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ORIGINAL RESEARCH

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Exploration of cardiopulmonary resuscitation teamwork training for maternal cardiac arrest using the SimMan intelligent simulation platform: A simulation teaching study

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Abstract

Background and Aims: Maternal cardiac arrest is the most urgent clinical event in obstetrics and can lead to serious consequences, such as maternal or fetal death. Therefore, the training of team cardiopulmonary resuscitation (CPR) skills for obstetricians is essential. The aim of this study was to investigate the effect of applying intelligent simulation to CPR in maternal cardiac arrest teamwork training for obstetricians.

Methods: Twenty-four obstetricians who participated in the "Maternal First Aid Workshop," organized by our hospital in 2018, were selected as training participants. The SimMan intelligent comprehensive patient simulator was used to train the CPR team collaboration with first-aid skills. Each team participating in the training was assessed before and after the training using a questionnaire survey.

Results: The evaluation of the results after the training showed that all four teams were qualified and that the timing of the cesarean section was 100% correct. The mean score, team collaboration score, and chest compression fraction were significantly higher than before training. Teamwork CPR assessment time, interruption time of chest compressions, and artificial airway establishment time were significantly shorter than before training. The questionnaire survey showed that 95.8% of the physicians reported that the training was rewarding and helpful to their clinical work, and 100% of the physicians believed that obstetricians require similar training.

Conclusion: Using the SimMan intelligent comprehensive patient simulator to train obstetricians for CPR of maternal cardiac arrest teamwork first-aid skills can significantly improve the training effect, clinical first-aid skills, and teamwork awareness.

KEYWORDS

cardiopulmonary resuscitation, intelligent simulator, pregnant women, simulation teaching, training

Ruirui Zhang and Yu Liu contributed equally to this study.

1 | INTRODUCTION

The maternal pathophysiology of pregnant women changes significantly compared with that before pregnancy, particularly after 20 weeks of gestation. For instance, pregnancy may result in an increased maternal cardiopulmonary burden, and susceptibility to complications, such as, gestational hypertension, diabetes mellitus, hemolysis, elevated liver enzymes and low platelets syndrome, and other obstetric emergencies.[1,2] Hence, the incidence of maternal cardiac arrest is higher than that of the general population; the current literature reports that the incidence of maternal cardiac arrest was 7.6 per 100,000 pregnancies.[3] This can lead to serious consequences, such as maternal or fetal death.[4] Cardiopulmonary resuscitation (CPR) is an effective method for treating cardiac arrest, and has saved many patients in clinical practice.

CPR is an emergency technique in which every healthcare worker should be proficient. Notably, team-based CPR places greater demands on both the individual and the team. International CPR guidelines are continuously being updated.[5,6] Maternal cardiac arrest is the most urgent clinical event in obstetrics,[7] where the patient's condition is critical, and resuscitation time is precious. Therefore, it is a race against time, and no errors can be tolerated during resuscitation. Due to its specificity, the team CPR method is different from usual methods.[6] In clinical practice, there are significant challenges associated with irregular operation and a low success rate of resuscitation for maternal team CPR.[3] This is because the vast majority of junior physicians and medical students are unable to practice on patients, resulting in few opportunities to practice relevant emergency skills and a lack of exercise in clinical thinking and practical operations. Therefore, training obstetricians in team CPR skills is essential as it directly affects the outcome and prognosis of maternal resuscitation treatment. Conventional training and teaching methods can no longer meet the training needs in these new situations[8] and the use of intelligent simulation (IS) technology for teaching first-aid skills has compensated for the lack of practical opportunities in clinical practice.[9] The aim of this study was to investigate the effect of applying IS to CPR of maternal cardiac arrest teamwork training for obstetricians, to develop training methods, and to improve clinical competency.

2 | MATERIALS AND METHODS

2.1 | Research participants

Twenty-four obstetricians who participated in the "Maternal Emergency Workshop" held at our hospital in 2018 were selected as training participants. Among them were 19 females and 5 males, aged 26–47 years, all of whom had obtained a practising physician qualification certificate.

2.2 | Grouping

The sample comprised 24 physicians who were randomly numbered according to repeats of 1–4. All physicians with the same number were then grouped into the same team. The four teams each had six members. Advanced IS was used for the team CPR training. Team CPR training and assessments were conducted using a fixed-team approach in which a designated team performed CPR on a pregnant woman experiencing cardiac arrest. This study was reviewed and approved by the Ethics Committee of The First Affiliated Hospital of Xi' an Jiaotong University (2018 G-178), and informed consent was obtained from all participants.

