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Two-Minute Home Wearable Vital-Sign Monitoring Around Thoracic Surgery: A Single-Participant Technical Feasibility and Data Quality Analysis

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Abstract

Background: High-frequency home wearable monitoring may offer longitudinal physiological recordings, but timestamp availability, signal-specific technical usability, and the impact of temporal subsampling require characterization before clinical interpretation.

Methodology: This single-participant methodological study examined a man in his 70s who underwent thoracoscopic right upper-lobe wedge resection. A nonmedical wrist-worn monitoring system (Vital Voice VX-2; Vital Voice Co., Ltd., Okayama, Japan) recorded heart rate (HR), peripheral oxygen saturation (SpO_2), systolic blood pressure (SBP), and diastolic blood pressure (DBP) during seven preoperative and 28 postoperative home-monitoring days, separated by hospitalization. Wearing was permitted as tolerated, without a fixed daily target. The primary objective was to quantify timestamp availability and signal-specific technically usable data yield using a hierarchical two-minute epoch framework. A retrospective exploratory secondary analysis examined the retention of operationally defined sustained episodes after four- and ten-minute subsampling.

Results: Among 25,200 planned epochs, 22,226 were timestamped (88.2% timestamp availability). Technically valid data yield was 96.7% for HR and the BP pair, but 46.7% for SpO_2; concurrent validity across all four vital signs was 46.6% of timestamped epochs. Zero-value outputs accounted for most technically invalid observations, particularly for SpO_2. There were 166 threshold-defined abnormal vital-direction epochs (four HR-high, eight HR-low, and 154 SpO_2-low) and 12 sustained episodes (one HR-high and 11 SpO_2-low). Under the specified retention criterion, four-minute subsampling retained all reference episodes, whereas ten-minute subsampling retained a median of nine of 11 SpO_2-low episodes across offsets (range, 8-11).

Conclusions: A hierarchical framework characterized recording availability and signal-specific data usability in this single-participant home-monitoring dataset. The exploratory findings on episode retention depended on operational definitions and sampling phase. The results do not establish device accuracy, patient adherence, or clinical event-detection performance.

Categories: Healthcare Technology, Cardiac/Thoracic/Vascular Surgery
Keywords: feasibility study, home monitoring, perioperative care, remote monitoring, vital signs, wearable devices

Introduction

Early recognition of postoperative physiological deterioration is important, but intermittent observations may fail to capture physiological abnormalities that occur between assessments, including postoperative oxygen desaturation [1]. Hospital-based pulse oximetry surveillance has been associated with fewer rescue events and intensive care unit transfers in a before-and-after study [2]. These studies motivate interest in longitudinal monitoring but do not demonstrate the diagnostic performance of any particular home wearable device.

Wearable devices may enable repeated vital-sign recording in the home setting. Whether such recordings are interpretable depends on data availability, technical usability, and signal quality, not merely on the number of timestamps collected. Studies of monitoring on hospital wards and in surgical populations have documented feasibility alongside missingness, artifacts, and signal-dependent performance [3-5]. In an observational home-monitoring study after esophagectomy, data loss and wearability were evaluated as distinct components of technical feasibility [6]. Feasibility-study methodology also supports characterizing these operational questions before making broader claims about effectiveness [7].

The primary objective of this single-participant technical feasibility and data-quality analysis was to

quantify timestamp availability and signal-specific technically usable data yield for 2-min home wearable recordings using a hierarchical denominator framework. The exploratory secondary objective was to examine the retention of operationally defined sustained abnormal episodes after retrospective down-sampling to 4- and 10-min intervals. Neither objective addressed measurement accuracy, patient adherence, clinical event diagnosis, or population-level effectiveness.

Materials And Methods

Study design and patient

This was a single-participant technical feasibility and data-quality analysis of home wearable vital-sign recordings. The participant was a man in his 70s who underwent surgery for the diagnostic and therapeutic management of a pulmonary nodule. As no malignancy was identified on intraoperative frozen-section examination, the final procedure was thoracoscopic right upper-lobe wedge resection. The postoperative course was uneventful, and the patient was discharged without postoperative complications. Vital signs were collected using the Vital Voice Online Automatic Monitoring System (VX-2; Vital Voice Co., Ltd., Okayama, Japan), which comprised a wrist-worn sensor and a dedicated receiver and was obtained under a paid rental agreement. The VX-2 was a nonmedical monitoring device. This study focused on data availability and technical usability during unrestricted home monitoring, rather than measurement accuracy against clinical reference instruments. Accordingly, criterion-validation testing was outside the study scope, and no concurrent reference measurements were performed. The participant was asked to wear the wrist sensor at home as tolerated, without interference with daily activities. No minimum daily wear time or detailed wearing and charging schedule was mandated. Actual wearing time was not independently verified; thus, adherence was not assessed as an outcome.

The study was approved by the Ethics Committee of Hashimoto Municipal Hospital, Japan, on October 18, 2023 (approval code R5.8-2). Written informed consent for participation and open-access publication was obtained from the patient.

