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Effect of continuous wireless vital sign monitoring on unplanned ICU admissions and rapid response team calls: a before-and-after study

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Abstract

Background: Continuous vital sign monitoring may potentially be improved through the use of wearable monitors linked wirelessly to hospital electronic patient records. By improving early detection of physiological deterioration this approach may save lives.

Methods: We performed a single-centre before-and-after study including surgical and medical patients at a university hospital in The Netherlands. The study intervention was continuous vital sign monitoring using wearable monitors linked wirelessly to hospital systems. The co-primary outcomes were unplanned ICU admission and rapid response team calls. Secondary outcomes were length of hospital stay and in-patient death.

Results: Our baseline cohort included 2466 admissions and our intervention cohort included 2303 admissions recruited from August 2017 to July 2019. Patients in the intervention cohort experienced fewer unplanned ICU admissions (84 [3.4%] *vs* 54 [2.3%]; P=0.03) and fewer rapid response team calls (107 [4.3%] *vs* 71 [3.1%]; P=0.02). The number of rapid response team calls that did not result in ICU admission also declined (70 [2.8%] *vs* 45 [2.0%]; P=0.05). The number of rapid response team calls that did result in ICU admission was not significantly different (52 [2.1%] *vs* 36 [1.6%]; P=0.16). There were no differences in hospital stay or in-patient deaths between the two study periods.

Conclusions: Continuous monitoring of patient vital signs using wearable monitoring technology linked wirelessly to hospital systems was associated with a reduction in unplanned ICU admissions and rapid response team calls. Further research is necessary to confirm the impact of this approach on patient survival.

Keywords: clinical deterioration; general ward; intensive care unit; patient safety; vital sign measurements; wearables

Editor's key points

- Postoperative complications commonly result in physiological deterioration, which must be detected and treated to prevent fatalities.
- This study shows that wearable monitoring devices wirelessly linked to hospital computer systems can improve early detection and treatment of physiological deterioration, reducing unplanned admissions to ICU.
- Further research is needed to confirm the patient benefits of this technology. This should include large cluster randomised trials and evaluation of artificial intelligence predictive algorithms.

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Vital sign derangements usually precede adverse events on hospital wards.[1,2] Some may be preventable if appropriate actions are taken after vital sign deterioration.[3] The first Early Warning Score (EWS) systems were developed more than two decades ago,[4] to identify patients at risk of clinical deterioration using simple physiological parameter-based protocols. These systems have since been modified and improved for widespread use.[5,6] Many hospitals have adopted these periodic vital sign monitoring protocols,[7] which often mandate a stepwise increase in vital sign measurement frequency when the EWS exceeds predefined levels. Early intervention has the potential to improve clinical outcomes,[8] although the impact on patient survival remains unconfirmed.[7,9] Poor protocol adherence and inaccurate vital sign recordings are two possible factors limiting the clinical effectiveness of EWS systems.[10–13]

The value of continuous vital sign monitoring in general ward patients compared with intermittent monitoring with EWS calculations is a topic of ongoing debate.[1,14,15] Continuous monitoring allows monitoring of vital sign trends and alarms at all times, as opposed to only at certain intervals. In light of this debate, we introduced continuous monitoring of four vital signs at a university hospital in The Netherlands. A wireless monitoring device worn by patients on their wrists offered the advantages of enabling full patient mobilisation and automated electronic medical record (EMR) linkage. In previous studies, both patients and clinicians anticipated earlier detection of clinical deterioration, and improvements in care quality, efficiency, and safety.[16–20] These expectations are supported by findings of increased accuracy compared with nurses' manual measurements, and detection of clinical deterioration at times patients would not otherwise have been observed.[21–23]

We conducted a before-and-after cohort study of the impact of continuous wireless vital sign monitoring on the incidence of unplanned admission to an ICU and rapid response team calls, and proxies for changes in clinician's awareness of clinical deterioration, such as continuous monitoring alarm frequency preceding adverse events. We hypothesised that this intervention would lead to a reduction of both adverse events and an increase in alarm frequency around the time of adverse events.

