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A retrospective cross-sectional study showing wearable smartwatches enhance patient safety and efficiency in the intensive care unit

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Abstract

Background Wearable smartwatches present a novel approach to continuous patient monitoring in ICU settings, with the potential to enhance patient safety and clinical efficiency.

Methods This retrospective cross-sectional study evaluated the impact of smartwatch use on alarm response rates and clinical outcomes in a 27-bed ICU. Data were collected over two periods: pre-implementation (May 12, 2023, to July 11, 2023) and post-implementation (October 22, 2023, to December 22, 2023) of smartwatches worn by healthcare workers.

Results Our findings indicate that the adoption of smartwatches significantly improves alarm response rates from 12.58% to 14.85% ($p < 0.0001$). In addition, the reduction in response time, fatal and high alert, medium alert, and low alert within 30 s response rates increased from 51.51%,70.42%, and 74.03% to 60.04%, 74.02%, and 76.71%, respectively ($p < 0.0001$), resulting in fewer high and fatal alerts. Moreover, the use of smartwatches is associated with reduced durations of mechanical ventilation and ICU stays, signifying improved clinical outcomes.

Conclusions Wearable technology has the potential to simplify ICU operations, reduce alarm fatigue, and ultimately improve patient care and reduce adverse events.

Plain language summary

The intensive care unit (ICU) uses a lot of technology, with each patient generating hundreds of alerts daily. As a result, the ICU is a stressful area for nursing staff to work in as they are constantly responding to these alerts. Nurses in the ICU wore smartwatches in the ICU wards and we evaluated their response to alarms and the efficiency of their nursing work. Our findings show that using wearable smartwatches can significantly improve alarm response rates, reduce alarm response times and the number of alarms, and decrease alarm fatigue and adverse events. Thus, introducing smartwatches more widely could improve the treatment of patients and improve the experience for nurses.

In the 1960s, wearable technology was first introduced by the Media Lab at the Massachusetts Institute of Technology[1]. Since then, this technology has evolved rapidly, finding significant applications in various fields, including healthcare[2]. In intensive care units (ICUs), where critically ill patients require constant monitoring, wearable devices offer a novel approach to patient care. These devices can continuously monitor vital signs such as heart rate, blood pressure, and oxygen saturation, providing real-time data to healthcare professionals and potentially improving patient outcomes[3]. Over the past decade, advances in wearable, implantable, and continuous monitoring technologies have significantly progressed. With the development of artificial intelligence, these technologies hold the potential for early disease diagnosis, comprehensive disease management, and the discovery of new biomarkers in future treatments[4,5].

The ICU environment is one of the most technologically advanced areas in healthcare. Patients in ICUs are connected to a myriad of devices that monitor their vital signs continuously. These devices include mechanical ventilators, infusion pumps, and various sensors that track parameters like heart rate and blood pressure. Despite the advanced monitoring capabilities, the integration of these devices often lacks coordination, leading to a fragmented data collection system. This fragmentation can delay the timely intervention needed to prevent patient deterioration[6].

The growing demand for critical care services necessitates not only an increase in ICU capacity but also enhancements in its functionality. Wearable devices can play a crucial role in this enhancement by reducing nursing time and improving the early detection of abnormal physiological

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parameters. When patient parameters deviate from preset ranges, wearable devices can alert ICU staff through visual or auditory alarms, thereby significantly improving patient safety[7].

However, the ICU's high degree of digitization introduces challenges such as alarm fatigue[8–10]. Alarm fatigue occurs when ICU staff become desensitized to the frequent alarms, which can lead to delayed or inadequate responses. This condition is exacerbated by the increasing number of devices, each with its own set of alarms. Excessive alarms not only cause stress and distraction for ICU staff but also directly harm patient recovery by contributing to alarm fatigue[11,12].

Over the past decade, advances in wearable, implantable, and continuous monitoring technologies have significantly progressed[13]. In previous studies, the primary focus has been on how to apply wearable devices to patients, improving data accuracy, transmission, and precision through material and technological innovations. Recently, there has been a deeper integration with AI to comprehensively assess patient conditions[14,15]. However, these advancements have not yet been fully applied in real-world settings[16]. Importantly, bedside observation by healthcare personnel remains essential, especially in regions with limited resources. Failure to detect and address changes in a patient's condition promptly can lead to fatal outcomes. To address these challenges, we develop smartwatches equipped with intelligent alarm chains. By integrating data from multiple monitoring devices, a more coordinated alert system is created, with alarm information distributed to nurses via the smartwatch, prompting timely intervention by medical staff. This alert system can distribute alerts and role push notifications in a hierarchical manner, which further simplifies the workflow, reduces the workload of ICU staff, and improves work efficiency.Nurses wearing these devices can detect accurate and meaningful alarms in time, make timely treatment for patients earlier, reduce the occurrence of adverse events, and identify errors and inoperable alarms.

