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RESEARCH ARTICLE

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Continuous monitoring is superior to manual measurements in detecting vital sign deviations in patients with COVID-19

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Abstract

Background: Patients admitted to the emergency care setting with COVID-19-infection can suffer from sudden clinical deterioration, but the extent of deviating vital signs in this group is still unclear. Wireless technology monitors patient vital signs continuously and might detect deviations earlier than intermittent measurements. The aim of this study was to determine frequency and duration of vital sign deviations using continuous monitoring compared to manual measurements. A secondary analysis was to compare deviations in patients admitted to ICU or having fatal outcome vs. those that were not.

Methods: Two wireless sensors continuously monitored (CM) respiratory rate (RR), heart rate (HR), and peripheral arterial oxygen saturation (SpO_2). Frequency and duration of vital sign deviations were compared with point measurements performed by clinical staff according to regional guidelines, the National Early Warning Score (NEWS).

Results: SpO_2 < 92% for more than 60 min was detected in 92% of the patients with CM vs. 40% with NEWS (p < .00001). RR > 24 breaths per minute for more than 5 min were detected in 70% with CM vs. 33% using NEWS (p = .0001). HR ≥ 111 for more than 60 min was seen in 51% with CM and 22% with NEWS (p = .0002).

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Patients admitted to ICU or having fatal outcome had longer durations of RR > 24 brpm ($p = .01$), RR > 21 brpm ($p = .01$), SpO_2 < 80% ($p = .01$), and SpO_2 < 85% ($p = .02$) compared to patients that were not.

Conclusion: Episodes of desaturation and tachypnea in hospitalized patients with COVID-19 infection are common and often not detected by routine measurements.

KEYWORDS

continuous monitoring, COVID-19, deterioration, early warning score, hospital admission, patient safety

Editorial Comment

Continuous wireless monitoring of vital signs of patients with COVID-19 treated at general wards allowed for quicker detection of abnormalities compared to vital sign monitoring with manual assessment using the National Early Warning Score.

1 | INTRODUCTION

The COVID-19 pandemic has put a tremendous strain on health care systems around the world, challenging the scarcity of resources of Intensive Care Units (ICU) as well as general wards. The pandemic has highlighted the need for better and more intelligent health care solutions, to be able to monitor and predict which COVID-19 patients are at risk of deterioration and thus require intensification of treatment.

Non-COVID-19 ICU-admissions, cardiac arrests and in-hospital deaths are often preceded by deviations in vital signs.[1–3] However, COVID-19 patients with clinical deterioration have small or few deviations in heart rate (HR), blood pressure and body temperature, whereas peripheral arterial oxygen saturation (SpO_2) decreases rapidly and often more severely than in patients with other viral pneumonias.[4,5] The rapid and clinically subtle worsening in COVID-19 patients has been described as "happy hypoxemia" or "silent hypoxemia" because of the seemingly small changes in other vital signs than SpO_2, including no respiratory distress felt by the patients but other symptoms such as confusion.[6]

Monitoring of vital signs in hospitalized patients in general wards relies on intermittent manual assessment performed by clinical staff at intervals of up to 12 h with the National Early Warning Score (NEWS)[7] or similar systems, despite their effectiveness in reducing in-hospital mortality remains unclear.[8,9] For patients with extremely deviating vital signs, the manual measurements done with the NEWS is taking up time and resources for personel.[10]

Recent medico-technical advances allow for clinical use of small wireless devices that continuously monitor cardiopulmonary status without restricting activity or requiring ICU admittance.[11,12] This monitoring approach may be more effective than manual measurements in detecting clinical deterioration at an earlier stage on the general wards, and together with an advanced trigger system for the clinical personnel—ultimately allow for earlier interventions.

The aim of this study was to describe the frequency and duration of deviations in vital signs in patients admitted to general wards with COVID-19 and to compare it with routine spot monitoring by NEWS measurements. We hypothesized that continuous monitoring (CM) would detect longer and more frequent periods of deviating vital signs compared with standard of care monitoring with manual measurements (NEWS).

