The impact of a 5G-based smart nursing information system and associated mobile hardware on clinical nurses' work stress: a randomized controlled study in a Chinese hospital

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Abstract

Background: Clinical nurses frequently endure substantial work-related stress, adversely affecting their well-being and potentially compromising patient care quality and safety. The integration of a 5G-based medical private network into smart nursing systems and mobile devices offers a promising solution to reduce this stress. This study evaluates the impact of a Smart Nursing Information System based on a 5G Medical Private Network and its Supporting Mobile Hardware (SNIS-SMH) on mitigating work-related stress among clinical nurses. The goal is to provide a scientific basis for nursing management, reduce error incidents, advance nursing procedures, and enhance productivity.

Results: A total of 226 nurses completed the study. The SNIS-SMH group showed significantly lower total work stress scores (66.16 ± 9.82) compared to the control group (70.65 ± 11.32, $P = 0.002$). In specific dimensions, the SNIS-SMH group had lower scores for nursing profession and work (14.17 ± 2.37 vs. 15.00 ± 3.06, $P = 0.023$), workload and time distribution (10.56 ± 2.45 vs. 12.42 ± 2.55, $P < 0.001$), and patient care (22.55 ± 3.34 vs. 23.70 ± 4.06, $P = 0.021$). No significant differences were found in the work environment and resource, and management and interpersonal relationships dimensions.

Conclusions: The SNIS-SMH system significantly alleviated work-related stress among clinical nurses, particularly in nursing duties, workload and time distribution, and patient care.

Keywords: Smart nursing information system, Supporting mobile hardware, Work stress, Randomized control

Background

Nurses, as the core providers of hospital nursing services [1], face work-related stress, which is recognized as a major challenge in the global nursing profession [2–5]. When nurses' abilities and resources are insufficient to meet job demands, stress manifests as physical and emotional responses [6]. This stress severely impacts nurses' emotional, physical, and psychological well-being, leading to symptoms such as burnout, obesity, dizziness, headaches, gastrointestinal discomfort, upper respiratory infections, cardiovascular diseases, sleep disorders, anxiety, and depression [2, 3, 7, 8]. Moreover, work-related stress directly affects the quality of care and increases medical costs [6]. Studies indicate that excessive work stress reduces nursing quality, which can decrease patient satisfaction [8] and potentially increase patient mortality rates [6].

Existing research has identified multiple sources of work-related stress among nurses, including high workloads, low income, staff shortages, frequent shift rotations, the demands of caring for critically ill patients, limited recognition from family and society, requirements for advanced technology use, and interpersonal conflicts with physicians or colleagues [2, 4, 6, 7]. To address these challenges, various strategies have been proposed, with electronic nursing information systems emerging as an effective solution [9]. An electronic nursing information systems integrates nursing personnel with computerized systems to facilitate the efficient collection, organization, and storage of clinical nursing data and hospital management information [10]. By merging modern information technology with traditional nursing practices, the electronic nursing information systems provide functionalities such as documentation, information retrieval, educational support, statistical analysis, data updating, storage, and resource sharing [11]. These features reduce the time spent by nurses on documentation [12], streamline nursing workflows [13], and increase time available for direct patient care [14]. Consequently, the electronic nursing information systems enhances care quality and efficiency [14], promoting the standardization and scientific management of hospital nursing practices [10].

Although electronic nursing information systems have had numerous positive impacts on nurses' work, its implementation has also revealed some significant issues, such as extended working hours, increased paperwork [15], and reduced opportunities for direct patient contact. Collectively, these factors may contribute to dissatisfaction among nurses with the existing documentation methods in the electronic nursing information system [15].

Based on a comprehensive assessment of clinical needs and an examination of the experiences of other healthcare institutions, a professional company was identified and engaged in accordance with the hospital's procurement procedures. This collaboration led to the proposal and development of a Smart Nursing Information System and its Supporting Mobile Hardware (SNIS-SMH) that is grounded in a 5G medical private network and accompanied by supporting mobile hardware. This system not only incorporates the core functions of an electronic nursing information system, but also leverages the 5G medical private network as a backbone for data transmission. As an emerging medical information transfer technology, 5G offers high speed, low latency, and massive connectivity, providing robust support for real-time data transmission, intelligent alerts, and decision support [16]. Additionally, with the growing trend of interoperability

and integration between electronic nursing information systems and other systems and data sources, privacy and confidentiality have become critical concerns; more than 40% of users report concerns regarding privacy and security within electronic nursing information systems [17]. Medical private networks, which are isolated from public network users, serve as a key technology to address these concerns, ensuring secure data transmission and providing reliable technical support for the safe operation of SNIS-SMH [16]. Furthermore, SNIS-SMH is equipped with mobile hardware that integrates wireless local area networks and mobile nursing software, enabling real-time data collection, processing and recording. This setup allows nurses to perform bedside data entry and access patient information instantly. Studies indicate that using mobile nursing carts and handheld devices not only enhances the convenience of information retrieval and adherence to clinical guidelines, but also improves the quality of diagnostic decision-making and data collection [18], potentially leading to better patient outcomes and significantly reducing clinical nurses' work stress.

This study aims to implement and evaluate the impact of a 5G medical private network-based Smart Nursing Information System (SNIS-SMH) on work-related stress among clinical nurses. A randomized controlled trial was conducted to assess the effectiveness of SNIS-SMH in alleviating work-related stress. The long-term objective is to compare the effects of SNIS-SMH with those of traditional electronic nursing records in reducing work stress. It is hypothesized that the intervention group using SNIS-SMH will experience a significant reduction in work-related stress. This paper presents detailed results from the clinical trial regarding the use of SNIS-SMH to alleviate work-related stress among clinical nurses.

Results

General information

The study concluded in May 2024, and the Consolidated Standards of Reporting Trials (CONSORT) flow diagram illustrating participant progression is presented in Fig. 1.
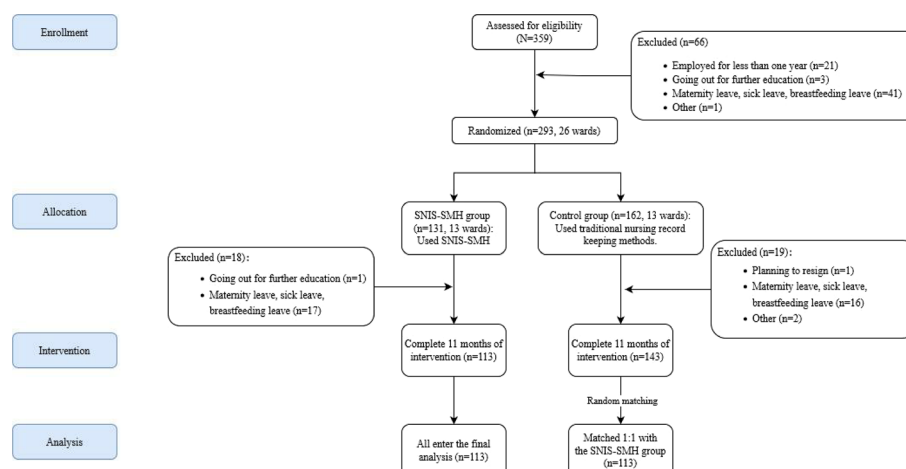

Fig. 1 Smart nursing information system based on 5G medical private network and supporting mobile hardware

Of the 359 clinical nurses who underwent screening, 293 met the inclusion criteria and completed the baseline survey.

They were randomly allocated to the SNIS-SMH group or the control group by ward, with the SNIS-SMH group comprising 131 nurses from various wards, including:

- Northern Ward: 4 (Cardiovascular Medicine), 6 (Gastroenterology), 7 (Orthopedics 1), 8 (Neurology), 10 (Respiratory Medicine 2);
- Southern Ward: 2 (Obstetrics), 4 (Emergency Surgery, Ophthalmology, Otolaryngology), 5 (Urology, Nephrology), 7 (Orthopedics 2), 10 (Hepatobiliary Surgery, Thyroid Surgery, Vascular Surgery);
- Other Wards: 17 (Breast Surgery, Otolaryngology), 18 (Oncology, Hematology, Endocrinology), 19 (General Practice, Geriatrics).