2.3 | Instrumentation

The SimMan IS system and its software, developed by Laerdal, Norway, were used. The system included the following: a case-writing simulation system, camera and projection system, normal model CPR simulator, handheld biphasic defibrillator, simple respirator, transoral tracheal intubation kit, stethoscope, oxygen bottle, intravenous infusion set, and drugs required for first aid.

2.4 | Training methods

2.4.1 | Training of instructors

All our selected instructors were experienced critical care medicine specialists with over 10 years of clinical experience. They were also American Heart Association (AHA) CPR training instructors who had been teaching and practising team CPR for over 5 years and were skilled in teaching medical simulation practices.

2.4.2 | Individual knowledge training and assessment

All participants involved in this study attended and passed the operational training on CPR, simple respiration, transoral endotracheal intubation, and electrical defibrillation, before the start of the study.

2.4.3 | Team CPR training

All the participants received uniform theoretical training for team CPR. Afterwards, each team was assessed separately for team CPR using the SimMan IS, and each team prepared cases before the practical team CPR training. After the assessment, team CPR practical training was conducted. The training was conducted using the SimMan IS and its software, a case-writing simulation system, and its

camera and projection system. The training was conducted using a pre-drafted unified training lesson plan; the case scenario simulation, team member standing, role assignments, and operational procedures were identical for each group.

2.4.4 | Training case writing and simulation

The case-writing principle was to simulate a clinical scenario and cover the operating points of teamwork CPR. For example, a pregnant woman at 32 weeks of gestation, in the hospital, suddenly developed cardiac arrest and required teamwork CPR. Clinical scenarios requiring CPR, such as ventricular fibrillation, pulseless ventricular tachycardia, electrocardiographic quiescence, and pulseless electrical activity, can be used during case simulation. Examples of the simulated case preparations are listed in Table 1.

2.4.5 | Procedure and role assignment

When using the cases prepared before the simulation training, the six members of each team were individually assigned roles of A, B, C, D, E, or F. In team CPR training, different roles were allocated according to different stations, as follows: A: (leader): responsible for commanding the resuscitation process, the review and adjustment of the resuscitation plan, the decision in certain situations, and communication with the patient's family; B (chest compressor): performed the first round of judgment and chest compressions; C (airway manager): performed airway management, including airway entry, ventilation, and artificial airway establishment; D (electrocardiography [ECG] and defibrillation management implementer): performed cardiac management and implemented defibrillation; E (implemented intravenous access and emergency medication): performed intravenous access, blood collection, and administration of emergency medication; and F (recorder and supervisor): recorded the resuscitation process, supervised, and reminded team members of their respective roles. During simulation training, the six people rotated through the different roles. During the resuscitation of pregnant women with gestational ages of more than 20 weeks, a technique was utilized in which one person pushed the patient's uterus to the left to relieve compression of the inferior vena cava and promote blood reflux. If voluntary circulation was not restored after 5 min of CPR, immediate cesarean delivery was performed (Figure 1).

2.4.6 | Team member positions

During team CPR, there were strict requirements for the position of each member to ensure consistency in team performance and efficient collaboration to complete resuscitation. The positions of the six participants are shown in Figure 2. The role of the compressor (B) must be changed once every 2 min and can be replaced by C and D Thus, the roles of B, C, and D can be interchanged during team CPR implementation. During simulation training, the six individuals in each group rotated through the different roles. At the end of the training, the instructors organized summary lectures, group discussions, and error analyses for students to learn and improve from their mistakes.

TABLE 1 Example of case preparation for intelligent simulation training on cardiopulmonary resuscitation teamwork.