Data Source and Monitoring Period

The source dataset consisted of timestamped measurements of heart rate (HR), peripheral oxygen saturation (SpO_2), systolic blood pressure (SBP), and diastolic blood pressure (DBP) obtained from the wearable monitoring system. The analysis included two separate home-monitoring windows: seven preoperative days and 28 postoperative days after discharge (four consecutive postoperative home-monitoring weeks). These 35 home-monitoring days were not 35 consecutive calendar days. The intervening inpatient period and records outside the defined home windows were excluded because hospital-based observations were not part of this analysis of home monitoring.

Planned Epoch Grid and Denominator Framework

A complete 2-min planned epoch grid was generated separately for the two home-monitoring windows and combined for analysis. Each day contained 720 planned epochs, yielding 5,040 planned epochs during the seven-day preoperative window and 20,160 during the 28-day postoperative window, for a total of 25,200 planned epochs across 35 nonconsecutive home-monitoring days.

A hierarchical denominator framework was used. A planned epoch was defined as every expected 2-min epoch within the two predefined home-monitoring windows. A timestamped epoch was defined as a planned epoch containing a recorded measurement timestamp after alignment to the 2-min grid. A technically valid epoch was defined as a timestamped epoch containing a nonmissing, nonzero, and nonoutlier value for the corresponding vital sign; this operational designation did not signify accuracy verified against a clinical reference standard. A BP-pair valid epoch was defined as a timestamped epoch in which both SBP and DBP met the validity and predefined BP-pair consistency rules. An all-four-vital valid epoch was one in which HR, SpO_2, SBP, and DBP were all technically valid concurrently. A threshold-defined abnormal epoch was a technically valid epoch breaching a prespecified threshold for the corresponding vital sign and direction. A sustained abnormal episode comprised at least three consecutive threshold-defined abnormal valid 2-min epochs involving the same vital sign and abnormality direction.

The main denominator metrics were defined as follows. Timestamp availability was calculated as the number of timestamped epochs divided by the number of planned epochs. Valid-data yield was calculated as the number of valid epochs divided by the number of timestamped epochs. Abnormality burden was calculated as the number of threshold-defined abnormal valid epochs divided by the number of valid epochs. Abnormal duration was calculated as the number of threshold-defined abnormal epochs multiplied by 2 min.

Technical Outlier and Valid Data Definitions

Technical invalidity was assessed before threshold-defined abnormality. Missing and zero outputs were treated as invalid. Zero outputs were excluded because a value of zero for these vital signs is physiologically

implausible in an ambulatory participant; this was an operational cleaning rule, not a manufacturer-validated interpretation of VX-2 zero-value coding. The causes of zero outputs could not be established. Range-defined technical outliers were HR below 30 or above 220 beats/min, SpO_2 below 70% or above 100%, SBP below 50 or above 250 mmHg, and DBP below 20 or above 200 mmHg. For BP-pair validity, both SBP and DBP had to be nonmissing, nonzero, and within these ranges. In addition, SBP had to exceed DBP, and pulse pressure had to be between 10 and 200 mmHg. Epochs failing any BP-pair criterion were invalid for BP-pair analyses. Passing these technical checks did not establish measurement accuracy.

Threshold-Defined Abnormality Definitions

Threshold-defined abnormality was assessed only among valid epochs. Prespecified thresholds were used to characterize the cleaned 2-min time series and to construct reference episodes for the down-sampling analysis. Threshold selection was informed by established vital-sign threshold frameworks and blood pressure criteria [8-9].

The prespecified thresholds were as follows: HR ⩾100 beats/min for the high direction and ⩽50 beats/min for the low direction; SpO_2 ⩽90% for the low direction; SBP ⩾180 mmHg for the high direction and ⩽90 mmHg for the low direction; and DBP ⩾120 mmHg for the high direction and ⩽50 mmHg for the low direction. High and low directions were analyzed separately.

Sustained Abnormal Episode Extraction

Sustained abnormal episodes were extracted using run-length encoding of the 2-min reference grid. For each vital sign and abnormality direction, consecutive abnormal valid epochs were grouped into runs. A run was retained as a sustained abnormal episode if it contained at least three consecutive abnormal valid epochs, corresponding to a minimum duration of 6 min.

Episode continuity required exact adjacency on the 2-min grid. Missing, invalid, or non-abnormal epochs interrupted an episode. For each sustained episode, the vital sign, abnormality direction, start time relative to the analysis period, end time, number of epochs, duration, minimum or maximum value, as appropriate, study period, and study-day index were recorded. Episode duration was calculated as the number of consecutive abnormal epochs multiplied by 2 min.

Down-Sampling Simulation

Retrospective down-sampling was an exploratory secondary analysis conducted on the recorded 2-min dataset; the complete 2-min grid was the internal reference, not an independently validated clinical standard. The 4-min interval served as a methodological reference comparison. The 10-min interval was selected exploratorily to illustrate the effects of a coarser sampling interval. Neither interval was prospectively selected as a clinically optimal monitoring frequency.

For the down-sampling analysis, 4-min sampling was evaluated at starting offsets of 0 and 2 min, and 10-min sampling at offsets of 0, 2, 4, 6, and 8 min. Offsets represented different sampling phases relative to the original 2-min grid and were applied separately from the start of each home-monitoring window. Data outside those home-monitoring windows were excluded.