Methods

We performed a single-centre before-and-after study including all adult patients aged ≥18 yr admitted to two general medical and surgical wards at Radboud university medical center in Nijmegen, The Netherlands. Patients on the 34-bed medical ward were admitted with conditions related to general internal medicine, rheumatology, and/or infectious diseases. The 26-bed surgical ward primarily consisted of patients undergoing surgery for upper gastrointestinal and hepato-pancreaticobiliary cancers. Both elective and emergency patient admissions were included. No substantive changes were made to unit staffing, nor to hospital or departmental safety and quality policies during the 2 yr study period. The study protocol was approved by the Radboud University Institutional Human Research Ethics Committee (METC 2018–4330).

Vital sign measurements and processing

Before implementation of the study intervention, nurses periodically measured and recorded five vital signs: respiratory frequency, heart rate, systolic and diastolic blood pressure, oxygen saturation, and core temperature in the EMR (Supplementary Appendix 1). Vital signs were manually measured using a blood pressure measuring device with a pulse oximeter, an ear thermometer, and by visual inspection of respiratory frequency to calculate a Modified Early Warning Score (MEWS) according to the hospital's protocol (Supplementary Appendix 2).

In the intervention period, patients were monitored with a wearable device (Supplementary Appendix 1), which provided continuous measurements of respiratory frequency, heart rate, systolic and diastolic blood pressure, and oxygen saturation, but not core temperature. Patient data were displayed on the device itself and wirelessly on monitors set up at the nurse stations and lunchrooms (Supplementary Appendix 3). The monitors provided clinicians with continuous real-time vital sign data trends of the preceding 96 h and displayed single channel alarms when a single vital sign reading fell outside pre-set safety limits (Supplementary Appendix 2). Once every minute, a vital sign set was automatically sent to the EMR with values made available to nurses for periodic EMR authorisation and MEWS calculation according to the hospital protocol (Supplementary Appendix 2). MEWS was calculated in the EMR only after manually registering the core temperature and verification of the automatically recorded vital sign set. During both the baseline and intervention periods, the system used zero scores for oxygen delivery and AVPU unless nurses simultaneously recorded differing values. Before authorisation of a continuously measured vital sign set for MEWS calculation, nurses roughly compared its values with measurements of the past 15–30 min to make sure to evaluate possible measurement errors. The main difference in the monitoring system during the intervention period was the use of a wearable monitoring device which provided continuous wireless monitoring, transmitting data to the EMR, and monitoring screens on the ward. Data were used whenever nurses deemed it was necessary. Patients were connected or disconnected from the device only after clinical assessment by a nurse or physician involved in the study. The predefined reasons for removal of the wireless monitoring device were hyperactive delirium, skin problems, and patients' refusal to be continuously monitored.

MEWS protocol

In 2010, the hospital introduced a MEWS, which is based on local expert opinion and existing EWS systems.[2,5] The MEWS protocol remained the same in both study periods (Supplementary Appendix 2). Vital signs were recorded and MEWS calculated every 8 h for all patients, and more frequently when the patient's MEWS increased to more than 3. At certain MEWS thresholds, the protocol mandated actions, such as consulting the ward physician or calling the rapid response team. All healthcare team members were able to call the rapid response team whenever they deemed this necessary, regardless of the presence of a MEWS trigger score. Neither the EMR nor the continuous monitoring system could trigger a rapid response team call automatically. The rapid response team consisted of an ICU physician and nurse, who were required to arrive within 10 min of the call. Rapid response team composition did not change between study periods, nor did training for ward nurses in acting on abnormal vital signs or calling the rapid

response team. In both periods the hospital's MEWS protocol served as a guideline. Nurses were able to calculate a MEWS score whenever they deemed it was necessary, as long as they adhered to the minimal requirements of the protocol.

Data collection

Patient characteristics, admission diagnoses, length of hospital stay, vital signs, MEWS recordings, unplanned ICU admissions, rapid response team calls, and deaths were retrospectively retrieved from the EMR. Data were checked for accuracy and completeness by an independent physician reading the clinical notes preceding the unplanned ICU admissions.

