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-Title:

Application of virtual simulation technology: a novel training mode on public health emergencies for emergency reserve nurses

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Authors' Contributions

Dandan ZHANG and Hongwu LIAO contributed equally to this work.

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Keywords: Disaster; nursing; virtual simulation; emergency; public health; respiratory infectious disease; epidemic situation of COVID-19

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ABSTRACT

Objective: To develop and evaluate a virtual simulation training program to improve the emergency reserve nurses' ability to respond to disasters such as public health emergencies.

Methods: A total of 120 emergency reserve nurses were enrolled and divided into control group and experimental group, with 60 in each group, by random number table method, for a 3-month training. The nurses in the control group received conventional training, while those in the experimental group received virtual simulation training combined with offline training on the basis of the intervention of the control group. Before and after intervention, the nurses of the two groups were evaluated on the knowledge and operation skills related to fulminating respiratory infectious diseases, as well as emergency rescue ability; and they were assessed by a disaster preparation questionnaire, the results of which were compared, and the influencing factors were analyzed.

Results: After intervention, the scores of related knowledges, emergency rescue ability, and disaster preparation in the experimental group showed significantly increased ($P < 0.01$). The score of operation skills in the control group increased higher than that in the experimental group ($P < 0.01$). The score of post-disaster recovery ability in two groups showed no significant difference ($P > 0.05$).

Conclusion: Virtual simulation training combined with offline practical training can improve the disaster preparation of reserve nurses than conventional training. This novel training mode on public health emergencies for nurses deserves further exploration and popularization.

SUMMARY BOX

1.What is already known about this subject:

Since December 2019, COVID-19 has widespread globally as a pandemic and seriously threatened the health of the world, which has imposed high requirements for the emergency rescue ability of medical staff. As one of the main forces of the rescue team, nurses play a significant role in disaster response.

According to the investigations conducted during the COVID-19 epidemic period in the Beijing and Jilin medical teams to support Wuhan, Hubei province and the

designated hospitals for treating COVID-19 in Beijing, Jilin province, and other places, the nurses had inadequate ability to respond to disasters such as public health emergencies. It, therefore, is necessary to improve nurses' ability on disaster preparation through practical training and simulation exercises.

As infectious diseases are highly contagious and harmful and its outbreak is unexpected and fulminant, it is difficult to carry out traditional on-the-spot teaching.

Virtual simulation training has been widely used in school and hospital for induction training and teaching, as it can provide a lifelike, intelligent, interactive, independent and open learning environment, which is conducive to cultivate students' critical thinking and clinical decision-making ability. However, there is few virtual simulation program providing nursing professional training on responding to public health emergencies, especially severe respiratory infectious diseases.

2.What are the new findings:

In this study, we introduced virtual simulation teaching technology and 3D virtual hospital real scene and the real cases of COVID-19 into emergency reserve nurses' training. The virtual environment simulated the real scene of isolation ward, COVID-19 patients' medical conditions, e.g., discomfort reactions, disease development, psychological changes, etc., and diagnosis and treatment, nursing care, standard operation procedures (SOPs) of disinfection and isolation, precautions against medication reactions. The trainees can conduct operations and practices in the immersive training environment, quickly grasp the essentials, adapt to the work context and improve their emergency rescue ability and comprehensive quality.

We compared conventional training with virtual simulation training combined with offline training, and found the latter one can significantly improve the disaster preparation of reserve nurses than the former one. Moreover, virtual simulation teaching combined with offline training has more advantages in the mastery of theoretical knowledge, and improving emergency rescue ability, disaster response and preparation ability.

3.Strengths and limitations of this study：

（1）the main strengths in our study: ① This study can provide the basis for the development of a scientific and reasonable emergency nursing training mode and the establishment emergency reserve nursing team.②Virtual simulation teaching combined with offline training, as a novel method, can be used in medical institution in emergency training for public health emergencies, preparing for an efficient and orderly emergency rescue in dealing with public health emergencies.

（2）limitations : ①The sample size of the study is small, and the subjects all come from only one hospital, so the reference significance of the analysis results on factors affecting disaster preparedness is limited. ② Due to the limitation of resources, the virtual scene of make shift hospital is not constructed in the virtual training program, which will be added in the future study. ③ The training related to post-disaster care and PTSD was not paid enough attention, which will be improved in the future.

INTRODUCTION

Since December 2019, COVID-19 has widespread globally as the severest pandemic in the past hundred years and seriously threatened human health. As of August 10, 2020, COVID-19, caused by SARS-CoV-2, resulted in more than 730 000 deaths in the worldwide.[1] Due to the sudden outbreak, rapid spread and no specific drug treatment, the emergency response mechanism of major public health emergencies around the world has been facing great challenges, which also called for competent emergency rescue ability of medical personnel.

As one of the essential forces in a rescue team, nurses play a significant role in disaster response.[2-3] At present, there is no disaster specialist nurses in China. Generally, the teams involved in emergency rescue were drafted from various hospitals. Investigations conducted during the epidemic of COVID-19 in China showed that the front-line clinical nurses sent to Wuhan, Hubei province and those worked in designated hospitals in Beijing, Jilin, and other places had a low-to-medium level of disaster preparation.[4-6] These emergency nurses only had participated in short-term emergency relief training or drills, and thus they lacked emergency response ability in practical work and had great psychological pressure.[7] According to the retrospective survey of nurses' disaster preparation involved SARS carried out 5 years after the outbreak of pandemic,[8] and surveys in the United States, Asia-Pacific, and other places,[9-13] those nurses' disaster preparation was at a low-middle or poor level, and they nurses cannot deal with disasters effectively. Therefore, it is of great importance now to figure out how to enhance the training of disaster nursing so as to strengthen the comprehensive ability of emergency reserve nurses in response to public health emergencies.

At present, researchers have proposed emergency drill, disaster simulation, and rescue drill, desktop maneuvers and other ways to help nurses gain more disaster relief experience,[7, 14-15] and also explored nursing students' training on emergency rescue by simulation teaching, disaster scenario reproduction and obstacle setting training, network distance education, and so on.[16-18] However, these studies lack long-term follow-up results, and the organization of simulated emergency drills is costly and inconvenient for students to practice repeatedly. On another hand, the outbreak of acute infectious disease is rare in chance and with some unusual physical signs, high infectivity and harmfulness, so it is difficult to realize on-site teaching. In order to cope with the sudden outbreak of infectious diseases, many medical

institutions regularly organize medical personnel to conduct drills according to the emergency plans. As the drill scenario is set in advance and all the patients role-played, these drills cannot simulate the real situation and provide on-site experience, so the trainees complain about not having sufficient ability in the face of sudden situation.[9, 19] Especially, during this pandemic of COVID-19, there were many problems emerged, e.g., insufficient emergency ability and high psychological pressure.[4-6]

Virtual simulation training has been widely used in school teaching and hospital induction training for its advantages of life-like simulation, intelligence, interaction, independence, and openness.[20] It is helpful for cultivating students' critical thinking and clinical decision-making ability. During the training, the trainees can log in the system with different roles, which can realize the training of different professional skills, teamwork and real-time interaction, and also facilitate the medical students of different majors to form a team to provide treatment and nursing care for patients.[7, 21] In China, the virtual simulation program for training infectious diseases nursing mainly includes the training of common infectious diseases nursing thinking and the experimental program of layout design of infectious diseases zone, but these programs are seldomly involved in the knowledge of new infectious disease. The virtual simulation programs related to emergency treatment of respiratory infectious diseases, e.g., avian influenza, plague, tuberculosis, mainly focus on how to conduct epidemic investigation, treatment, reporting, sterilization, etc.[22] are usually designed for preventive medicine and public health students. However, there is no virtual simulation program that is suitable for nursing professional training on emergency treatment of severe respiratory infectious diseases emergencies.

This study reconstructed 3D virtual hospital real scene, incorporated COVID-19 cases in to the training, and showed the real scenes of isolation ward and patient's discomfort by virtual simulation technology. The trainees can carry out the operation and practice[23] in the immersive environment, so as to quickly master the essentials, adapt to the work context, improve the emergency rescue ability and comprehensive quality, thus to provide a basis for training emergency rescue nursing for public health emergencies and establishing emergency reserve nursing rescue team in the future.

METHODS

The study was conducted at a general hospital in Hengyang, Hunan Province, China. From January to March 2020, the hospital treated 80% of the local COVID-19 confirmed patients; and by March 2, all those patients recovered and were discharged from the hospital. Since then, there has been no more newly confirmed COVID-19 case in the region. In May 2020 (two months after the stability of the local epidemic situation), 120 eligible nurses were enrolled in this study and randomly divided into control group and experimental group. All nurses are managed by the Emergency Prep Nurse Training Team of the hospital. When the nurse passed the assessment after training, he/she would be directly selected into the emergency nurse talent bank of the local public health emergency.

Ethics

This study was approved by the Ethics Committee of Affiliated Nanhua Hospital of University of South China (2020-ky-49). All subjects were informed of voluntarily participating and could withdraw from the study at any time. The participant's personal information is confidential and can only be accessed by the authors.

Patient and Public Involvement statement

No patients were involved in this study. This study/article focused on a novel training mode with virtual reality technology for nurses dealing with public health emergencies.

Training

From May to July in 2020, the nurses in the control and experimental groups were trained according to the following program.

(1) Control group received traditional training.

A 10-member emergency nursing instructor team was set up, including the experts in medical treatment, nursing care, nosocomial infection control, psychology, and teaching had been working in the front-line treatment of COVID-19. The task of the instructors was to teach theory, train operational skills, and organize emergency drills. The training lasted 3 months, once a week, and 4 class hours of each secession,

including 2 class hours of lecture on theory and 2 class hours of demonstration and intensive training. The contents of training included the guidelines of COVID-19 prevention and treatment, disinfection, quarantine, and nosocomial infection control, rescue and psychological care of patients in critical condition, experience sharing of frontline anti-epidemic medical care, as well as preparation of common epidemic prevention materials, general skills of epidemic control, and advanced life support. Especially, the training attached great importance to self-protection and anti-pressure ability in the anti-epidemic effort. The basic operation skills training included donning and doffing personal protective equipment, common disinfection and isolation technologies in the ward, CPR, sputum aspiration, oxygen inhalation, trachea cannula, arteriopuncture and venepuncture, simple respirator, defibrillator, various types of ventilators, high-frequency oxygen flow ventilation support, etc. During the rest of the training time, training in small group was organized. At the end of the training, two comprehensive simulation exercises based on emergency plan were conducted in batches.

(2) The experimental group received virtual simulation training on the basis of the traditional training.

Firstly, setting up a team and preparing cases: we set up an instructor team of virtual simulation training for emergency rescue of respiratory infectious diseases (one teacher for virtual training and information technology support was enrolled on the basis of the instructor team of the control group). The instructor team was responsible for selecting three typical cases of COVID-19 (the private information of the patients in the cases, e.g., name, telephone number, address, were removed) including one severe case of an adult patient, one critical case of an elderly patient complicated with underlying diseases such as diabetes, and one critical case of an eight-year-old child patient. The whole treatment processes of those 3 cases were analyzed, from which the high-frequently used operations, key operations, difficult operations involved in first-aid nursing, key points in nursing work, possible problems, difficulties, and feasible solutions were sorted out and compiled into the cases of virtual simulation training.

Secondly, setting the scenario and building up the platform: we created four virtual scenes, i.e., pre-hospital reception, fever clinics reception and transferring, intensive care unit, and general ward, for the trainees getting familiar with different work environments. At the same time, the cases in the training system can simulate the real pathological development process, diagnosis and treatment, nursing care, disinfection and quarantine, drug reaction prevention, psychological change, etc. The

tasks include all the training items related to COVID-19, e.g., operational skills training, comprehensive clinical capability training, disinfection and quarantine standard operating procedure (SOP), standard occupational protection, and occupational exposure emergency handling, patient going out for medical examination, and specimen transportation, SOP of entry and exit of the isolation ward, and SOP for donning and doffing personal protective equipment (see Fig.1).

Third, implementing the training: the training lasted 3 months, once a week, 4 class hours each time, among which, 2 h for the trainees to practice with the simulated cases in the virtual system, 1.5 h for the trainees to get real practice in small groups, for example, they could use multi-functional dummies or models for actual nursing operation practice, 0.5 h for summarizing and exchanges, such as asking questions on the training, discussing unexpected situations or emergencies handling, and sharing views on the nursing problems and measures in the cases. In their spare time, the trainees can make appointment on the hospital virtual training platform to repeat and review the practices.