2 | METHODS

2.1 | Study design and setting

This prospective observational study was completed in the Capital Region of Denmark in three Hospitals: Hvidovre Hospital, Bispebjerg Hospital, and North Zealand Hospital Hillerød. All hospitals are regional emergency hospitals with between 530 and 685 beds. All hospitals have ICU departments with 12 beds and the same protocol for Early Warning Score and rapid response team activation. Patients were observed between March 2020 and October 2020, during the first and second wave of the COVID-19 pandemic. Monitoring was approved as quality assurance by hospital executive boards.

2.2 | Participants

Participants were adults (≥18 years) hospitalized with suspected COVID-19 infection. Exclusion criteria from data analysis were negative polymerase chain reaction COVID-19 test and CM time <6 h.

2.3 | Patient consent

In compliance with local guidelines, any patient eligible for participation was informed verbally and written and gave their oral consent before participating.

Physiological parameter	3	2	1	0	1	2	3
Respiration rate (per minute)	≤8		9-11	12-20		21-24	≥25
SpO2 (%)	≤91	92-93	94-95	≥96			
Oxygen		Oxygen		No oxygen			
Systolic blood pressure (mmHg)	≤90	91-100	101-110	111-219			≥220
Heart rate (per minute)	≤40		41-50	51-90	91-110	111-130	≥131
Consciousness				Alert			VPU
Temperature ◦C	≤35.0		35.1-36.0	36.1-38.0	38.1-39.0	≥39.1	

FIGURE 1 The National Early Warning Score thresholds and vital signs weightings used in the Capital Region of Denmark.[13] VPU; responsive to verbal or pain stimulation or unresponsive.

2.4 | Ethical approval

This project was approved as a project of quality assurance by local institutional review boards in each Hospital (WZ 20024184), and thus research ethics committee approval was not required.

The research was conducted in accordance with the principles embodied in the Declaration of Helsinki[13] and in accordance with local statutory requirements.

2.5 | Monitoring

Participants received both standard of care NEWS monitoring following reginal guidelines and CM. The regionally used system is identical with the National Early Warning Score (NEWS) Developed and published by the Royal College of Physicians in 2012.[7] The NEWS consists of point measurements of respiratory rate (RR), SpO_2, oxygen supplementation, pulse, blood pressure, level of consciousness and temperature with specific thresholds for the different modalities (Figure 1). NEWS was done with intervals between measurements up to 12 h and escalation of frequency with rising NEWS score, up until measurements done every 30 min. We only compared three modalities from the NEWS system with CM (HR, RR, SpO_2). CM comprised two wireless sensors: Isansys Lifetouch (Isansys Lifecare Ltd, Oxfordshire, UK) and Nonin WristOx 3150 (Nonin Medical Inc., Minnesota, USA), measuring HR, RR and SpO_2. Real-time data were transmitted via Bluetooth to a tablet placed outside the patient's room. The tablet served as a gateway (and storage of data) and as real-time visualization of vital signs for personnel. Monitoring was initiated as soon as possible after the patients arrived at the general ward and continued until discharge or the clinical personnel did not find the CM relevant anymore, whichever came first.

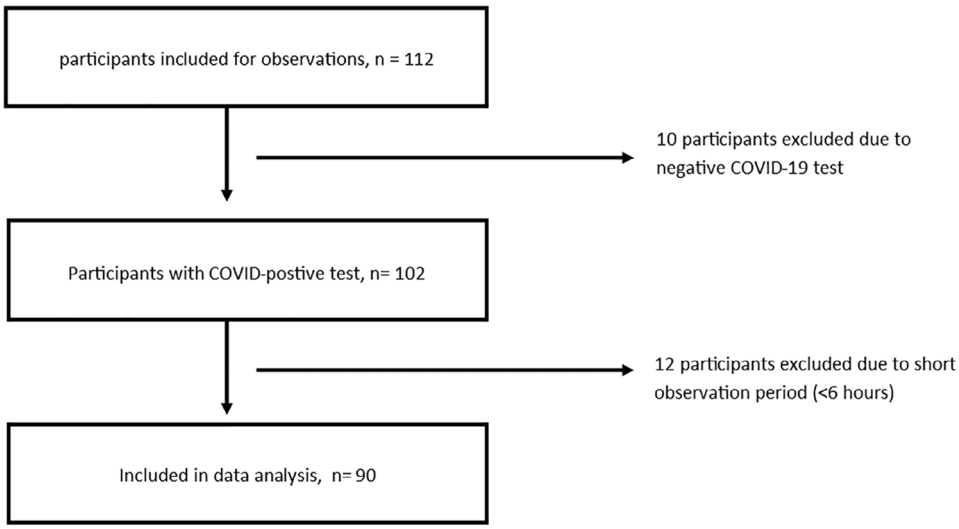
TABLE 1 Predefined vital sign events.