ICU admissions of all other non-guarded wards were collected for comparison.

Study outcome measures

The co-primary outcome measures were unplanned patient admission to ICU, and rapid response team calls. An unplanned ICU admission was defined as one attributable to patient deterioration or to treat postoperative complications. The secondary outcome measures were rapid response team calls, which did or did not result in an ICU transfer, in-patient deaths, and length of hospital stay.

Statistical analysis

Data are presented as mean (standard deviation [SD]), median (inter-quartile range [IQR]), or *n* (%). We used a Mann–Whitney *U*-test to compare non-normally distributed data, and the χ^2 test for categorical variables. To test for skewness, we used a Shapiro–Wilk test. A *P*-value below 0.05 was considered statistically significant. The same methods were used for subgroup analyses during the 24 h before adverse events (during all shifts and during night shifts) and for comparing the 24 h before adverse events with the rest of the admission. We took an exploratory approach to analysis, and hence did not correct for multiple comparisons. Control for potentially confounding factors was done by comparing patient characteristics between both groups. All admitted ward patients were included for analysis, and no selection was made based on some missing continuous vital sign data or other criteria. All analyses were performed using SPSS package version 25.0 (SPSS Inc., Chicago, IL, USA).

Results

Patients were included during a 2-yr period with a 1 yr baseline period from August 1, 2017 to July 31, 2018, and an intervention period from August 1, 2018 to July 31, 2019 (Fig. 1). We included 2023 patients with 2466 hospital admissions during the baseline period, and 1873 patients with 2303 admissions during the