Evaluation Criteria

(1) Assessment of theory and skills: the nurses of the two groups were assessed on their relevant theoretical knowledge and skills before and after the intervention.

(2) Emergency rescue ability scoring: the instructors as the judge evaluate the emergency rescue ability of the nurses of the two groups before and after the intervention. The design of the scoring scale was based on the study of Wang.[24] It focuses five dimensions with 100 points in total, including the ability of occupational protection, disinfection, and quarantine (20), observation and judgment of disease (20), preliminary examination, classification, and treatment of the patients in severe or critical condition (20), cooperation and coordination (20), and crisis assessment and management (20). The higher score the nurse gained, the greater ability of rescuing and dealing with emergencies the nurse has. The Cronbach's α coefficient was 0.79.

(3) The Chinese version of Nurse Disaster Preparedness Scale: the scale was prepared by LI,[25] which was translated and adjusted culturally from Tichy's scale.[26] The Cronbach's α coefficient is 0.865, including 45 items of three dimensions: knowledge on disaster (13 items), technology for disaster relief (11 items) and post-disaster

management (21 items). The contents of the scale included risk reduction, disease prevention and health promotion, policy making and development, ethics, legal practices and liabilities, communication and information sharing, education and preparedness for disaster, community care, individual and home care, psychological care, care for vulnerable groups, long-term rehabilitation of individual, family, and community, etc.,[5] which could comprehensively reflect the situation of nurses' disaster preparedness. Items were scored 1 ~ 6 points from "strongly disagree" to "strongly agree." The higher the score gained, the better the disaster preparedness the nurse had.

Statistical Analysis

All data were input into SPSS 18.0 and were statistical analyzed. The *P value* less than 0.05 was considered statistically significant.

RESULTS

(1) **Demographic Data**

Table 1 presents the demographic data comparison between the two groups of participants. The majority of the 120 subjects in this study were women (control group: 91.67%, experimental group: 88.33%).

The differences in sex, age, education background, and work experience between the two groups were not statistically significant (P> 0.05) and were comparable.

Table 1 **Demographic Data**

basic characteristics		control group (n=60)	experimental group (n=60)	t/χ2	P
sex	male	5	7	0.093	0.761
	female	55	53		
age	⩽30 years old	29	28	0.255	0.754
	31-39 years old	24	24		
	⩾40 years old	7	8		
years of service	⩽5 years	26	23	0.111	0.912
	6-14 years	21	25		
	⩾15 years	13	12		
education background	diploma /associate degree	11	10	0.06	0.97
	Bachelor's degree	40	41		
	Master's degree	9	9		
professional title	primary	29	29	0.165	0.921
	intermediate	21	21		

	senior	10	10		
emergency/critical care specialist nurse	No	38	37	0.036	0.850
	Yes	22	23		
nursing experience of fighting against SARS/COVID-9	No	45	43	0.17	0.68
	Yes	15	17		
infectious diseases care experience	No	39	37	0.144	0.705
	Yes	21	23		
department	medical ward	19	19	0.27	0.998
	surgical ward	14	15		
	emergency department	8	7		
	ICU	8	9		
	pediatric ward	5	5		
	others	6	5		

(2) Comparison of the scores of disaster preparedness before and after intervention

Before intervention, there was no significant difference in the score of disaster preparedness between the two groups (P> 0.05, Table 2). After intervention, the total disaster preparedness score of the experimental group was significantly higher than that of the control group (P = 0.000, Table 2). The scores of disaster preparedness and response of the experimental group were significantly higher than those of the control group (P <0.001, Table 2), while the scores of post-disaster recovery between the groups were not statistically significant (P> 0.05, Table 2).

Table 2 **Comparison of the scores of disaster preparedness before and after intervention**

	disaster preparedness (mean ± SD)		disaster response (mean ± SD)		Post-disaster recovery (mean ± SD)		total score (mean ± SD)	
	pre-intervention	post-intervention	pre-intervention	post-intervention	pre-intervention	post-intervention	pre-intervention	post-intervention
control group(n=60)	101.73±17.94	122±12.79	52.2±10.52	69.42±7.89	24.08±5.68	27.47±4.77	178.02±30.60	218.88±21.34
experimental group(n=60)	104.38±14.47	131.22±6.99	51.55±8.72	75.95±4.52	23.82±4.68	28.05±3.26	179.75±20.23	235.22±10.75
t	0.891	4.9	0.369	5.566	0.281	0.782	0.366	5.295
P	0.375	<0.001	0.713	<0.001	0.779	0.436	0.715	<0.001

SD: standard deviation, using t (t test).

(3) Comparison of the scores of theoretical and skill assessments and emergency rescue ability before and after intervention

There was no significant difference in the scores of theoretical and skill assessments and emergency rescue ability between the two groups before intervention (P> 0.05, Table 3). After intervention, the theoretical assessment score and the score of emergency rescue ability of the two groups were improved. The theoretical assessment and emergency rescue capability scores of the experimental group were significantly higher than those of the control group (P <0.001, Table 3), while the practical skill score of the control group was significantly higher than that of the experimental group (P <0.01, Table 3).

Table 3 **Comparison of the scores of theoretical and skill assessments and emergency rescue ability before and after intervention**

	Theoretical assessment score (mean ± SD)		Practical skills score (mean ± SD)		emergency rescue ability score (mean ± SD)	
	pre-intervention	post-intervention	pre-intervention	post-intervention	pre-intervention	post-intervention
control group(n=60)	65.12±7.04	82.92±4.55	71.13±4.57	90.35±3.38	63.1±7.23	81.97±4.45
experimental group(n=60)	65.62±7.16	86.62±3.91	71.77±5.66	88.47±4.19	63.93±6.65	85.35±3.93
t	0.386	4.783	0.035	2.708	0.657	4.416
P	0.7	< 0.001 **	0.972	0.008 **	0.516	< 0.001**

**: $p < 0.01$

(4) Analysis of influence factors on disaster preparedness of nurses in experimental group

In order to find out the factors influencing the disaster preparedness of the experimental group, we conducted a related factor analysis among sex, age, length of service, education background, first-aid/intensive care work experience, and nursing experience of fighting against SARS/COVID-9. The results showed that age, length of service, working experience of emergency department or intensive care unit, and nursing experience of fighting against SARS/COVID-9 had statistically significant impacts on disaster preparedness of the reserve nurses (P <0.05, Table 4), while education background, sex, and professional title had no statistically significant impact (P> 0.05, Table 4).

Table 4 **Analysis of influence factors on disaster preparedness of nurses in experimental group (Mean ± SD)**

category		case	Disaster preparedness		Disaster response		Post-disaster recovery		Total score		*P*
			pre-intervention	post-intervention	pre-intervention	post-intervention	pre-intervention	post-intervention	pre-intervention	post-intervention	
sex	male	7	103±15.41	133.57±8.34	51.57±5.13	75.57±3.5	25.86±2.97	29.29±2.06	180.4±18.43	238.43±10.61	>0.05
	female	53	104.57±14.49	130.91±6.82	51.55±9.12	76±4.66	23.55±4.82	27.89±3.37	179.7±20.62	234.79±10.8	
age	≤30 years old	28	100.1±16.95	129.71±6.81	48.79±9.62	75.07±4.69	22.86±4.95	27.61±3.29	170.9±21.8[a]	232.4±10.65[b]	<0.05
	31-39 years old	24	110.25±10.04	133.21±7	55.46±6.15	77.54±3.2	25±4.33	28.83±3.21	190.7±14.99[a]	239.58±10.1[b]	
	≥40 years old	8	101.75±11.18	130.5±6.93	52.63±6.3	74.25±6.2	23.63±4.47	27.25±3.2	178±20.23[a]	232±9.62[b]	
years of service	≤5 years	23	99.52±16.48[c]	129.71±1.62	48.26±8.66[d]	76.05±3.87	22.91±5.11	27.76±3.14	170.7±23.72[e]	233.5±10.27	>0.05
	6-14years	25	110.8±10.36[c]	132.44±76.42	52.68±8.50[d]	76.2±4.92	24.48±4.37	28.64±3.67	187.24±15.99[e]	237.28±11.97	
	≥15years	12	101.83±14.01[c]	131.29±7.32	55.5±7.55[d]	75.35±4.96	24.17±4.55	27.43±3.3	181.5±14.5[e]	234.07±9.14	
education	diploma /associate	10	104.5±16.41	132.2±7.11	53.4±3.74	76.8±3.65	22.5±3.41	26.7±2.5	180.4±17.85	235.7±7.83	>0.05

background	degree										
	Bachelor's degree	41	105.02±15.05	130.56±7.15	51.46±9.21	75.9±4.58	23.46±4.81	28.02±3.34	179.95±22.64	234.49±11.86	
	Master's degree	9	101.33±9.72	133.11±6.33	49.89±10.62	75.22±5.43	26.89±4.4	29.67±3.24	178.11±9.63	238±8.31	
	primary	29	101.97±15.63	130.14±7.18	49.69±9.34	75.69±4.45	23.1±5.07	27.76±3.43	174.76±23.11	233.59±10.06	
professional title	Intermediate	21	110.29±14.16	132.86±6.66	51.67±8.24	76.05±5.03	24.57±4.34	28.48±3.3	186.53±17.47	237.38±12.15	>0.05
	senior	10	99±5.79	130.9±7.14	56.7±5.93	76.5±3.92	24.3±4.3	28±2.87	180±12.45	235.4±9.79	
emergency/ICU specialist nurse	No	37	100.78±13.98[f]	130.51±6.86	50.86±9.07	76.14±4.18	23.7±4.89	28.22±3.43	175.35±20.68[g]	234.87±10.27	>0.05
	Yes	23	110.17±13.98[f]	132.35±7.2	52.65±8.19	75.65±5.1	24±4.43	27.78±3.01	186.83±17.69[g]	235.78±11.7	
nursing experience of fighting against SARS/COVID-9	No	43	101.62±14.73	130.4±6.81	49.36±7.75	75.27±4.56	23.67±4.49	27.73±3.20	174.64±19.4	233.4±9.99	<0.05
	Yes	17	112.67±10.08	133.67±7.16	58.13±8.34	78±3.84	24.27±5.36	29±3.36	195.07±14.4	240.67±11.44	
infectious diseases care work experience in infectious diseases dept.	No	37	99.49±13.07[h]	130.56±7.14	50.44±8.81	74.85±4.93[i]	24.46±4.05	28.51±2.94	174.39±18.81	233.92±11.33	>0.05
	Yes	23	108.19±15.36[h]	132.43±6.68	54.05±7.52	78±2.7[i]	22.62±5.58	27.19±3.71	184.86±23.57	237.62±9.38	

Department	medical ward	19	105.1±12.12	129.68±6.75	54.1±8.56	78.05±3.27	22.9±5.56	27.26±3.41	182.1±19.62	235±9.96	>0.05
	surgical ward	15	99.27±16.93	131.8±7.39	47.87±10.17	75.4±5.19	24.2±4.66	28.67±3.5	171.33±25.3	235.87±11.92	
	emergency department	5	97.29±15.85	133.29±8.38	52.29±2.14	74.57±5.03	23±4.65	26.71±3.14	172.57±17.79	234.57±12.69	
	ICU	9	116.11±8.64	130.78±6.63	48.89±11.59	73.33±5.17	24.11±4.31	27.67±3	189.11±13.63	231.78±11.43	
	pediatric ward	7	107.6±12.86	136.6±5.5	53.6±5.37	76.8±2.39	25.2±3.56	29.4±2.07	186.4±17.05	242.8±7.05	
	others	5	102.6±14.69	127.8±5.4	54.6±2.88	75.4±4.39	25.4±3.78	30.4±2.7	182.6±16.8	233.6±10.24	

SD: standard deviation, using t/F (t test or ANOVA).

Age: P^a=0.01, T=7.671; P^b=0.034, T=3.592

Years of service: P^c=0.03, T=3.743; P^d=0.043, T=3.324; T=4.551, P^e=0.015

Emergency/critical care specialist nurse: P^f=0.013, F=2.557; P^g=0.026, F=2.288

Infectious diseases care experience: P^h=0.034, F=2.202; P^i=0.002, F=3.201.

DISCUSSION

The results of this study showed that after three months of training, compared with the control group, the virtual simulation training combined with off-line operation training improved the disaster preparedness of reserve nurses and achieved a better outcome ($P < 0.05$, Table 2). We, therefore, think that the virtual simulation training combined with off-line operation training mode is more beneficial to improving the disaster preparedness of reserve nurses than the traditional training mode, it is a kind of emergency response to intensive respiratory infectious diseases emergency, and it is suitable for nursing professional training, thus it is worthy of further exploration and promotion.