The control group consisted of 162 nurses from the following wards:

- Northern Ward: 1 (Emergency Internal Medicine), 2 (Obstetric VIP), 9 (Orthopedics 3), 12 (Rehabilitation, Traditional Chinese Medicine);
- Southern Ward: 3 (ICU), 6 (Gastrointestinal Surgery, Anorectal Surgery, Pediatric Surgery), 8 (Neurosurgery, Neurology), 9 (Respiratory Medicine);
- Other Wards: 12 (Gynecology), 13 (Neonatology), 14 (Pediatrics 3), 15 (Pediatrics 1), and 16 (Pediatrics 2).

Of the 293 nurses, 256 completed the final survey after 11 months, with 113 in the SNIS-SMH group and 143 in the control group. To minimize the impact of external factors on the results, a 1:1 random matching method was employed to select control group participants. Ultimately, both the SNIS-SMH group and the control group comprised 113 clinical nurses each, totaling 226 participants in the study.

All participants in the study were female, with ages ranging from 23 to 54 years and a mean age of 34.69 years. The duration of their nursing careers varied from 1 to 39 years, with an average of 11.81 years of experience. No statistically significant differences in general demographic information or work-related stress levels were observed between the SNIS-SMH group and the control group ($P > 0.05$), as shown in Tables 1 and 2.

Impact of SNIS-SMH on clinical nurses' work-related stress

In this study, compared to the control group, clinical nurses in the SNIS-SMH group exhibited a significant reduction in work-related stress after 11 months of system use ($P = 0.002$). Furthermore, within the SNIS-SMH group, pre- and post-intervention comparisons revealed a substantial decrease in work-related stress following the implementation of the SNIS-SMH system ($P < 0.001$). In contrast, no significant change in work-related stress was observed in the control group after 11 months ($P = 0.329$). Detailed results are presented in Table 3 and Table 4.

Professional and work-related issues (Dimension I):

(1) The intergroup comparison between the SNIS-SMH group and the control group, as well as the pre- and post-comparison within the SNIS-SMH group after 11 months, revealed a significant reduction in professional and work-related stress

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Table 1 General characteristics of participants in the SNIS-SMH and control groups

Variables	Total (*n* = 226)	SNIS-SMH (*n* = 113)	Control (*n* = 113)	*P*-value
Demographic information				
Age, mean ± SD, years	34.69 ± 7.06	34.61 ± 7.59	34.78 ± 6.52	0.858
Years of work, mean ± SD, years	11.81 ± 7.71	11.62 ± 7.83	12.01 ± 7.62	0.705
Highest education level, *n* (%)				0.349
College diploma	15 (6.64)	6 (5.31)	9 (7.96)	
Bachelor's degree	209 (92.48)	105 (92.92)	104 (92.04)	
Master's degree or higher	2 (0.88)	2 (1.77)	0 (0.00)	
Current marital status, *n* (%)				0.092
Single	29 (12.83)	18 (15.93)	11 (9.73)	
Married	194 (85.84)	95 (84.07)	99 (87.61)	
Divorced	3 (1.33)	0 (0.00)	3 (2.65)	
Current personnel relationship, *n* (%)				0.605
Permanent	41 (18.14)	22 (19.47)	19 (16.81)	
Contract	185 (81.86)	91 (80.53)	94 (83.19)	
Current position, *n* (%)				0.722
Quality control nurse	23 (10.18)	13 (11.50)	10 (8.85)	
Infection control nurse	9 (3.98)	3 (2.65)	6 (5.31)	
Education nurse	24 (10.62)	12 (10.62)	12 (10.62)	
Teaching nurse	28 (12.39)	12 (10.62)	16 (14.16)	
Other	142 (62.83)	73 (64.60)	69 (61.06)	
Professional title, *n* (%)				0.164
Nurse	29 (12.83)	20 (17.70)	9 (7.96)	
Senior nurse	66 (29.20)	30 (26.55)	36 (31.86)	
Charge nurse	125 (55.31)	60 (53.10)	65 (57.52)	
Deputy chief nurse	6 (2.65)	3 (2.65)	3 (2.65)	
Chief nurse	0 (0.00)	0 (0.00)	0 (0.00)	
Night shift, *n* (%)				0.749
Yes	176 (77.88)	87 (76.99)	89 (78.76)	
No	50 (22.12)	26 (23.01)	24 (21.24)	
Childcare responsibilities, *n* (%)				0.168
Yes	169 (74.78)	80 (70.80)	89 (78.76)	
No	57 (25.22)	33 (29.20)	24 (21.24)	
Elderly care responsibilities, *n* (%)				0.200
Yes	176 (77.88)	84 (74.34)	92 (81.42)	
No	50 (22.12)	29 (25.66)	21 (18.58)	
Participates in sports (last month), *n* (%)				0.085
Almost never participate (less than once a month)	105 (46.46)	45 (39.82)	60 (53.10)	
Occasionally participate (1 to 3 times a month)	103 (45.58)	56 (49.56)	47 (41.59)	
Frequently participate (1 to 3 times a week)	18 (7.96)	12 (10.62)	6 (5.31)	
Nearly every day participate (more than 4 times a week)	105 (46.46)	45 (39.82)	60 (53.10)	
Typical bedtime, n (%)				0.635
Before 22:00	20 (8.85)	12 (10.62)	8 (7.08)	
Between 22:00 and 24:00	148 (65.49)	72 (63.72)	76 (67.26)	
After 24:00	58 (25.66)	29 (25.66)	29 (25.66)	
Sleep onset, n(%)				0.577
Fall asleep quickly	122 (53.98)	63 (55.75)	59 (52.21)	
Have some difficulty falling asleep	77 (34.07)	35 (30.97)	42 (37.17)	
Toss and turn	27 (11.95)	15 (13.27)	12 (10.62)	

SNIS-SMH smart nursing information system based on 5G medical private network and supporting mobile hardware, *SD* standard deviation

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Table 2 Chinese Nursing Work Stress Scale scores for SNIS-SMH and control groups before intervention