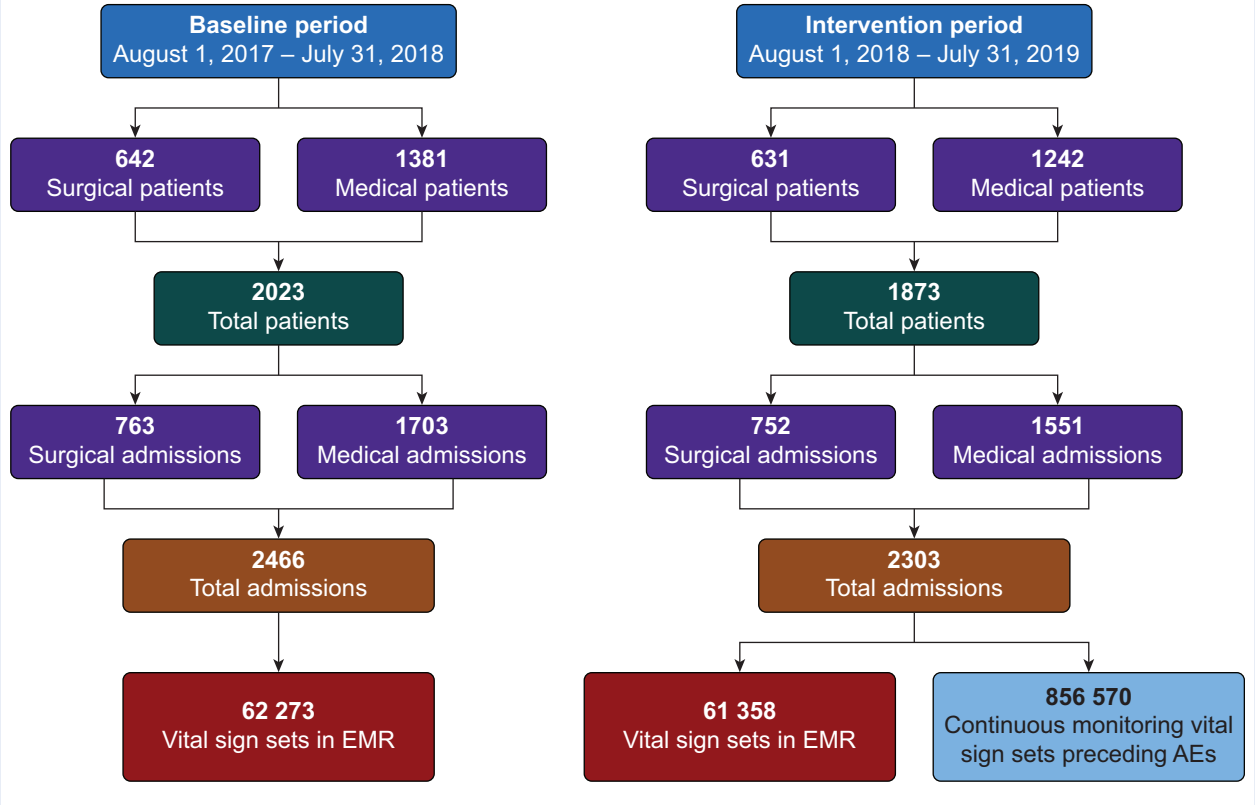

Fig 1. Patient inclusion in the study. EMR, electronic medical record; AEs, adverse events.

intervention period (Table 1). There were no significant differences in patient characteristics, admission diagnoses, unplanned admissions, or readmissions between the two periods.

Co-primary outcomes

The total number of hospital admissions with an unplanned ICU admission was higher in the baseline period compared with the intervention period (Baseline: 84 ICU admissions [3.4%] *vs* Intervention: 54 ICU admissions [2.3%]; *P*=0.03) (Fig. 2). The number of admissions with a rapid response team call was also higher in the baseline period compared with the intervention period (Baseline: 107 calls [4.3%] *vs* Intervention 71 calls [3.1%]; *P*=0.02). Co-primary outcomes for the surgical and internal medicine wards are presented in Table 2. Hospital wards not included in this study experienced a total of 229 unplanned ICU admissions in the baseline period and 217 unplanned ICU admissions in the intervention period (*P*=0.36).

Table 1 Patient and admission characteristics. Data are presented as mean (standard deviation) or *n* (%). IQR, interquartile range; HPB, hepatopancreaticobiliary; GI, gastrointestinal.

	Baseline period	Intervention period	*P* -value
Patients	**2023**	**1873**	0.19
Surgery	642	631	
Internal medicine	1381	1242	
Age, yr	60 (17)	59 (16)	0.43
Female sex, %	49.8	51.3	0.36
Male sex, %	50.2	48.7	
Total in-patient days	14 821	14 348	
Hospital admissions	**2466**	**2303**	0.60
Planned, *n* (%)	1311 (53)	1207 (52)	
Unplanned, *n* (%)	1155 (47)	1096 (48)	
Readmissions, *n* (%)	399 (16)	400 (17)	0.27
Total surgical admissions	**763**	**752**	0.20
First admissions	665	648	0.57
Readmissions	98	104	
Planned surgical admissions	**549**	**518**	0.19
Operative	523	473	**0.01**
Conservative	26	45	
Unplanned surgical admissions	**214**	**234**	
Operative	113	101	0.19
Conservative	101	133	0.23
Surgical admission diagnoses, *n*			
Major HPB and upper GI surgery	220	225	0.64
Colorectal and liver surgery	286	253	0.12
Minor surgery	171	168	0.97
Other	85	102	0.15
Unknown	1	4	0.17
Total internal medicine admissions, *n*	**1703**	**1551**	
First admissions	1402	1255	0.20
Readmissions	301	296	0.30
Planned internal medicine admissions	762 (45)	689 (44)	0.85
Unplanned internal medicine admissions	941 (55)	862 (56)	
Internal medicine admission diagnoses, *n*			
General internal medicine	845	771	0.70
Infectious diseases	402	403	0.12
Rheumatology	344	301	0.57
Other	85	67	0.37
Unknown	27	9	**0.01**

Secondary outcomes

The number of rapid response team calls which did not result in ICU admission decreased in the intervention period (Baseline: 70 calls [2.8%] *vs* Intervention: 45 calls [2.0%]; *P*=0.05). The number of rapid response team calls which did result in ICU admission was not significantly different between the two study periods (Baseline: 52 calls [2.1%] *vs* Intervention 36 calls [1.6%]; *P*=0.16). The number of in-patient deaths was similar in the two periods (Baseline: 12 deaths *vs* Intervention: 14 deaths; *P*=0.57) as was hospital length of stay (Baseline: 5.2 [3.0–9.7] days *vs* Intervention: 5.2 [2.9–9.8] days; *P*=0.77). The wireless monitoring device was removed for 386 patients (21%).