Steps	Scene settings	Examination point	Time
Step 1	Medical history: A 30-year-old pregnant woman, 32 weeks gestation, was admitted to our hospital complaining of palpitation and dizziness with clear consciousness, and regular prenatal care, which was previously unremarkable. The analog monitor showed a heart rate of 180 beats per minute (narrow, fast unidirectional heart rate), respiratory rate of 24 breaths per minute, blood pressure of 90/50 mmHg, and SPO_2 94%	Identification and treatment of tachyarrhythmia (including electrical cardioversion), rapid inquiry	2 min
Step 2	Simulated monitor showed ventricular fibrillation after electrical cardioversion, patient lost consciousness, vital signs disappeared	Identification of malignant arrhythmia, command and coordination ability of group leader, division of labor and cooperation of team members, correct action of each member, defibrillable CPR process and electrical defibrillation, high-quality CPR, airway management, preparation for cesarean section	2 min
Step 3	Analog monitor showed a heart rate of 40 beats per minute and no pulse	Team member transposition, correct drug and dose administered, pulseless electrical activity CPR process, high quality CPR, potential etiological analysis of pulseless electrical activity, artificial airway establishment and management, emergency cesarean section	4 min
Step 4	CPR succeeded if above steps were performed correctly, otherwise patient died	Identify ROSC, target temperature management, ROSC post-processing	2 min

Abbreviations: CPR, cardiopulmonary resuscitation; ROSC, return of spontaneous circulation; SPO_2, peripheral capillary oxygen saturation.

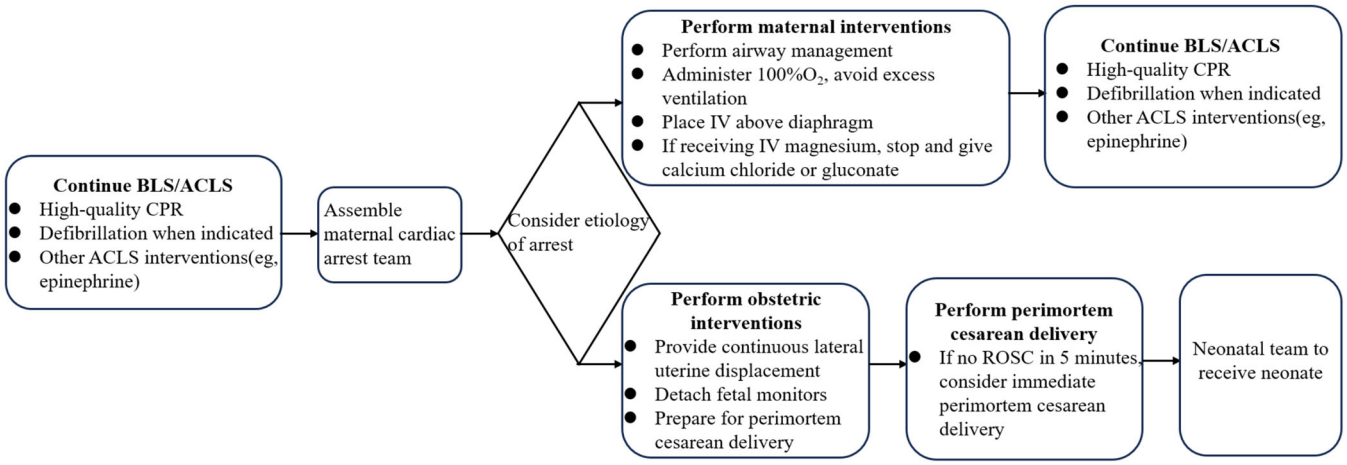

FIGURE 1 Flow chart of advanced life support in hospital for maternal cardiac arrest.[6]

