BMC Nursing

RESEARCH Open Access

Evaluation of the effectiveness of a segmented alternating shift pattern based on wearable vital signs monitoring devices during COVID-19: a cross-sectional study

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Abstract

Aim To explore the feasibility and effectiveness of an alternating shift pattern in two-hour segments in the state of emergency management of public health events.

Methods A cross-sectional research design was conducted in our study. The nursing staff working in the admission ward of suspected or confirmed patients with COVID-19 in December 2022 were selected as subjects by the whole-group sampling method. We adopted a shift pattern of alternating shifts every two-hour in the isolation wards. The vital signs parameters were captured by uniformly wearing the multi-signs sensing devices, and the questionnaires collected the symptoms.

Results Sixty-seven female participants, with a mean age of 33.09 ± 5.96 years, were included in this study. Measurements of body temperature (T), blood oxygen saturation (SpO_2), respiratory rate (RR), and heart rate (HR) while wearing personal protective equipment (PPE) all remained within normal limits. None of the nurses reported sweating, dizziness, blurred vision, palpitations, or dyspnea. Statistical analysis showed significant differences between the critical care group and the non-critical care group in terms of age ($P = 0.041$), working duration ($P = 0.036$), and the total number of entries into isolation areas for nursing care (rounds) ($P = 0.007$). However, there were no statistically significant differences in vital signs based on age, work duration, or body mass index (BMI). The data indicated a notable increase in body temperature compared to other vital sign parameters with increasing work time while wearing PPE. Body temperature approached the upper limit when working close to 2 h long.

Conclusions The alternating shift pattern in two-hour segments can effectively maintain the physical well-being of nurses wearing PPE without increasing the burden on nursing staff or the wastage of protective materials. This approach is recommended for addressing similar public health events in the future.

Keywords COVID-19, Shift pattern, Human resources, Nursing

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Introduction

The COVID-19 epidemic spread rapidly to most parts of the world three years ago(Umakanthan et al., 2020); scientists, medical professionals, and researchers struggled to control this contagious disease [1]. Due to a lack of available nurses to respond to the urgent need to care for COVID-19 patients worldwide, providing care and managing healthcare became complicated [2]. Therefore, nurse managers have had to face the changing workforce and exhausted staff who must cope with fear, uncertainty, and the helplessness of not being able to ensure humanized care for patients with COVID-19 and their families [2, 3]. Due to the nature of the job and patient care requirements, the global rampage of COVID-19 puts nurses in a vulnerable and high-risk situation [4]. However, they are also exposed to a huge workload [5], and the heavy burden under the encasement of protective equipment [6].

Some international guidelines state that nurses who enter the room of a patient with suspected or confirmed SARS-CoV-2 infection should adhere to Standard Precautions and use a particulate respirator with N95 filters or higher, gown, gloves, and eye protection [7, 8]. Nevertheless, qualitative research revealed that nurses believed personal protective equipment (PPE) contributed to discomfort, headaches, exhaustion, and sleep disturbances [6]. Hoedl [9] reported the relationship between PPE and stress among nurses in this COVID-19 pandemic. Therefore, reducing the amount of time nurses spend wearing PPE can effectively alleviate the above confusion. Additionally, these recommendations also state that such masks should be used for extended periods, as touching them less frequently might result in a lower risk of contact transmission as opposed to taking the mask off and putting the same mask back on, which means that frequent putting on and taking off is not a good strategy, but wearing them for too long also poses a risk of infection due to the deterioration of protective properties, it is vital to explore the appropriate wearing time for nurses.

