physiological signals. Integrating wearable-derived data with validated risk stratification tools like the Hospital Frailty Risk Score (HFRS) allows for earlier detection of functional decline across adults of all ages and supports timely, targeted interventions to prevent progression to severe frailty. However, deploying AI-enabled, wearable-based remote patient monitoring at scale requires confronting both device-related measurement biases and algorithmic inequities, particularly those affecting racially minoritized groups. Without rigorous validation and equity-driven calibration, these biases risk amplifying disparities in triage and clinical outcomes. This Perspective reviews recent advances in national-scale frailty risk analysis, the practical application of wearables in patient monitoring, and the critical need for performance auditing and inclusive algorithm design. It proposes a path forward for extending frailty dashboards with wearable data, emphasizing transparent validation across demographic strata, continuous post-deployment monitoring, equitable device access, and governance centered on clinical relevance. This proposal integrates continuous wearable monitoring data with the HFRS framework while centering equity-by-design principles and governance recommendations as co-equal priorities alongside technical integration. By prioritizing health need and function in algorithmic targets and validating models with locally representative data, health systems can realize the promise of AI-augmented frailty care while advancing equity and precision for all populations.

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Objective, continuous measurements from wearable devices offer a powerful complement to traditional, episodic clinical assessments. By passively capturing real-world data on mobility, activity, heart rate, and other physiological signals, these tools can reveal subtle signs of functional decline or recovery that intermittent clinic visits or questionnaires may miss, enabling earlier detection and more timely intervention. This capability positions wearables within the broader paradigm of remote patient monitoring (RPM), extending clinician oversight beyond episodic encounters into patients' daily lives. Recent analysis of the Hospital Frailty Risk Score (HFRS) across 1.48 million emergency admissions in England makes this opportunity urgent: frailty-related risks affect adults across all age groups, not just those aged ≥ 75 years: longer hospital stays and higher costs both increase with age, and frailty was also associated with higher in-hospital mortality, with the strongest association in the 65-74-year group.¹ We focus on HFRS because its reliance on administrative and ICD-coded data creates a natural integration point for continuous wearable-derived features, though other validated instruments, including the Clinical Frailty Scale (CFS) and electronic Frailty Index (eFI), could similarly benefit from wearable augmentation.² By identifying frailty risk in younger hospitalized adults through validated tools, health systems can implement targeted interventions. Including exercise, nutritional support, addressing socioeconomic barriers, that may prevent progression to severe frailty, expand years lived in good health, and reduce future demand for expensive acute care. This Perspective proposes integrating continuous wearable monitoring with the HFRS framework while centering equity-by-design principles, bias auditing, and governance as co-equal priorities alongside technical integration. However, realizing this potential requires pairing validated risk stratification with wearable-derived, AI-enabled monitoring to enable continuous, proactive assessment while deliberately addressing equity and measurement bias to avoid amplifying health disparities as data streams diversify.

Wearable sensors can augment frailty dashboards by surfacing dynamic signals, including step count, gait speed proxies, physical activity duration, sleep architecture, and heart rate variability, that enable earlier detection and targeted interventions. As a proof of concept for large-scale

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passive wearable monitoring, smartwatch-based atrial fibrillation screening at national scale demonstrated clinically meaningful positive predictive value, illustrating the feasibility of integrating passively collected physiological data into clinical decision-making.³ Digital phenotyping has similarly shown promise: smartphone-derived GPS data have been used to assess mobility in patients with glioblastoma, demonstrating how passively collected metrics such as time spent at home and distance traveled can objectively monitor functional status following neurosurgical interventions.⁴ Importantly, validated frailty-specific wearable algorithms remain limited, though accelerometry-derived gait speed estimation and continuous physical activity phenotyping are under active development. Integration into clinical workflows will also require regulatory clarity, including distinguishing FDA-cleared medical devices from consumer wearables, and reimbursement pathways such as CMS RPM codes to sustain adoption. For internists, wearable-augmented dashboards could generate alerts for declining activity or gait patterns, inform prehabilitation referrals, and support post-discharge frailty monitoring alongside HFRS scores.

Yet the translation of wearables into equitable frailty care hinges on rigorous validation across demographic groups and contexts, because device performance varies by activity state and device design, and error characteristics can shift with signal dynamics relevant to daily living.⁵ PPG accuracy is sensitive to motion and hardware/software pipelines, and comparative studies show significant device- and activity-dependent error even when mean accuracy at rest appears acceptable—an issue that can mislead AI models trained on free-living data if not explicitly modeled.⁵ Frailty-relevant wearable metrics (such as step count, gait speed, sleep duration) face analogous bias risks from sensor inaccuracy across skin tones and body habitus. The clinical consequences of optical sensing bias are well documented: pulse oximetry, a canonical PPG-based technology, has repeatedly been shown to overestimate arterial oxygenation more often in Black and other racially minoritized patients, producing “hidden hypoxemia” with downstream risks for undertreatment and worse outcomes.^{6–8} This pathway from PPG measurement bias to clinical decision disparities is depicted in Fig. 1. Without corrective calibration, stratified validation,