The interviews after the training showed that more than 95% of the nurses in the experimental group were satisfied with the virtual simulation training mode. They considered this training method was novel. During the training, when facing lifelike scenes and COVID-19 cases, they could not only be quickly familiar with the special layout of zone and work environment for infectious diseases and master the SOP of emergency response, but also had a better understanding of the dynamic changes of the patient's condition and the whole process of treatment. It is convenient for trainees to be familiar with their professional roles, learn actively, dare to operate, so as to deepen and consolidate the theories and skills of emergency rescue. In the cases, various unexpected conditions in the nursing work, such as the changes of patient's condition, the psychological change of patients, and some settings of the difficulties, can improve nurses' psychological resilience and the ability of responding to the changes.[17] The simulation training program also has the mode of team/group training, which can quickly mobilize the initiative of the trainees and let them cooperate with the team members while completing their own tasks. This role training enables the trainees to have a global view and helps them to find their own positions in team, so as to improve the cooperation and coordination within a team. In the event of a disaster, the trainees can quickly mobilize their reserve capacity to participate in a highly cooperative rescue operation. In addition, as this training program has been incorporated into the virtual teaching platform of the hospital, the trainees can make appointment for repeating and reviewing what they have learnt at their spare time, which can make up the limitations of place, time, and learning time of the traditional centralized face-to-face training.

However, most of the trainees considered the virtual simulation was not so helpful in real operations, and they need more time for off-line training. In this study, the scores

of practical operation skills in the control group were significantly higher than those in the experimental group (P<0.01, Table 3), which indicated that the traditional mode was better than the virtual simulation training mode in respect of skill training. Therefore, virtual simulation training in the future should pay more attention to the balance of virtual and real training and increase the training time of the real practice.[27-28] Some researchers[29] have mixed standardized patient simulation teaching, 3D virtual environment team learning of Second life software, and the interdisciplinary cooperative learning of Neighborhood software, and picked up the advantages of each approach to cultivate trainees' comprehensive clinical ability, which is worthy of reference.

This study found that the post-disaster recovery scores of the nurses of the two groups before intervention were low. After intervention, the scores of both two groups were only slightly improved, and there was no statistical difference between the scores of the two groups (P>0.05, Table 2).

The possible reason was that the training of the two groups paid attention to the psychological nursing support to the patients in hospital, but neglected the psychological nursing support to the patients after being discharged from hospital and lacked the related knowledge of post-traumatic stress disorder (PTSD). The result also reflected the emergency reserve nurses in the region currently lacked knowledge of post-traumatic stress, suggesting that our training program should pay enough attention to post-traumatic recovery of our nurses in the future.

Analysis of influencing factors of disaster nursing ability: (1) The nurses with work experience in SARS/COVID-19 ward and infectious diseases ward had higher disaster preparedness, indicating that the nurses with disaster relief experience had higher disaster preparedness than those lacked disaster relief experience. (2) Scores of disaster preparedness of nurses with different years of service: the nurses with 6~14 years of service > 15 years of service > 1~5 years of service. The possible reasons were as follows: the nurses with 6~14 years of service were the backbone of the hospital and the focuses of training and assessment, as they had strong learning and practicing ability. Those with more than 15 years of service generally engaged in management or non-clinical work. Although they have rich work experience, they

received less assessment or lacked learning motivation, thus their emergency preparedness and ability of response had declined. The nurses with 1~5 years of service had high learning enthusiasm and could acquire new knowledge quickly, but they lacked work experience and professional ability, so their emergency response capacity also needed to be improved. This result was generally consistent with the investigations during COVID-19 epidemic period[4-6].

Limitations

There are some limitations in our study: (1) The sample size of the study is small, and the subjects all come from only one hospital, so the reference significance of the analysis results on factors affecting disaster preparedness is limited. (2) Due to the limitation of resources, the virtual scene of make shift hospital is not constructed in the virtual training program, which will be added in the future study. (3) The training related to post-disaster care and PTSD was not paid enough attention, which will be improved in the future.

CONCLUSION

On training the disaster preparedness of reserve nurses, the virtual simulation training combined with off-line training can achieve better outcomes than the conventional training. This novel training mode has more advantages in improving the theoretical knowledge, emergency rescue ability, disaster preparedness, and disaster response ability, which can be adopted as a new approach to the emergency training in medical institutions in response to public security emergencies.

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Conflict of Interest

The authors declare that there are no conflicts of interest.

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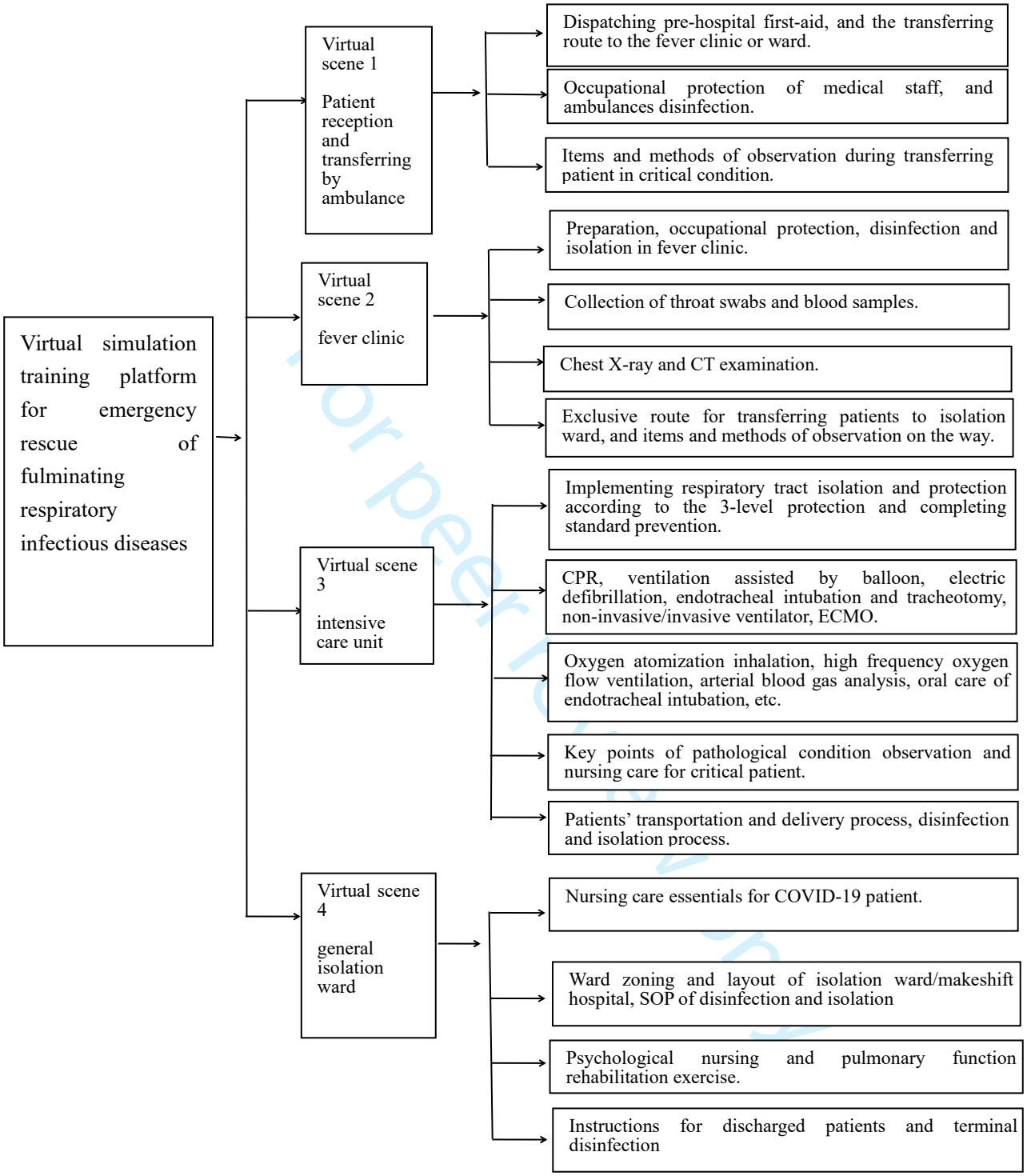

Fig.1 Design of virtual simulation training platform for emergency rescue of fulminating respiratory infectious diseases

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Effect of virtual reality simulation training on the response capability of public health emergency reserve nurses in China: a quasi-experimental study

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Title:

Effect of virtual reality simulation training on the response capability of public health emergency reserve nurses in China: a quasi-experimental study

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ABSTRACT

Objective: To develop a virtual reality simulation training program, and further verify the effect of the program on improving the response capacity of emergency reserve nurses confronting public health emergencies.

Design: A pre-test and post-test quasi-experimental study was conducted with a control group.

Methods: Overall, 120 nurses were recruited and randomly fell to the control group and the intervention group with the number table method. Participants underwent a 3-month training. To be specific, the control group received the conventional training of emergency response (e.g., theoretical lectures, technical skills and psychological training), while the intervention group underwent the virtual reality simulation training in combination with skill training. The training model incorporated COVID-19 cases into the virtual reality simulation training and then conducted the skills training. The psychological training was identical to that of the control group. At the end of the training, both groups conducted emergency drills twice. Before and after the intervention, the two groups were assessed for the knowledge and technical skills regarding responses to fulminating respiratory infectious diseases, as well as the capacity of emergency care. Furthermore, their pandemic preparedness was assessed with a disaster preparedness questionnaire.

Results: After the intervention, the scores of the relevant knowledge, the capacity of emergency care, and disaster preparedness in the intervention group significantly increased (p<0.01). The score of technical skills in the control increased more significantly than the intervention group's (p<0.01). No significant difference was identified in the score of post disaster management in two groups (p>0.05). **Conclusion:** Overall, the results suggest that the use of the virtual reality simulation training in combination with technical skills training is an effective way for reserve

nurses to improve the response capacity of emergency. Such a novel training mode on public health emergencies for nurses requires to be explored and popularized in depth.

Keywords: virtual simulation; public health emergency; reserve nurse; respiratory infectious disease; COVID-19

Strengths and limitations of this study:

- This study established a novel emergency nursing training protocol for improving the response capacity of emergency reserve nurses confronting infectious pandemics and epidemics.
- Virtual reality simulation training protocol enables nurses to quickly understand the environment and layout of the infectious department, and be familiar with the patient care process.
- An emergency reserve nursing team which can quickly respond to respiratory epidemic was built based on the virtual reality training which resulted in relatively robust and generalisable results.
- The participants were recruited from one hospital and in a relatively small sample size may limit the reference value of the study.
- In the method, virtual reality training includes some nursing skills practice, so the training time of technical skills of the intervention group is reduced, however, the results show that the training time of technical skills should be increased in the future.

INTRODUCTION

Respiratory infectious pandemics and epidemics are often highly contagious diseases, affecting large amounts of people. Coronavirus disease 2019 (COVID-19), caused by SARS-CoV-2, has resulted substantial deaths worldwide.[1] The emergency response to the virulent public health crisis has been facing great challenges. As the member of emergency medical team, nurses have played important roles in prevention and treatment of the COVID-19 pandemics. The Emergency reserve nurses play crucial roles in the public health response to pandemics and epidemics.[2]

According to the results, including those of a retrospective research conducted on the SARS-related disaster preparedness among nurse 5 years after the severe acute respiratory syndrome （SARS） pandemic,[3] and the investigations carried out in the United States and other places,[4-8] especially the surveys conducted amid the COVID-19 epidemic,[9-11] the disaster preparedness of clinical nurses was at medium-to-low level, which was largely attributed to the lack of systematic training received on emergency response. Therefore, it is a pressing need to explore how to enhance the training received by nursing staff on the response to pandemic, which is required to improve the overall capabilities of emergency reserve nurses to cope with public health emergency.