In light of this, the strain on nursing human resources and the sharp increase in nurses' physical and mental burdens during the pandemic have compelled nursing managers to focus on effective, scientific human resource allocation and work patterns that ensure the smooth operation of patient care, resulting from the widely accepted viewpoint: unreasonable allocation of nursing human resources will affect the quality of nursing work, and it may eventually affect patients' safety. Some studies explored the value of different scheduling patterns during the COVID-19 pandemic. According to the Guidelines on the Scope of Use of Common Medical Protective Equipment in the Prevention and Control of Novel Coronavirus Pneumonia (Trial) [10], N95 masks and other protective equipment should be replaced every 4 h to ensure the full rest of nursing staff. Thus, the scheduling pattern adopted is a four-hour shift in most medical institutions in China [11]. However, the four-hour shift scheduling pattern subjects nurses to various discomforts while wearing tightly sealed protective suits [12].

To conserve nursing human resources and ensure the quality and safety of care, our study investigates a segmented rotating shift scheduling pattern, aiming to minimize the time spent wearing PPE among nurses while maintaining a steady level of nursing human resources, alleviate discomfort, and reduce the risk of infection associated with prolonged use of protective equipment.

Methods

Participants

The study was a cross-sectional research design with a whole group sampling method, and nurses working in the wards where patients with suspected or confirmed cases of COVID-19 were admitted in December 2022 were selected for the study. Inclusion criteria: (i) nurses working in the isolation area; (ii) nursing staff formally employed in the hospital; (iii) licensed nurses and able to work independently; (iv) those who voluntarily participated in this study. Exclusion criteria: nurses working in the isolation area but not entering the isolation ward. All nurses participated in the study after signing the informed consent.

Measurements

Multi-signs sensing device

Applying the multi-signs sensing devices independently developed by Beijing Microchip Sensing Technology Co., Ltd, the device collected the nursing staff's body temperature, blood oxygen saturation, respiratory rate, and heart rate. The device integrates temperature, photo electricity, motion, and other high-precision sensors and realizes compact layout and ultra-low power consumption through 3D packaging and other technologies; based on particular hardware optimization and software algorithm optimization, it realizes high-precision collection and monitoring of multi-dimensional data.

Demographic characteristics and symptoms information sheet

A self-developed recording sheet was used to collect demographic characteristics of the nurses such as gender, age, working duration, temperature and humidity of the wards, height, weight, and symptom experiences of the nurses while working in an isolation ward under PPE such as sweating, dizziness, blurred vision, palpitations, and respiratory distress.

Acquisition and management of research data in the isolation area

Establishment of a research team

There were twelve members of the research team, including one director of the nursing department, eight head nurses of the isolation wards, and three research nurses. Two of the twelve were outside the isolation area, called peripheral researchers, who were mainly responsible for the study design, organizing all related meetings, supervising and controlling the quality of the study process, etc. The rest of the members were mainly distributed in each isolation ward, and they were responsible for recruiting the study subjects in isolation areas, training them on wearing this device, and collecting data.

Training

The research nurses within the isolation area collaborate with the nursing managers of each ward to conduct training on the wearing of multi-sign sensing devices, ensuring that nurses can grasp the methods of device wearing, duration of wearing, and device maintenance. Simultaneously, each wearer must be taught to promptly and accurately report personal symptoms and other information while working in the isolation wards at specified times. Peripheral researchers need to homogenize the management of data validity, accuracy collection, and uploading within the isolation area and unify training for isolation area researchers.

Establishment of a scheduling system

Following a preliminary estimation of nursing manpower and material consumption across the entire hospital, the core management team of the Nursing Department, in conjunction with the Human Resources Department and Hospital Administration, has established a segmented alternating shift pattern based on an 8 h work duration. In this model, nurses continued to work 8 h shifts, but they were rotated in groups to the isolation ward (patient area - contaminated area) to provide care for patients. After 2 h of working in the patient area while wearing PPE, the nurses were rotated with their cohort. Those who had just completed their duties in the patient area removed their PPE and returned to the healthcare workers' office area, which was designated as the semi-contaminated area. Here, they resumed their regular work, including the processing of medical prescriptions. The number of nurses rotating in each shift is determined by the number of patients and their health conditions in each ward. This ensures quality of care and patient safety while adhering to the principle of minimizing manpower consumption. Compared to a 4 h rotation shift pattern, this new pattern demonstrated equivalent or reduced consumption trends in personnel and material costs.