For each sampling interval and offset, planned sampled epochs, timestamped sampled epochs, valid sampled epochs, timestamp availability, valid-data yield, retained threshold-defined abnormal epochs, and estimated abnormal duration were calculated. Estimated abnormal duration after down-sampling was calculated as the number of retained abnormal epochs multiplied by the corresponding sampling interval.

Reference sustained episodes were defined using the full 2-min grid. A reference episode was counted as retained after down-sampling when at least one sampled epoch within it remained technically valid and threshold-defined abnormal. The three-consecutive-epoch rule was not reapplied after down-sampling. The operational episode-level sensitivity reported here was calculated as the proportion of internally defined reference episodes retained by the subsample; it was not sensitivity for clinically confirmed physiological events.

Statistical analysis

All analyses were descriptive. Continuous monitoring performance was summarized using counts, percentages, and durations. Timestamp availability and valid-data yield were calculated using the hierarchical denominator framework described above. Threshold-defined abnormality burden was calculated using signal-specific valid epochs as the denominator. Sustained episodes were summarized by number, duration, and longest episode.

For the exploratory down-sampling analysis, results were calculated separately for each sampling phase (offset). Summary values across offsets were expressed as medians and ranges, which represented phase-

related variation rather than between-patient variability. No inferential statistical testing or p-values were calculated because the study was descriptive and included only one participant.

All data processing and analyses were performed using Python version 3.x with the pandas, NumPy, and matplotlib libraries. The complete analysis code is available from the corresponding author upon reasonable request.

Results

Data inclusion and timestamp availability

After restriction to the two prespecified home-monitoring windows (35 home-monitoring days in total), a 2-min planned epoch grid was generated, corresponding to 720 planned epochs per day and 25,200 in total. After alignment to this grid, 22,226 planned epochs contained recorded timestamps, yielding an overall timestamp availability of 88.2%; 2,974 had no timestamped record. This metric did not measure wearing adherence because actual wearing time was not independently verified. The hierarchical flow from planned epochs to sustained episodes is shown in Figure *1*.

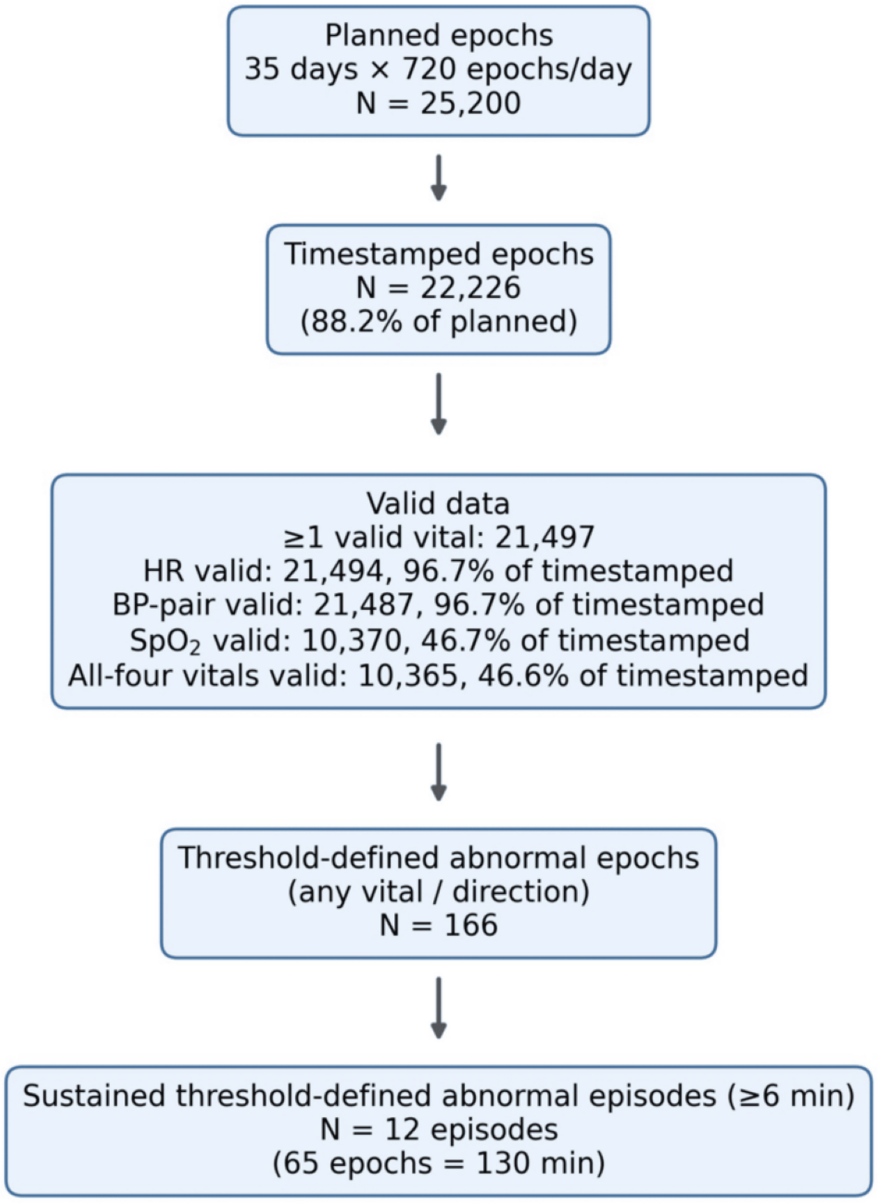


FIGURE 1: Hierarchical data flow from planned epochs to sustained threshold-defined abnormal episodes