Variables	Total (n = 226)	SNIS-SMH (n = 113)	Control (n = 113)	*P*-value
I. Professional and work-related issues				
Low social status of nursing work	2.60 ± 0.75	2.62 ± 0.72	2.58 ± 0.78	0.658
Limited opportunities for further education	2.18 ± 0.79	2.21 ± 0.83	2.15 ± 0.76	0.558
Low salary and other benefits	2.28 ± 0.72	2.26 ± 0.74	2.31 ± 0.71	0.582
Few promotion opportunities	1.98 ± 0.73	1.95 ± 0.74	2.01 ± 0.73	0.526
Frequent shift changes	2.59 ± 0.87	2.61 ± 0.84	2.57 ± 0.91	0.703
Limited independence in work	2.01 ± 0.81	2.04 ± 0.82	1.98 ± 0.81	0.568
Ambiguity in work division	1.59 ± 0.58	1.59 ± 0.56	1.59 ± 0.59	1.000
Average scores	2.18 ± 0.46	2.18 ± 0.49	2.17 ± 0.44	0.822
Dimensional scores	15.23 ± 3.25	15.28 ± 3.40	15.19 ± 3.11	0.822
II. Workload and time allocation issues				
Excessive workload	2.25 ± 0.74	2.23 ± 0.76	2.27 ± 0.72	0.719
Insufficient number of nurses on duty	2.58 ± 0.83	2.65 ± 0.82	2.51 ± 0.84	0.230
Lack of time for providing psychological care to patients	2.82 ± 0.97	2.86 ± 0.98	2.78 ± 0.97	0.540
Excessive non-nursing tasks	2.55 ± 0.87	2.52 ± 0.84	2.58 ± 0.90	0.647
Excessive paperwork	2.45 ± 0.89	2.35 ± 0.82	2.55 ± 0.94	0.100
Average scores	2.53 ± 0.64	2.52 ± 0.61	2.54 ± 0.67	0.868
Dimensional scores	12.65 ± 3.20	12.61 ± 3.05	12.68 ± 3.35	0.868
III. Work environment and resource issues				
Poor working environment	2.17 ± 1.12	2.19 ± 1.18	2.15 ± 1.05	0.813
Insufficient medical equipment and instruments	2.23 ± 1.06	2.29 ± 1.07	2.16 ± 1.06	0.348
Overcrowded wards	1.94 ± 0.99	1.90 ± 0.93	1.98 ± 1.05	0.546
Average scores	2.11 ± 0.88	2.13 ± 0.87	2.10 ± 0.89	0.802
Dimensional scores	6.34 ± 2.64	6.38 ± 2.60	6.29 ± 2.68	0.802
IV. Patient care issues				
Concern about errors and accidents in work	2.28 ± 0.73	2.28 ± 0.73	2.28 ± 0.74	0.947
Lack of recognition from patients and their families	2.28 ± 0.73	2.28 ± 0.73	2.28 ± 0.74	1.000
High severity of patients' conditions	2.24 ± 0.71	2.26 ± 0.74	2.22 ± 0.68	0.708
Rudeness from patients' families	2.26 ± 0.70	2.27 ± 0.68	2.25 ± 0.71	0.849
Excessive or unreasonable demands from patients	2.48 ± 0.76	2.51 ± 0.79	2.44 ± 0.73	0.486
Rudeness from patients	2.35 ± 0.70	2.30 ± 0.64	2.39 ± 0.76	0.345
Non-cooperation from patients	2.38 ± 0.67	2.34 ± 0.69	2.43 ± 0.64	0.272
Insufficient knowledge to meet patients' and families' psychological needs	2.31 ± 0.66	2.31 ± 0.64	2.30 ± 0.68	0.920
Lack of knowledge related to patient education	2.17 ± 0.62	2.16 ± 0.61	2.18 ± 0.63	0.830
Concern that nursing procedures may cause patient pain	2.01 ± 0.64	1.97 ± 0.60	2.05 ± 0.68	0.353
Sudden death of patients under care	2.12 ± 0.76	2.12 ± 0.79	2.13 ± 0.73	0.861
Average scores	2.20 ± 0.43	2.19 ± 0.40	2.21 ± 0.47	0.803
Dimensional scores	24.19 ± 4.78	24.11 ± 4.38	24.27 ± 5.16	0.803
V. Management and interpersonal relationship issues				
Lack of understanding and respect from other health-care staff	1.87 ± 0.72	1.86 ± 0.71	1.88 ± 0.73	0.853
Insufficient understanding and support from nursing managers	1.59 ± 0.58	1.58 ± 0.58	1.60 ± 0.58	0.818
Excessive criticism from nursing managers	1.51 ± 0.51	1.50 ± 0.50	1.51 ± 0.52	0.897
Excessive scrutiny from doctors regarding nursing work	1.57 ± 0.53	1.58 ± 0.55	1.56 ± 0.52	0.708
Lack of understanding and support among colleagues	1.50 ± 0.58	1.49 ± 0.57	1.51 ± 0.58	0.730
Conflicts with nursing managers	1.35 ± 0.48	1.34 ± 0.47	1.36 ± 0.48	0.677
Difficult working relationships with certain ward nurses	1.40 ± 0.49	1.42 ± 0.50	1.39 ± 0.49	0.686

Table 2 (continued)

Variables	Total (n = 226)	SNIS-SMH (n = 113)	Control (n = 113)	*P*-value
Conflicts with doctors	1.39 ± 0.50	1.40 ± 0.51	1.39 ± 0.49	0.894
Lack of a cooperative and friendly atmosphere among colleagues	1.42 ± 0.53	1.43 ± 0.53	1.41 ± 0.53	0.707
Average scores	1.51 ± 0.37	1.51 ± 0.41	1.51 ± 0.34	0.984
Dimensional scores	13.61 ± 3.37	13.60 ± 3.66	13.61 ± 3.07	0.984
Total average scores	2.06 ± 0.36	2.06 ± 0.37	2.06 ± 0.35	0.975
Total scores	72.01 ± 12.51	71.98 ± 12.79	72.04 ± 12.29	0.975

SNIS-SMH smart nursing information system based on 5G medical private network and supporting mobile hardware, *SD* standard deviation

among clinical nurses in the SNIS-SMH group ($P = 0.023$, $P = 0.004$). Specifically, there were notable improvements in nurses' sense of independence ($P < 0.001$, $P < 0.001$) and role clarity ($P = 0.042$, $P = 0.003$). However, stress related to salary and benefits, social status of the nursing profession, opportunities for further promotion, and the frequency of shift work did not show significant changes ($P > 0.05$).

(2) In the control group, the pre- and post-comparison analysis indicated no significant changes in professional and work-related stress among clinical nurses ($P = 0.642$).

Workload and time allocation issues (Dimension II):

(1) The intergroup comparison between the SNIS-SMH group and the control group, as well as the pre- and post-comparison within the SNIS-SMH group after 11 months, revealed a significant reduction in stress related to workload and time allocation among clinical nurses in the SNIS-SMH group ($P < 0.001$, $P < 0.001$). Specifically, there were significant decreases in workload ($P = 0.006$, $P = 0.005$), non-nursing tasks ($P < 0.001$, $P < 0.001$), and unnecessary paperwork ($P = 0.01$, $P < 0.001$), while time allocated for psychological care significantly increased ($P < 0.001$, $P < 0.001$). However, the pressure arising from insufficient nursing staff during shifts did not demonstrate significant changes ($P = 0.936$, $P = 0.227$).

(2) The pre- and post-comparison within the control group indicated that stress related to workload and time allocation showed no significant changes ($P = 0.461$).

Work environment and resource issues (Dimension III):

(1) The intergroup comparison between the SNIS-SMH group and the control group, as well as the pre- and post-comparison within both the SNIS-SMH group and the control group after 11 months, revealed no significant changes in stress related to work environment and resources among clinical nurses ($P = 0.602$, $P = 0.160$, $P = 0.459$).

(2) However, the pre- and post-comparison within the SNIS-SMH group indicated that the application of the SNIS-SMH system significantly alleviated stress arising from a poor work environment ($P = 0.024$).

Patient care issues (Dimension IV):

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Table 3 The impact of SNIS-SMH usage on nurses' work stress after 11 months