Vital sign set recordings in the EMR

The total number of recorded vital sign sets was 62 273 in the baseline period and 61 358 in the intervention period. The number of MEWS recordings per patient per day was comparable (Baseline: 3.0 [2.0–4.0] *vs* Intervention: 3.0 [2.0–4.0]). The proportion of MEWS scores ≥6 was 4.6% in the baseline period compared with 6.6% in the implementation period (Supplementary Appendix 4). The mean MEWS during the 24 h preceding an unplanned ICU admission or rapid response team call was 5.3 (2.9) during the baseline period compared with 5.7 (3.0) during the intervention period. The number of vital sign recordings in the 24 h preceding an unplanned ICU

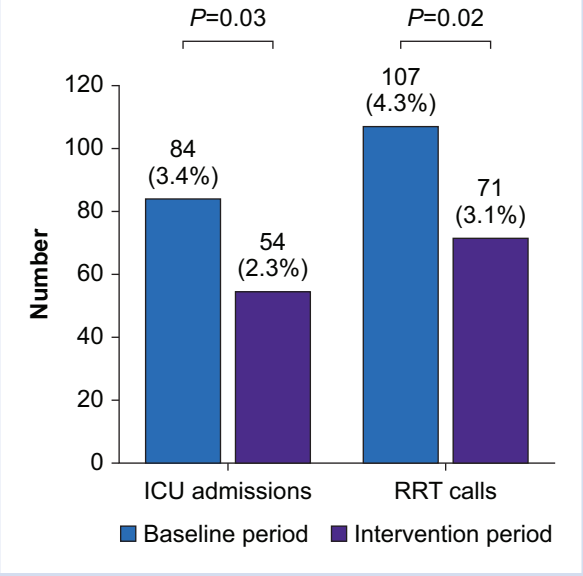

Fig 2. Unplanned ICU admissions and rapid response team calls during the baseline and intervention periods. ICU admissions, unplanned intensive care unit admissions; RRT calls, rapid response team calls.

Table 2 Events at surgical and internal medicine ward. Rapid response call with ICU admission, rapid response team call directly resulting in an ICU transfer; rapid response call with no ICU admission, rapid response team call during which it was decided not to transfer the patient or to re-evaluate at a later moment.

Event	Surgery		Medicine	
	Baseline period (*n*)	Intervention period (*n*)	Baseline period (*n*)	Intervention period (*n*)
Unplanned ICU transfers	50	32	43	27
Total rapid response team calls	72	42	66	52
Rapid response calls with no ICU admission	45	24	39	33
Rapid response calls with ICU admission	27	18	27	19
Deaths	3	0	9	14

admission or rapid response team call was comparable in the two periods (Table 3). Measurement frequency in between complete MEWS recordings during these 24 h periods increased during both day and night shifts (Table 3).

Continuous monitoring vital sign measurements

The median duration of contact loss for the continuous monitoring device was 334 (84–1038) min, which was 6.5% (2.3–13.6%) of the total monitoring time. More single channel alarms were generated in the 24 h preceding an unplanned ICU admission or rapid response team call compared with the rest of the admission (4.1 [0–32] *vs* 1.4 [0–13], $P \leq 0.001$) (Supplementary Appendix 5). Unplanned ICU transfers were preceded by a heart rate alarm in 23% of cases, respiratory frequency alarm in 38%, oxygen saturation alarm in 27%, systolic blood pressure alarm in 21%, and mean arterial pressure alarm in 10% of cases. Rapid response team calls were preceded by a heart rate alarm in 19% of cases, respiratory frequency alarm in 42%, oxygen saturation alarm in 22%, systolic blood pressure alarm in 18%, and mean arterial pressure alarm in 11% of cases.