Method

Setting and design

This study was conducted in the ICU F area of the First Affiliated Hospital of Harbin Medical University, which includes 27 beds, the First Affiliated Hospital of Harbin Medical University is a large general clinical hospital, ICUF area is a part of the comprehensive ICU, which admits more than 2000 patients each year and has more than 100 medical staff. Each device in the ICU ward is equipped with advanced monitoring systems such as bedside monitors and ventilators, integrated into the E-care intelligent monitoring system(Mindray Benevision CMS V07.38). The monitored parameters included ECG arrhythmia, SpO2, NIBP, IBP, respiration rate, and body temperature. All alert data generated by these systems was collected and recorded by the smart alarm system. The system organizes the collected alarm information and divides the alarm into four categories according to the urgency and severity (fatal alarm, high alarm, intermediate alarm, low alarm)[Supplementary Data file 1]. These Alarm data were uniformly transmitted to the central monitoring station and to the responsible nurses through the smart Watch network (Minrebenevic Alarm Protector (Watch) V01.25), which allowed the nurses who were not at the bedside to receive accurate and effective alarm information in time. According to the actual clinical situation of the alarm system, the response rate and response time are directly sorted out and exported by the background control center of the smart watch, without secondary calculation.

This study does not need to be approved by the ethics committee, because the data used are non-identifying data, and there is no potential risk to the personal rights and privacy of patients. Such research that does not involve patients' privacy information can be exempted from ethical approval. All nurses gave consent for their data to be used in this study. Although this study was exempted from ethical approval, we still adhere to a rigorous and responsible attitude to carry out the research. All data collection, processing and analysis processes strictly abide by the principles of data security and confidentiality, and adopt safe and reliable data storage and transmission methods to prevent data leakage and abuse.

Data collection and deidentification

A retrospective cross-sectional design was employed, analyzing alarm log data from two distinct periods: before (May 12, 2023, to July 11, 2023) and after (October 22, 2023, to December 22, 2023) the implementation of wearable smartwatches by healthcare workers, all nurses working in this period at the ICU. During the intervention, the nurse wore a smartwatch to detect the patient's vital signs and receive alerts, while the nurses in the control group did not wear smart watches and provided standard care to the patients. In the control group, the vital signs of patients were monitored by bedside monitor, and the vital signs of each patient could be seen on the screen of the central monitoring station. Before the use of smart watches, the nurses were trained for two months and successfully assessed. The basic characteristics of all nurses were counted [Supplementary Information-Supplementary Table 1].

Data collection involved manually extracting clinical audit logs, including alert data from the ICU E-care system. Patient privacy was preserved by deidentifying the data: dates were shifted into the future using a pseudorandom offset, and bed numbers were replaced with pseudonyms. The experimental group and the control group were consistent in the overall treatment principles, guardians, and monitoring implementation, which could minimize the differences. Patient severity was judged according to APACHEII score, and the characteristics of circadian rhythm, weekend, season, and bed type (double or single) did not affect alert analysis.

Alarm load

To thoroughly analyze the alarm load, each alarm was categorized by its parameters and the corresponding monitoring devices. The alarms were classified into two main types: technical alarms and physiological alarms. The severity levels were also noted, ranging from fatal, high, intermediate, low, to prompt.

The most common physiological alarms in both groups, such as high heart rate (excessive heart rate) and high arterial pressure (excessive Art-S) and technical alarms, including volume limitation (CL) and pressure limitation (PL), were also analyzed. The integration of smartwatch technology facilitates more accurate and coordinated alert management, reduces false alarms, and ensures that emergency alerts receive immediate attention. In addition, the alarm distribution of different shifts was analyzed.

Avoidable alarms

To optimize alarm management, it is crucial to identify and reduce avoidable alarms, which include false alarms and non-actionable alerts. In this study, alarms were meticulously categorized into technical and physiological types to assess their avoidability.

The analysis was conducted to understand the incidence and distribution of avoidable alarms within the ICU setting. This included examining how these alarms affected the workload of ICU staff and their ability to respond promptly to critical alerts. Additionally, the study looked into the hierarchical distribution of alarms and role-specific push notifications to ensure that the most relevant alerts were directed to the appropriate healthcare personnel. Hierarchical intelligent alarm distribution was adopted, and important alarm was pushed by different roles of the whole device (Hierarchical alarm push of role definition: important alarm will be pushed to the watch of the responsible nurse, and the alarm that has not been dealt with will be pushed to the nurse team leader; Advanced/fatal alerts pushed to nurse strengths; fatal and special concern alerts pushed to doctors; fatal arrhythmia and rescue alerts were sent to the Respiratory Therapist. The director is on call and responds to alarms.