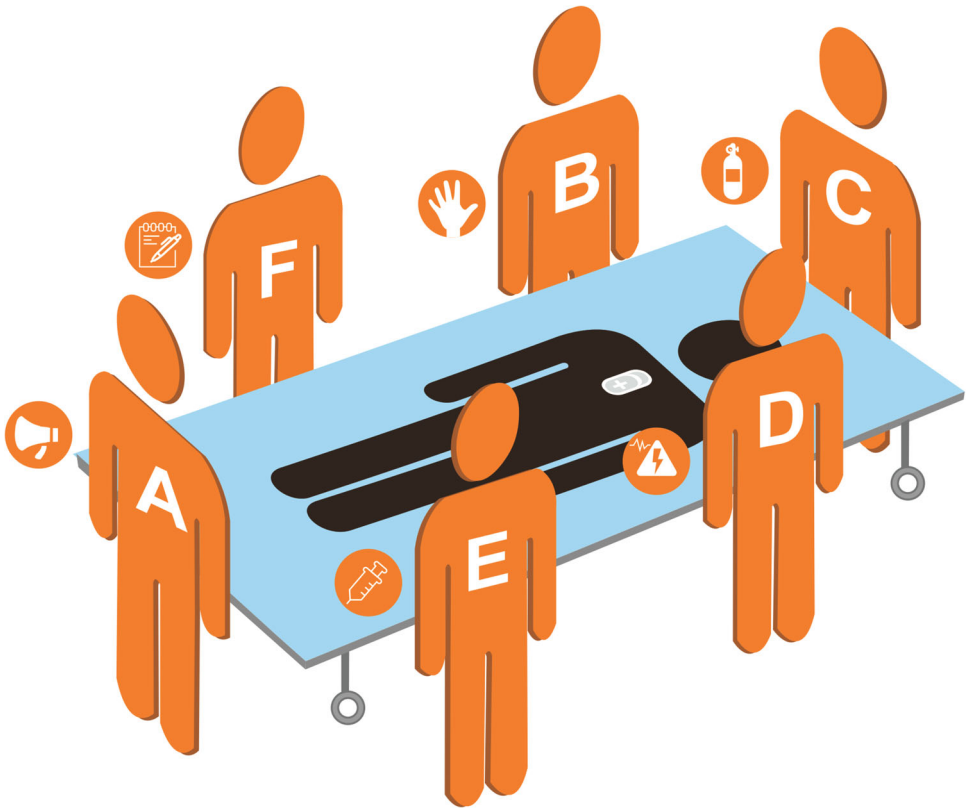

FIGURE 2 Positions of a team of six people during CPR implementation.

2.5 | Assessment and evaluation

Before and after team CPR practice training, the SimMan IS was used to prepare a case, in advance, for assessment. The assessment duration was 10 min, and the score was determined in strict accordance with the scoring standards, with a total score of 100 points, by two physicians who were attending physicians or held more senior positions in the field. The passing score was 70. The score table includes the operational score table of the different roles of the team members (100 points), the team collaboration score table (100 points), and other materials as required. The team cooperation score table was used to evaluate the collaborative performance among team members, such as the leader's commanding ability, cooperation, communication, and collaboration among members. Scene setting and operation of the IS platform were performed by clinicians familiar with SimMan. If the resuscitation procedure was correct, the simulated patient resumed spontaneous circulation, which was regarded as a successful (i.e., qualified) resuscitation. Otherwise, it was considered to be

resuscitation failure and was judged as failed. The assessment process was supervised by a chief physician for emergency-related professionals. The assessment was conducted in the intensive care unit simulation ward, and all participants were isolated from each other while waiting for the assessment.

2.6 | Questionnaire content

After the training and assessment, the 24 obstetricians were investigated using a questionnaire that assessed their involvement in similar training programs, the benefits of training with an intelligence-simulated human, the helpfulness and effectiveness of the training program, the necessity of such a course, and problems experienced during training. The questionnaire was designed by two senior intensive care unit physicians engaged in teamwork CPR simulation training to investigate the training effects, training courses, and personal experience of the trainers. The questionnaire provided relevant options for participants to choose freely. The results provide a reference for further training courses and implementation.

2.7 | Statistical analysis

All statistical analyses were conducted using SPSS software (version 24.0; SPSS Inc., Xi'an Jiaotong University, China). Measurement data were expressed as the mean ± standard deviation, and count data were expressed as a percentage. Count data, rate comparison, and correlations between groups were analyzed using the chi-square test. Individual operational assessment results were compared using the independent sample *t*-test. Measurement data before and after training and the time spent were compared using a paired *t*-test. Statistical significance was set at $p < 0.05$.

3 | RESULTS

3.1 | Single operational assessment before training

Before commencing training for the study, each team member was trained and assessed for every individual operational skill, such as CPR, simple respirator, transoral tracheal intubation, and defibrillation, with a total score of 100 points. A score of ≥70 points was a passing score. All participants had passing scores for each individual operation, after training.

3.2 | Results of the assessment of each team before and after team CPR practice training

The post-training assessment results showed that all four teams completed the assessment within 10 min and passed the assessment with correct Cesarean timing, whereas for the pre-training assessment, only one team passed and all four teams had incorrect Cesarean timing. The team results, teamwork, and chest compression fraction (CCF) of the post-training assessment teams were statistically significantly higher than before training. Teamwork CPR assessment time, interruption time of chest compressions, and the time taken to establish an artificial airway were all significantly shorter after training. These differences were statistically significant ($p < 0.05$) (Table 2).

TABLE 2 Results of the assessment before and after team CPR practice training.