Planned epochs were defined as all expected 2-min epochs within the 35-day home-monitoring period. Timestamped epochs were planned epochs with a recorded timestamp after alignment to the 2-min grid. Validity was evaluated at the signal-specific level. BP-pair validity required valid SBP and DBP values and fulfillment of predefined pair-consistency rules. Threshold-defined abnormal epochs were valid signal-direction epochs that breached prespecified thresholds. Sustained abnormal episodes were defined as ≥3 consecutive abnormal valid 2-min epochs involving the same vital sign and direction.

HR, heart rate; BP, blood pressure; SpO_2, peripheral oxygen saturation.

Valid-Data Yield

Period-specific timestamp availability and valid-data yield are summarized in Table *1*. Timestamp availability was 86.0% during the preoperative week and ranged from 84.1% to 94.5% across the four postoperative home-monitoring weeks.

period	planned_epochs	timestamped_epochs	timestamp_availability	valid_HR	valid_HR_yield	valid_SpO2	valid_SpO2_yield	valid_BPpair	valid_BPpair_yield	valid_all4	valid_all4_yield
Preoperative week	5040	4332	86.0%	4309	99.5%	1825	42.1%	4306	99.4%	1823	42.1%
Postoperative week 1	5040	4462	88.5%	4326	97.0%	1920	43.0%	4325	96.9%	1919	43.0%
Postoperative week 2	5040	4239	84.1%	4100	96.7%	1966	46.4%	4098	96.7%	1966	46.4%
Postoperative week 3	5040	4429	87.9%	4335	97.9%	2297	51.9%	4336	97.9%	2296	51.8%
Postoperative week 4	5040	4764	94.5%	4424	92.9%	2362	49.6%	4422	92.8%	2361	49.6%
Overall	25200	22226	88.2%	21494	96.7%	10370	46.7%	21487	96.7%	10365	46.6%

TABLE 1: Period-specific timestamp availability and signal-specific valid-data yield.

HR, heart rate; SpO_2, peripheral oxygen saturation; BP, blood pressure

Among timestamped epochs, signal-specific valid-data yield was high for HR and the BP pair but substantially lower for SpO_2. Overall, HR was valid in 21,494 epochs, corresponding to a valid-data yield of 96.7%. The BP pair was valid in 21,487 epochs, also corresponding to a valid-data yield of 96.7%. In contrast, SpO_2 was valid in 10,370 epochs, corresponding to a valid-data yield of 46.7%. Concurrent validity of all four vital signs was observed in 10,365 timestamped epochs, giving an all-four-vital valid-data yield of 46.6%.

Across the five weekly periods, HR and BP-pair valid-data yields remained consistently high, whereas SpO_2 valid-data yield ranged from 42.1% to 51.9%. Consequently, the all-four-vital valid-data yield closely followed SpO_2 availability. Figure 2 shows that HR and BP-pair validity were broadly preserved across the monitoring period, whereas SpO_2 validity was more heterogeneous across both study day and time of day. The all-four-vital validity panel visually mirrored the SpO_2 panel, indicating that SpO_2 was the main limiting factor for complete multi-parameter epoch-level analysis.

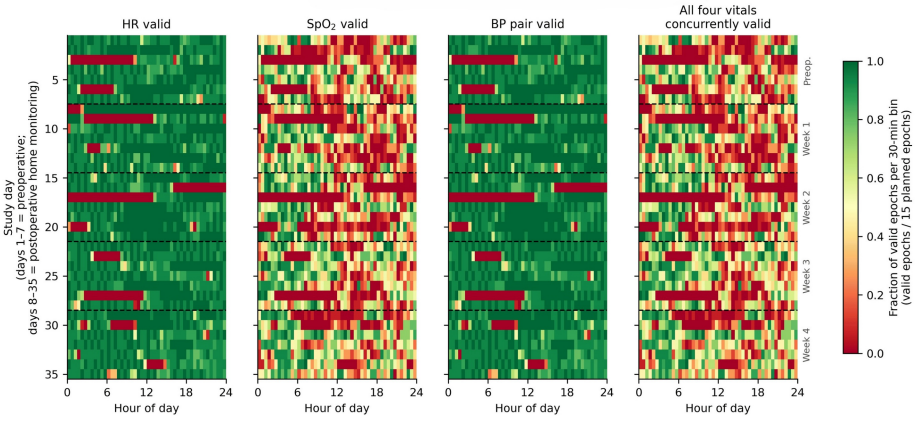


FIGURE 2: Valid-data availability by study day and time of day.

Heatmaps show valid-data availability across study day and time of day for HR, SpO_2, BP-pair, and concurrent all-four-vital validity. Each cell represents the fraction of valid 2-min epochs within the corresponding time bin. Days 1-7 correspond to the preoperative home-monitoring period, and days 8-35 correspond to the postoperative home-monitoring period.