Researchers have proposed emergency drill, simulation teaching, desktop maneuvers and other solutions to support health care professionals in gaining more experience in the response to pandemic.[12-14]However, these studies are common in lacking long-term follow-up results. Besides, the organization of simulated emergency drills is costly and difficult for students to practice repeatedly. Due to the abrupt, highly transmissible, and detrimental nature of acute infectious diseases, it is

difficult to deliver clinical teaching in the ward. In order to cope with the sudden outbreak of infectious diseases, there have been many medical institutions putting in place regular drills for their medical staff according to the exact emergency plans. As the setting of drill is predetermined and all the patients are role-played, these drills are ineffective in reflecting the reality and providing practical experience. As a result, the trainees naturally lack the ability to deal with emergencies, [5 15] particularly, during the COVID-19 pandemic, there were many problems exposed, e.g., the inability to cope with emergency and enormous psychological pressure. [16 17]

Currently, virtual reality simulation training has been commonly adopted by schools and hospitals due to such advantages as realistic simulation, intelligence, interaction, independence, and openness.[18] It is thus conducive to cultivate critical thinking and clinical decision-making ability for students. At the time of training, the trainees can log into the system in different roles, which not only facilitates the training on different professional skills, teamwork and real-time interaction, but also supports the medical students of different majors in working as a team to provide treatment and nursing care for patients.[19-22] In China, the virtual reality simulation program intended for the training on infectious diseases nursing mainly includes the training on nursing thinking for common infectious diseases and the experimental program for layout design of infectious diseases zone. However, it is rare for these programs to cover the knowledge of new infectious disease. The virtual reality simulation programs on emergency treatment of avian influenza, plague, tuberculosis, and other respiratory infectious diseases are purposed mainly to train the students on how to investigate and verify the identified cases after the outbreak of pandemic, determine its nature and report it, and then conduct epidemic investigation, sampling, and disinfection and isolation of the scene to contain transmission, etc., which is usually designed for those students majoring in preventive medicine and public health.[23] However, these programs do not cover the clinical manifestations, treatment,

and care of patients. Moreover, there is no virtual reality simulation program in place for nursing professionals to make response to the emergencies involving severe respiratory infectious diseases, while covering the medical condition, treatment, and care of patients.

To improve the capabilities of nurses to respond to public health emergency, this study constructed 3D virtual reality scenes of isolation ward, incorporated COVID-19 cases in to the training by virtual simulation technology. In immersive learning environment, the trainees can learn the pre-set theories and practice the technical skills that are essential to treat and care COVID-19 patients.[24] After the training, the qualified trainees were selected to build up an emergency reserve nursing team to respond to epidemic at local city or other cities.

METHODS

Participants

The study was conducted at a general hospital in Hengyang, Hunan Province, China. From January to March 2020, the hospital treated 80% of the local COVID-19 confirmed patients; and by March 2, all those patients recovered and were discharged from the hospital. Since then, there has been no more newly confirmed COVID-19 case in the region. In May 2020 (two months after the stability of the local epidemic situation), 120 eligible nurses were enrolled in this study and divided into control group and intervention group via a computer-generated random numbers table. All nurses are managed by the Emergency Prep Nurse Training Team of the hospital. When the nurse passed the assessment after training, he/she would be directly selected into the emergency nurse bank of the local public health emergency.

Design

This was a pre-test and post-test quasi-experimental study with a control group.

Ethics

This study was approved by the Ethics Committee of Affiliated Nanhua Hospital，University of South China (2020-ky-49). All subjects were informed of voluntarily participating and could withdraw from the study at any time. The participant's personal information is confidential and can only be accessed by the authors.

Patient and Public Involvement statement

No patients were involved in this study. This study/article focused on a novel training

mode with virtual reality technology for nurses dealing with public health emergencies.

Training

From May to July in 2020, the nurses in the control and intervention groups were trained according to the following program.

(1) Control group received conventional training.

A 10-member emergency nursing instructor team was set up, including the experts in treatment, nursing care, nosocomial infection control, psychological support, and teaching who had the experience of working on the front-line to fight against COVID-19. The instructors were responsible for teaching theory, delivering training on technical skills, and organizing emergency drills. Lasting 3 months, the training consists of 12 sessions , with 4 class hours each session per week, 48 class hours in total, including 10 lectures on theoretical aspects for 18 hours in total (including a test), intensive training and test on 14 technical skills for 18 hours in total, a 4-hour-long meeting on the sharing of experience in carrying out treatment amid the COVID-19 pandemic, and an 8-hour-long, twice, emergency drill for trainees in batches to the plan made for emergency response to the outbreak of respiratory epidemic. The instructors were divided into two groups for supervision on exercise and the evaluation of each trainee for their individual performance in each batch of exercise using the emergency capability rating scale developed for nursing staff. As for the content of training, it includes the interim clinical guidance intended for the management of COVID-19 patients, infection control guidance, disinfection, quarantine, psychological training, as well as the preparation of personal protective equipment. Especially, much importance is attached to the training on how to practice self-protection and relieve the psychological stress felt by the patients. The 14 basic technical skills required for the training include putting on and off personal protective

equipment, disinfection and isolation, respiratory tract sampling, cardiopulmonary resuscitation (CPR), sputum aspiration, oxygen inhalation, aerosol inhalation, tracheal intubation, mechanical ventilation, etc. The training and assessment plan is detailed in Appendix.

(2) The intervention group received virtual reality simulation training in combination with technical skills training.

With the assistance of computer-based VR equipment, there are 4 scenarios constructed for this project:

Firstly, a team was put in place and the cases were prepared. An instructor team was set up to deliver virtual reality simulation training, with one teacher enrolled on the basis of the instructor team of the control group for virtual training and information technology support. The instructor team was tasked with the selection of three typical COVID-19 cases after the private details of the patients were removed, including one severe case of an adult patient, one critical case of an elderly patient with such complications as diabetes, and one critical case of an eight-year-old child patient. The whole treatment process carried out in those 3 cases was analyzed, based on which the commonly used skills, nursing measures, possible difficulties in nursing care were identified and factored into the cases of virtual reality simulation training.

Secondly, the scenario was set and the platform was constructed. There were four virtual scenes created, including pre-hospital management, fever clinics reception, intensive care unit, and isolation ward, which is aimed to familiarize the trainees with different working environments. In the meantime, the cases in the training system can be used to simulate the real clinical symptoms, clinical manifestations, disease progression, diagnosis and treatment, nursing care,

psychological changes, the standard procedures of disinfection and isolation, etc. The relevant tasks include application of the guidance for management of patients and infection control on COVID-19, with all the key elements covered by the virtual reality training simulation program. (Fig.1).

Thirdly, training was delivered. The training lasted 4 h per week for 3 months.

Compared with the training plan made for the control group, the lectures focusing on the theoretical aspects of the conventional training has been adjusted to 18 h scenario training in the virtual reality system. Besides, the trainees were also required to attend technical skills training for 12 hours in total. Each session is comprised of virtual reality practice for 2 hours, the practice of technical skills on multifunctional simulation/models for 1.5 hours, the recapping and exchanging of views on the handling of unexpected situations or emergencies, the sharing of nursing experience, and the discussion on the relevant questions and procedures to the scenarios for 1/2 hour. At the end of the training, 4 hours of psychological training and an 8-hour-long emergency exercise took place, which was no different to the control group. In their spare time, the trainees were allowed to make appointment on the hospital virtual training platform for repeating and reviewing the practices. Each trainee can make two appointments with 2 instructors under on-spot supervision and have 2 hours allowed for each practice.

Evaluation

Main outcome indicator： The capacity of emergency care scoring: the instructors as the judge were responsible for evaluating the nurses of the two groups for their capacity of emergency care before and after the intervention. The design of emergency capability rating scale intended for nursing staff was based on the study of

Wang.[25] It focuses on five dimensions with 100 points in total, including the ability of occupational protection, disinfection, and quarantine (20), the observation and judgment of disease (20), the preliminary examination, classification, and treatment of the patients in severe or critical condition (20), cooperation and coordination (20), as well as the assessment and management of crisis (20). The higher score the nurse achieved, the greater the capability of the nursing staff to deal with emergence. Before adopting the assessment, we predetermined the reliability of the scale. The Cronbach's α was 0.79, indicating the reliability of the scale is acceptable. Extracting the average scores of twice drill.

Secondary outcome measures：

①Assessment of theory and skills: The nurses in the two groups were assessed for their relevant theoretical knowledge and skills before and after the intervention. The theoretical examination was conducted through MCQ test.[26] The skill assessment was completed on site during the practice class. Each trainee was allowed to make two attempts during the skill assessment, with the higher one achieved in the two attempts taken as the assessment result.

②The Chinese version of Disaster Preparedness Evaluation Tool (DPET): this scale was applied to assess the nursing staff for their preparedness for possible pandemic. Proposed by LI,[27] the scale was translated and adjusted culturally from Tichy's scale.[28] The Cronbach's α coefficient was set to 0.865, involving 45 items of three dimensions: the knowledge about disaster (13 items), the skills regarding disaster (11 items) and post disaster management (21 items). The scale covers risk reduction, disease prevention and health promotion, policy making and development, ethics,

legal practices and liabilities, communication and information sharing, the education about and preparedness for disaster, community care, individual and home care, psychological care, the care for vulnerable groups, the long-term rehabilitation of individual, family, and community, etc, so as to fully reflect the state of disaster preparedness among the nursing staff. The items were scored 1 ~ 6 points from "strongly disagree" to "strongly agree." The higher the score was, the more prepared the nursing staff were.

Statistical Analysis

All data were input into SPSS 18.0 and were statistical analyzed. The *p-value* less than 0.05 was considered statistically significant.

RESULTS

(1) Demographic Data

Table 1 presents the demographic data comparison between the two groups of participants. The majority of the 120 subjects in this study were women (control group: 91.7%, intervention group: 88.3%).

The differences in gender, age, highest degree, and work experience between the two groups were not statistically significant ($p > 0.05$) and were comparable.

Table 1 Demographic Data(N =120)

Variable	Control group (n=60) n (%)	Intervention group (n=60) n (%)	t/χ2	*P-value*
Gender				
Male	5 (8.3)	7 (11.7)	0.093	0.761
Female	55 (91.7)	53 (88.3)		
Age				
≤30 years old	29 (48.3)	28 (46.7)		
31-39 years old	24 (40.0)	24 (40.0)	0.255	0.754
≥40 years old	7 (11.7)	8 (13.3)		
Clinical experience				
≤5 years	26 (43.3)	23 (38.3)		
6-14 years	21 (35.0)	25 (41.7)	0.111	0.912
≥15 years	13 (21.7)	12 (20.0)		

Highest degree				
Diploma/associate degree	11 (18.3)	10 (16.7)		
Bachelor's degree	40 (66.7)	41 (68.3)	0.060	0.970
Master's degree	9 (15.0)	9 (15.0)		
Professional title				
Primary	29 (48.3)	29 (48.3)		
Intermediate	21 (35.0)	21 (35.0)	0.165	0.921
Senior	10 (16.7)	10 (16.7)		
Work experience in Emergency/Intensive care unit				
Yes	22 (36.7)	23 (38.3)	0.036	0.850
No	38 (63.3)	37 (61.7)		
Work experience in infectious departments				
Yes	21 (35.0)	23 (38.3)	0.144	0.705
No	39 (65.0)	37 (61.7)		
Experience of caring for patients with COVID-19/SARS				
Yes	15 (25.0)	17 (28.3)	0.170	0.680
No	45 (75.0)	43 (71.7)		
Hospital department of work				
Medical ward	19 (31.7)	19 (31.7)		
Surgical ward	14 (23.3)	15 (25.0)		
Emergency department	8 (13.3)	7 (11.7)		
Intensive care unit	8 (13.3)	9 (15.0)		
Pediatrics department	5 (8.3)	5 (8.3)	0.270	0.998
Others	6 (10.0)	5 (8.3)		

(2) Comparison of the DPET scores between groups before and after intervention

Prior to intervention, there was no significant difference found in the score of disaster preparedness between the two groups ($p > 0.05$, Table 2). After intervention, however, the total score of disaster preparedness among the intervention group was significantly higher than among the control group ($p < 0.001$, Table 2). The scores of knowledge regarding disaster and skills regarding disaster in the intervention group were significantly higher than in the control group ($p<0.001$, Table 2), while the scores of post disaster management showed no statistical significance between the groups ($p > 0.05$, Table 2).

Table 2 Comparison of the DPET scores between groups before and after intervention (N=120)

	Control group (n=60) (M±SD)	Intervention group (n=60) (M±SD)	t	*P-value*
Knowledge regarding disaster				
Pre-intervention	101.73±17.94	104.38±14.47	0.891	0.375
Post-intervention	122.00±12.79	131.22±6.99	4.900	**<0.001**
Skills regarding disaster				
Pre-intervention	52.20±10.52	51.55±8.72	0.369	0.713
Post-intervention	69.42±7.89	75.95±4.52	5.566	**<0.001**

Post disaster management				
Pre-intervention	24.08±5.68	23.82±4.68	0.281	0.779
Post-intervention	27.47±4.77	28.05±3.26	0.782	0.436
Total score				
Pre-intervention	178.02±30.60	179.75±20.23	0.366	0.715
Post-intervention	218.88±21.34	235.22±10.75	5.295	**<0.001**

Bold type p values represent significant values.