Variable	Pre-training	Post-training	*p* Value
The team result,[a] points	63.25 ± 6.60	84.50 ± 3.42	0.006
Teamwork,[a] points	67.50 ± 7.33	93.00 ± 3.56	0.002
Chest compression fraction, %	53.30 ± 2.88	69.51 ± 2.41	0.001
Teamwork CPR assessment time, s	590.50 ± 10.08	535.00 ± 21.28	0.037
Tnterruption time of chest compressions, s	275.00 ± 16.73	163.50 ± 18.70	0.003
The establishment of an artificial airway, s	40.25 ± 9.46	27.75 ± 4.86	0.013

[a]100 points for each item.

3.3 | Questionnaire results

A total of 24 questionnaires were distributed, and 24 were returned, with a 100% questionnaire completion rate. Two physicians involved in the training collected and analyzed the questionnaires. The survey results showed that 95.8% of obstetricians reported that the training was very rewarding and helpful to their clinical work, 100% of the physicians believed that obstetricians were in great need of similar training, 87.5% of the physicians had not been exposed to similar training before, and most physicians only had partial knowledge of the team CPR process for maternal cardiac arrest and were not familiar with the complete process. During training, 100% of the physicians thought that they had mastered the team CPR process for maternal cardiac arrest and that they had improved their comprehensive first-aid skills, clinical practice, theory-practice integration, and teamwork skills. For conducting team CPR in maternal cardiac arrest, however, there are still challenges, such as an unclear process, unclear knowledge of the use of emergency drugs and timing of cesarean section, irregular operation, and poor teamwork during resuscitation (Table 3).

4 | DISCUSSION

Cardiac arrest can be induced by various cardiogenic or non-cardiogenic factors. Timely and effective clinical implementation of CPR in patients with cardiac and respiratory arrest is important to

TABLE 3 Results of the questionnaire survey.

Evaluation item	Composition ratio, *n* (%)
Knowledge of team CPR procedures of maternal cardiac arrest before training	
Very familiar	3/24 (12.5)
Somewhat familiar	18/24 (75.0)
Unfamiliar	3/24 (12.5)
Whether obstetricians need to be trained	
Extremely required	24/24 (100.0)
Not required	0/24 (0.0)
Was this training rewarding?	
Very rewarding	23/24 (95.8)
Somewhat rewarding	1/24(4.2)
Not rewarding	0/24 (0.0)
Will the training be useful for clinical work	
Very helpful	23/24 (95.8)
Somewhat helpful	1/24(4.2)
Not helpful	0/24 (0.0)
Exposure to similar training before training	
Prior exposure	3/24 (12.5)
No exposure	21/24 (87.5)
What were the takeaways from this training (multiple choice)	
Mastered the team CPR process of maternal cardiac arrest	24/24 (100.0)
Improved integrated first aid capacity	20/24 (83.3)
Improved clinical practice skills	19/24 (79.2)
Improving the ability to integrate theory and practice	18/24 (75.0)
Enhancing teamwork skills	23/24 (95.8)
Problems you see in team CPR (multiple choice)	
Emergency team CPR process of maternal cardiac arrest unclear	19/24 (79.2)
Unfamiliarity with the use of first aid drugs	22/24 (91.7)
The timing of the Cesarean section is unclear	22/24 (91.7)
Irregularities in resuscitation	17/24 (70.8)
Poor teamwork	20/24 (83.3)

increase the success rate of emergency care and improve the long-term prognosis of patients.[10] The quality of CPR performed by healthcare professionals is closely related to the outcome of patients in cardiac arrest,[11] and good team mobilization is a guaranteed factor for the implementation of high-quality CPR.[12]