HR, heart rate; SpO_2, peripheral oxygen saturation; BP, blood pressure.

Invalid and Technical-Outlier Values

The breakdown of invalid and technical-outlier values is shown in Table 2. Among timestamped epochs, no

missing values were observed for HR, SpO_2, SBP, or DBP. No range-defined technical outliers were identified for any vital sign, and no BP-pair rule violations were observed.

Invalid data were therefore attributable to zero-value recordings. Zero values occurred in 732 HR epochs, 11,856 SpO_2 epochs, and 739 BP epochs. SpO_2 zero-value recordings accounted for 53.3% of all timestamped epochs, explaining the markedly lower SpO_2 valid-data yield compared with HR and BP. These findings indicate that, in this dataset, data invalidity was driven primarily by zero-value recordings rather than by physiologically implausible range outliers or BP-pair inconsistency.

vital	missing	zero	range_outlier	bp_pair_error	valid_epochs	valid_yield
HR	0	732	0		21494	96.7%
SpO_2	0	11856	0		10370	46.7%
BP_pair	0	739	0	0	21487	96.7%

TABLE 2: Breakdown of invalid and technical-outlier values among timestamped epochs.

HR, heart rate; SpO_2, peripheral oxygen saturation; BP, blood pressure

Threshold-Defined Abnormal Epochs and Sustained Abnormal Episodes

Threshold-defined abnormal epochs and sustained abnormal episodes on the 2-min reference grid are summarized in Table *3*. Overall, 166 threshold-defined abnormal vital-direction epochs were identified.

For HR, four epochs met the high threshold of ⩾100/min, corresponding to an abnormality burden of 0.019% and an abnormal duration of 8 min. Eight epochs met the low HR threshold of ⩽50/min, corresponding to an abnormality burden of 0.037% and an abnormal duration of 16 min. For SpO_2, 154 epochs met the low threshold of ⩽90%, corresponding to an abnormality burden of 1.485% and an abnormal duration of 308 min. No threshold-defined abnormal epochs were identified for SBP or DBP in either the high or low direction.

A total of 12 sustained abnormal episodes were identified, comprising 65 epochs and 130 min of sustained abnormal duration. These consisted of one HR-high episode lasting 6 min and 11 SpO_2-low episodes with a combined sustained duration of 124 min. The longest sustained SpO_2-low episode lasted 18 min. Although low-HR abnormal epochs were present, none formed a sustained episode.

Vital_sign	Direction	Threshold-defined_epochs	Threshold-defined_burden	Threshold-defined_duration_min	Sustained_episodes	Sustained_duration_min	Longest_episode_min
HR	High	4	0.019%	8	1	6	6
HR	Low	8	0.037%	16	0	0	0
SpO_2	Low	154	1.485%	308	11	124	18
SBP	High	0	0.000%	0	0	0	0
SBP	Low	0	0.000%	0	0	0	0
DBP	High	0	0.000%	0	0	0	0
DBP	Low	0	0.000%	0	0	0	0

TABLE 3: Threshold-defined abnormal epochs and sustained abnormal episodes on the 2-min reference grid.

HR, heart rate; SpO_2, peripheral oxygen saturation; BP, blood pressure

Figure *3* illustrates the 2-min vital-sign time series and the distribution of threshold-defined abnormalities. In Figure *3A*, HR remained generally within the prespecified range, with one sustained HR-high episode identified. In Figure *3B*, SpO_2 showed several threshold-defined low episodes, including 11 sustained SpO_2-

low episodes, whereas Figures *3C*-*3D* show no threshold-defined abnormalities in SBP or DBP. These findings demonstrate that the 2-min time series allowed signal-specific abnormal patterns and their temporal persistence to be visualized. Figure *4* shows the timing and duration of each sustained episode across the 35-day study period.