Statistics and reproducibility

SAS9.4 software was used for statistical analysis. The quantitative data of normal distribution were described by the mean ± standard deviation ($\bar{x} \pm s$), and the two groups were compared by two independent samples t-test (the statistic was the t-value). The continuous data with skewed distribution were described by median and interquartile range [M(P25, P75)], and the Wilcoxon rank sum test was used for comparison between the two groups (the statistic was Z score). Categorical data were described by frequency (percentage), and χ2 test or Fisher exact probability method was used to compare the composition between the two groups (the statistic was χ2 value). logistics regression model was used to analyze the influencing factors. $P < 0.05$ think the difference was statistically significant.

Reporting summary
Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Results
Characteristics of the patients
Patients were enrolled over two periods: May to July 2023 (control group) and October to December 2023 (smartwatch group). In total, 602 patients were included in the study, with 287 in the control group and 315 in the smartwatch group.

The median age in the control group was 64 years (interquartile range [IQR], 53–72), while in the smartwatch group it was 62 years (IQR, 51–71). Both groups had a similar gender distribution, with males constituting 61.32% of the control group and 60.63% of the smartwatch group (Table 1). The median APACHE II score, which assesses the severity of disease in ICU patients, was slightly higher in the control group (21, IQR 16–27) compared to the smartwatch group (19, IQR 15–24). This difference was statistically significant ($p = 0.0017$).

Because the baseline levels of the control group and the smartwatch group were not consistent (APACHE II $p = 0.0017$), logistic regression was used to analyze the influencing factors of death to determine whether APACHE II score was a confounding factor. In logistic regression, the OR value is used to compare the degree of influence of two values of an independent variable on the dependent variable. OR greater than 1 indicates that the factor is a risk factor, and less than 1 indicates that the factor is a protective factor. Only the baseline indicators of the study subjects were considered in our regression model, and the indicators in Supplementary Information-Supplementary Tables 2 and Supplementary Information-Supplementary Table 3 were also outcome indicators and were not included in the regression model.

The analysis results of the influencing factors of death are shown in Supplementary Information-Supplementary Table 2, and the results of univariate regression analysis show that age and APACHEII are the influencing factors of death. All variables were included in the multivariate regression model, the results showed that age, APACHEII, mechatronics, and ICU time were the influencing factors of death. Patients in the control group had a longer median ICU stay (4 days, IQR 2–11) compared to the smartwatch group (3 days, IQR 2-7). The duration of mechanical ventilation was also longer in the control group (4 days, IQR 2–11) than in the smartwatch group (3 days, IQR 2–6).

The analysis results of the influencing factors of the group are shown in Supplementary Information-Supplementary Table 3. The results of single factor regression analysis showed that APACHEII, days of mechanical ventilation, and days in the department were the influencing factors of the group. All variables were included in the multivariate regression model, and the results showed that APACHEII, days of mechanical ventilation, and days in the department were the influencing factors of the group. The in-hospital mortality rate was 7.67% in the control group and 9.52% in the smartwatch group, without a statistically significant difference ($p = 0.41$). The 28-day mortality rate was higher in the control group (40.07%) compared to the smartwatch group (32.38%), with a p-value of 0.05, indicating statistical significance.

These characteristics provide a baseline for comparing clinical outcomes and the efficacy of alarm management between the two groups. The slightly lower APACHE II scores and shorter ICU stays in the smartwatch group suggest a trend towards better initial patient conditions or more effective management, which will be further explored in subsequent sections of the study.

Comparison of response rate
The response rate to alarms was a key metric evaluated in this study. A comparison was made between the smartwatch group and the control group to assess the effectiveness of wearable smartwatches in improving alarm response as shown in Table 2.

After adjusting for APACHEII scores, the smartwatch group had a significantly higher rate of response to alerts. Out of the total alarms, 14.85% (44,135 alarms) were responded to in the smartwatch group. In contrast, the control group had a lower response rate, with 12.58% (51,873 alarms) of the alarms being responded to. The difference in response rates between the two groups was statistically significant ($\chi^2 = 760.84$, $p < 0.0001$).

The higher response rate in the smartwatch group indicates that the use of wearable smartwatches enhances the ability of healthcare workers to respond promptly to alarms. This improvement is crucial in an ICU setting, where timely responses to alarms can significantly impact patient outcomes.