SD: standard deviation, using t (t test).

(3) Comparison of the scores of theoretical and skill assessments and the capacity of emergency care before and after intervention

There was no significant difference observed in the scores of theoretical and skill assessments or the capacity of emergency care between the two groups before intervention (p> 0.05, Table 3). After intervention, however, both the score of theoretical assessment and that for the capacity of emergency care were improved for the two groups. The scores of theoretical assessment and that for the capacity of emergency care were significantly higher among the intervention group than among the control group (p<0.001, Table 3), while the score of technical skills was slightly higher for the control group than for the intervention group (p<0.01, Table 3).

Table 3 Comparison of the scores of theoretical and skill assessments and the capacity of emergency care between groups before and after intervention (N=120)

	Control group	Intervention group	t	*P-value*

	(n=60) (M±SD)	(n=60) (M±SD)		
Theoretical assessment				
Pre-intervention	65.12±7.04	65.62±7.16	0.386	0.700
Post-intervention	82.92±4.55	86.62±3.91	4.783	**<0.001**
Technical skills				
Pre-intervention	71.13±4.57	71.77±5.66	0.035	0.972
Post-intervention	90.35±3.38	88.47±4.19	2.708	**0.008**
Capacity of emergency care				
Pre-intervention	63.10±7.23	63.93±6.65	0.657	0.516
Post-intervention	81.97±4.45	85.35±3.93	4.416	**< 0.001**

Bold type p values represent significant values.

DISCUSSION

In this quasi-experimental study, we evaluated the effectiveness of a novel virtual simulation training in reserve nurses for pandemic respiratory infectious disease. One hundred and twenty reserve nurses participated in the training program and completed both the pre- and post-test measures comprised the sample for this study. All the participants were Chinese clinical nurses who volunteered to be the emergency reserve nurses for public health emergencies. The results of this study showed that the virtual simulation technology in combination with technical skill training significantly improved the respiratory infectious emergency preparedness of reserve nurses. The theoretical assessment and emergency rescue capability scores of the intervention group significantly increased compared to the nurses in the traditional training group after intervention ($p<0.001$). These findings indicate a critical need for virtual simulation training for reserve nurse training before they go to the respiratory infectious disease front line.

Different from the conventional form of training, this novel virtual reality simulation training provides simulated isolation ward. The training is flexible and capable to create real-world settings. Thus, it is convenient for the trainees to get familiar fast with the special layout of zone, the working environment and the standard procedure. These are extremely important for the emerging infectious diseases. Compared with other virtual simulation programs, [29-31] we selected typical cases of COVID-19 in our program. Since the COVID-19 has not subsided yet worldwide. It is a hard and longtime work to deal with the epidemic. Thus, it is crucial important to train the theory, technical skills, and knowledge of emergency drills about COVID-19 for emergency reserve nurses, so as to help them quickly master the essentials, adapt to the work context, improve the emergency rescue ability .The program simulated the clinical manifestations, disease progression,

psychosocial problems of COVID-19 patients, as well as diagnosis and treatment, nursing care, standard procedures of disinfection and isolation. In the immersive learning environment, the trainees can learn the theories and practice the technical skills, which are essential to treat and care COVID-19 patients. What's more, this program can prevent the reserve nurses from directly contacting COVID-19 patients, thus reducing the risk of infection and ensuring the safety of the trainees. In addition, the reserve nurses can define their job responsibilities, engage with learning proactively and develop the confidence of practice through this novel training. They can also improve their capabilities of emergency response during the training, as various unexpected scenarios in the nursing work were pre-set in the training cases, such as patient with sudden suffocation or severe hypoxia, and restless, refusing to cooperate with treatment, and so on. This simulation training program also has the mode of team/group training, which mobilizes the nurses rapidly to collaborate with other team members in completing their own tasks. Since this training program has been included as part of the virtual teaching platform operated by the hospital, the trainees can make appointment for repeating and reviewing what they have learned during their spare time, which breaks the time and spatial limits of conventional in-person training delivered.

Similarly, Many studies reported the effectiveness of virtual reality simulation training （VRS） in medical/nursing training.[20 30-34] Luca Ragazzoni, et al.[35] used VRS to train medical staff on the operational public health skills related to the infection control and Ebola treatment management. They proposed a model of the VRS in combination with hybrid skills training exercises. Finally they found that the hybrid approach can effectively raise the educational target level from a level of understanding to a level of training. Therefore, in our study, reserve nurses in the intervention group received virtual reality simulation training in combination with technical skills training. Sparkes L, et al.[31] trialed an online simulation program for

the management of deteriorating patients and found it can significantly improve knowledge, skills, self-rating of performance, confidence, and competence of nursing students. In Iran, Tahereh Najafifi Ghezeljeh, et al.[29] used the virtual social network education to improve the knowledge and attitude related to emergency preparedness of emergency nurses. These were partly similar to our research, but these studies have not been applied to the training of epidemic response. However, some studies have different results. Abeer William, et al.[36] indicated that in phlebotomy training, there was no significant difference between the VRS and the traditional method (simulated limbs). In another study,[37] researchers found that VRS increased nursing students' knowledge but did not significantly contribute to improved skill performance.

After the intervention, the score of technical skill for the control group (90.35±3.38) was slightly higher than for the intervention group (88.47±4.19) ($p<0.01$). As for the differences between the two groups, one reason may be that the technical skills training time of the intervention group getting reduced by 1/3 as compared to the control group. Alternately, it may also be related to the fact that the trainees got more accustomed to the traditional way of skill practice. Therefore, our plan for the future training is to extend skills training time for the virtual simulation group by 1/3, to the same level as the control group. It is essential that more attention is brought to ensuring balance between virtual training and conventional training.[38-40] In addition, it was found out that the scores of post disaster management were low for the nurses in the two groups before intervention. After intervention, however, the scores were only slightly improved for both groups, with no statistical difference observed between these two groups ($p>0.05$). This finding demonstrated that the emergency reserve nurses in the region currently lacked the knowledge of post-traumatic stress, suggesting the need for our training program to prioritize post-traumatic recovery of our nurses in the future.

Limitations

There are some limitations faced by our study. Firstly, the sample size of the study was small, as all of the participants came from the same hospital, thus restricting the reference value of the study. Secondly, due to the limit of resources, the virtual scene of mobile cabin hospital was not constructed under the virtual training program, which will be carried out in the future study. Thirdly, the time of skill training needs to be extended, as there was a lack of attention paid to the training related to post-disaster care and post-traumatic recovery, which should be improved in the future.

CONCLUSION

As for the training on the pandemic response of reserve nurses, the virtual reality simulation training in combination with technical skills training is effective in achieving better outcomes than the conventional training. This novel model of training shows more advantages in improving the theoretical knowledge, the capacity of emergency care, the preparedness for pandemic, and the response capacity of pandemic, which makes it applicable as a new approach to the emergency training in medical institutions for better response to public emergencies. In the future, we can optimize our training model by integrating simulator-based training with that in the 3D virtual environment, so as to give full play to their respective advantage, thus improving the overall clinical capabilities of nurses. Besides, we can explore the virtual reality team training for interdisciplinary cooperation. We also hope to provide the training for other universities and hospitals based on the virtual experiment project platform in China, and even for the institutes outside of China.

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Contributors DZ and YZ designed the study. HL, PH, DW and WY helped develop the study measures and data collection. WrY and YC contributed to study delivery, interpretation of the data. DZ, YJ and YZ wrote the manuscript and all authors read the final manuscript and approved its submission.

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Data availability statement All data relevant to the study are included in the article or uploaded as supplementary information.

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Fig.1 Design of virtual simulation training platform for emergency response of respiratory infectious diseases

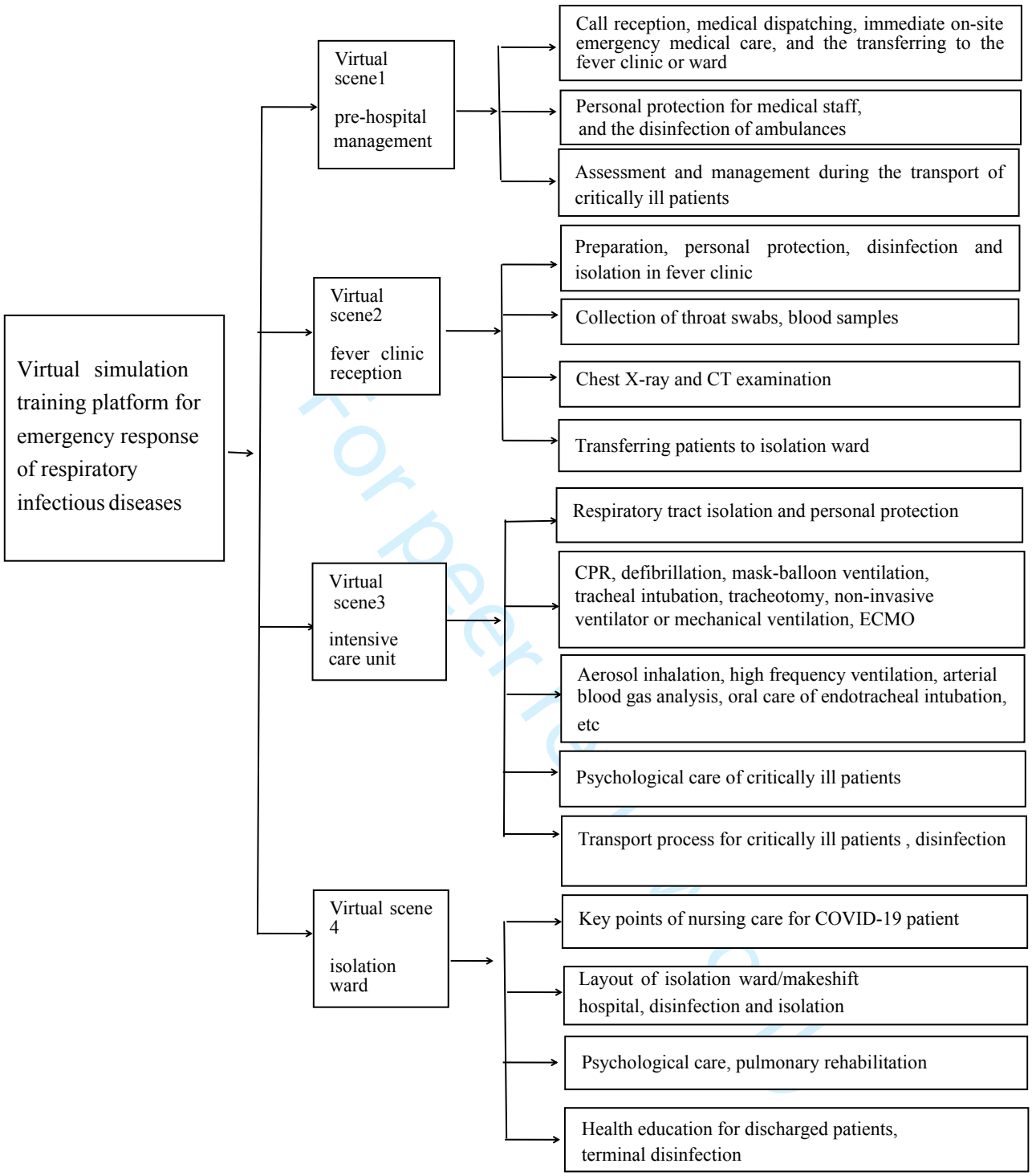

Fig.1 Design of virtual simulation training platform for emergency response of respiratory infectious diseases

Appendix:

The traditional training and assessment plan of the control group

Month	Content and class hours	
First Month	**Session 1**	**Lecture (2 h):** clinical guidance intended for the management of COVID-19 patients, infection control guidance, and the key points of nursing care **Practical skill (2 h):** demonstration and practice in teams on respiratory tract sampling, putting on and off personal protective equipment
	Session 2	**Lecture (2 h):** disinfection, quarantine, and nosocomial infection control **Practical skill (2 h):** review and assess the practical skills learned in the last session
	Session 3	**Lecture (2 h):** Guidelines for the treatment and care of the COVID-19 patients in critically condition (I) **Practical skill (2 h):** demonstration and practice in teams on CPR, sputum aspiration, oxygen inhalation, simple respirator operation
	Session 4	**Lecture (2 h):** Guidelines for the treatment and care of the COVID-19 patients in critically condition (I) **Practical skill (2 h):** demonstration and practice in teams on arterial puncture and venipuncture, trachea cannula, defibrillator operation
Second Month	**Session 1**	**Lecture (2 h):** psychological nursing of patients **Practical skill (2 h):** review and assess the practical skills of CPR, sputum aspiration, oxygen inhalation, simple respirator operation
	Session 2	**Lecture (2 h):** trainees' psychological support, relax training, relieving stress, and releasing negative emotions **Practical skill (2 h):** review and assess the practical skills of arterial puncture and venipuncture, trachea cannula, defibrillator operation
	Session 3	**Lecture (2 h):** preparation of common epidemic prevention materials, basic life support and advanced life support (I) **Practical skill (2 h):** practicing material preparation, high-frequency ventilation support, aerosol inhalation
	Session 4	**4 h：** a meeting on experience sharing with the professionals working on the front-line of treating COVID-19
Third Month	**Session 1**	**Lecture (2h):** basic life support and advanced life support (II) **Practical skill (2h):** review and assess the practical skills of high-frequency ventilation support, aerosol inhalation
	Session 2	**Lecture (2h):** test on theories

		Practical skill (2h): demonstration and assessment of ventilators(the ICU nurse needs to attend the assessment, while others only need to learn but no test requirements)
	Session 3	Emergency Drill, the emergency procedures for responding to respiratory epidemic, practice and exercise in two groups after explaining the procedures and plan (3 h) Recapping and exchanging of views after exercise (0.5 h) Fill the scale of disaster preparedness, explain the grading criteria of the emergency response capability assessment (0.5 h)
	Session 4	Twice emergency response exercise for two groups (4 h): the contents of the twice exercises are the same, with 30 trainees in each. Each trainee is designated one role. In the second exercise, the trainee should play a different role. The instructors should be divided into two groups to supervise the exercise and evaluate each trainee's performance with the emergency nursing capacity evaluation sheet.