Discussion

The principal finding of this study was that continuous monitoring of patient vital signs using wearable monitoring technology linked wirelessly to hospital systems was associated with a reduction in unplanned ICU admissions and rapid response team calls. The continuous monitoring intervention was also associated with a reduction in the number of rapid response team calls which resulted in admission to ICU. Although this wireless continuous monitoring system provided significantly more single channel alarms near the time of adverse events, the overall number of alarms was low. These findings suggest that implementation of continuous vital sign monitoring may have enabled clinicians to more rapidly detect and intervene in cases of clinical deterioration. Larger studies are now warranted to confirm the generalisability of our findings and to describe the impact of this intervention on patient survival.

Comparison of our main results with those of prior studies is difficult given differences in study design, patient population, monitoring approaches, measured vital signs, and outcome measures. For example, we collected data using a wrist device capable of measuring multiple vital signs, and enabling full patient mobilisation. We are unaware of other large-scale studies utilising such a device. Two smaller studies with shorter study durations reported benefit of the device detecting early signs of deterioration.[24,25] Fewer ICU transfers and rapid response team calls have been demonstrated in a large study of orthopaedic patients where continuous heart rate and oxygen saturation were monitored through use of a bedside pulse oximeter.[26] Comparisons were made with non-orthopaedic surgical wards, which may have resulted in overestimation of the monitoring effect. When comparing two neighbouring wards, one with and one without continuous

Table 3 Recording frequency of vital sign sets within 24 h of patient outcome events during all shifts and during night shifts. *All vital sign recordings (complete [all mandatory vital signs present that are needed to calculate a MEWS] and incomplete sets [not all mandatory vital signs present to calculate a MEWS]). †Only vital signs sets that included all mandatory vital signs and therefore resulted in a MEWS calculation. ‡Only incomplete sets that did not include all mandatory vital signs to calculate a MEWS. SD, standard deviation; IQR, inter-quartile range; MEWS, Modified Early Warning Score.

	Total number of sets pre/post	Median pre (IQR)	Median post (IQR)	Mean pre (SD)	Mean post (SD)	*P*-value
All shifts						
All vital sign sets*	1551/1186	8 (5–11)	8 (6–12.5)	8.8 (5.2)	10.2 (7.4)	0.35
Complete sets†	1166/763	6 (5–8)	6 (4–8)	6.6 (3.1)	6.6 (3.4)	0.80
Extra sets 'in between'‡	385/423	2 (1–4)	3 (2–6)	3.3 (3.6)	5.5 (7.0)	0.03
Alarming MEWS count	1166/763	2 (1–5)	3 (1–5.5)	3.0 (2.9)	3.5 (3.3)	0.37
Alarming MEWS, %	1166/763	46%	53%			0.002
MEWS	1166/763	5 (3–7)	6 (4–8)	5.3 (2.9)	5.7 (3.0)	0.001
Night shifts						
All vital sign sets*	436/356	2 (1–4)	2 (1–4.5)	2.5 (2.4)	3.1 (3.7)	0.41
Complete sets†	319/221	1 (1–3)	1.5 (0–3)	1.8 (1.7)	1.9 (1.9)	0.83
Extra sets 'in between'‡	117/135	1 (1–2)	2 (1–4)	1.9 (1.6)	3.5 (4.5)	0.02