Data collection and management

This study utilizes a combination of ecological instantaneous assessment, biological measurement methods, and the observation sheet to collect data. (Figure1) Nurses enter the isolation areas to perform nursing duties while wearing multi-sign sensing devices as required. These devices utilize a MySQL database server to provide data persistence storage services. Real-time monitoring of vital signs of these nurses, centralized data collection with a "one-click" approach, and bluetooth-to-public network uploading enable real-time collection of vital signs data. The operational management backend provides researchers with multidimensional displays of vital signs information and real-time status. Demographic characteristics and symptom information were collected when they first wore the multi-sign sensing devices and were

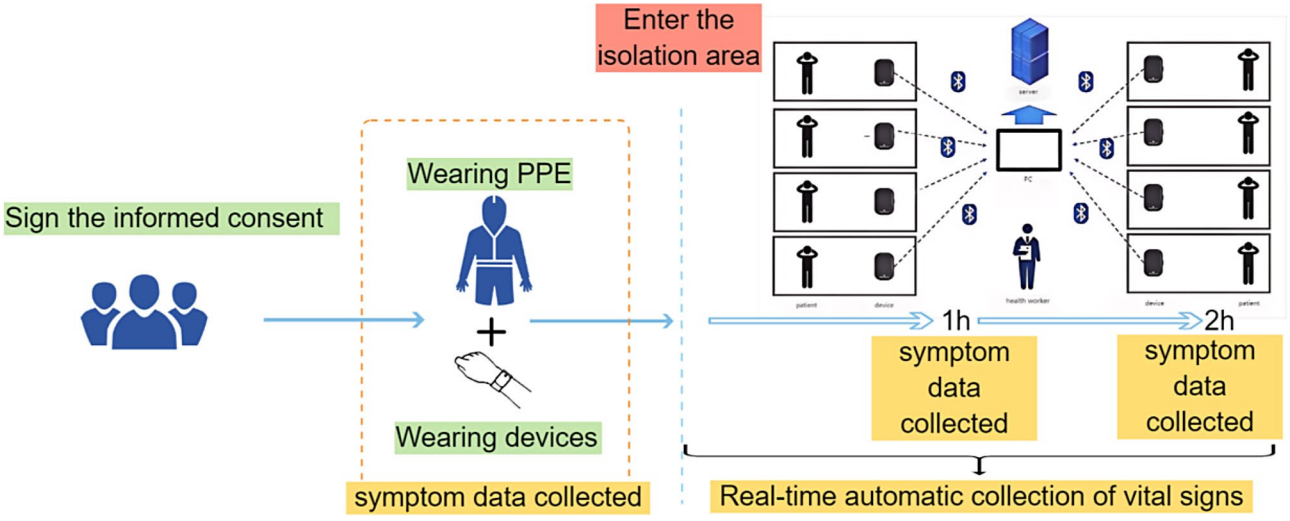

Fig. 1 The workflow of data collection

prepared to enter the isolation area. Due to the unique nature of the contaminated wards, nurses wearing PPE are not allowed to carry personal items while caring for patients in the isolation wards. All paper records about symptom information were photographed using work smartphones at the isolation wards and transmitted to the public smart devices in the healthcare worker zone (semi-contaminated area) within the isolation areas. Research nurses within the isolation areas are responsible for summarizing, organizing, and securely managing the data. Paper documents generated during the research process in the isolation wards are uniformly destroyed after disinfection.