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Title:

Effect of virtual reality simulation training on the response capability of public health emergency reserve nurses in China: a quasi-experimental study

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Conflict of Interest

The authors declare that there are no conflicts of interest.

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ABSTRACT

Objective To develop a virtual reality simulation training program, and further verify the effect of the program on improving the response capacity of emergency reserve nurses confronting public health emergencies.

Design A prospective quasi-experimental design with a control group.

Participants A total of 120 nurses were recruited and randomly divided into the control group and the intervention group.

Intervention Participants underwent a 3-month training. The control group received the conventional training of emergency response (e.g., theoretical lectures, technical skills and psychological training), while the intervention group underwent the virtual reality simulation training in combination with skills training. The COVID-19 cases were incorporated into the intervention group training. And the psychological training was identical to both groups. At the end of the training, each group conducted emergency drills twice. Before and after the intervention, the two groups were assessed for the knowledge and technical skills regarding responses to fulminate respiratory infectious diseases, as well as the capacity of emergency care. Furthermore, their pandemic preparedness was assessed with a disaster preparedness questionnaire.

Results After the intervention, the scores of the relevant knowledge, the capacity of emergency care, and disaster preparedness in the intervention group significantly increased ($p<0.01$). The score of technical skills in the control group increased more significantly than that of the intervention group ($p<0.01$). No significant difference was identified in the scores of post disaster management in two groups ($p>0.05$).

Conclusion The virtual reality simulation training in combination with technical skills training can improve the response capacity of emergency reserve nurses as compared with the conventional training. The findings of the study provide some evidence for the emergency training of reserve nurses in better response to public

health emergencies and suggest this methodology is worthy of further research and popularization.

Keywords: virtual simulation; public health emergency; reserve nurse; respiratory infectious disease; COVID-19

Strengths and limitations of this study:

- This study established a novel emergency nursing training protocol for improving the response capacity of emergency reserve nurses confronting an infectious disease epidemic or even pandemic.
- Virtual reality simulation training protocol enables nurses to quickly understand the environment and layout of the infectious department, and be familiar with the patient care process.
- An emergency reserve nursing team aiming to quickly respond to respiratory epidemic was built based on the virtual reality training, which gained relatively robust and generalisable results.
- The participants recruited from one hospital and a relatively small sample size may limit the reference value of the study.
- In the methods, virtual reality training included some nursing skills practice, so the training time of technical skills in the intervention group was reduced, however, the results showed that the training time of technical skills should be increased in the future.

INTRODUCTION

As the virulent public health crisis, the Coronavirus disease 2019 (COVID-19) has resulted substantial deaths worldwide.[1] Nurses have played extremely important roles in the prevention and treatment of the COVID-19 pandemics. [2] During the COVID-19 pandemic, nurses are urgently called from different areas to provide help. In order to effectively respond to the respiratory infectious disease pandemic, nurses need to quickly learn the comprehensive professional knowledge and skills. [3] The professional training must be carried out as soon as possible so that they can quickly master the correct donning and doffing personal protection equipment (PPE),[4 5] the management of critically ill patients, [6 7]and the prevention and control of nosocomial infection, etc.[6 8 9]

Ideally, in order to improve preparations for pandemics, planning should be made in advance and a large number of medical staffs should be sufficiently trained.[3 9]Due to the abrupt, highly transmissible, and detrimental nature of acute infectious diseases, it is difficult to deliver clinical training in the real ward. Thus, training programs, e.g. emergency drills, simulation-based training, tabletop exercises, role playing, and online learning, are expected to develop and support healthcare workers to gain more experience in responding to pandemics.[10-14]However, the previous training programmes were commonly ineffective in reflecting the reality and providing practical experience for the recent outbreak of Covid-19. As a result, the nurses naturally lacked the ability to deal with emergencies,[15-22] and felt enormous psychological pressure in responding to the COVID-19 pandemic. [19 20 23 24]

Simulation-based training in response to epidemics has lots of advantages, e.g. providing a safe environment to train medical staff to quickly master specific technical skills, working closely with the team and optimizing work processes and systems,[5 20] while protecting patients from further harm.[25 26] In China, the virtual reality simulation programs for the respiratory infectious diseases were mainly used to

train the students majoring in preventive medicine and public health[27] on conducting epidemic investigation, sampling, and disinfection and isolation, etc. Very few virtual reality simulation programs, covering the medical condition, treatment, and care of patients, are developed to train nurses in response to a respiratory infectious disease epidemic. Thus, this study aims to develop a virtual reality simulation training program incorporated with the COVID-19 cases, and further verify the effect of the program on improving the response capacity of emergency reserve nurses confronting public health emergencies. The highly qualified trainees are expected to build up an emergency reserve nursing team to respond to epidemic at local city or other cities after training.

METHODS

Participants

The study was conducted at a general hospital in Hengyang, Hunan Province, China. From January to March 2020, the hospital treated 80% of the local COVID-19 confirmed patients; and by March 2, all those patients recovered and were discharged from the hospital. Since then, there has been no more newly confirmed COVID-19 case in the region. In May 2020 (two months after the stability of the local epidemic situation), 120 eligible nurses were enrolled in this study and randomly divided into control group and intervention group according to a computer-generated random numbers table. When the nurse passed the assessment after training, he/she would be selected into the emergency nurse bank of the local public health emergency.

Design

This is a prospective quasi-experimental design with a control group.

Ethics

This study was approved by the Ethics Committee of Affiliated Nanhua Hospital，University of South China (2020-ky-49). After signing informed consent, all participants voluntarily participated in the study and were informed they could withdraw from the study at any time without consequences. Their personal information could only be accessed by the authors.

Patient and Public Involvement statement

No patients were involved in this study. This study/article focused on a novel training mode with virtual reality technology for nurses dealing with public health emergencies.

Training

From May to July in 2020, the nurses in the control and intervention groups were trained according to the following program.

(1) The control group received conventional training.

A 10-member emergency nursing instructor team was set up, consisting of the experts in medical treatment, nursing care, nosocomial infection control, psychological support, and teaching. Some of them had the experience of working on the front-line to fight against COVID-19. The instructors were responsible for teaching theories, delivering training on technical skills, and organizing emergency drills. The 3-month training had 12 sessions with 48 class hours in total (Figure.1), including theoretical lectures, individual technical skills training, psychological training, an experience sharing meeting on the medical work in the COVID-19 pandemic, and emergency drill for trainees in the background of a respiratory epidemic outbreak. The instructors were divided into two groups for supervising exercise and evaluating the individual performance of each trainee in emergency drill with the emergency care capability rating scale.[28] As for the content of training, it included the interim clinical guidance for the management of COVID-19 patients, infection control guidance, disinfection, quarantine, psychological training, as well as the preparation of PPE. Especially, much importance was attached to the training on how to practice self-protection and relieve the nurses' psychological stress. The 14 basic technical skills in the training included donning and doffing PPE, disinfection and isolation, respiratory tract sampling, cardiopulmonary resuscitation (CPR), sputum aspiration, oxygen inhalation, aerosol inhalation, tracheal intubation, mechanical ventilation, etc. The training and assessment plan is detailed in Appendix.

(2) The intervention group received virtual reality simulation training in combination with technical skills training.

With the assistance of computer-based virtual reality equipment, there were 4 steps to fulfill this project:

Firstly, an instructor team was set up and the training cases were prepared. Different from the instructor team in the control group, the instructor team in the intervention group had one specific teacher for virtual training and information technology support. The instructor team was tasked with selecting three typical COVID-19 cases in which the private details of the patients were removed. The three cases included one severe case of an adult patient, one critical case of an elderly patient with complications such as diabetes, and one critical case of an eight-year-old child patient. The whole processes of treatment in those 3 cases, such as the commonly used skills, nursing measures, and possible difficulties in nursing care, were analyzed, identified, and factored into the cases of virtual reality simulation training.

Secondly, the virtual scene was set and the platform was constructed. Four virtual scenes, including pre-hospital management, fever clinics reception, intensive care unit, and isolation ward, were set with the aim of familiarizing the trainees with different layout of zone and working environments. Meanwhile, the cases could simulate the real clinical symptoms, clinical manifestations, disease progression, diagnosis and treatment, nursing care, psychological changes, the standard operating procedures of disinfection and isolation, etc. The relevant tasks included all the key elements of the guidance for management of patients and infection control on COVID-19 (Figure.2).

Thirdly, training was delivered. The training lasted 4 hours per week for 3 months (Figure.1). Compared with the trainees in the control group, the trainees in the intervention group received both the individual and team training based on virtual reality technology. Besides, the trainees were also required to attend individual technical skills training. Each session was comprised of virtual reality simulation training for 2 hours, the practice of technical skills on multifunctional simulation/models for 1.5 hours, a recapping and exchanging of views on the

handling of unexpected situations or emergencies, a meeting for sharing nursing experience, and a group discussion on the relevant questions and procedures to the cases for 1/2 hour. The psychological training and the emergency drill at the end of the training were as same as those in the control group. The trainees were allowed to make appointments on the hospital virtual training platform for repeating and reviewing the practices in their spare time. Each trainee can make two appointments of training under a 2-instructors on-spot supervision and have 2 hours allowed for each practice. The training and assessment plan is detailed in Appendix

Evaluation

Main outcome: The emergency care capability rating scale: the instructors as the judge were responsible for evaluating the nurses of the two groups for their capacities of emergency care before and after the intervention. The design of emergency care capability rating scale for nursing staff was based on the study of Wang[28], which focused on five dimensions with 100 points in total, including the ability of occupational protection, disinfection, and quarantine (20), the observation and judgment of disease (20), the preliminary examination, classification, and treatment of the patients in severe or critical condition (20), cooperation and coordination (20), as well as the assessment and management of crisis (20). The higher score the nurse achieved, the greater the capability of the nursing staff to deal with emergences. At the end of the training, all the trainees should undergo twice drills. The capacity score of emergency care was the average of the results of the twice drills.

Before the assessment, we conducted a pilot study to assess the reliability of the scale. The Cronbach's α was 0.79, indicating the reliability of the scale was acceptable.

Secondary outcome：

①Assessment of theories and skills: The trainees in the two groups were assessed for their relevant theoretical knowledge and skills before and after the intervention. The theoretical examination was conducted through MCQ test.[29] The skill assessment was

completed on site during the practice. Each trainee was allowed to make two attempts during the skill assessment, with the higher one achieved in the two attempts taken as the assessment result.

②The Chinese version of Disaster Preparedness Evaluation Tool (DPET): this scale was used to assess the nursing staff for their preparedness for possible pandemic. Proposed by LI,[30] the scale was translated and adjusted culturally from Tichy's scale.[31] The Cronbach's α coefficient was set to 0.865, involving 45 items of three dimensions: the knowledge about disaster (13 items), the skills regarding disaster (11 items) and post disaster management (21 items). The scale covered risk reduction, disease prevention and health promotion, policy making and development, ethics, legal practices and liabilities, communication and information sharing, the education about and preparedness for disaster, community care, individual and home care, psychological care, the care for vulnerable groups, the long-term rehabilitation of individual, family, and community, etc., which could fully reflected the state of disaster preparedness among the nursing staff. The items were scored 1 ~ 6 points from "strongly disagree" to "strongly agree." The higher the score was, the more prepared the nursing staff were.