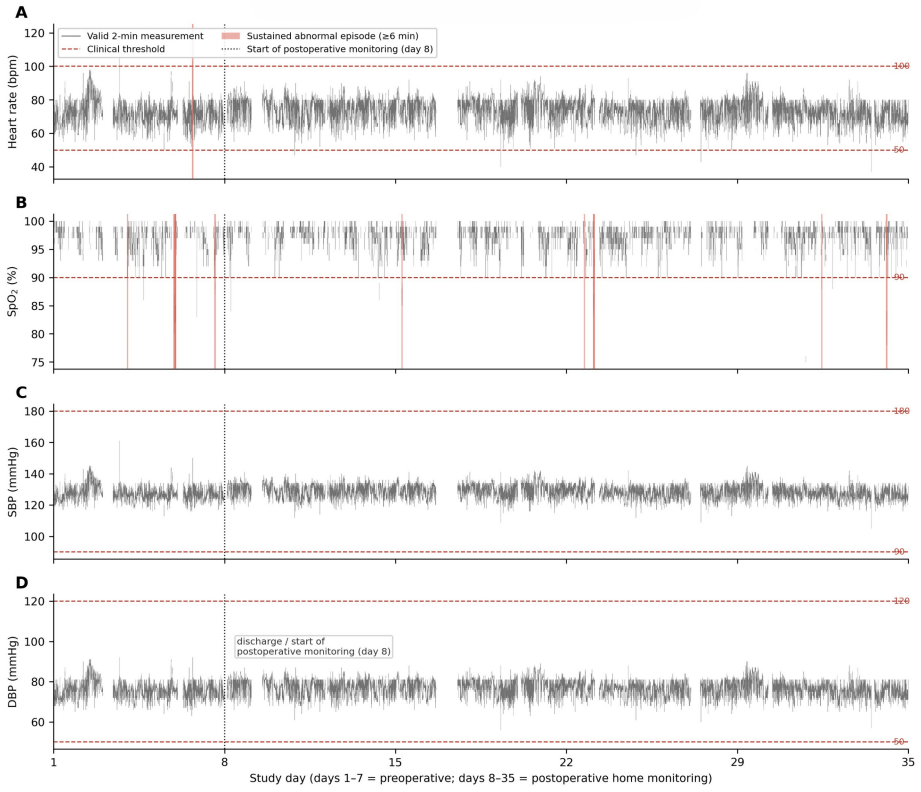


FIGURE 3: Two-minute vital-sign time series with prespecified threshold lines and sustained episodes.

(A) HR, (B) SpO_2, (C) SBP, and (D) DBP. Gray traces represent valid 2-min measurements. Red dashed lines indicate prespecified thresholds. Red shaded regions indicate sustained abnormal episodes, defined as ≥3 consecutive abnormal valid 2-min epochs of the same vital sign and direction.

HR, heart rate; SpO_2, peripheral oxygen saturation; SBP, systolic blood pressure; DBP, diastolic blood pressure.

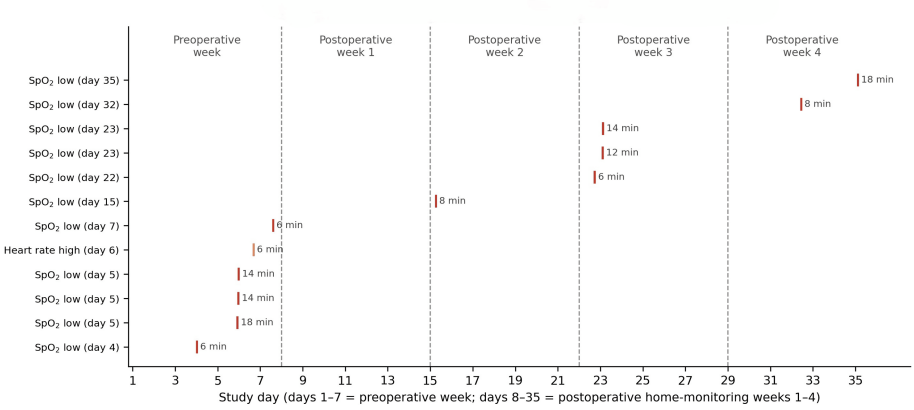


FIGURE 4: Timeline of sustained threshold-defined abnormal episodes.

Each horizontal segment represents one sustained abnormal episode. The x-axis represents study day, with days 1-7 corresponding to the preoperative home-monitoring period and days 8-35 corresponding to the postoperative home-monitoring period. Episode duration was calculated as the number of consecutive abnormal 2-min epochs multiplied by 2 min.

SpO_2, peripheral oxygen saturation

Retrospective down-sampling simulation

The results of the retrospective down-sampling simulation are shown in Table *4* and Figure *5*. Sustained episodes defined on the 2-min grid were the internal reference. A reference episode was counted as retained if at least one sampled epoch within that episode remained technically valid and threshold-defined abnormal; the three-consecutive-epoch rule was not reapplied. Hence, the reported episode-level sensitivity is an operational reference-episode retention proportion, not clinical diagnostic sensitivity.

With 4-min subsampling, all internally defined reference episodes were retained under both evaluated offsets. The single HR-high episode and all 11 SpO_2-low episodes were retained (operational episode-level sensitivity, 100.0%). The relative abnormal burden for SpO_2 varied by offset (0.870-1.130) despite complete episode retention. As discussed below, complete episode retention follows from the episode and detection definitions used here.

Sampling interval	Vital-direction	Reference episodes	Detected episodes, median (range)	Sensitivity, median (range)	Relative abnormal burden, median (range)
4 min	HR high	1	1 (1-1)	100.0% (100.0-100.0)	1.000 (1.000-1.000)
4 min	SpO_2 low	11	11 (11-11)	100.0% (100.0-100.0)	1.000 (0.870-1.130)
10 min	HR high	1	1 (0-1)	100.0% (0.0-100.0)	1.248 (0.000-2.505)
10 min	SpO_2 low	11	9 (8-11)	81.8% (72.7-100.0)	0.969 (0.881-1.140)

TABLE 4: Summary of episode-level detection after retrospective down-sampling.