Statistical analyses

All statistical analyses were performed with the software packages R (http://www.R-project.org, The R Foundation) and Free Statistics software version 1.9(www.freestatistics.tk). A 2-tailed *P* value of <0.05 was considered statistically significant. The continuous variables were expressed as x±s, while count data were presented as frequencies and percentages. Inter-group comparisons were conducted using independent sample t-tests, Mann-Whitney Wilcoxon tests, analysis of variance (ANOVA), and Pearson Chi-squared tests. Curve graphs were used to illustrate the trend of changes in body temperature, blood oxygen saturation, respiratory rate, and heart rate over time among nurses in PPE during patient care. The nurses' vital signs data was collected through multi-sign sensing devices obtained through ecological instantaneous assessment methods. Since no abnormal conditions were observed in the vital signs data of all wearing nurses, mean values were applied for all analyses except for trend analysis, which used the original data or standardized data.

Results

Characteristics of participants

A total of 67 female nurses, with a mean age of 33.09±5.96 years, participated in this study (see Table 1). The temperature of all the isolation wards involved in the study was between 18 °C and 22 °C, and the humidity was between 50% and 55%. Body temperature, blood oxygen saturation, respiratory rate, and heart rate measured during nursing care remained within the normal range, and the mean values of each index are shown in Table 1. All participants were divided into a critical care group and a non-critical care group according to the severity of the disease. Our results showed that except for the age (31.23±5.76 vs. 34.27±5.86, $P=0.041$), work duration (9.38±5.90 vs. 12.74±6.50, $P=0.036$), and rounds (9.08±4.50 vs. 6.49±3.10, $P=0.007$), there were no statistically significant differences in any of the other characteristics or signs and symptoms. (See Table 1)

Comparison of vital signs parameters in nurses of different ages, work duration, and BMI

Based on the average age and work duration level of all participants and combined with the actual clinical significance, the statistical analysis of the data of each subgroup's signs was carried out, respectively, with age=35 years, work duration=15 years, and BMI=24 as the cut-off point. The results showed that the differences in comparing the subgroups' vital signs parameters did not

Table 1 Characteristics of participants

Variables	Total (*n*=67)	Non-Critical Care Group (*n*=26)	Critical Care Group (*n*=41)	*P*
Tall (m), Mean±SD	1.64±0.05	1.63±0.05	1.64±0.05	0.168
Weight (kg), Mean±SD	60.10±9.46	57.88±9.04	61.51±9.56	0.127
BMI(kg/m^2), Mean±SD	22.45±3.33	21.87±3.07	22.81±3.48	0.265
Age (years), Mean±SD	33.09±5.96	31.23±5.76	34.27±5.86	0.041*
Working duration (years), Mean±SD	11.44±6.44	9.38±5.90	12.74±6.50	0.036*
Education level, n (%)				0.560
College	10 (14.93)	4 (15.38)	6 (14.63)	
Undergraduate	57 (85.07)	22 (84.62)	35 (85.37)	
Rounds(times), Mean±SD	7.49±3.89	9.08±4.50	6.49±3.10	0.007*
T(℃), Mean±SD	36.61±0.54	36.57±0.60	36.63±0.49	0.629
SpO2(%), Mean±SD	97.67±0.60	97.63±0.65	97.70±0.57	0.645
RR(times/min), Mean±SD	16.18±1.62	16.11±1.46	16.22±1.73	0.776
HR(times/min), Mean±SD	76.81±7.42	78.49±6.75	75.74±7.70	0.141

*, P < 0.05

T, body temperature; SpO2, blood oxygen saturation; RR, respiratory rate; HR, heart rate

Table 2 Comparison of Vital Signs Parameters in nurses with different characteristics