Variables	Total ($n = 226$)	SNIS-SMH ($n = 113$)	Control ($n = 113$)	P-value
I. Professional and work-related issues				
Low social status of nursing work	2.54 ± 0.79	2.48 ± 0.81	2.60 ± 0.76	0.239
Limited opportunities for further education	2.16 ± 0.79	2.14 ± 0.78	2.19 ± 0.81	0.675
Low salary and other benefits	2.15 ± 0.71	2.06 ± 0.72	2.24 ± 0.68	0.060
Few promotion opportunities	1.95 ± 0.70	1.94 ± 0.74	1.96 ± 0.67	0.777
Frequent shift changes	2.57 ± 0.87	2.59 ± 0.84	2.54 ± 0.90	0.647
Limited independence in work	1.76 ± 0.77	1.58 ± 0.70	1.95 ± 0.79	< 0.001***
Ambiguity in work division	1.45 ± 0.52	1.38 ± 0.52	1.52 ± 0.52	0.042*
Average scores	2.08 ± 0.39	2.02 ± 0.34	2.14 ± 0.44	0.023*
Dimensional scores	14.58 ± 2.76	14.17 ± 2.37	15.00 ± 3.06	0.023*
II. Workload and time allocation issues				
Excessive workload	2.05 ± 0.68	1.93 ± 0.68	2.18 ± 0.67	0.006**
Insufficient number of nurses on duty	2.52 ± 0.82	2.51 ± 0.83	2.52 ± 0.82	0.936
Lack of time for providing psychological care to patients	2.40 ± 0.92	2.07 ± 0.75	2.73 ± 0.97	< 0.001***
Excessive non-nursing tasks	2.36 ± 0.86	2.08 ± 0.70	2.64 ± 0.92	< 0.001***
Excessive paperwork	2.16 ± 0.80	1.96 ± 0.65	2.35 ± 0.89	0.001**
Average scores	2.30 ± 0.53	2.11 ± 0.49	2.48 ± 0.51	< 0.001***
Dimensional scores	11.49 ± 2.66	10.56 ± 2.45	12.42 ± 2.55	< 0.001***
III. Work environment and resource issues				
Poor working environment	1.92 ± 1.08	1.81 ± 1.15	2.04 ± 0.99	0.123
Insufficient medical equipment and instruments	2.11 ± 1.08	2.14 ± 1.12	2.08 ± 1.04	0.666
Overcrowded wards	1.95 ± 1.15	1.94 ± 1.14	1.96 ± 1.16	0.908
Average scores	1.99 ± 0.85	1.96 ± 0.87	2.02 ± 0.82	0.602
Dimensional scores	5.98 ± 2.54	5.89 ± 2.62	6.07 ± 2.47	0.602
IV. Patient care issues				
Concern about errors and accidents in work	2.04 ± 0.64	1.94 ± 0.52	2.13 ± 0.73	0.022*
Lack of recognition from patients and their families	2.13 ± 0.69	2.15 ± 0.71	2.11 ± 0.67	0.631
High severity of patients' conditions	2.24 ± 0.72	2.22 ± 0.69	2.26 ± 0.74	0.711
Rudeness from patients' families	2.42 ± 0.75	2.44 ± 0.80	2.39 ± 0.69	0.593
Excessive or unreasonable demands from patients	2.26 ± 0.70	2.15 ± 0.62	2.36 ± 0.76	0.022*
Rudeness from patients	2.37 ± 0.69	2.30 ± 0.69	2.43 ± 0.69	0.151
Non-cooperation from patients	2.30 ± 0.66	2.26 ± 0.64	2.34 ± 0.68	0.363
Insufficient knowledge to meet patients' and families' psychological needs	2.02 ± 0.52	1.94 ± 0.43	2.10 ± 0.58	0.020*
Lack of knowledge related to patient education	1.80 ± 0.64	1.69 ± 0.57	1.90 ± 0.69	0.013*
Concern that nursing procedures may cause patient pain	2.00 ± 0.68	1.94 ± 0.63	2.07 ± 0.73	0.145
Sudden death of patients under care	1.57 ± 0.64	1.52 ± 0.58	1.61 ± 0.70	0.303
Average scores	2.10 ± 0.34	2.05 ± 0.30	2.15 ± 0.37	0.021*
Dimensional scores	23.12 ± 3.76	22.55 ± 3.34	23.70 ± 4.06	0.021*
V. Management and interpersonal relationship issues				
Lack of understanding and respect from other health-care staff	1.77 ± 0.67	1.72 ± 0.67	1.81 ± 0.66	0.275
Insufficient understanding and support from nursing managers	1.55 ± 0.55	1.55 ± 0.57	1.56 ± 0.53	0.904
Excessive criticism from nursing managers	1.52 ± 0.51	1.49 ± 0.50	1.55 ± 0.52	0.362
Excessive scrutiny from doctors regarding nursing work	1.43 ± 0.50	1.34 ± 0.47	1.52 ± 0.50	0.005**
Lack of understanding and support among colleagues	1.45 ± 0.54	1.47 ± 0.57	1.43 ± 0.52	0.624
Conflicts with nursing managers	1.34 ± 0.47	1.31 ± 0.46	1.37 ± 0.49	0.328

Table 3 (continued)

Variables	Total (*n* = 226)	SNIS-SMH (*n* = 113)	Control (*n* = 113)	*P*-value
Difficult working relationships with certain ward nurses	1.38 ± 0.49	1.39 ± 0.49	1.38 ± 0.49	0.892
Conflicts with doctors	1.43 ± 0.57	1.39 ± 0.51	1.48 ± 0.63	0.245
Lack of a cooperative and friendly atmosphere among colleagues	1.35 ± 0.48	1.35 ± 0.48	1.36 ± 0.48	0.782
Average scores	1.47 ± 0.34	1.44 ± 0.31	1.50 ± 0.36	0.237
Dimensional scores	13.23 ± 3.03	12.99 ± 2.81	13.47 ± 3.24	0.237
Total average score	1.95 ± 0.31	1.89 ± 0.28	2.02 ± 0.32	0.002**
Total scores	68.41 ± 10.81	66.16 ± 9.82	70.65 ± 11.32	0.002**

Results are expressed as mean ± standard deviation

SNIS-SMH smart nursing information system based on 5G medical private network and supporting mobile hardware

*p < 0.05

**p < 0.01

***p < 0.001

(1) The intergroup comparison between the SNIS-SMH group and the control group, as well as the pre- and post-comparison within the SNIS-SMH group after 11 months, demonstrated a significant reduction in stress related to patient care issues ($P = 0.021$, $P = 0.004$). Notably, the stress associated with concerns about mistakes and incidents during work showed a significant decline ($P = 0.022$, $P < 0.001$).

(2) In contrast, the intergroup comparison between the SNIS-SMH group and the control group, along with the pre- and post-comparisons within both the SNIS-SMH group and the control group, revealed no significant changes in stress related to the lack of recognition from patients and their families, severity of patients' conditions, rudeness from patients' families, patient non-cooperation, concerns about the potential pain caused by nursing procedures, and instances of sudden patient death during care ($P > 0.05$). Additionally, stress related to nurses' insufficient knowledge in meeting the psychological needs of patients and families, as well as a lack of knowledge regarding patient education, showed significant reductions, with statistically significant differences observed in intergroup comparisons ($P = 0.020$), pre- and post-comparisons within the SNIS-SMH group ($P < 0.001$), and pre- and post-comparisons within the control group ($P = 0.028$).

(3) Furthermore, only in the intergroup comparison between the SNIS-SMH group and the control group after 11 months, a significant alleviation of stress related to patients making excessive or unreasonable demands was observed ($P = 0.022$).

Management and interpersonal relationships (Dimension V):

(1) In the intergroup comparison between the SNIS-SMH group and the control group after 11 months, as well as in the pre- and post-comparison within the SNIS-SMH group and the control group, no significant changes were observed in the stress related to management and interpersonal relationships among clinical nurses in the SNIS-SMH group ($P = 0.237$, $P = 0.081$, $P = 0.692$).