HR, heart rate; SpO_2, peripheral oxygen saturation

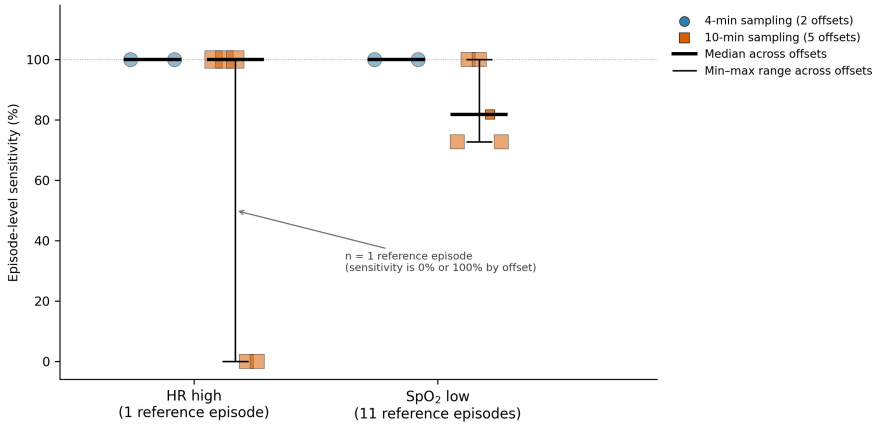


FIGURE 5: Episode-level sensitivity of retrospective down-sampling.

The 2-min grid was used as the reference. A reference episode was considered detected after down-sampling if at least one retained sampled epoch within the episode remained valid and threshold-defined abnormal. The three-consecutive-epoch rule was not reapplied after down-sampling. Vital-sign directions with no reference sustained episodes were omitted.

HR, heart rate; SpO_2, peripheral oxygen saturation

With 10-min subsampling, retention varied by offset. For the single HR-high reference episode, the operational episode-level sensitivity ranged from 0.0% to 100.0%; its median of 100.0% was based on only one episode and should not be interpreted as a stable estimate. For the 11 SpO_2-low reference episodes, a median of nine episodes were retained (range, 8-11), corresponding to a median operational retention proportion of 81.8% (range, 72.7%-100.0%). The relative abnormal burden for SpO_2-low episodes ranged from 0.881 to 1.140.

Discussion

Principal findings

This single-participant analysis applied a hierarchical framework to high-frequency home recordings obtained over seven preoperative and 28 postoperative home-monitoring days. Across 25,200 planned epochs, timestamp availability was 88.2%. Technically usable data differed substantially by signal: 96.7% of timestamped epochs for HR and the BP pair, but 46.7% for SpO_2. Concurrent four-vital usability was 46.6%, largely limited by SpO_2 zero outputs. These proportions characterize the recorded data and do not establish device accuracy or patient adherence.

Operationally defined abnormalities were infrequent in this dataset. There were 154 SpO_2-low abnormal epochs and 11 sustained SpO_2-low episodes, as well as one sustained HR-high episode. The exploratory subsampling comparison illustrated phase-dependent retention at 10-min intervals; the 4-min comparison served mainly as a methodological reference and did not constitute evidence of superior clinical detection performance.

Interpretation of feasibility

This study should be interpreted as a single-participant technical feasibility and data-quality analysis rather than an evaluation of patient adherence, diagnostic accuracy, or clinical effectiveness. Feasibility methodology can be used to examine whether data acquisition, processing, and outcome definitions are workable before larger studies [7]. Here, a planned epoch grid was constructed, timestamped records aligned, and data classified into signal-specific technical validity and operationally defined episodes. However, the application of a data-processing framework to one dataset cannot establish population-level feasibility.

Timestamp availability of 88.2% indicated that most planned 2-min epochs had a corresponding recorded timestamp but did not establish how consistently the device was worn. Under flexible home-wearing instructions, periods without data could reflect non-wearing, sensor contact, device operation, connectivity, or other causes that were not independently differentiated. The hierarchical denominator framework therefore separated timestamp availability from signal-specific technical usability and threshold-defined evaluation. Previous studies have also emphasized data loss, signal quality, and practical implementation challenges [3-4,6].

Importance of signal-specific valid data yield

A major finding was the discrepancy between HR/BP and SpO_2 technical usability. HR and BP-pair recordings met the predefined data-cleaning criteria in more than 96% of timestamped epochs, whereas SpO_2 met them in fewer than half. These are operational data-quality proportions, not estimates of measurement accuracy. The observed contrast demonstrates why a single timestamp-completeness metric is insufficient for characterizing multiple recorded signals.

Frequent SpO_2 zero outputs accounted for the low proportion of technically usable SpO_2 readings. They were treated as invalid because zero is not a plausible measurement in an ambulatory participant. However, the VX-2 zero-value coding rule was not independently confirmed, and zeros could reflect sensor non-contact, motion artifact, failed acquisition, device-specific coding, or other mechanisms. Their exact cause cannot be inferred from the available dataset. This issue especially limits concurrent all-four-vital analysis.

Wearable studies in ward and surgical settings have identified differences in signal quality and data loss [3-5]. A home-monitoring study after esophagectomy also evaluated data loss and wearability as separate feasibility dimensions [6]. These reports provide methodological context; they neither establish the technical performance of the VX-2 nor validate its measurements. The present single-participant findings describe how a dense timestamp series can nevertheless be constrained by one recorded parameter.