Variables	Age (years)			Working duration (years)			BMI		
	<35 (*n* = 35)	≥35 (*n* = 32)	*P*	<15 (*n* = 46)	≥15 (*n* = 21)	*P*	<24 (*n* = 49)	≥24 (*n* = 18)	*P*
T(℃), Mean ± SD	36.619 ± 0.530	36.590 ± 0.549	0.826	36.558 ± 0.640	36.710 ± 0.080	0.284	36.612 ± 0.546	36.587 ± 0.518	0.863
SpO2(%), Mean ± SD	97.685 ± 0.626	97.659 ± 0.582	0.859	97.660 ± 0.705	97.700 ± 0.269	0.803	97.658 ± 0.535	97.712 ± 0.768	0.749
RR(/min), Mean ± SD	16.357 ± 1.881	15.984 ± 1.276	0.350	16.295 ± 1.810	15.925 ± 1.089	0.391	16.171 ± 1.691	16.200 ± 1.452	0.949
HR(/min), Mean ± SD	77.040 ± 8.304	76.551 ± 6.439	0.790	77.252 ± 8.140	75.831 ± 5.581	0.471	76.641 ± 7.504	77.257 ± 7.379	0.766

T, body temperature; SpO2, blood oxygen saturation; RR, respiratory rate; HR, heart rate

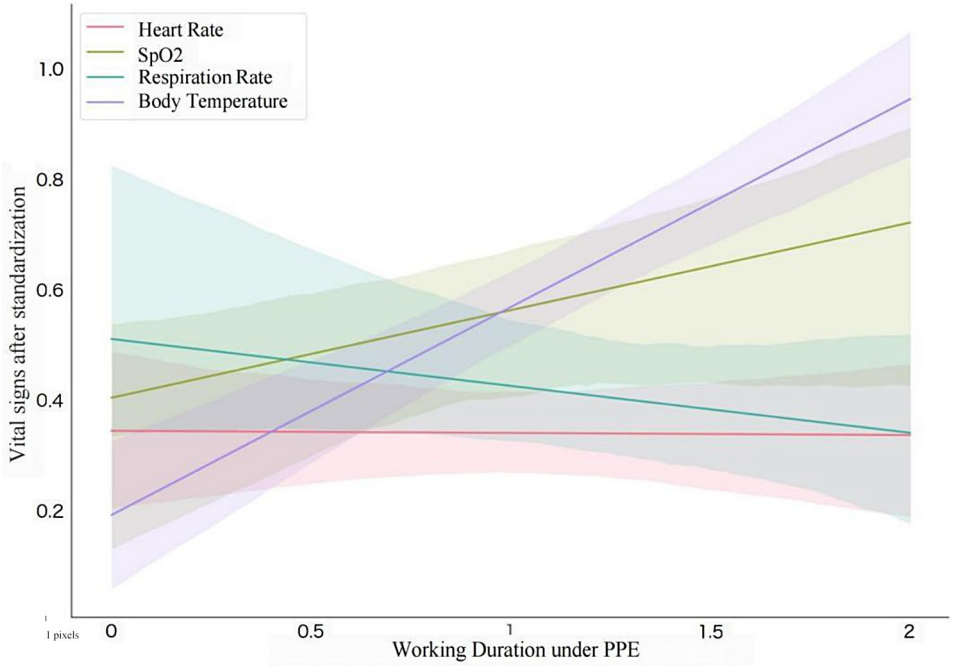

Fig. 2 Total trends of vital signs of in nurses with increasing of working duration under PPE. PPE: personal protective equipment; SpO2: blood oxygen saturation

appear statistically significant. The *P*-value ranged from 0.256 to 0.949 (see Table 2).

Trend analysis of vital signs parameters during different working hours in PPE

Figure 2 shows the trend of the vital signs with the duration of participation in the work while wearing PPE, showing that the individual's body temperature and blood oxygen saturation gradually increased with the duration of the work, in which the increase in body temperature was more prominent, especially when working for up to 2 h, which indicated that the body temperature was approached or would exceed the peak value of the normal range. However, changes in respiratory rate and heart rate were not significant. Continuing with the subgroup analysis, nurses in the ≥35-year-old group showed a significant increase in body temperature relative to the <35-year-old group, with no significant differences in other physical parameters. Relative to the BMI<24 group, nurses in the BMI≥24 group had a significant upward trend in body temperature, but other parameters did not change significantly. Nurses in the critical care group also showed a significant increase in body temperature relative to the non-critical care group. The trends of other parameters did not differ significantly between the two groups. (Fig. 3)