Pathway from Optical Sensing Bias to Clinical Disparity

How PPG measurement error may perpetuate inequitable care

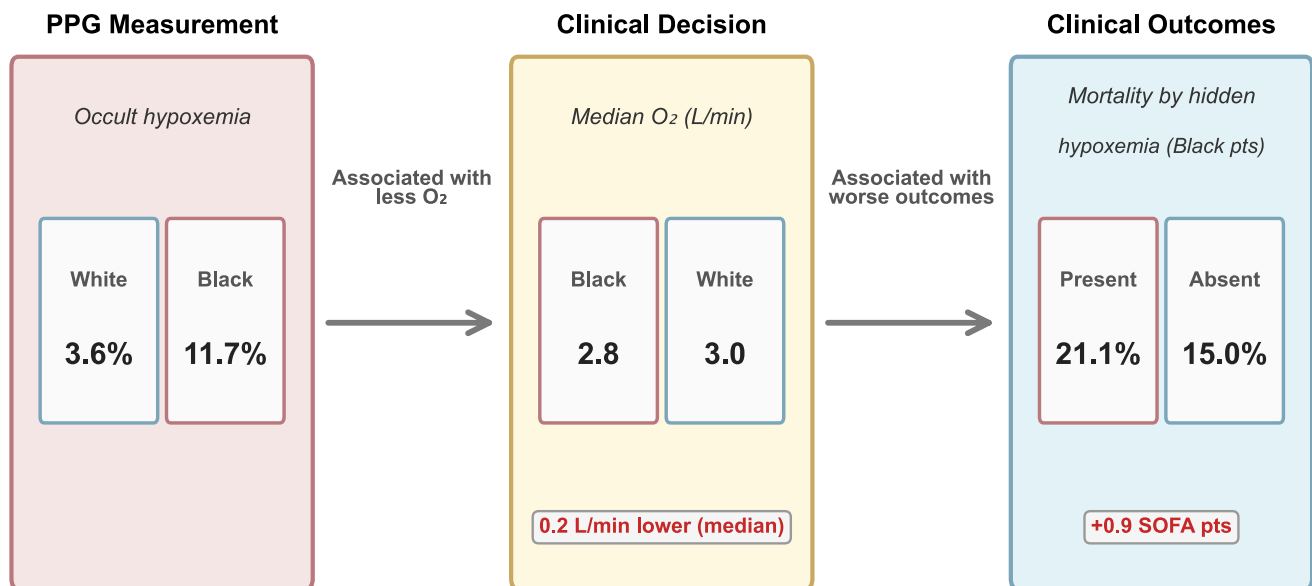


Figure 1 Pathway from optical sensing bias to clinical disparity in PPG-based measurements. PPG-based pulse oximetry overestimates arterial oxygen saturation more often in patients with darker skin, which raises the rate of occult (“hidden”) hypoxemia. The left panel shows occult hypoxemia, defined as an arterial oxygen saturation below 88% despite an SpO₂ of 92–96%, which occurred in 11.7% of Black patients and 3.6% of White patients in a University of Michigan cohort (Sjoding et al.). In the intensive care unit, Black patients received less supplemental oxygen than White patients (center panel; median 2.8 vs 3.0 L/min; adjusted difference –0.29 L/min, 95% CI –0.46 to –0.13) (Gottlieb et al.). The right panel reports outcomes: among Black patients, in-hospital mortality was higher in those with hidden hypoxemia than in those without it (21.1% vs 15.0%), and patients with hidden hypoxemia had greater organ dysfunction 24 h after measurement (mean Sequential Organ Failure Assessment [SOFA] score 7.2 vs 6.29) (Wong et al.). These associations are observational and do not establish causation

and fairness auditing, embedding wearable data streams that rely on similar optical and inertial principles into AI-driven frailty monitoring risks encoding these same inequities into triage decisions, monitoring thresholds, and clinical alerts.^{5,6}

Algorithm design choices compound these risks when proxies stand in for need: the widely cited examination of a commercial population-health algorithm showed that using health care cost as a target variable systematically under-identified Black patients with equal clinical need, illustrating how structural access differentials can masquerade as clinical severity within AI optimization objectives.⁹ For frailty analytics, targets should prioritize health need and function rather than utilization or spend; furthermore, models should report subgroup performance, calibration, and error decompositions, with pre-specified mitigation strategies when disparities are detected.⁹ As a concrete example, a walking-recognition method designed to generalize across smartphones, smartwatches, and wrist- or hip-worn accelerometers was validated against many annotated datasets and held high sensitivity and specificity across device types and wear locations, showing how an activity algorithm can be built to perform consistently across heterogeneous users rather than being tuned to a single cohort.¹⁰

A practical, phased path forward emerges. As an essential first phase, health systems should:

- (1) Extend HFRS-based dashboards with wearable features only after transparent, pre-registered validation across race/ethnicity, skin tone, age, and comorbidity strata^{1,6}
- (2) Require device vendors to disclose sensor performance disaggregated by skin tone, body habitus, and activity context⁵
- (3) Implement continuous post-deployment monitoring for “hidden risk” analogous to hidden hypoxemia auditing, with pre-specified fairness thresholds⁶
- (4) Ensure inclusive recruitment for training datasets, and validate models on locally representative patient populations to maximize clinical relevance and minimize bias
- (5) Pursue equitable access through low-cost form factors, device-lending or subsidy programs, and reimbursement pathways (e.g., CMS RPM codes), recognizing that wearables can reduce and not entrench disparities when engineered for universal accuracy and access^{5,11}

Subsequent phases must address equally critical challenges: standardized data pipelines (e.g., FHIR-based APIs) for EHR integration, clinical workflow design specifying how alerts reach providers and trigger action, patient adherence strategies (particularly for older adults), and health system governance for wearable-derived clinical data. Both consumer-grade wearables already in patients’ possession and clinician-prescribed monitoring devices have roles to play, and health systems will need

to define which contexts warrant each model. In sum, the promise of AI-augmented frailty care is substantial, but realizing it safely requires confronting optical sensing limitations and algorithmic proxies across multiple implementation phases, so that precision for the many does not become precision for the few.^{1,9}

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Declarations

Competing interests PE-N is CEO of Olira. No other conflicts of interest are declared.

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