Events		
Definition	**Threshold**	**Time**
Tachypnoea	RR > 24 breaths per minute	>5 consecutive minutes
	RR > 21 breaths per minute	>60 consecutive minutes
Desaturation	SpO_2 < 80%	>1 consecutive minute
	SpO_2 < 85%	>5 consecutive minutes
	SpO_2 < 88%	>10 consecutive minutes
	SpO_2 < 92%	>60 consecutive minutes
Tachycardia	HR > 130 beats per minute	>30 consecutive minutes
	HR > 111 beats per minute	>60 consecutive minutes
Bradycardia	HR < 30 beats per minute	>1 consecutive minute
	HR < 40 beats per minute	>5 consecutive minutes

2.6 | Data analysis

Data was collected from validated and CE- and FDA-approved monitors. HR and RR were recorded with a 1-min sampling frequency derived from automatic detection of the QRS complex and R peaks in the single-lead electrocardiogram (ECG), digitized at 1000 samples per second. Every minute, 10 s of the ECG was available, and it was assessed if the heart rate was representative or not. The 10-s segments underwent a computerized filtration process. The signal quality

FIGURE 2 Study flowchart.



was determined based on correlation analysis between each QRS complex, and a template based on the average QRS complex in the segment. At low correlation, the segment would be considered an artifact and thus removed. The HR, RR, and SpO_2 included both raw values and a calculated average per minute. An SpO_2 change >4% per second was considered an artifact, and these segments were removed from the final analysis. This has also been described thoroughly in previous publications.[14,15]

We defined deviations in vital signs as vital signs exceeding a threshold for at predefined period. This was done to avoid minor physiological changes in vital signs being misread as actual deviations (Table 1). Each vital sign could deviate outside the threshold for up to 10% of the intervals in Table 1, to avoid artifacts to hinder events from occurring.

We compared the frequency and duration of deviating vital signs found using the manual measurements monitoring with the measurements done by the CM. The manual measurement system is defined by vital parameters exceeding a threshold at a point measurement without a time dimension, thus the system is not created for evaluation of duration. Considering this, we defined the duration of abnormal vital signs by a linear interpolation between two consecutive point-measurements.

2.7 | Outcome measures

The primary outcome was frequency of patients with at least one events of SpO_2 < 92% for more than 60 min as measured with CM and with manual measurements.

Secondary outcomes were cumulative duration of each vital sign deviation as measured with CM and with manual measurements. For another secondary outcome we used only continuous monitoring data to compare groups with different outcome (patients that were transferred to the ICU or died within 30 days of admission, compared to patients that survived and/or were not transferred to the ICU within 30 days of admission) to compare durations of deviations between the groups.

2.8 | Statistical analysis

Data are presented as numbers and frequency of patients with deviating vital signs or median with Interquartile Range for the duration of deviations. Associations between categorical variables were analyzed with the Fisher's exact test and continuous variables were analyzed with Wilcoxon rank sum test considering $p < .05$ statistically significant.

For the statistical analyses, R Statistical Software (version 4.1.2; R Core Team 2021) and Matlab (version R2021a) was used.

3 | RESULTS

3.1 | Details of the cohort

We successfully monitored 113 consecutive patients. Ten patients were excluded from data analysis due to negative COVID-19 test and another 10 were excluded due to observation time <6 h. Six patients were excluded due to missing data, leaving 87 patients to be included in the data analysis (Figure 2).