Discussion

Under the unexpected outbreak of a pandemic and the surge in patient numbers, efficiently mobilizing and deploying nursing manpower with professional expertise is the foremost concern for countries, regions, and medical institutions. It is crucial for ensuring orderly medical responses [13]. Grounded in the practical medical

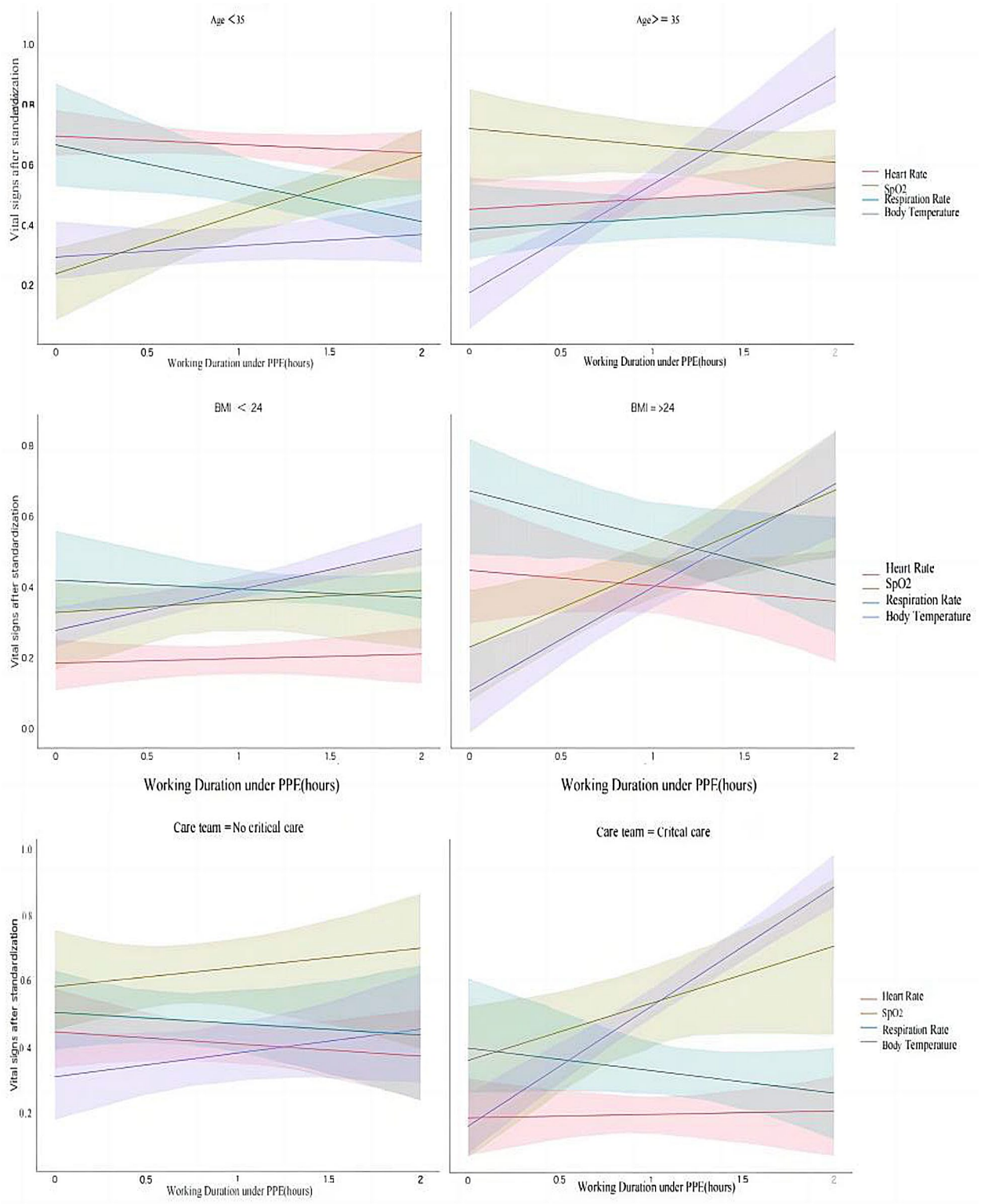

Fig. 3 Trends in vital signs of nurses in different subgroups with working duration under PPE. PPE: personal protective equipment; SpO2: blood oxygen saturation; BMI: body mass index