Comparison of alarm response time
The comparison results of alarm response time between the smart watch group and the control group are shown in Table 3. After adjusting for APACHEII scores, the difference of alarm response time between the two groups was statistically significant, which showed that the proportion of response time < 30 s was larger and the response time was shorter in the smart watch group when the alarm was generated at all levels.

The smartwatch group had significantly faster response times, with 60.04% of fatal and high alarms, 74.02% of intermediate alarms, and 76.71% of low and prompt alarms being responded to within 30 s, compared to the control group, which had response rates of 51.51%, 70.42%, and 74.03% for the same alarm levels, respectively.

These findings suggest that the implementation of wearable smartwatches significantly improves the speed of response to alarms, particularly for high-priority alarms, which is crucial for patient safety and outcomes in ICU settings.

Response situation under alarm level
The response rates to alarms were further analyzed by severity levels—fatal, high, intermediate, and low (Table 4). The response rates for alarms by severity levels showed that the smartwatch group had significantly higher response rates: 57.58% for fatal alarms compared to 37.49% in the control group, 23.75% for high alarms compared to 18.38%, 13.53% for intermediate alarms compared to 11.23%, and 7.84% for low alarms compared to 7.81%.The differences in response rates for fatal, high, and intermediate alarms between the two groups were statistically significant ($p < 0.0001$), while the response rates for low alarms were not significantly different (p = 0.81).

Alarm load
The wearable alert watch alerted each patient, and the use of the wearable smartwatch significantly reduced the total number of alerts, with 345,807 alerts in the smartwatch group (214.5 alerts per bed per day) versus 467,814 alerts in the control group (295 alerts per bed per day). Most alarms in both groups were low-level, followed by high-level alarms, with fatal alarms being rare (Fig. 1-A). Among the physiological alarms, the most common alarms in the control group were HR too high (HH) and Art-S too high (ASH), as shown in Fig. 2-B. The most common alarms in the smart watch group were Art-S too high, HR too high, and CVP-M too high (CMH), as shown in Fig. 2-A. When each alarm parameter is assigned to the corresponding medical device, it is clear that monitors emit the most alarms, and ventilators and infusion pumps emit fewer alarms, as shown in Fig. 1-B. The distribution of alarms across different shifts showed that the smartwatch group had 37.51% of alarms during the day, 32.21% in the evening, and 30.28% at night, compared to the control group's 38.59% during the day, 31.45% in the evening, and 29.96% at night. This reduction and balanced distribution of alarms help mitigate alarm fatigue among ICU staff and improve overall patient care.

Table 1 | Patient and admission characteristics

Indicators	Smart Watch Group	Control Group	Z/χ²	P
APACHEII	19 (15–24)	21 (16–27)	3.13	0.0017
Age	62 (51–71)	64 (53–72)	0.97	0.33
Gender			0.03	0.86
male	191 (60.63)	176 (61.32)		
female	124 (39.37)	111 (38.68)		
Days of mechanical ventilation	3 (2–6)	4 (2–11)	2.97	0.0029
Days in department	3 (2–7)	4 (2–11)	3.26	0.0011
Death in the hospital			0.66	0.41
yes	30 (9.52)	22 (7.67)		
no	285 (90.48)	265 (92.33)		

Bracketed numbers indicate the percentage (%) of each group in Gender and Death in the hospital; the other meaning is interquartile range [M(P25, P75)].

Table 2 | Comparison of response rate

Indicators	Smart Watch Group	Control Group	χ²	P
Response to			760.84	<0.0001
yes	44,135 (14.85)	51,873 (12.58)		
no	253,028 (85.15)	360,420 (87.42)		

Bracketed numbers indicate the percentage (%) of each group.

Table 3 | Comparison of response times

Indicators	Smart Watch Group	Control Group	χ²	P
F&Aresponse times			413.30	<0.0001
<30 s	16295(60.04)	15001(51.51)		
>30 s	10847(39.96)	14119(48.49)		
M response times			23.63	<0.0001
<30 s	4518(74.02)	6565(70.42)		
>30 s	1586(25.98)	2758(29.58)		
L&H response times			29.06	<0.0001
<30 s	10265(76.71)	12807(74.03)		
>30 s	3116(23.29)	4492(25.97)		

Bracketed numbers indicate the percentage (%) of each group.
F fatal alarm, *A* high alarm, *M* intermediate alarm, *L* low alarm, *H* prompt alarm.