heart and respiratory frequency monitoring, no reduction was found in unplanned ICU transfers.[27] However, these studies used continuous monitoring of two vital signs, compared with four in our study. Another study did not identify differences in unscheduled critical care team consultations with continuous monitoring of five vital signs. However, this study had several limitations, such as inclusion of continuously monitored patients in the control arm and premature cessation of monitoring to allow patient mobilisation.[28] Although the absolute number of daily MEWS recordings was unchanged across both periods in our study, a greater number of MEWS scores greater than 6 were noted during the intervention period. Previous feasibility studies showed this device to be as accurate as manual nurse measurements and even more accurate for respiratory frequency, generally resulting in higher rates and MEWS scores.[19,21] This may have important clinical significance, as respiratory frequency is an important parameter in predicting adverse events.[26,29] Given the higher proportion of alarming MEWS scores in the intervention period, we might have expected an increase in rapid response team calls. Indeed, most prior studies assessing the effect of increased attention have found an increase in care escalation events (albeit with generally intermittent vital sign checks).[30] An increase was also reported when vital sign monitoring was combined with an electronic automated advisory and notification system, thereby bypassing clinical validation and interpretation of abnormal vital sign measurements or early warning scores.[31] We hypothesise that the continuous vital sign data and trends available to clinicians in our study may have supported ward nurses and physicians in their management of deteriorating patients.[18,32] This hypothesis is also supported by increased frequency of vital sign recordings in the EMR in between complete MEWS recordings. Differences in diagnostic and therapeutic interventions between the two study periods may also explain this observation, but we did not record this activity. Continuous monitoring was not associated with reduced mortality or length of hospital stay. However, these outcomes are affected by multiple factors, such as early discharge policies and do-not-resuscitate orders and have previously been variably associated with continuous monitoring.[18,26–28] Moreover, we did not combine implementation with any treatment algorithm which might be expected to reduce mortality rates. Alarm fatigue as a result of too many non-actionable alarms has been a major concern for ICU and anaesthesia staff and has also become relevant to general wards introducing continuous monitoring.[33] In this study, the number of alarms were higher when close to adverse events compared with the rest of the admission. However, the overall alarm frequency was low, suggesting alarm fatigue to be unlikely.

This study has both strengths and limitations. We included a large number of patients with both surgical and medical disease, and a vital sign dataset with minimal loss of monitoring data. Our study was conducted within the context of a standardised EWS system, which triggered a rapid response team attendance, which was the same throughout the study period. Patient characteristics, admission diagnoses, and rates of emergency admissions and readmissions were comparable before and after implementation. Aside from continuous monitoring implementation, there were no other significant procedural changes made between the baseline and intervention periods. However, a before-and-after study design remains vulnerable to bias and precludes a detailed analysis of alternative causal factors that may have affected patient outcomes.[34] We did not undertake a multivariable analysis, and time-series analysis was inconclusive because of the low adverse event rate (data not shown). A robust, large multicentre cluster trial design would be necessary to provide generalisable findings and confirm the clinical effectiveness of our continuous monitoring intervention.

In conclusion, we found that implementation of continuous monitoring of patient vital signs using wearable monitoring technology linked wirelessly to hospital systems was associated with a reduction in unplanned ICU admissions and rapid response team calls amongst hospitalised general medical and surgical patients. These findings indicate the efficacy of this approach to patient monitoring on hospital wards, allowing earlier recognition, and more appropriate management of clinical deterioration of patients in the general ward setting. Future research should also evaluate artificial intelligence predictive algorithms to further improve the predictive capacity of continuous monitoring systems. However, this technology is still in early development, and the added value is yet to be determined.[35]

Authors' contributions

Conceptualisation: YE, RVP, HT, HvG, SJHB
Data curation: YE, RVP, MK
Formal analysis: YE, RVP, MK
Methodology: YE, RVP, MK, HT, HvG, SJHB
Project administration: YE
Visualisation: YE
Supervision: HT, HvG, SJHB
Resources: HvG, SJHB
Writing of the original draft: YE, RVP, MK, HT, HvG, SJHB
Review and editing: RVP, MK, HT, HvG, SJHB
Manuscript revisions: YE, RVP, MK, HvG, SJHB
Project administration: MK
All authors approve the version to be submitted, and all authors agree to be accountable for all aspects of the manuscript.

Declarations of interest

All authors declare that there are no conflicts of interests.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bja.2022.01.036.

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