(2) However, a significant reduction in stress associated with excessive scrutiny from physicians regarding nursing work was noted only in the intergroup comparison

Table 4 Comparison of Chinese Nursing Work Stress Scale scores in SNIS-SMH and control groups before and after intervention

Variables	SNIS-SMH (*n* = 113)			Control (*n* = 113)		
	Before	After	*P*-value	Before	After	*P*-value
I. Professional and work-related issues						
Low social status of nursing work	2.62 ± 0.72	2.48 ± 0.81	0.165	2.58 ± 0.78	2.60 ± 0.76	0.771
Limited opportunities for further education	2.21 ± 0.83	2.14 ± 0.78	0.519	2.15 ± 0.76	2.19 ± 0.81	0.737
Low salary and other benefits	2.26 ± 0.74	2.06 ± 0.72	0.057	2.31 ± 0.71	2.24 ± 0.68	0.435
Few promotion opportunities	1.95 ± 0.74	1.94 ± 0.74	0.925	2.01 ± 0.73	1.96 ± 0.67	0.606
Frequent shift changes	2.61 ± 0.84	2.59 ± 0.84	0.868	2.57 ± 0.91	2.54 ± 0.90	0.814
Limited independence in work	2.04 ± 0.82	1.58 ± 0.70	< 0.001***	1.98 ± 0.81	1.95 ± 0.79	0.697
Ambiguity in work division	1.59 ± 0.56	1.38 ± 0.52	0.003**	1.59 ± 0.59	1.52 ± 0.52	0.312
Average scores	2.18 ± 0.49	2.02 ± 0.34	0.004**	2.17 ± 0.44	2.14 ± 0.44	0.642
Dimensional scores	15.28 ± 3.40	14.17 ± 2.37	0.004**	15.19 ± 3.11	15.00 ± 3.06	0.642
II. Workload and time allocation issues						
Excessive workload	2.23 ± 0.76	1.93 ± 0.68	0.005**	2.27 ± 0.72	2.18 ± 0.67	0.283
Insufficient number of nurses on duty	2.65 ± 0.82	2.51 ± 0.83	0.227	2.51 ± 0.84	2.52 ± 0.82	0.932
Lack of time for providing psychological care to patients	2.86 ± 0.98	2.07 ± 0.75	< 0.001***	2.78 ± 0.97	2.73 ± 0.97	0.660
Excessive non-nursing tasks	2.52 ± 0.84	2.08 ± 0.70	< 0.001***	2.58 ± 0.90	2.64 ± 0.92	0.603
Excessive paperwork	2.35 ± 0.82	1.96 ± 0.65	< 0.001***	2.55 ± 0.94	2.35 ± 0.89	0.109
Average scores	2.52 ± 0.61	2.11 ± 0.49	< 0.001***	2.54 ± 0.67	2.48 ± 0.51	0.461
Dimensional scores	12.61 ± 3.05	10.56 ± 2.45	< 0.001***	12.68 ± 3.35	12.42 ± 2.55	0.461
III. Work environment and resource issues						
Poor working environment	2.19 ± 1.18	1.81 ± 1.15	0.024*	2.15 ± 1.05	2.04 ± 0.99	0.373
Insufficient medical equipment and instruments	2.29 ± 1.07	2.14 ± 1.12	0.300	2.16 ± 1.06	2.08 ± 1.04	0.532
Overcrowded wards	1.90 ± 0.93	1.94 ± 1.14	0.800	1.98 ± 1.05	1.96 ± 1.16	0.833
Average scores	2.13 ± 0.87	1.96 ± 0.87	0.160	2.10 ± 0.89	2.02 ± 0.82	0.459
Dimensional scores	6.38 ± 2.60	5.89 ± 2.62	0.160	6.29 ± 2.68	6.07 ± 2.47	0.459
IV. Patient care issues						
Concern about errors and accidents in work	2.28 ± 0.73	1.94 ± 0.52	< 0.001***	2.28 ± 0.74	2.13 ± 0.73	0.094
Lack of recognition from patients and their families	2.28 ± 0.73	2.15 ± 0.71	0.291	2.28 ± 0.74	2.11 ± 0.67	0.139
High severity of patients' conditions	2.26 ± 0.74	2.22 ± 0.69	0.621	2.22 ± 0.68	2.26 ± 0.74	0.920
Rudeness from patients' families	2.27 ± 0.68	2.44 ± 0.80	0.516	2.25 ± 0.71	2.39 ± 0.69	0.573
Excessive or unreasonable demands from patients	2.51 ± 0.79	2.15 ± 0.62	0.081	2.44 ± 0.73	2.36 ± 0.76	0.788
Rudeness from patients	2.30 ± 0.64	2.30 ± 0.69	0.702	2.39 ± 0.76	2.43 ± 0.69	1.000
Non-cooperation from patients	2.34 ± 0.69	2.26 ± 0.64	0.510	2.43 ± 0.64	2.34 ± 0.68	0.697
Insufficient knowledge to meet patients' and families' psychological needs	2.31 ± 0.64	1.94 ± 0.43	< 0.001***	2.30 ± 0.68	2.10 ± 0.58	0.028*
Lack of knowledge related to patient education	2.16 ± 0.61	1.69 ± 0.57	< 0.001***	2.18 ± 0.63	1.90 ± 0.69	0.006**
Concern that nursing procedures may cause patient pain	1.97 ± 0.60	1.94 ± 0.63	0.070	2.05 ± 0.68	2.07 ± 0.73	0.470

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Table 4 (continued)

Variables	SNIS-SMH (*n* = 113)			Control (*n* = 113)		
	Before	**After**	***P*-value**	**Before**	**After**	***P*-value**
Sudden death of patients under care	2.12 ± 0.79	1.52 ± 0.58	0.240	2.13 ± 0.73	1.61 ± 0.70	0.769
Average scores	2.19 ± 0.40	2.05 ± 0.30	0.004**	2.21 ± 0.47	2.15 ± 0.37	0.272
Dimensional scores	24.11 ± 4.38	22.55 ± 3.34	0.004**	24.27 ± 5.16	23.70 ± 4.06	0.272
V. Management and interpersonal relationship issues						
Lack of understanding and respect from other healthcare staff	1.87 ± 0.72	1.72 ± 0.67	0.099	1.88 ± 0.73	1.81 ± 0.66	0.484
Insufficient understanding and support from nursing managers	1.59 ± 0.58	1.55 ± 0.57	0.630	1.60 ± 0.58	1.56 ± 0.53	0.544
Excessive criticism from nursing managers	1.51 ± 0.51	1.49 ± 0.50	0.747	1.51 ± 0.52	1.55 ± 0.52	0.566
Excessive scrutiny from doctors regarding nursing work	1.57 ± 0.53	1.34 ± 0.47	< 0.001***	1.56 ± 0.52	1.52 ± 0.50	0.549
Lack of understanding and support among colleagues	1.50 ± 0.58	1.47 ± 0.57	0.807	1.51 ± 0.58	1.43 ± 0.52	0.226
Conflicts with nursing managers	1.35 ± 0.48	1.31 ± 0.46	0.633	1.36 ± 0.48	1.37 ± 0.49	0.863
Difficult working relationships with certain ward nurses	1.40 ± 0.49	1.39 ± 0.49	0.494	1.39 ± 0.49	1.38 ± 0.49	0.880
Conflicts with doctors	1.39 ± 0.50	1.39 ± 0.51	0.882	1.39 ± 0.49	1.48 ± 0.63	0.205
Lack of a cooperative and friendly atmosphere among colleagues	1.42 ± 0.53	1.35 ± 0.48	0.105	1.41 ± 0.53	1.36 ± 0.48	0.426
Average scores	1.51 ± 0.37	1.44 ± 0.31	0.081	1.51 ± 0.34	1.50 ± 0.36	0.692
Dimensional scores	13.61 ± 3.37	12.99 ± 2.81	0.081	13.61 ± 3.07	13.47 ± 3.24	0.692
Total average score	2.06 ± 0.36	1.89 ± 0.28	< 0.001***	2.06 ± 0.35	2.02 ± 0.32	0.329
Total scores	72.01 ± 12.51	66.16 ± 9.82	< 0.001***	72.04 ± 12.29	70.65 ± 11.32	0.329

Results are expressed as mean ± standard deviation

SNIS-SMH smart nursing information system based on 5G medical private network and supporting mobile hardware

*$p < 0.05$

**$p < 0.01$

***$p < 0.001$

between the SNIS-SMH group and the control group after 11 months, as well as in the pre- and post-comparison within the SNIS-SMH group ($P = 0.005$, $P < 0.001$). Other sources of stress, such as a lack of understanding and respect from other healthcare personnel, insufficient support from nursing management, excessive and unfriendly scrutiny from physicians, and conflicts among colleagues, did not show significant reductions ($P > 0.05$).