Interpretation of threshold-defined abnormalities and continuous-data metrics

The threshold-defined abnormal epochs in this study represent departures of technically usable recorded values from operational thresholds; they are not independently verified physiological abnormalities or clinically adjudicated adverse events. The VX-2 was not a medical device, its accuracy against reference instruments was not established in this study, and the clinical significance of individual threshold crossings was not evaluated. The thresholds were therefore used to structure time-series summaries and internal reference episodes, not to diagnose postoperative complications.

Postoperative hypoxemia may occur between routine observations [1], while hospital-based pulse oximetry surveillance has been associated with improved recognition of ward deterioration [2]. These findings provide a rationale for investigating longitudinal measurement. They do not imply that the VX-2 recordings provide clinically accurate measurements or that operationally defined episodes predict complications. In the present work, continuous-data metrics were examined solely as descriptive analytical features.

The sustained-episode definition used here, requiring ⩾3 consecutive abnormal valid 2-min epochs of the same vital sign and direction, was exploratory. The rationale was to use temporal continuity to distinguish isolated threshold crossings, which may reflect artifact, activity-related variation, or clinically unimportant fluctuation, from longer runs of threshold-defined deviation. This rule should not be regarded as a validated clinical event definition. Rather, it represents one possible method for summarizing high-frequency wearable data. Alternative approaches may include simple epoch-level burden, cumulative duration beyond thresholds, different minimum-duration criteria, gap-tolerant episode definitions, moving-window rules, severity- or time-weighted burden, and patient-specific baseline-adjusted thresholds.

Temporal resolution and down-sampling

The 4-min simulation should not be considered an independent test of superior episode detection: because a reference episode was defined by at least three consecutive abnormal 2-min epochs and retention required just one sampled abnormal epoch, each such episode necessarily contributed at least one point under either 4-min offset. Accordingly, the 100% retention at 4 min was expected by construction and served as a methodological reference. With 10-min sampling, retention varied with the starting offset in this dataset, illustrating sensitivity to the choice of sampling phase. These results do not establish clinical diagnostic sensitivity or an optimal acquisition interval.

Future research

Future studies should validate wearable readings against clinical reference standards, assess actual wearing adherence and usability prospectively, and investigate whether longitudinal data-quality and episode-derived metrics are associated with postoperative outcomes in larger samples. Alternative episode definitions and sampling intervals should also be tested prospectively.

Limitations

This study has several limitations. First, it was a single-participant analysis of a man in his 70s with an uncomplicated postoperative course; results cannot be generalized to the broader thoracic surgical population or to patients with postoperative complications. The participant was permitted to wear the device according to daily circumstances, without a prescribed minimum duration, and actual wearing time was not independently tracked. Consequently, patient adherence, acceptability, and the contributions of

non-wearing to missing or unusable data could not be quantified.

Second, the VX-2 was a nonmedical monitoring device, and its measurement accuracy under unrestricted daily-life conditions was not evaluated in this study. Comparison with clinical reference instruments was outside the study scope, and no simultaneous hospital-grade pulse oximetry, cuff blood pressure, or other criterion-standard measurements were performed. Thus, technically usable data cannot be assumed to be clinically accurate, and threshold-defined episodes cannot be treated as verified physiological deterioration or diagnostic events.

Third, zero values, especially for SpO_2, were classified as technically invalid, but the device's zero-output coding convention was not independently validated. The available data could not determine whether these values represented failed acquisition, poor sensor contact, motion artifact, device-specific coding, or another cause.

Fourth, the exploratory sustained-episode rule required exact adjacency of at least three abnormal valid 2-min epochs. Missing, invalid, or non-abnormal epochs split runs, potentially dividing related signals into separate episodes. This was an operational definition and has not been validated as a clinical event definition.

Fifth, the retrospective down-sampling analysis retained selected recorded epochs without reproducing how a real device operated at a lower measurement frequency. It did not capture possible effects on battery life, sensor behavior, wearing practices, or signal quality. The 4-min complete-retention result was determined by the operational definitions, and the 10-min phase-dependent results were specific to these internally defined episodes. Finally, this descriptive single-participant analysis did not include inferential statistical testing.

Conclusions

In this single-participant study, 2-min home wearable monitoring provided recorded data to apply a hierarchical framework for describing timestamp availability and signal-specific technical usability. Substantial differences between signals, particularly frequent zero outputs for SpO_2, highlighted the importance of evaluating each parameter separately. Exploratory down-sampling showed that retention of predefined episodes depended on operational definitions and sampling phase. These observations do not establish device accuracy, patient adherence, or clinical effectiveness.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Takuya Ohashi

Acquisition, analysis, or interpretation of data: Takuya Ohashi

Drafting of the manuscript: Takuya Ohashi

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Disclosures

Human subjects: Informed consent for treatment and open access publication was obtained or waived by all participants in this study. Institutional Review Board, Hashimoto Municipal Hospital issued approval R5.8-2; October 18, 2023. Written informed consent for the use of anonymized data was obtained from the participant. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** The authors declare no financial conflicts of interest related to this study. The VX-2 wearable monitoring system used in this study was rented from Vital Voice Co., Ltd. (Okayama, Japan) under a paid rental agreement. No financial support, free equipment, honoraria, consulting fees, or other payments were received from the company in relation to this study. .

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