Patient age was median 74 years (IQR 65–83) and all patients had comorbidities. Monitoring began on median on day 3 (IQR 1–9) of admission and a total of 405,139 min (6752 h) of monitoring were collected, median 49.9 h (IQR 27.9–113.4) per patient. Length of hospital stay was median 11 days (IQR 5–19.2) and seven patients (8%) were readmitted to a hospital within 30 days of first admission. Seven patients (8%) were admitted to ICU within 30 days of admission and, overall 30-day mortality was 24.1% (21 patients) (Table 2).

For the HR and RR there were valid data 84% of the time and for SpO_2 this was 54% of the time.

TABLE 2 Demographics and clinical characteristics.

	$n = 87$
Sex (women)	35 (40.2%)
Age, years	74 [65–83]
Hospital	
A	42 (48.2%)
B	25 (28.7%)
C	20 (23.1%)
BMI (kg/m^2)	25.6 [22.7–30.1]
Smoking status	
Never smoked	42 (48.2%)
Former smoker	36 (41.4%)
Current smoker	5 (5.7%)
Pack years	30 [14.3–37.7]
Alcohol consumption above 7/14 units of alcohol per week	11 (11.5%)
Comorbidities	87 (100%)
Ischemic heart disease	8 (9.2%)
Congestive heart failure	9 (10.3%)
Peripheral vascular disease	16 (18.4%)
Dementia	6 (6.9%)
Chronic obstructive pulmonary disease	8 (9.2%)
Rheumatologic disease	10 (11.5%)
Peptic ulcer disease	2 (2.3%)
Diabetes mellitus	10 (11.5%)
Cerebrovascular event	10 (11.5%)
Moderate-to-severe renal disease	6 (6.9%)
Diabetes with complications	8 (9.2%)
Cancer without metastases	6 (6.9%)
Moderate to severe liver disease	2 (2.3%)
Metastatic solid tumor	4 (4.6%)
Length of stay, days	11 [5–19.2]
Readmission within 30 days	7 (8%)
ICU-admissions within 30 days	7 (8%)
30-day mortality	21 (24.1%)
Treatments limitations (do not resuscitate)	36 (41%)

Note: Demographics and clinical characteristics. Data are median [IQR], or *n* (%).

3.2 | Frequency and duration of vital sign deviations

Significantly, more events of deviating vital signs were detected by CM than manual measurements. SpO_2 < 92% for more than 60 consecutive minutes was recorded in 92% of patients with CM vs. 40% of patients with manual measurements (Table 3). Median duration of SpO_2 below 92% was 193 [IQR 90–367] minutes per 24 h vs. 0 [IQR 0–94] minutes per 24 h (p < .00001). Tachypnea (RR > 24 brpm for more than five consecutive minutes) was detected in more patients using CM 70% of patients vs. 33% using manual measurements. Episodes of brady- and tachycardia were also discovered in more patients using CM than manual measurements, HR > 130 bpm for more than 30 consecutive minutes was seen in 24% of patients vs. 6% and HR < 40 bpm for more than five consecutive minutes was discovered in 26% patients using CM vs. 0 using manual measurements (Table 3).

3.3 | Association with patient outcomes

Using only the CM data in a separate analysis, patients who were admitted to the ICU and/or died, had longer durations of RR > 24 brpm (median 95 min per day vs. 38 min per day [$p = .01$]) and RR > 21 brpm (median 384 min per day vs. 145 min per day [$p = .01$]). They also had longer durations of SpO_2 < 80% (median 5 min per day vs. 1 min per day [$p = .001$]) and SpO_2 < 85% (median 23 min per day vs. 9 min per day [$p = .02$]). Duration of HR > 110 bpm was also significantly longer (median 91 min per day vs. 10 min per day [$p = .01$]), whereas the rest of the vital sign thresholds did not differ between groups (Table 4).