Discussion

This study is the first to evaluate the impact of the SNIS-SMH on nurses' work-related stress. The results indicate that the SNIS-SMH system clarifies nursing tasks and enhances nurses' autonomy, effectively alleviating stress stemming from task ambiguity and reliance on others for assistance. Furthermore, the system significantly reduces the workload and optimizes time allocation, particularly in high-demand environments

where non-nursing tasks are prevalent. By minimizing the time nurses spend on repetitive tasks, work-related stress is further diminished. Additionally, the system improves patient care management and enhances the quality of nursing, thereby reducing the psychological burden and stress associated with concerns about making errors or failing to meet the psychological care and educational needs of patients and their families. However, it is unfortunate that the system did not effectively address stress related to the work environment and resources, as well as management and interpersonal relationships.

Differences in intergroup comparisons between the SNIS-SMH group and the control group after 11 months, and pre- and post-comparisons within the SNIS-SMH group

The SNIS-SMH system effectively reduced work-related stress among clinical nurses by enhancing work independence ($P < 0.001$, $P < 0.001$) and task clarity ($P = 0.042$, $P = 0.003$). This efficacy is likely closely related to the support of the 5G medical private network and the system's various functionalities. Key features such as closed-loop order management and vital signs monitoring ensure that nurses can upload patient condition data in real time and receive timely support and feedback from physicians. Additionally, features such as paperless handover and patient transfer display enable nurses to manage patient handovers and transfers more independently, thereby reducing reliance on other wards and healthcare personnel, which enhances nursing coordination and communication [17]. The use of mobile nursing carts and handheld devices further allows nurses to record and access information anytime and anywhere, further decreasing dependence on fixed workstations. The health education and clinical decision support functionalities enhance the clinical capabilities of less experienced nurses while providing comprehensive oversight for senior nurses, thus improving the autonomy of novice nurses. These features significantly enhance nurses' ability to handle complex nursing tasks and alleviate stress resulting from reliance on others for assistance. Moreover, the nursing task list feature helps nurses clearly understand and execute their tasks, thereby preventing overlaps and omissions. The interactive display screens in smart wards ensure that each nurse is well aware of their work arrangements and responsibilities, reducing confusion and communication barriers, which in turn enhances work coordination and further mitigates stress related to task ambiguity. In the future, when designing and implementing new nursing processes, healthcare institutions should prioritize increasing nurses' autonomy and clarifying work responsibilities to effectively reduce work-related stress among clinical nurses, ultimately leading to more efficient and satisfying nursing services.

The SNIS-SMH significantly alleviated work-related stress among clinical nurses by markedly reducing workload, non-nursing tasks, repetitive duties, and unnecessary paperwork, allowing nurses to dedicate more time and energy to patient care, thus optimizing time management and work distribution ($P < 0.001$, $P < 0.001$). This shift maximizes patient recovery during working hours and prevents nurses from spending valuable time on non-nursing activities, consistent with previous research findings [17, 28]. The system lightens the burden of manual documentation and duplicate data entry through standardized and paperless clinical nursing processes. Nurses can quickly access and manage patient information, reducing the time traditionally required for paper handovers and information retrieval, thereby decreasing workload and stress

and enabling greater focus on direct patient care. Moreover, the use of mobile nursing carts and handheld devices further shortens the time needed for recording and retrieving patient medical information [18, 29], allowing nurses to manage and execute nursing tasks efficiently while significantly increasing the time available for providing psychological care to patients, thereby enhancing overall nursing quality and patient satisfaction. In the future, developers should place greater emphasis on task optimization and information management modules to rationalize nurses' work distribution and optimize time management, further reducing nurses' work-related stress and enhancing nursing efficiency and quality.

Surprisingly, although the SNIS-SMH system significantly reduced work-related stress among clinical nurses, no substantial improvement was observed in the overall stress associated with the work environment and resources. Both intergroup comparisons and pre- and post-assessments within the SNIS-SMH group revealed no significant changes ($P=0.602$, $P=0.160$, $P=0.459$). This may be attributed to the complexity of stressors related to the work environment and resources, coupled with the system's design focus on enhancing nursing processes and work efficiency. Issues such as resource shortages, inadequate workspaces, and aging equipment are typically challenging to resolve solely through system improvements, particularly as they often require ongoing investments from hospital management in hardware and environmental resources, necessitating interdepartmental collaboration beyond mere system enhancements. Furthermore, while the core modules of the SNIS-SMH system emphasize task management, information flow, and the reduction of unnecessary burdens, they lack dedicated features for environmental improvement and resource allocation. Despite the significant alleviation of stress related to poor working conditions observed in the pre- and post-comparisons within the SNIS-SMH group ($P=0.024$), this was insufficient to markedly diminish overall stress associated with the work environment and resources. Future iterations of the system could benefit from the integration of modules for environmental and resource management, such as work resource scheduling and inventory monitoring, to facilitate quicker support during resource shortages, thereby optimizing the clinical care environment, reducing work stress, and enhancing nurses' job satisfaction and occupational health.

The SNIS-SMH system significantly alleviated work-related stress among clinical nurses by addressing patient care issues ($P=0.021$, $P=0.004$), particularly in areas such as fear of making mistakes, insufficient knowledge to meet the psychological needs of patients and their families, and a lack of patient education knowledge. This improvement not only ensured patient safety, but also enhanced the quality of care, attributable to the standardized nursing processes, strengthened medication verification, and knowledge base functions provided by SNIS-SMH, consistent with previous research findings [28]. The system supports identity and order verification by generating QR codes and barcodes and utilizing PDAs to scan various nursing procedures, including intravenous infusions, oral medications, specimen collection, nursing tasks, skin tests, and blood transfusions. When a mismatch occurs between the scanned wristbands and labels, the PDA issues an alert, displays the error, and prevents the execution of the medical order, eliminating the need for manual verification and ensuring consistency between treatment content and patient information, thereby safeguarding medication and treatment

safety and alleviating the psychological burden on nurses due to concerns about making errors. Moreover, the system's health education feature provides systematic and standardized educational content, enabling nurses to effectively deliver health information to patients and their families anytime and anywhere via mobile nursing carts and handheld devices, addressing questions and reducing the anxiety associated with inadequate patient education stemming from their own knowledge limitations. Enhanced clinical reporting and nursing documentation functions streamline the recording and tracking of health education, ensuring that every patient receives continuous health guidance [18]. If nurses feel their medical knowledge is lacking, they can access relevant content within the nursing training and education module to continuously update their knowledge and skills, thereby better meeting the educational and psychological care needs of patients and their families and further alleviating work-related stress associated with feelings of inadequacy in patient care. Future research should focus on how to further enhance the effectiveness of patient care, such as exploring additional educational modules and resources to help nurses better meet patient needs, thereby reducing nurse work-related stress while improving patient satisfaction.

Management and interpersonal relationship issues are significant factors affecting nurses' work-related stress. Previous research has demonstrated that poor management and interpersonal relationships—such as conflicts among colleagues, communication barriers between medical staff, and a lack of support and understanding from management—negatively impact nurses' psychological well-being [7, 30]. This stress not only leads to emotional exhaustion but may also trigger burnout, further exacerbating work-related stress [31, 32]. Therefore, improving management and interpersonal relationships is essential for reducing nurses' work-related stress, enhancing the quality of care, and promoting overall team harmony. In this study, the SNIS-SMH system exhibited a positive effect on alleviating management and interpersonal relationship-related stress by reducing the pressure from excessive scrutiny by physicians ($P=0.005$), effectively mitigating some of the stress associated with management and interpersonal dynamics. This may be related to the system's significant improvements in the quality and independence of nursing work. However, the system's impact on reducing nurses' management and interpersonal relationship stress remains limited. Due to the lack of specific modules for management and interpersonal support, the SNIS-SMH system is unable to directly address other stressors arising from these areas. Future system designs could incorporate relevant content, such as management training modules, conflict resolution strategies, and team-building guidelines, to further alleviate clinical nurses' stress in these aspects.