Table 4 | Response at alarm level

Indicators	Smart Watch Group	Control Group	χ²	P
F			74.66	<0.0001
Response to	490 (57.58)	376 (37.49)		
No response	361 (42.42)	627 (62.51)		
A			1148.62	<0.0001
Response to	26652 (23.75)	28744 (18.38)		
No response	85588 (76.25)	127633 (81.62)		
M			145.71	<0.0001
Response to	6104 (13.53)	9323 (11.23)		
No response	39022 (86.47)	73701 (88.77)		
L			0.06	0.81
Response to	10889 (7.84)	13430 (7.81)		
No response	128057 (92.16)	158459 (92.19)		

Bracketed numbers indicate the percentage (%) of each group.
F fatal alarm, *A* high alarm, *M* intermediate alarm, *L* low alarm.

Table 5 | Comparison of alarm types

Indicators	Smart Watch Group	Control Group	Z/χ²	P
Type of alarm			2110.18	<0.0001
Technology	208766 (60.37)	258594 (55.28)		
Physiology	137041 (39.63)	209220 (44.72)		

Bracketed numbers indicate the percentage (%) of each type of alarm.

Figure 2 illustrates the distribution and trends of alarms between the smartwatch and control groups. The sample size for Fig. 2A-D is shown in the supplementary data file 2. Fig. 2A–D show that both groups have similar types of top 10 physiological and technical alarms, but the smartwatch group generally has fewer alarms. Figure 2E, F indicate that the smartwatch group experiences fewer and more stable alarm frequencies over time compared to the control group. This reduction in alarms, particularly technical ones, suggests that wearable smartwatches improve alarm management by reducing non-critical issues and enhancing response times to critical alarms. Overall, the data indicate that smartwatches can alleviate alarm fatigue among ICU staff, improve patient outcomes, and reduce staff workload.

Avoidable alarms

The results of the comparison of alarm types between the smartwatch group and the control group are shown in Table 5. The two groups of patients had statistically significant differences in the proportional distribution of alarm types, which showed that the incidence of physiological alarms was lower in the smartwatch group ($p < 0.0001$). The smartwatch group recorded a total of 208,766 technical alarms, and the most technical alarm generated by the monitoring system was capacity limitation (CL), as shown in Fig. 2-C. A total of 258,594 alarms were recorded in the control group, and the most technical alarms generated by the monitoring system were CL, followed by pressure limitation (PL), as shown in Fig. 2-D.

The implementation of wearable smartwatches in ICU settings significantly reduced avoidable alarms, including false alarms and non-actionable alerts, particularly in technical alarms like capacity and pressure limitations, as well as physiological alarms such as high heart rate and arterial pressure. This reduction led to decreased alarm fatigue among ICU staff, allowing them to focus more on critical alarms that required immediate attention, thereby improving patient care and safety.

Comparison of alarm distributions

The implementation of wearable smartwatches resulted in a more balanced distribution of alarms across day, evening, and night shifts. Specifically, the smartwatch group had 37.51% of alarms during the day, 32.21% in the evening, and 30.28% at night, compared to the control group's 38.59% during the day, 31.45% in the evening, and 29.96% at night. This even distribution helps mitigate periods of high alarm activity, ensuring that ICU staff are not overwhelmed during specific shifts and can maintain a consistent level of patient monitoring and care (Table 6.).

Discussion

Staff in the intensive care unit (ICU), one of the most advanced areas of digital health, have used monitoring technology for decades[17,18], and the continuous integration of new devices, each with its own alarm system, has resulted in a large number of alerts. Studies have documented an average of more than 700 alerts per patient per day[19]. This excessive number of alarms not only causes stress and distraction for ICU staff[9,10], but also contributes to alarm fatigue, which can compromise patient safety. To tackle this pressing issue, we have introduced a solution: outfitting ICU nurses with