Statistical Analysis

All data were input into SPSS 18.0 and were statistical analyzed. Descriptive analysis was used to describe the demographic data. The continuous data were summarized using mean and standard deviation (SD), and categorical data were summarized using percentage. The chi-square test and Student's *t*-test were used to analyze the comparability of the baseline between the two groups. The differences before and after intervention in the results of DPET, theoretical and skill assessments, and the capacity of emergency care scores between the groups were evaluated by the Student's *t*-test. The *p-value* less than 0.05 was considered statistically significant.

RESULTS

(1) Demographic Data

Table 1 presents the demographic data comparison between the two groups of participants. The majority of the 120 subjects in this study were women (control group: 91.7%, intervention group: 88.3%).

The differences in gender, age, highest degree, and work experience between the two groups were not statistically significant (p>0.05) and were comparable.

Table 1 Demographic Data(N =120)

Variable	Control group (n=60) n (%)	Intervention group (n=60) n (%)	t/χ2	*P-value*
Gender				
Male	5 (8.3)	7 (11.7)	0.093	0.761
Female	55 (91.7)	53 (88.3)		
Age				
≤30 years old	29 (48.3)	28 (46.7)		
31-39 years old	24 (40.0)	24 (40.0)	0.255	0.754
≥40 years old	7 (11.7)	8 (13.3)		
Clinical experience				
≤5 years	26 (43.3)	23 (38.3)		
6-14 years	21 (35.0)	25 (41.7)	0.111	0.912
≥15 years	13 (21.7)	12 (20.0)		
Highest degree				
Diploma/associate degree	11 (18.3)	10 (16.7)		
Bachelor's degree	40 (66.7)	41 (68.3)	0.060	0.970
Master's degree	9 (15.0)	9 (15.0)		
Professional title				
Primary	29 (48.3)	29 (48.3)		
Intermediate	21 (35.0)	21 (35.0)	0.165	0.921
Senior	10 (16.7)	10 (16.7)		

Work experience in Emergency/Intensive care unit				
Yes	22 (36.7)	23 (38.3)	0.036	0.850
No	38 (63.3)	37 (61.7)		
Work experience in infectious departments				
Yes	21 (35.0)	23 (38.3)	0.144	0.705
No	39 (65.0)	37 (61.7)		
Experience of caring for patients with COVID-19/SARS				
Yes	15 (25.0)	17 (28.3)	0.170	0.680
No	45 (75.0)	43 (71.7)		
Hospital department of work				
Medical ward	19 (31.7)	19 (31.7)		
Surgical ward	14 (23.3)	15 (25.0)		
Emergency department	8 (13.3)	7 (11.7)		
Intensive care unit	8 (13.3)	9 (15.0)		
Pediatrics department	5 (8.3)	5 (8.3)	0.270	0.998
Others	6 (10.0)	5 (8.3)		

(2) Comparison of the DPET scores between two groups before and after intervention

Prior to intervention, there was no significant difference found in the scores of disaster preparedness between the two groups (p>0.05, Table 2). After intervention, however, the total score of disaster preparedness of the intervention group was significantly higher than that of the control group (p<0.001, Table 2). The scores of knowledge and skills regarding disaster in the intervention group were significantly higher than those in the control group (p<0.001, Table 2), while the scores of post disaster management showed no statistical significance between two groups (p>0.05, Table 2).

Table 2 Comparison of the DPET scores between groups before and after intervention (N=120)

	Control group (n=60) (M±SD)	Intervention group (n=60) (M±SD)	t	*P-value*
Knowledge regarding disaster				
Pre-intervention	101.73±17.94	104.38±14.47	0.891	0.375
Post-intervention	122.00±12.79	131.22±6.99	4.900	**<0.001**
Skills regarding disaster				
Pre-intervention	52.20±10.52	51.55±8.72	0.369	0.713
Post-intervention	69.42±7.89	75.95±4.52	5.566	**<0.001**
Post disaster management				
Pre-intervention	24.08±5.68	23.82±4.68	0.281	0.779
Post-intervention	27.47±4.77	28.05±3.26	0.782	0.436
Total score				
Pre-intervention	178.02±30.60	179.75±20.23	0.366	0.715
Post-intervention	218.88±21.34	235.22±10.75	5.295	**<0.001**

Bold type p values represent significant values.

SD: standard deviation, using t (t test).

(3) Comparison of the scores of theoretical and skill assessments and the capacity of emergency care before and after intervention

There was no significant difference observed in the scores of theoretical and skill assessments or the capacity of emergency care between the two groups before intervention (p>0.05, Table 3). After intervention, however, both the score of theoretical assessment and the capacity of emergency care were improved in the two groups. The score of theoretical assessment and the capacity of emergency care in the intervention group were significantly higher than those in the control group (p<0.001, Table 3), while the score of technical skills in the control group was slightly higher than that in the intervention group (p<0.01, Table 3).

Table 3 Comparison of the scores of theoretical and skill assessments and the capacity of emergency care between groups before and after intervention (N=120)

	Control group (n=60) (M±SD)	Intervention group (n=60) (M±SD)	t	*P-value*
Theoretical assessment				
Pre-intervention	65.12±7.04	65.62±7.16	0.386	0.700
Post-intervention	82.92±4.55	86.62±3.91	4.783	**<0.001**
Technical skills				
Pre-intervention	71.13±4.57	71.77±5.66	0.035	0.972
Post-intervention	90.35±3.38	88.47±4.19	2.708	**0.008**
Capacity of emergency care				
Pre-intervention	63.10±7.23	63.93±6.65	0.657	0.516
Post-intervention	81.97±4.45	85.35±3.93	4.416	**< 0.001**

Bold type p values represent significant values.

DISCUSSION

In this quasi-experimental study, we developed a virtual reality simulation training program that included typical COVID-19 cases and evaluated the effectiveness of a novel virtual simulation training in the reserve nurses for an infectious respiratory disease pandemic. One hundred and twenty reserve nurses, as the sample for this study, participated in the training program and completed both the pre- and post-test evaluation. All the participants were Chinese clinical nurses who volunteered to be the emergency reserve nurses for public health emergencies. The results of this study showed that the virtual simulation technology in combination with technical skills training can significantly improve the preparedness of reserve nurses for the respiratory infectious emergencies. The theoretical assessment and the emergency care capability of the intervention group were significantly increased comparing with those in the control group after conventional training (p<0.001). These findings indicated a critical need for virtual simulation training for the reserve nurses before they went to the front line of responding infectious respiratory disease.

Different from the conventional training, this virtual reality simulation training provided a simulated scene of the isolation ward. The training was flexible and could simulate real-world settings. Thus, it was convenient for the trainees to quickly get familiar with the special layout of zone, the working environment, and the standard procedure. These were extremely important for the emerging infectious diseases. Compared with other virtual simulation programs[32-34], we integrated typical cases of COVID-19 into our training program. Since the COVID-19 has not subsided worldwide, it still is a hard and longtime work to deal with the epidemic. Thus, it is crucial important to train the technical skills, and carry out emergency drills in the background of COVID-19 for emergency reserve nurses, so as to help the trainees quickly master the essentials, adapt to the work context, improve their emergency rescue abilities. In the immersive learning environment of our program, the trainees can learn the theories and practice technical skills, which are essential to treat and

care COVID-19 patients.[35] Moreover, this program can prevent the trainees from directly contacting COVID-19 patients, thus reducing the risk of infection and ensuring the safety of the trainees.[25] This virtual reality simulation training program also has the mode of team/group training, the nursing trainees can log into the system in different roles, conduct teamwork training and real-time interaction, [36-39] which can mobilize the trainees rapidly to collaborate with team members in completing their own tasks. Since this training program has been included as part of the virtual teaching platform operated by the hospital, the nursing trainees can make appointments for repeating and reviewing what they have learned during their spare time, which breaks the time and place limits of conventional training.

Several studies reported the application of virtual reality simulation training in medical/nursing training.[37 40-48] Leizl Joy Nayahangan, et al.[9] systematically reviewed the training and education of medical staff during the infectious disease epidemic, and indicated that the studies about the simulation-based training mostly focused on training practical skills related clinical procedures. Sunil S. Nair, et al.[7] used simulation to train ICU staff and non-critical care unit staff to familiarize themselves with the revised COVID-19 care procedures, including respiratory failure, circulatory failure, bedside ultrasound, bedside ICU procedures, and elements of COVID-19-specific care, finally found it had a good training effect. Our program was designed for reserve nurses and simulated the clinical manifestations, disease progression, psychosocial problems of COVID-19 patients, as well as diagnosis and treatment, nursing care, and standard procedures of disinfection and isolation. In our study, trainees in the intervention group received virtual reality simulation training in combination with technical skills training, which was similar to the previous study by Luca Ragazzoni et al.[49] They used virtual reality simulation to train medical staff on the operational public health skills related to the infection control and Ebola treatment management and also proposed a model of the virtual reality simulation in combination with hybrid skills training exercises.

After the intervention, the scores of technical skills in the control group (90.35±3.38) were slightly higher than those in the intervention group (88.47±4.19) ($p<0.01$), which may be explained by the two reasons: firstly, the technical skills training time of the intervention group was 4 hours less than that of the control group; secondly, the trainees got more accustomed to the traditional way of skill practice. Therefore, in the future training, the skills training time for the virtual simulation group will be added four more hours to the same level as that of the control group. It is essential that more attention should be brought to ensure the balance between virtual training and conventional training.[50-52] In addition, the scores of post disaster management were low among the nurses in the two groups before intervention. After intervention, however, the scores were only slightly improved in both groups, with no statistical difference between the two groups ($p>0.05$). This finding demonstrated that the emergency reserve nurses in the region currently lacked the knowledge of post-traumatic stress, suggesting our training program need to prioritize post-disaster care and post-traumatic recovery of the nurses in the future.

In the future, we will optimize our training model by integrating simulator training with that in the 3D virtual environment, so as to give full play to their respective advantage, thus improving the overall clinical capabilities of nurses. Besides, we can explore the virtual reality team training for interdisciplinary cooperation. We also hope to provide the training for other universities and hospitals based on the virtual experiment project platform in China, and even for the institutes outside of China.

Limitations

There are some limitations faced by our study. Firstly, the sample size of the study was small, as all of the participants came from the same hospital, thus restricting the reference value of the study. Secondly, due to limited resources, the virtual scene of mobile cabin hospital was not constructed in the virtual training program, which will be improved in the future study. Thirdly, the time of skills training need to be extended, as there was a lack of attention paid to the training related to post-disaster care and post-traumatic recovery, which should also be improved in the future.

CONCLUSION

Our study has developed a virtual reality simulation training program that included typical COVID-19 cases. As for the training on the pandemic response of reserve nurses, the virtual reality simulation training in combination with technical skills training is effective in achieving better outcomes than the conventional training.This training program shows more advantages in improving the theoretical knowledge, the capacity of emergency care and the preparedness for pandemic, which makes it applicable to the emergency training for nurses in better response to public health emergencies.

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Data availability statement All data relevant to the study are included in the article or uploaded as supplementary information.