Differences in pre- and post-comparison within the control group

The analysis of pre- and post-comparisons within the control group indicated a significant reduction in stress related to patient care (Dimension IV), specifically concerning nurses' knowledge deficits in meeting the psychological needs of patients and their families ($P=0.028$) and a lack of knowledge related to patient education ($P=0.006$). This change may be attributed to the natural enhancement of nurses' work performance that comes with increased years of experience. This observation could reflect the natural fluctuations or stability in work-related stress among nurses when no intervention is

implemented. In contrast, the experimental group utilizing the SNIS-SMH system demonstrated lower associated work-related stress on the same issues ($P=0.020$, $P=0.013$), further emphasizing the significant positive impact of the SNIS-SMH system in alleviating work-related stress among clinical nurses. In the future, healthcare institutions should consider the integration of similar smart nursing systems to systematically reduce work-related stress among clinical nurses, thereby improving the quality of care and patient satisfaction.

Advantages and limitations

The significant advantage of this study lies in the comprehensive support provided by the SNIS-SMH system, which includes 49 functional modules that cover various aspects of nursing work. This study is the first to explore the system's impact on the sources and severity of work-related stress among Chinese nurses, particularly through detailed assessments of multiple stress dimensions. Furthermore, a randomized controlled trial design is employed in a real-world setting, enhancing the practical value of the results.

However, there are certain limitations to this study. It was conducted in a single hospital, which may restrict the generalizability of the findings. However, there were certain limitations to this study. Firstly, it was conducted in only one hospital, which may have restricted the generalizability of the findings. Secondly, although the statistical analysts maintained blinding, the open-label design of the SNIS-SMH intervention could have introduced bias, as participants were not blinded to their group assignment. The results indicated that the system had a minimal impact on stress related to the work environment, resources, management, and interpersonal relationships. Future iterations of the system could have benefited from the addition of features such as real-time inventory updates, resource allocation modules, management training, and team-building support to more effectively alleviate stress in these areas. Additionally, due to initial supply limitations, this study was confined to a limited number of wards. Future research could expand the system's application throughout the hospital, particularly in specialized areas such as operating rooms, intensive care units, and dialysis units, to further explore its effectiveness in alleviating work-related stress in different nursing environments.

Conclusion

This study demonstrates that the integration of the SNIS-SMH system into nurses' daily clinical and management activities effectively alleviates work-related stress among clinical nurses, enhances nursing efficiency, and improves both nursing quality and patient satisfaction. The SNIS-SMH system produces positive impacts in several areas: first, it significantly increases nurses' independence and task clarity, thereby reducing stress associated with reliance on others and ambiguous responsibilities. Second, by streamlining workflows and minimizing non-nursing tasks, it optimizes time allocation, allowing nurses to devote more energy to direct patient care, which in turn enhances nursing quality and patient satisfaction, facilitating faster patient recovery. Additionally, modules for medication management, vital signs monitoring, and health education support patient care management, alleviating nurses' psychological stress related to concerns about errors and knowledge gaps in addressing patients' and families' psychological needs. However, the impact of the SNIS-SMH system on improving the

work environment and resource, as well as management and interpersonal relationships, remains limited. Future optimizations of the system should address these aspects. Although this study is based on single-center data, it still provides valuable insights for alleviating work-related stress among nurses. Future research could further refine the system's functionalities and expand its application across various specialized departments to assess its practical effectiveness in different nursing environments.

Methods

Study design and setting

This study was a single-center, prospective, randomized controlled trial conducted in accordance with the CONSORT-eHEALTH (Consolidated Standards of Reporting Trials of Electronic and Mobile Health Applications and Online Telehealth) guidelines [19] (see Multimedia Appendix 1). A parallel-group design was employed. The research was conducted from June 2023 to May 2024 at a tertiary A-grade general hospital in Anhui Province, China, which encompasses 1,500 beds and 26 general clinical wards. The primary objective of the study was to evaluate the effectiveness of the SNIS-SMH in alleviating work-related stress among clinical nurses.

Ethics approval

Ethical approval for the study was obtained from the Ethics Committee of the First People's Hospital of Wuhu City (No. YYLL20220094), and informed consent waiver was also obtained.

Subjects and public participation

During the research planning phase, we initiated a preliminary pilot project. From July 2022 to March 2023, the project leader conducted in-hospital clinical research and explored other healthcare facilities to delineate specific functional requirements for the upcoming tender of the intelligent nursing system, aimed at optimizing nursing workflows. Meetings were convened with the information technology construction team, and a convenience sampling method was employed to select 23 clinical nurses from general wards, 1 nursing department officer, 5 physicians, and 4 nursing managers to evaluate the design and applicability of the SNIS-SMH. The system's functions and modules were continually refined in response to clinical work demands, thereby enhancing its service to clinical operations. The findings of the study were disseminated to all medical professionals within our institution.

Inclusion and exclusion criteria

The inclusion criteria were as follows:

- Held a valid professional certification: To ensure that participants were qualified registered nurses who met the necessary licensing requirements.
- Voluntary participation in this study: To reduce biases associated with involuntary factors, this standard was designed to ensure the authenticity of the collected data.

- Completed all phases of the research survey process: To guarantee data completeness and consistency, this requirement aimed to minimize potential data loss or inconsistencies that may arise if participants withdraw from the study.

The exclusion criteria were as follows:

- Employed at the hospital for at least one year (as of the day before the study began): To account for the one-year rotation period post-hire, during which nurses may not be familiar with specific departments, potentially leading to non-representative levels of work-related stress.
- Planning to resign during the study period (resignation application submitted): To avoid the influence of impending departure on work attitudes and emotional fluctuations, which could affect data integrity and ensure the stability and continuity of the research.
- Pregnant or breastfeeding: To recognize that nurses in these conditions may face additional physiological stress, which could affect data outcomes and hinder effective comparisons with other samples.
- Affected by illness (e.g., poorly controlled chronic diseases, undergoing treatment for major illnesses, requiring long-term recovery from acute illnesses): To reduce confounding factors related to health status, nurses with chronic illnesses or those undergoing significant treatment may experience altered perceptions of work-related stress.
- On leave for further education, maternity leave, or unable to work for 6 months or more for other reasons: To ensure that nurses who have been absent from the workplace are familiar enough with the current work environment and processes to accurately reflect the actual levels of work-related stress.
- Incomplete survey responses: To maintain data integrity and ensure the accuracy and completeness of data analysis.
- Experiencing excessive work-related stress and receiving related treatment: To account for the possibility that these participants may respond to stress differently than their peers, and the treatment received could interfere with stress perception, thus violating the study's homogeneity requirements.
- Participating in other studies related to work-related stress: To prevent potential cross-study effects that may compromise the independence of this research's results, nurses engaged in other stress-related studies will be excluded.

Random allocation

Clinical nurses from all 26 general clinical wards of the hospital who met the inclusion and exclusion criteria were selected as research subjects. After coding the 26 wards, the project leader used an online standard random number generator to produce a random sequence within the range of 1 to 26 (e.g., https://www.random.org/sequences/), with the ward managers supervising the generation process. The wards corresponding to

the first 13 numbers in the random sequence were classified as the intervention group (SNIS-SMH), while the remaining wards were designated as the control group.

The study determined the sample size for each group based on the number of participants who completed the study in the smaller group. A 1:1 random matching was performed using an online random number generator to match participants from the larger group. The randomization process of the clinical wards occurred after the baseline assessment to minimize reporting and selection bias.