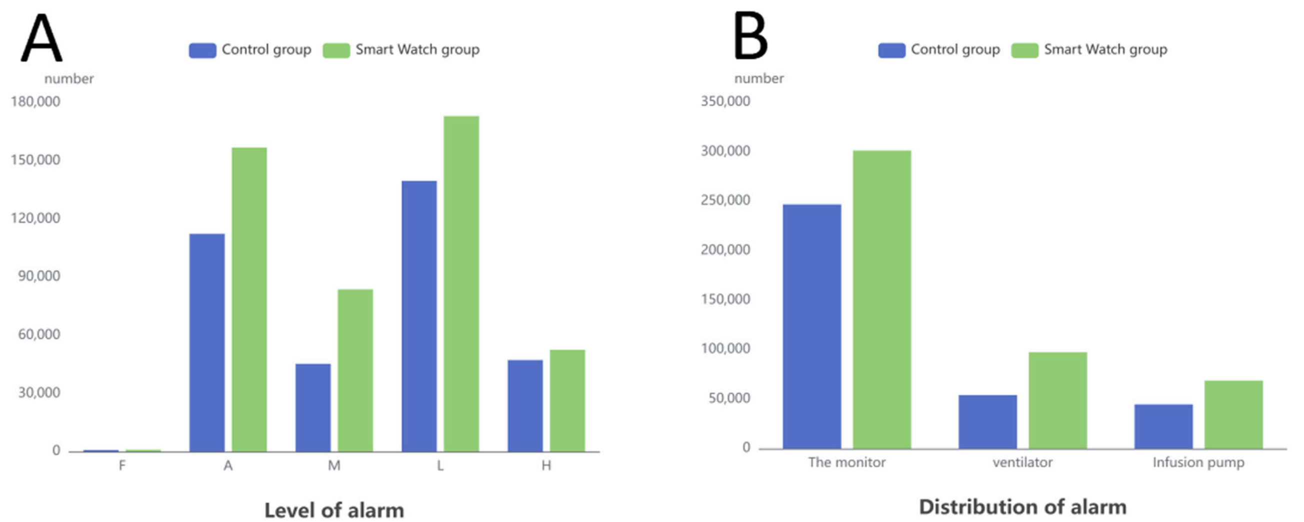

Fig. 1 | The influence of smart watches on alarm levels and alarm distribution. A Alarm level of the smart watch group and the control group.**B** alarm distribution of the smart watch group and the control group. F: fatal alarm, A: high alarm, M: intermediate alarm, L: low alarm, H: prompt alarm.

smartwatches. These wearable devices are more than just time—tellers; they serve as a crucial tool in the fight against alarm overload. The smartwatches are designed to enable the nursing staff to swiftly respond to high—priority alerts. Moreover, they can accurately differentiate between physiological alerts, which are directly related to a patient's health status, and technical alerts, which might be due to device malfunctions or improper setups. By doing so, the smartwatches effectively lighten the workload and ease the stress of healthcare workers. As a result, they play a pivotal role in enhancing the overall efficiency and quality of patient care in the ICU, ensuring that patients receive the best possible treatment in this high—stakes environment.

In our study, as shown in Table 1, disparities were observed in the baseline levels between the two patient groups. Even though the two groups were largely comparable, the data suggested that wearable smartwatches might have an impact on 28—day mortality. Therefore, we used a multivariate regression model to analyze the factors influencing mortality, as shown in Supplementary Information-Supplementary Table 2. The analysis demonstrated that there was no statistically significant difference in mortality between the group using wearable smartwatches and the group that did not. However, mechanical ventilation duration and length of hospital stay emerged as significant mortality predictors. Due to the difference in APACHE II scores between the two groups, we equalized these scores for regression analysis. The results indicated that APACHE II scores, days of mechanical ventilation, and days in the department were significant influencing factors. This implies that the utilization of smart wearable watches can shorten both the duration of mechanical ventilation and the length of stay in the department.

The response rate and response time in the smartwatch group were significantly improved, as shown in Tables 2 and 3. We categorized all alarms into low-level, medium-level, high-level, and fatal categories. After the adoption of smart wearable watches, we discovered that nurses were more inclined to respond promptly to high—level alarms. Meanwhile, they didn't always detect low—level alarms that had no impact on vital signs. As shown in Table 4, in both groups, the majority of alarms were low—level, followed by high—level alarms, and fatal alarms were the least frequent. These alarms predominantly originated from monitors, while a smaller proportion came from ventilators and infusion pumps. As depicted in Fig. 1, there was a significant reduction in the number of technical alarms in the smartwatch group. This reduction can considerably alleviate the workload of doctors and nurses, thus enhancing work efficiency.

In the context of physiological alarms, the control group experienced a higher overall number of alarms. However, the number of alarms significantly decreased during the day shift and increased during lunch breaks and night shifts, likely due to the increased attention nurses could provide during the day shift. Conversely, the number of alarms in the smartwatch group was more evenly distributed throughout the day, contributing to a more stable patient state and facilitating better patient monitoring. From 10 PM to 6 AM, the frequency of technical alarms, such as CL (circuit leak) and PL (pressure loss), was higher. Nurses should thus pay extra attention during the night shift, as illustrated in Fig. 2. Our study also identified a disparity in the number of alerts across different shifts. Night shifts consistently exhibited higher alert counts. In the smartwatch group, although the number of alerts during night shifts was also higher, this actually had a positive impact. The increased alert count helped in streamlining the workflow by reducing avoidable workload. Nurses were able to focus on critical alerts promptly, preventing any delays in addressing patient conditions and ultimately safeguarding patient safety.