4 | DISCUSSION

4.1 | Summary of major findings

Continuous monitoring found longer durations of vital sign deviations than routine measurements did. The median duration of desaturation below 92% was more than 3 h pr. 24 h. Patients who were transferred to the ICU or died within 30 days of admission had significantly longer duration of vital signs outside thresholds for RR > 21, RR > 24, SpO_2 < 80%, SpO_2 < 85%, and HR > 110 bpm. This is important because mortality increases with increasing number of abnormal observations in vital signs.

4.2 | Comparison with previous studies

Buist et al. investigated 6303 general ward patients, with the aim of determining which deviations in vital signs were associated with mortality.[3] Six clinical observations were significant predictors of mortality (a decrease in Glasgow Coma Score by two points, onset of coma, hypotension (<90 mmHg), respiratory rate <6 min (−1), oxygen saturation <90%, and bradycardia >30 min (−1)) and the most common deviation was desaturation <90%, which compiled over 50% of all deviations. The group determined that for every additional event of SpO_2 < 90%, mortality increased 3-fold, suggesting that SpO_2 deviations have significant clinical impact.

A recent study monitored patients admitted with acute exacerbation of chronic obstructive pulmonary disease (COPD)[12] and detected episodes of SpO_2 < 92% for more than 60 consecutive minutes in 80% of patients, indicating that the magnitude of desaturations of COVID-19 patients exceeds that of patients with acute exacerbation of COPD, highlighting the respiratory severeness of the disease.

TABLE 3 Continuous vital signs and EWS.

n = 87				
Vital sign	**Continuous monitoring**	**EWS**	***p***	**Mean diff. (95% CI)**
RR > 24 brpm for more than 5 min				
Duration, minutes, median [IQR]	57 [7–222]	0 [0–85]	<.00001	54 (20–88)
Patients with at least one event	61 (70%)	29 (33%)	<.00001	
RR > 21 brpm for more than 60 min				
Duration, minutes, median [IQR]	168 [50–458]	60 [0–276]	<.00001	83 (28–138)
Patients with at least one event	53 (61%)	50 (57%)	.38	
SpO_2 < 80% for more than 1 min				
Duration, minutes, median [IQR]	2 [0–8]	0 [0–0]	<.00001	8 (4–12)
Patients with at least one event	77 (89%)	4 (5%)	<.00001	
SpO_2 < 85% for more than 5 min				
Duration, minutes, median [IQR]	11 [3–38]	0 [0–0]	<.00001	29 (19–40)
Patients with at least one event	68 (78%)	13 (15%)	<.00001	
SpO_2 < 88% for more than 10 min				
Duration, minutes, median [IQR]	41 [10–109]	0 [0–0]	<.00001	61 (43–80)
Patients with at least one event	75 (86%)	20 (23%)	<.00001	
SpO_2 < 92% for more than 60 min				
Duration, minutes, median [IQR]	193 [90–367]	0 [0–94]	<.00001	159 (112–206)
Patients with at least one event	80 (92%)	35 (40%)	<.00001	
HR > 130 bpm for more than 30 min				
Duration, minutes, median [IQR]	0 [0–6]	0 [0–0]	<.00001	17 (6–27)
Patients with at least one event	21 (24%)	5 (6%)	.0005	
HR > 111 bpm for more than 60 min				
Duration, minutes, median [IQR]	15 [1–79]	0 [0–0]	<.00001	30 (−2–62)
Patients with at least one event	44 (51%)	19 (22%)	.0001	
HR < 30 bpm for more than 1 min				
Duration, minutes, median [IQR]	0 [0–0]	0 [0–0]	.0002	0 (0–1)
Patients with at least one event	18 (21%)	0 (0%)	<.00001	
HR < 40 bpm for more than 5 min				
Duration, minutes, median [IQR]	0 [0–0]	0 [0–0]	<.00001	1 (0–2)
Patients with at least one event	23 (26%)	0 (0%)	<.00001	

Note: Numbers are median duration of deviations in min/24 h [IQR], and number of patients (percentage) with at least one event.