Blinding

Given that this study employed an open-label design—where nurses in the SNIS-SMH group utilize the system while those in the control group did not—blinding of clinical nurses and ward managers was not feasible. Blinding was applied only during the analysis phase of the primary endpoint (changes in nurses' work-related stress). To ensure a blind analysis of this primary endpoint, data analysts would remain unaware of the nurses' group assignments. Specifically, the project leader was responsible for data coding, and data analysts only had access to the coded data, thereby ensuring the objectivity and credibility of the analysis results.

Study interventions

Control group: traditional nursing documentation

The traditional nursing documentation method, which was integrated with the physician's medical record system, supported only routine nursing records. Its functionalities included: (1) electronic order execution: nurses log into the electronic medical record system at designated times to sign off on order execution forms after carrying out medical orders; (2) nursing documentation: nurses manually record routine nursing assessment results, such as blood pressure and blood glucose levels, on paper before transcribing this information into the system at specified times.

Intervention group: SNIS-SMH

SNIS-SMH was designed to comprehensively address the practical needs of clinical nurses, encompassing various aspects of ward nursing and nursing management. Its functionalities were divided into three main components, with their interrelationships illustrated in Fig. 2 and further detailed in Appendix 1:

(1) Nursing system: clinical software system, built on a 5G medical private network, includes features such as system management, secure login, auxiliary functions, comprehensive patient management, order closure management, vital signs monitoring, health education, clinical and ward reports, nursing documentation management, clinical decision support, task list management, critical value management, and blood transfusion records. Management system: encompassed adverse event management, knowledge base, personnel management, nursing quality management, nursing-sensitive quality indicators, and training and educational functions.

(2) Smart nursing information touchscreen interaction system: provided an interactive display screen for smart wards with functionalities including patient overview
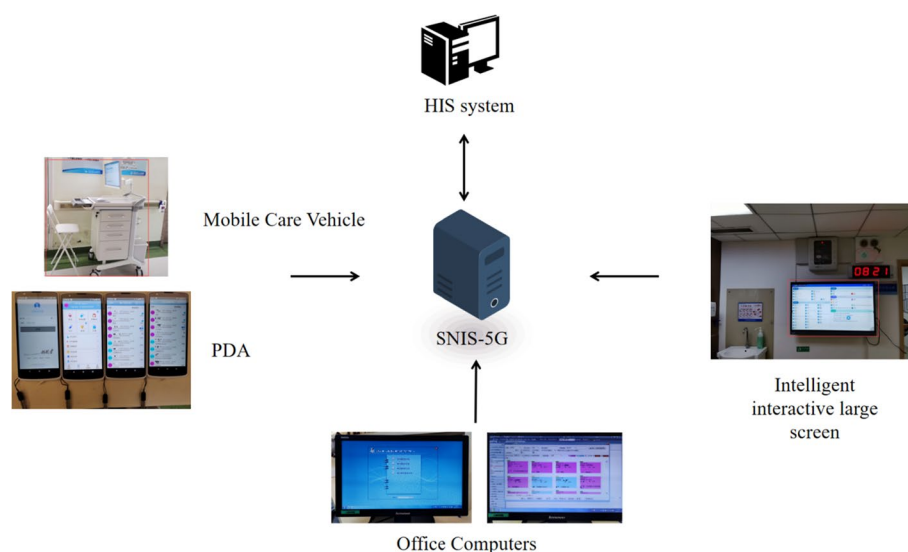
Fig. 2 A CONSORT (Consolidated Standards of Reporting Trials) flowchart. *SNIS-SMH* smart nursing information system based on 5G medical private network and supporting mobile hardware

cards, ward bed lists, care sign display, patient classification and paperless handover, nursing transfer display, nursing safety display, smart memo, contact list, call information display, responsible nurse bed information, scheduling information display, real-time nursing plan update reminders, infusion status monitoring, surgical status inquiry, and a 360° view of the patient.

(3) Mobile nursing hardware: included mobile nursing carts and handheld data collection terminals (medical PDAs) that supported real-time data collection and processing.

Implementation and training for SNIS-SMH

System implementation: one week prior to the intervention, the system was deployed within the hospital to ensure seamless integration with existing information platforms. Initial testing and adjustments were conducted in the wards assigned to the SNIS-SMH group. The intervention period lasted for 11 months.

Nurse training: before the intervention began, all nurses in the SNIS-SMH group underwent 5–10 h of training. This training included clinical simulation practice conducted in groups of 2–3 nurses to ensure proficiency with the SNIS-SMH system.

Data collection

Prior to the commencement of the study, standardized training on the research procedures was provided to the head nurses of the 26 wards to ensure their ability to select nurses according to the established inclusion and exclusion criteria. One week before the study began, during the ward meetings, head nurses distributed questionnaires to all eligible nurses. The questionnaires included a basic demographic survey and the Chinese Nursing Work Stress Scale for the baseline survey. Once completed, the head nurses counted and collected the completed questionnaires on-site.

Following this, random group assignment was conducted at the ward level. The hospital's information department subsequently installed and adjusted the SNIS-SMH in the wards designated for the intervention group. After 11 months of using the SNIS-SMH, head nurses distributed the Chinese Nursing Work Stress Scale again to the nurses who had previously completed the baseline survey. Finally, the study included only those samples where the questionnaires were fully completed both before and after the intervention for analysis.

Outcomes

The core objective of this study was to compare the work-related stress levels between the SNIS-SMH group and the control group. Stress levels for all participants were measured at baseline and after 11 months.

The assessment utilized the Chinese Nursing Work Stress Scale [20], developed by Li and Liu in 2000. This scale was redesigned based on two widely used nursing work stress scales: the Nursing Stress Scale by American psychologist Grey-Toft and Anderson [21], and the Nurse Stress Scale by British researchers Wheeler and Riding [22]. The redesign process incorporated insights from nursing experts in the United States, Thailand, and China, ensuring that it aligned with China's national context. A rigorous translation and cross-cultural adaptation process was followed [23], and the scale has been applied in multiple studies within China, demonstrating good reliability and validity [24, 25]. The Chinese Nursing Work Stress Scale consists of 35 items categorized into five dimensions: issues related to the nursing profession and work, workload and time allocation, work environment and resource, patient care, and management and interpersonal relationships. Each item is scored on a 1 to 4 scale, with higher scores indicating greater levels of stress. The overall Cronbach's α coefficient for the scale is 0.98, with individual dimensions ranging from 0.83 to 0.95. This scale is regarded as a reliable tool for accurately assessing work-related stress among clinical nurses.

Sample size

Sample size estimation was conducted using G*Power (version 3.1.9.7; Heinrich-Heine-Universität Düsseldorf) [26]. Given that no prior studies have evaluated the impact of 5G-based smart nursing systems and mobile devices on nurses' work-related stress, this study anticipated a conservative medium effect size (0.5) [27]. At a 5% significance level (2-sided) with 80% power, a total of 64 participants were required in each group. Considering a potential dropout rate of 20%, the target sample size was set to at least 80 participants per group, totaling 160 participants.

Data analysis

We conducted our statistical analyses using SPSS 26.0 software, with a significance level set at $\alpha = 0.05$. Continuous data were presented as mean ± standard deviation. Between-group differences were assessed using the independent two-sample t-test, while differences before and after the intervention were analyzed using the paired sample t-test. Categorical data were presented as frequencies, and percentages (%), with between-group differences analyzed using the Chi-square (χ^2) test.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12938-025-01344-1.

> Supplementary Material 1.

Data availability
No datasets were generated or analyzed during the current study.

Declarations

Ethics approval and consent to participate
Ethical approval was received from the First People's Hospital of Wuhu City (No.:YYLL20220094). To protect participants privacy, all personal identifiers were systematically removed.

Consent for publication
Informed consent was waived by our Institutional Review Board.

Competing interests
The authors declare no competing interests.

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