In previous studies, ICU staff have used wireless, noninvasive, and interoperable monitoring sensors to enhance alarm management for future patient monitoring systems and lay the technical foundation for upgrading the patient monitoring system[19,20]. Patient wearable monitoring devices for vital sign detection and alarm management have been extensively studied. Wearable monitoring systems (WMS) have been shown to provide an intermediate level of monitoring between continuous, highly dependent monitoring and intermittent manual measurements, facilitating early deterioration detection in high-risk patients, such as those recently discharged from the ICU[21]. Clinical studies have confirmed that the use of wireless monitoring in pediatric populations improves the recognition of exacerbations[22]. Continuous monitoring of patient vital signs using wearable monitoring technology that is wirelessly connected to hospital systems reduces unplanned ICU admissions, while rapid response team calls decline[23]. Studies have found that wearable devices can measure abnormalities in vital signs before clinical deterioration[24,25]. Take the new patch device as an example, this wearable patch previously shown to be clinically acceptable in terms of accuracy[26,27], along with a remote warning score system for vital parameters measured by this patch, provides predictive performance comparable to the Modified Early Warning Score (MEWS) in patients after major abdominal cancer surgery[28]. It not only improves the patient's activity tolerance and comfort, but also reduces the load of nursing operation[29]. However, these wearable monitoring devices primarily focus on observing patient conditions, and there are few studies on monitoring basic vital signs. These devices still require intervention from doctors and nurses. Given that there are many beds in the ICU and each medical worker needs to