Clinical deterioration is often preceded by deviations in physiological parameters.[1–3,16] Previous studies indicate that COVID-19 patients deteriorate more quickly than patients with other viral pneumonias, and that hypoxemic events are linked to poorer outcomes. It also seems that hypoxemic events are a larger risk factor for poor outcome than HR and BP deviations.[17,18] Lower SpO_2 and increasing oxygen demand often occur with only minor changes in other vital signs in COVID-19, suggesting that clinical deterioration might go unnoticed for periods of time.[19] Studies suggest that, besides age, decreasing oxygen saturation and increasing RR are some of the most important predictors of COVID-19 related mortality.[20,21] A study on 2634 patients admitted to non-ICU level of care suggests that this patient population could benefit from CM of SpO_2, because they often suffered rapid clinical deterioration, with a sudden decrease in oxygen saturation.[22] We also expect patients in the general ward could benefit from CM even though there is no current evidence to suggest, that CM improves clinical outcomes. A recent review concludes that there is a need for bigger RCTs to determine if CM effects patient outcomes, however it also shows that there is a trend for CM to be beneficial even on outcomes such as rapid response team activation, in-hospital cardiac arrest, ICU-transfers, clinical complications, mortality and length of stay, but neither statistically significant.[23] In our study, patients with severe outcomes (mortality or ICU-admission within 30 days) had longer durations of tachypnea and severe desaturations compared with patients surviving without ICU admission. We were not able to determine if CM itself reduces mortality, as this would need a well-designed large RCT.

TABLE 4 Continuous monitoring data: comparison of vital sign durations outside thresholds for patients divided according to clinical outcome.

Condition	ICU-admission/death within 30 days $N = 25$	No ICU admission/death within 30 days $N = 62$	p
RR > 24 brpm	95 [41–487]	38 [4–129]	.01
RR > 21 brpm	384 [150–764]	145 [29–338]	.01
SpO_2 < 80%	5 [1–22]	1 [0–4]	.001
SpO_2 < 85%	23 [7–94]	9 [2–34]	.02
SpO_2 < 88%	62 [15–155]	36 [8–76]	.07
SpO_2 < 92%	200 [68–337]	190 [91–397]	.64
HR > 130 bpm	1 [0–30]	0 [0–4]	.28
HR > 110 bpm	91 [2–216]	10 [0–41]	.01
HR < 30 bpm	0 [0–0]	0 [0–0]	.88
HR < 40 bpm	0 [0–0]	0 [0–0]	.66

Note: Continuous monitoring data: Vital sign durations outside thresholds for patients that died or were transferred to the ICU vs. patients that survived or was not admitted to the ICU. Numbers are median minutes/24 h [IQR] that lies outside thresholds.

4.3 | Strengths and limitations

The primary strengths of this study are the prospective design and multicenter participation. Our findings are in line with an earlier study of CM that included 34 patients with COVID-19, concluding that CM might help detect deterioration earlier.[24] CM might be part of the future in-hospital monitoring, but barriers for this include use of wireless sensors and real-time vital signs display.

This study had several limitations. First, not all the patients admitted with COVID-19 participated in this study. The patients were included on median day three of admission suggesting that we missed important information about vital signs from the initial part of the hospitalization. Also, the CM was done for a median of 49 h even though the median hospitalization was 11 days. This was due to patients transferred between wards or to the ICU or patients being withdrawn by the investigator due to increasing delirium or problems tolerating the devices. The recorded vital sign values might therefore represent a best-case scenario, as patients might suffer from more deviations in the unmonitored time. Furthermore, the CM comprised only two devices with three modalities and the comparison with manual measurements could therefore only be calculated for some of the manual measurements. With the technological advances, more and more sensors will be available and implementable in the hospital setting and hopefully more modalities will be applicable.

In this study we were able to measure vital signs continuously in the general ward and contribute to the sparse knowledge about how vital signs change and deviate outside the ICU. This is still not done routinely and thus poses challenges. The deviations found in this study were surprisingly severe and sustained, but the patients included were both full-support patients (59%) and patients with treatment limitation protocols such as do not resuscitate. These patients might have been getting their maximum support, despite severe deviations. We experienced missing data due to the sensors being removed by patients or nurses, failure with connection (Bluetooth or Wi-Fi) and low battery status. We had valid data for HR and RR for 84% of the time while SpO_2 gave valid data 54% of the time. This is similar to our own previous studies,[14,15] and other studies also display challenges with CM in terms of missing data.[25,26] Considerations to limit missing data must be performed if CM is to be implemented in the general ward.