situation in China, this study considers the requirements of medical rescue tasks and the physical and mental well-being of nursing staff. It introduces an innovative and challenging attempt - a segmented alternating shift pattern every 2 h. This approach represents a novel, exploratory initiative that provides new insights and methods for future global public health crisis management. In this study we collected data on participants' vital signs by means of transient assessment, thus testing our hypotheses using a quantitative approach.

The age range of the 67 nurses involved in this study falls between 22 and 46 years old, representing the overall age structure of nurses currently engaged in frontline clinical nursing work. Analysis of nurses' ages and work duration in non-critical and critical care groups suggests that nurses involved in caring for critically ill patients tend to be older, have longer work experience, and possess multiple experiences in responding to epidemic situations. As Wu Yuqin et al. (Yuqin Wu, 2021) state, critical care is a complex field requiring nurses to have higher professional qualifications, a solid theoretical foundation, and precise technical skills. Therefore, cultivating such talent is a long-term investment process. In this study, the 41 nurses involved in the critical care group have longer work duration and are older. These nurses are rigorously selected by the hospital based on criteria such as their technical proficiency, multidisciplinary knowledge, and experience in critical care. They are nurtured by the hospital over the long term, aligning with the career development path of nursing personnel.

No matter which group, all nurses' vital signs remained within normal ranges without noticeable symptom responses. Moreover, statistical comparisons between groups did not yield any significant differences. This outcome underscores the correctness of the segmented alternating shift pattern every 2 h. Furthermore, as nurses spent more time wearing PPE in the isolation wards, the primary impact observed was a slight increase in body temperature and blood oxygen saturation, with minimal changes in respiratory and heart rates. This reflects advancements in the manufacturing processes and materials of modern protective equipment, which ensure airtightness and improved breathability, making nurses' physical activities easier and more comfortable while wearing PPE. Although nurses' vital signs and symptoms remained unchanged during PPE use, trend analysis with prolonged working hours revealed that at 2 h of working, body temperature and blood oxygen saturation levels approached the peak value of the normal range. If the current work status is sustained, these parameters will likely exceed normal levels, emphasizing the feasibility of shifts every 2 h. Moreover, the mean temperature and humidity measured in the isolation wards of this study were 19.73±1.65 °C and 47.31±4.65%, respectively. This indicates that the moderate and stable working environment temperature and humidity are fundamental factors in maintaining nurses' vital signs and comfort while working in PPE for extended periods within the isolation wards.

Further subgroup analyses revealed that none of the vital signs of the relatively young nurses exhibited significant changes within two hours of work. However, the body temperatures of older nurses increased rapidly during their time in the isolation wards, nearly reaching the upper limit of the normal body temperature range by the two-hour mark. This suggests that as individuals age, their bodily functions and self-repair mechanisms may weaken and diminish [14]. Additionally, obese nurses experienced a more pronounced rise in body temperature during work, likely due to higher body fat content, which provides an insulating effect that facilitates a quicker increase in body temperature. Furthermore, the metabolic rate in obese individuals may be elevated, and there could also be a disruption in calorie regulation [15]. Meanwhile, the findings of the present study indicated that blood oxygen saturation did not decrease in obese individuals working longer hours; instead, it demonstrated a trend of gradual increase. The relationship between obesity and blood oxygen saturation remains complex, with studies yielding varying results [16]. Further research is needed to explore and clarify this relationship.