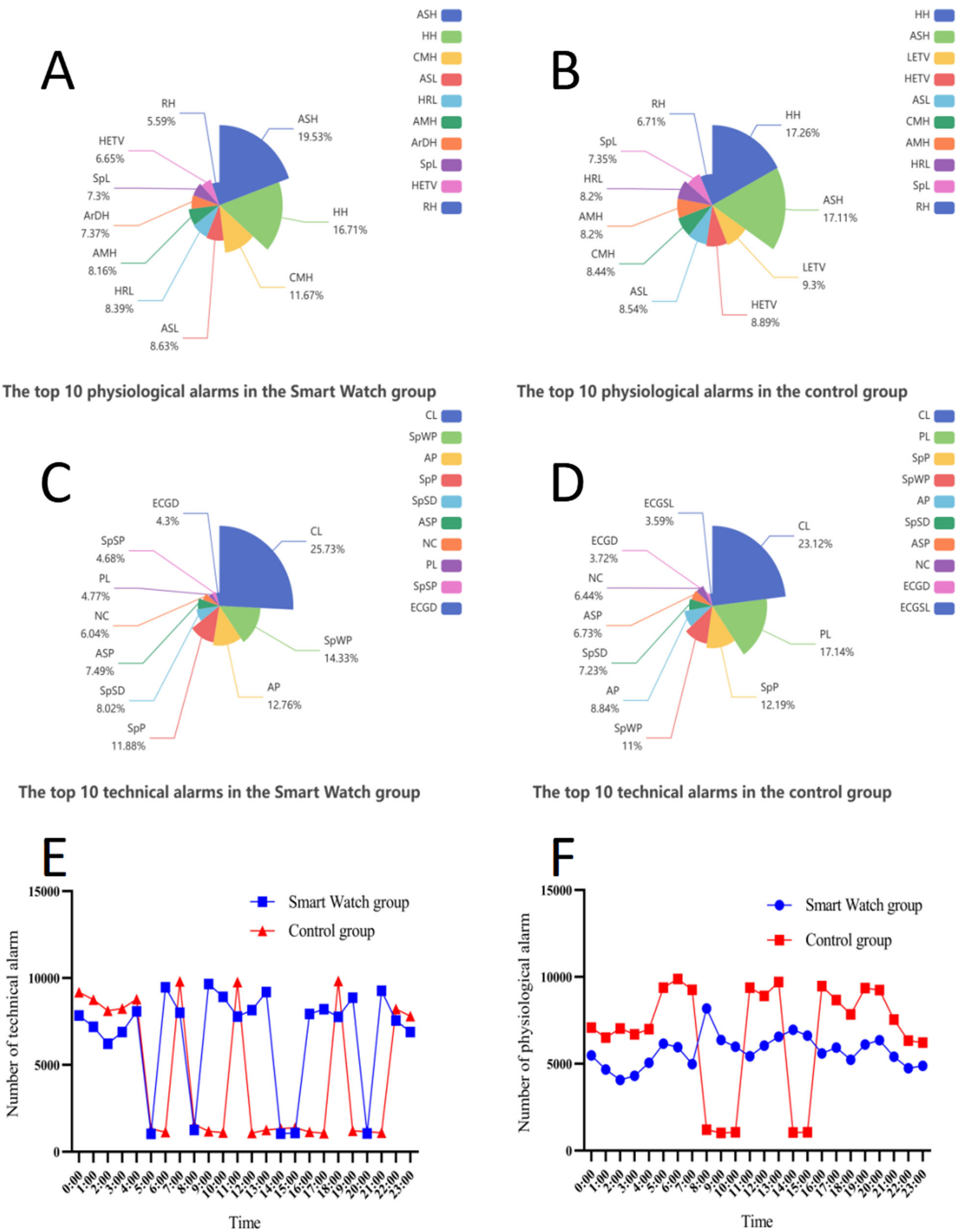

Fig. 2 | The effect of smart watches on alarm types and time distribution. **A** The top 10 physiological alarms in the Smart Watch group. **B** The top 10 physiological alarms in the control group. **C** The top 10 technical alarms in the Smart Watch group. **D** The top 10 technical alarms in the control group. **E** Distribution of 24 h technical alarms in control group and smart watch group. **F** Distribution of 24 h physiological alarms in control group and smart watch group. ASH Art—S too High, HH HR is too High, CMH High CVP—M, ASL Art—S is too low, HRL HR is too low, AMH Art—M High, ArDH Art—D is too High, SpL: SpO2 is too low, HETV: High exhaled tidal volume, RH RR too high, LETV Low exhaled tidal volume, CL Capacity limitations, SpWP SpO2 weak perfusion, AP Art without pulsation, SpP SpO2 without pulsation, SpSD SpO2 sensor detached, ASP Art search for pulse, NC near completion, PL Pressure limit, SpSP SpO2 search pulse, ECGLD Electrocardiograph lead detachment, ECGSL Electrocardiograph is self-learning.

Table 6 | Comparison of alarm distributions

Indicators	Smart Watch Group	Control Group	Z/χ^2	P
Distribution of alarms			103.41	<0.0001
Day	129,712 (37.51)	180,527 (38.59)		
Evening	111,384 (32.21)	147,149 (31.45)		
Night	104,711 (30.28)	140,138 (29.96)		

Bracketed numbers indicate the percentage (%) of each time distribution.

monitor the vital signs of 3-4 patients, the monitoring system cannot always respond promptly when alarms occur.

Effective alert management can mitigate the harm associated with clinical alerts by reducing the number of unnecessary alerts, such as false, inoperable, and avoidable technical alerts[30]. This reduction in unnecessary alerts helps decrease the overall number of alarms, thereby alleviating alarm fatigue among staff. Traditional alarm management methods have been shown to effectively reduce the total number of alarms[31]. These methods include muting alarms after patient assessment[32], introducing a delay between measurement and alarm activation, using patient-specific thresholds instead of default equipment thresholds, disabling non-life-threatening arrhythmia alerts, and changing ECG leads daily[33,34].This study investigates the efficacy of employing wearable smartwatches by ICU staff to enhance alarm response and improve patient outcomes, addressing both the technological advancements and the practical challenges faced in critical care settings.

This study, while demonstrating the potential benefits of wearable smartwatches in ICU settings, has several limitations that must be acknowledged. The study employed a retrospective cross-sectional design, which limits the ability to establish causality. While the association between the use of smartwatches and improved alarm management and clinical outcomes is evident, prospective studies are needed to confirm these findings and understand the causal mechanisms involved. The research was conducted in a single ICU at the First Affiliated Hospital of Harbin Medical University. This limits the generalizability of the results. ICU environments, patient populations, and staff protocols can vary significantly between institutions. Multi-center trials would provide a more comprehensive understanding of the effectiveness of wearable smartwatches across diverse settings. While the study showed improved 28-day mortality rates, it did not provide long-term follow-up data. Assessing the impact of wearable smartwatches on patient outcomes beyond the immediate post-discharge period would offer valuable insights into the sustained benefits of this technology.

Data availability

All data generated or analysed during this study are included in this published article and Supplementary Data file 2, and also are available from the corresponding author upon request. Source data are provided as Supplementary Data file 2. Source data are provided with this paper.

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Author contributions

Wei Yang conceptualized, designed the experiments, and Ruifeng Xu, Ru Chen, Xiuhua Zhang, Mengyang Xin performed the experiments, Jiannan Zhang, Yang Zhong, Peiyao Luo, Yiqi Wang, Mingbo Zhao, and Mingyan Zhao collected data. Xinyue Ma, Lei Wang, and Shishuai Meng analysed the data and wrote the original draft.

Competing interests

The authors declare no competing interests.

Additional information

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