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Figure 1 Training plan for reserve nurses in two groups

Figure 2 Design of virtual simulation training platform for emergency response of respiratory infectious diseases

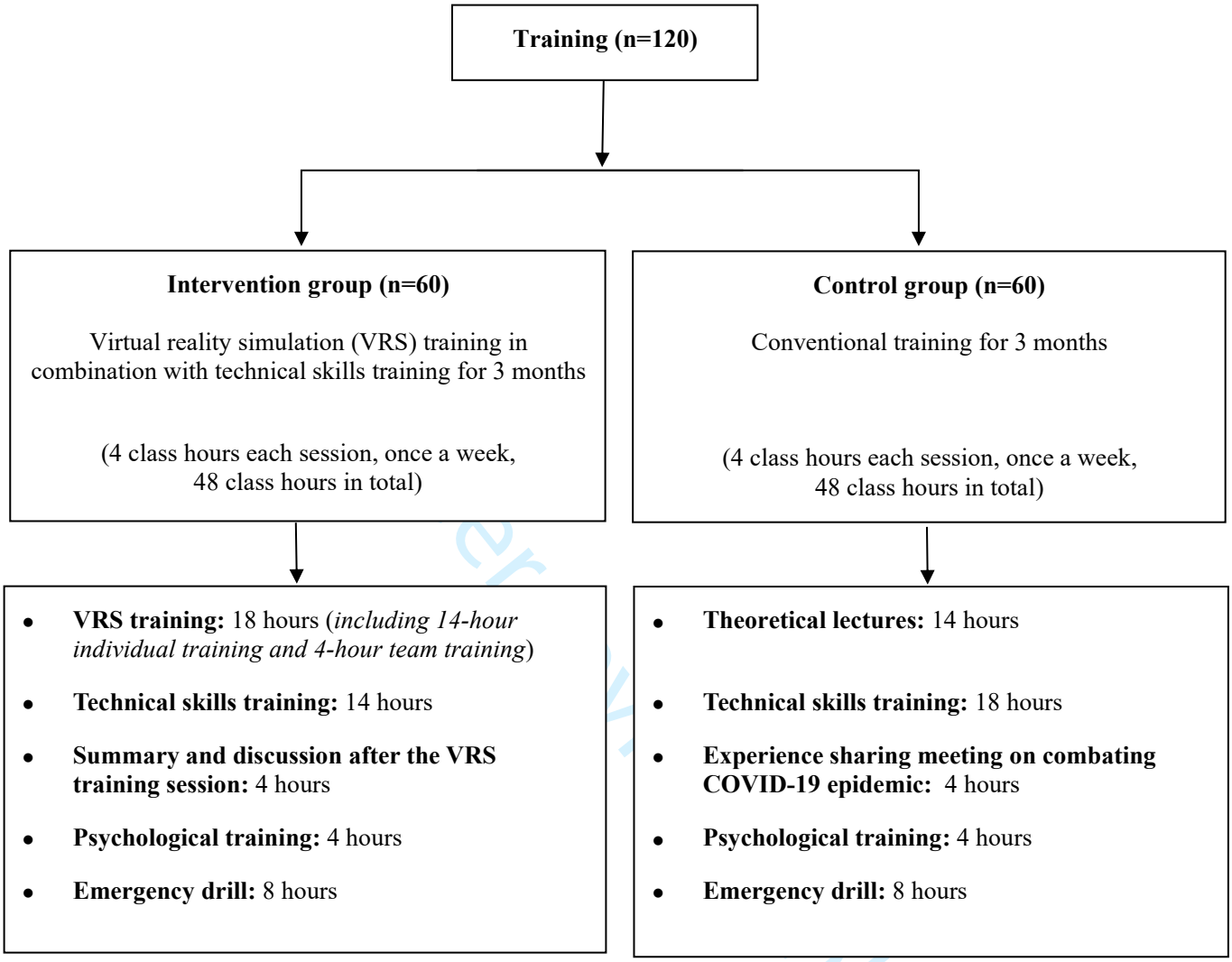

Figure 1 Training plan for reserve nurses in two groups

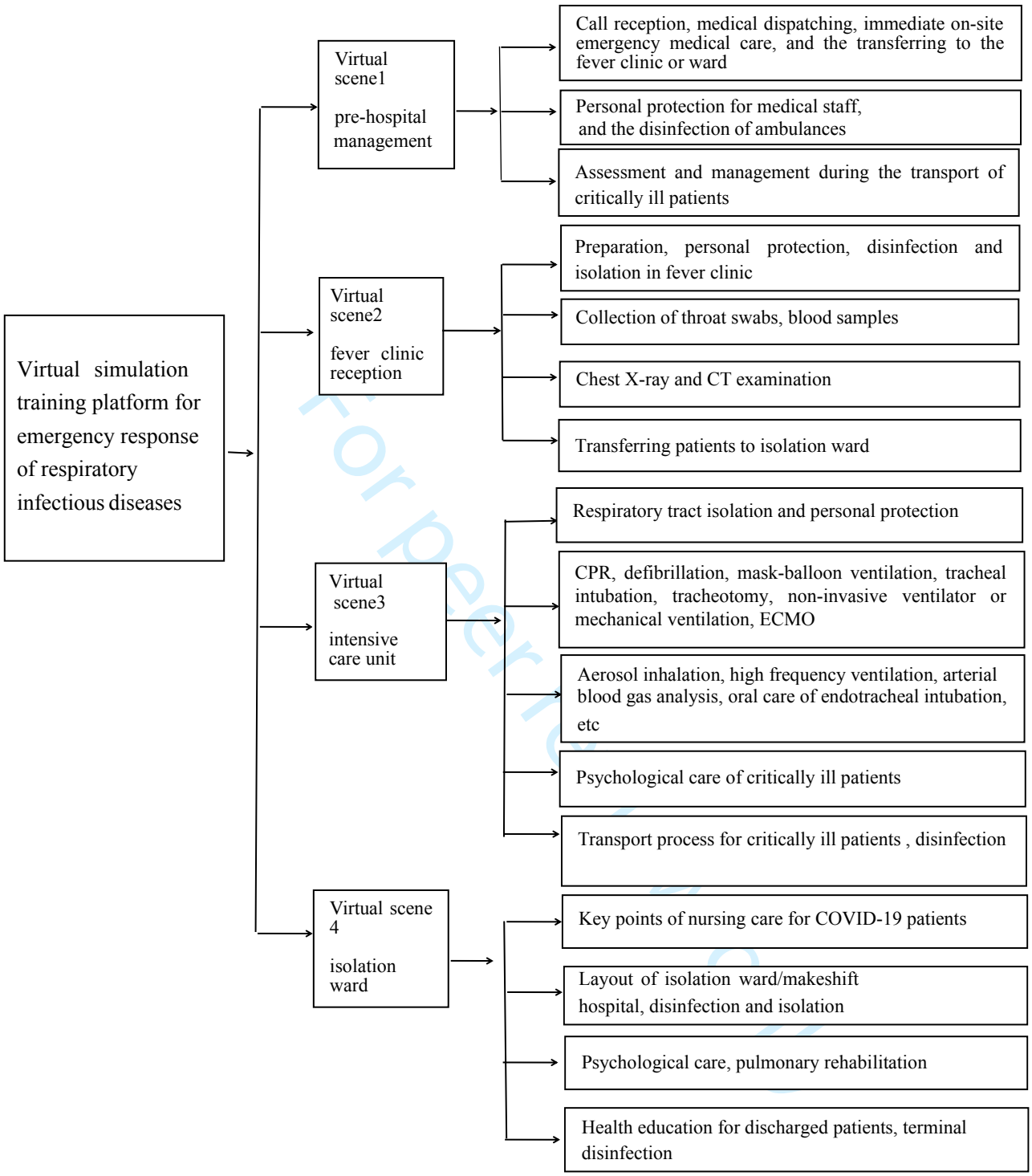

Figure 2 Design of virtual simulation training platform for emergency response of respiratory infectious diseases

Appendix:

The conventional training and assessment plan of the control group

Month	Every Wednesday: 2:00-6:00 pm	**Content and class hours**
First Month	**Session 1**	**Lecture (2 h):** clinical guidance for the management of COVID-19 patients, infection control guidance, and the key points of nursing care **Technical skills (2 h):** demonstration and practice on respiratory tract sampling, donning and doffing personal protective equipment
	Session 2	**Lecture (2 h):** disinfection, quarantine, and nosocomial infection control **Technical skills (2 h):** review and assess the practical skills learned in the last session
	Session 3	**Lecture (2 h):** guidelines for the treatment and care of the COVID-19 patients in critically condition (I) **Technical skills (2 h):** demonstration and practice on CPR, sputum aspiration, oxygen inhalation, simple respirator operation
	Session 4	**Lecture (2 h):** guidelines for the treatment and care of the COVID-19 patients in critically condition (I) **Technical skills (2 h):** demonstration and practice on arterial puncture and venipuncture, trachea cannula, defibrillator operation
Second Month	**Session 1**	**Lecture (2 h):** psychological nursing of patients **Technical skills (2 h):** review and assess the practical skills of CPR, sputum aspiration, oxygen inhalation, simple respirator operation
	Session 2	**Lecture (2 h):** nurses' psychological support, relax training, relieving stress, and releasing negative emotions **Technical skills (2 h):** review and assess the practical skills of arterial puncture and venipuncture, trachea cannula, defibrillator operation
	Session 3	**Lecture (2 h):** preparation of common epidemic prevention materials, basic life support and advanced life support (I) **Technical skills (2 h):** practicing material preparation, high-frequency ventilation support, aerosol inhalation
	Session 4	**Experience sharing (4 h):**a meeting on experience sharing with the professionals working on the front-line of treating COVID-19

Third Month	**Session 1**	**Lecture (2h):** basic life support and advanced life support (II) **Technical skills(2h):** review and assess the practical skills of high-frequency ventilation support, aerosol inhalation
	Session 2	**Lecture (2h):** test on theories **Technical skills(2h):** demonstration and assessment of ventilators (the ICU nurse needs to attend the assessment, while others only need to learn but no test requirements)
	Session 3	Emergency Drill, the emergency procedures for responding to respiratory epidemic, practice and exercise in two groups after briefing the procedures and plan (3 h) Recapping and exchanging of views after exercise (0.5 h) Fill the scale of disaster preparedness, explain the grading criteria of the emergency response capability assessment (0.5 h)
	Session 4	Twice emergency response exercises for two groups (4 h): the contents of the twice exercises are the same, with 30 trainees in each. Each trainee is designated one role. In the second exercise, the trainee should play a different role. The instructors should be divided into two groups to supervise the exercise and evaluate each trainee's performance with the emergency nursing capacity evaluation sheet.

Virtual reality simulation (VRS) training in combination with technical skills training and assessment plan of the intervention group

Month	Every Tuesday or Friday: 2:00-6:00 pm	**Content and class hours**
First Month	**Session 1**	**VRS training (2 h): Introduction and use of virtual projects,** **Individual training: pre-hospital management** **Technical skills (1.5 h):** demonstration and practice in teams on respiratory tract sampling, donning and doffing personal protective equipment **Summary and discussion (0.5 h)**
	Session 2	**VRS training (2 h):** Individual training on Fever Clinic Reception **Technical skills (1.5 h):** review and assess the practical skills learned in the last session **Summary and discussion (0.5 h)**
	Session 3	**VRS training (2 h):**Individual training on Intensive Care Unit(I)

		Technical skills (1.5h): demonstration and practice on CPR, sputum aspiration, oxygen inhalation, simple respirator operation **Summary and discussion (0.5 h)**
	Session 4	**VRS training (2 h):**Individual training on Intensive Care Unit (II) **Technical skills (1.5 h):** demonstration and practice on arterial puncture and venipuncture, trachea cannula, defibrillator operation **Summary and discussion (0.5 h)**
Second Month	**Session 1**	**VRS training (2 h):** Individual training on Isolation ward **Technical skills (1.5h):** review and assess the practical skills of CPR, sputum aspiration, oxygen inhalation, simple respirator operation **Summary and discussion (0.5 h)**
	Session 2	**VRS training (2 h):** Comprehensive training (Individual training) **Technical skills (1.5 h):** review and assess the practical skills of arterial puncture and venipuncture, trachea cannula, defibrillator operation **Summary and discussion (0.5 h)**
	Session 3	**VRS training (2 h):**Comprehensive training (Team training) **Technical skills (1.5 h):** practicing material preparation, high-frequency ventilation support, aerosol inhalation **Summary and discussion (0.5 h)**
	Session 4	**Lecture (4 h):** nurses' psychological support, relax training, relieving stress, and releasing negative emotions; psychological nursing of patients
Third Month	**Session 1**	**VRS training (2 h):** Comprehensive training (Team training) **Technical skills (1.5 h):** review and assess the practical skills of high-frequency ventilation support, aerosol inhalation **Summary and discussion (0.5 h)**
	Session 2	**VRS training (2 h):** test on theories **Technical skills (2 h):** demonstration and assessment of ventilators (the ICU nurse needs to attend the assessment, while others only need to learn but no test requirements)
	Session 3	Emergency Drill, the emergency procedures for responding to respiratory epidemic, practice and exercise in two groups after explaining the procedures and plan (3 h) Recapping and exchanging of views after exercise (0.5 h) Fill the scale of disaster preparedness, explain the grading criteria of the emergency response capability assessment (0.5 h)
	Session 4	Twice emergency response exercise for two groups (4 h): the contents of the twice exercises are the same, with 30 trainees in

		each. Each trainee is designated one role. In the second exercise, the trainee should play a different role. The instructors should be divided into two groups to supervise the exercise and evaluate each trainee's performance with the emergency nursing capacity evaluation sheet.

All technical skills training in two groups were individual training.