It is also important to empathize that CM cannot stand alone in the chain of survival. When implementing CM in a general ward, the rest of the track-and-trigger system should be revised to fit a different observation modus, since CM is only a diagnostic and not therapeutic.

4.4 | Future implications and research

To give clinical staff a relevant display of vital signs, a robust and intelligent software should be developed to interpret and present data from the wireless sensors, to avoid alarm fatigue. Alarm fatigue is a threat to patient safety,[27] and keeping this to a minimum will be a primary objective for a CM software. The digitalization of healthcare is fueled by technological advances, but also by the global shortage of healthcare workers. Estimations conclude that by 2030 there will be a global shortage of nurses of 13 million, making up for almost 50% of the 28 million entire global workforce of nurses.[28] It is important for the development of digital healthcare to take this into account. The results from this study highlight the necessity of a closer monitoring of COVID-19 patients outside the ICU. For patients admitted with COVID-19, we found that severe vital sign deviations were undetected by manual rounds by clinical staff. Most common deviations were severe and moderate desaturations (respectively experienced by 92%, 89%, and 86% of the patients) followed by tachypnoea and tachycardia. Our data also suggest that there is an association between severity of outcomes (ICU admissions and/or death) and longer durations outside thresholds. Additional studies are needed to further confirm if deviations have clinical impact on the clinical outcome.

5 | CONCLUSION

We conclude that episodes of moderate and severe deviating vital signs in hospitalized patients with COVID-19 are common, and that this is detected by continuous monitoring but are often not detected by routine measurements.

AUTHOR CONTRIBUTIONS

Katja Kjær Grønbæk: project administration, investigation, formal analysis, writing – original draft; Søren Møller Rasmussen: Software, validation, formal analysis, data curation, visualization;

Natasha Hemicke Langer: Investigation, writing – review and editing; Mette Vincentz: Investigation, writing – review and editing; Anne-Britt Oxbøll: Investigation, writing – review and editing; Marlene Søgaard: Investigation, writing – review and editing; Hussein Nasser Awada: Investigation, writing – review and editing; Tomas O. Jensen: Investigation, resources, writing – review and editing; Magnus Thorsten Jensen: Investigation, resources, writing – review and editing; Helge BD Sørensen: software, conceptualization, methodology, supervision, funding, acquisition, writing – review and editing; Eske Kvanner Aasvang: conceptualization, methodology, supervision, funding, acquisition, writing – review and editing; Christian Sylvest Meyhoff: Conceptualization, methodology, supervision, funding, acquisition, writing – review and editing.

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CONFLICT OF INTEREST STATEMENT

The WARD-project (Wireless Assessment of Respiratory and Circulatory Distress) has received grants from the Innovation Fund Denmark, the Novo Nordic Foundation, the Danish Cancer Society, Steno Diabetes Center Denmark, The Danish Regions, The Agency for Digitization, Copenhagen Center for Health Technology, Isansys Ltd., Radiometer, A.P. Møller Foundation as well as internal institutional funding. The WARD founders (CSM, EKA, and HBDS) have created a start-up company, WARD247 ApS, with the aim of pursuing the regulatory and commercial activities of the WARD-project. WARD247 ApS has obtained license agreement for any WARD-project software and patents. One patent has been filed: "Wireless Assessment of Respiratory and circulatory Distress (WARD)—Clinical Support System (CSS)—an automated clinical support system to improve patient safety and outcomes." CSM also reports lecture fees from Radiometer. EKA reports institutional research funding from Norpharma A/S as well as lecture fees from Radiometer, and advisory roles for Concentric analgesics and GenEdit without relation to the present work.

DATA AVAILABILITY STATEMENT

Data will only be shared upon reasonable request and in agreement with the data providing site.

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