The nurses in the group caring for critically ill patients showed an increasing trend in body temperature and blood oxygen saturation, while the non-critical care group showed a stable performance in all vital signs, which was analyzed for the following reasons: firstly, it may be due to the higher intensity of work when caring for critically ill patients, which is the main reason for the increase in body temperature; secondly, it may be due to the fact that the ratio of nurses to patients in critical care is quite different from the rationing requirements for caring for general patients, and that in an intensive care ward each nurse only needs to focus on caring for 1 to 6 patients, which determines the space and scope of the nurse's activities are narrowed down to a confined area, and due to the critical condition of the critically ill patients, reduces the possibility of the nurse's verbal communication with the patients, the above may be the essential reasons for the impact on the reduction of oxygen consumption of the nursing staff in critical care group. In the future, in response to similar public health events in nursing, human resource management not only needs to combine the patient's condition, ward environment, and other external factors configuration of human resources but also needs to consider the nurse's age, BMI, physical health and other factors.

Limitation

This study is a practical study based on nursing manpower arrangements during a new crown pandemic, and the pattern is generalizable for public health emergency management of similar respiratory infectious diseases. Further exploration is still needed in the response management of other diseases. Secondly, although this study can briefly argue the effectiveness of the 2-hour segmented alternating shift scheduling pattern, the in-depth analysis and interpretation of the data are slightly lacking due to the limited number of participants in the study during the pandemic. Secondly, due to ethical considerations, this study could not directly conduct a comparative study for more time periods, such as four-hour of continuous work in the state of wearing PPE.

Conclusions

Infectious diseases have accompanied the evolution of humankind, and China's and the world's valuable experience in overcoming many infectious disease epidemics has contributed to the advancement of human medicine. When countries face major public health events, a situation of high demand for nursing human resources, high professional and technical requirements, and high timeliness occurs in the short term. This dramatically impacts medical resources and is a severe test for nursing personnel. It is a high priority for every healthcare organization to ensure the efficient allocation and use of nursing human resources while protecting nurses' physical and mental health in high-risk medical environments and heavy nursing work. The 2-hour segmented alternating shift pattern explored in this study not only meets the overall staff utilization requirements of the National Health Commission but also better allows nurses to participate in patient care while wearing PPE and in good physical condition, and still usually work with the same number of existing nurses, which is a guiding exploration and attempt to provide a new model for the future response to similar epidemics and other major public health events.

Acknowledgements

We would like to express our special gratitude to all study participants for their time during data collection. We are grateful to our colleagues who strongly supported the study, especially Yonghao Lu, Weihao Sun, and Hongrui Li from Beijing Weixin Perception Technology Co., Ltd.

Author contributions

All authors have made substantial contributions to the study design and data interpretation. MeiLian Xie and ZhiYun Zhang conducted the methodology, design, and quality management. JianPing Ma and Zhe Liu recruited a sample population and collected data. MeiLian Xie and WenYing Qiao performed a statistical analysis of the data. RongHua Jin, XiaoYou Chen and ZhiYun Zhang were responsible for matching and coordinating resources. MeiLian Xie wrote the manuscript mainly, and ZhiYun Zhang read and revised it. All authors are responsible for the content and have approved this final version of the manuscript.

Funding

This research received a specific grant from Capital's Funds for Health Improvement and Research (CFH): 2022-1G-2173.

Data availability

The data that support the findings of this study are available on request from the corresponding author and the first author. The data are not publicly available due to privacy or ethical restrictions.

Declarations

Ethics approval and consent to participate

The Ethics Committee of Beijing Ditan Hospital, Capital Medical University (NO.DTEC-KY2022-017-01) reviewed and approved the studies involving human participants. Written informed consent to participate in this study was provided.

Consent for publication

Not Applicable.

Competing interests

The authors declare no competing interests.

Received: 15 June 2024 / Accepted: 20 August 2024
Published online: 04 September 2024

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