The pregnant mother is more susceptible to cardiac arrest as hypoxia is poorly tolerated.[13] It was reported in the literature that maternal deaths due to cardiac arrest account for 10% of all maternal deaths.[14] The success rate of resuscitation after the occurrence of cardiac arrest remains low, with a survival rate of approximately 41%,[3,4] with 41 cases of cardiac arrest during pregnancy reported in China, with a survival rate of less than 29% (12 survivors).[15] This is related to many factors, one of which is the unfamiliarity of physicians with CPR knowledge and techniques. Unclear division of labor, unclear instructions, irregular use of emergency medications, lack of teamwork, and confusion when encountering a need for cardiac and respiratory arrest resuscitation ultimately lead to a delay in acting within the optimum time period for resuscitation.[16] A survey showed that obstetricians had a 25%–40% error rate in answering questions about their knowledge of CPR.[14] Our questionnaire showed that 87.5% of the 24 physicians who participated in the study had no previous exposure to team CPR training, and that most of them had only some knowledge of team CPR procedures for maternal cardiac arrest, and were unfamiliar with them. The 2020 AHA guidelines updated the emergency CPR procedures and recommendations for maternal cardiac arrest procedures such that lateral uterine transfer maneuvers can be performed continuously during CPR to reduce spontaneous inferior vena cava compression. Immediate perimortem cesarean delivery should be considered if the restoration of voluntary circulation is not achieved within 5 min. The current study showed that obstetricians were unfamiliar with the timing of performing uterine lateral transfer maneuvers and cesarean delivery during CPR after maternal cardiac arrest in both simulated training and with questionnaires.[14] Our study showed that in the pre-practice training assessment, all four teams had incorrect timing for performing uterine lateral transfer maneuvers and cesarean delivery during team CPR. However, all assessments after the SimMan IS training yielded correct responses. Therefore, it is crucial to conduct orderly and efficient team CPR training.

In recent years, intelligent integrated medical simulation teaching has played an increasingly important role in the clinical skill training of physicians, and the use of IS for skill training of healthcare workers can significantly improve their mastery of medical knowledge and skills, medical behavior, and quality.[8,17] By writing and simulating clinical emergency cases, SimMan can simulate "real" clinical cases and realistic emergency scenarios, thus creating a fully functional, simulated, comprehensive emergency teaching environment for physicians. This allows physicians to actively participate in skills training, identify and solve problems, exercise clinical thinking abilities, and narrow the gap between classroom theory teaching and clinical practice. It also solves practical problems in clinical practice and provides significantly improved training results. One study used advanced simulators to train anesthesiology residents on simulated cardiac arrest in pregnant women and it showed that it could significantly improve the residents' ability to manage cardiac arrest in pregnant women.[18] Our study showed that all four teams passed the assessment after the training, while only one team passed the assessment before training. The post-training mean score, teamwork score, and CCF of all four teams were significantly higher ($p < 0.05$) than at pre-training. The post-training mean time spent on

resuscitation, time to interruption of chest compressions, and time to establishment of the artificial airway were all significantly shorter ($p < 0.05$) than at pre-training. In the simulation training, we focused on the training and assessment of all four teams to improve the CCF, which is the ratio of the sum of the compression duration to the total resuscitation duration, during the resuscitation process. There was a linear relationship between CCF and the recovery of spontaneous circulation, which was also correlated with the immediate and long-term prognoses; lower CCF is associated with higher patient mortality.[19–21] Therefore, during simulation training and clinical maternal resuscitation, every effort should be made to perform teamwork efficiently and in an orderly manner to facilitate CCF improvement.

The questionnaire showed that after the training, the physicians had better mastery of the team CPR process for maternal cardiac arrest, improved comprehensive first aid ability, clinical practice ability, the ability to combine theory and practice, and teamwork. Simultaneously, obstetricians were able to better judge critical maternal conditions, and their awareness of resuscitation, resuscitation efficiency, command ability, and ability to use first aid instruments and equipment also significantly improved, fully reflecting the advantages of applying IS for comprehensive clinical first aid skills training. The results of the survey showed that the participating physicians widely recognized that this new training method significantly improved their knowledge and their clinical work benefited from their participation in this training and they hoped that relevant training courses could be conducted with other obstetricians. At the same time, during the training, they also recognized problems that existed, such as lack of clarity about the team CPR process of maternal cardiac arrest, lack of familiarity with the use of emergency drugs, lack of clarity about the timing of cesarean delivery, lack of standardization of operations during resuscitation, and poor teamwork. These are the problems encountered during resuscitation in clinical practice, which may directly affect the success rate of resuscitation in our patients and maternal mortality. These aspects should be strengthened continuously during similar training sessions in the future.

This study had certain limitations. While the sample size of the included studies was small, the training methods used were relatively simple, and the training time was short, which might have had an impact on the results. However, this was a single-center study, and the sources of personnel were relatively scattered. Differences in clinical skill may have affected these results. Third, although we used randomization, differences in the abilities or experience of the team members could also have affected the results. Therefore, more rigorous designs and studies with larger sample sizes are required.

5 | CONCLUSION

The intelligent integrated simulator helped build a platform for team CPR training in cases of maternal cardiac arrest. It enables trained physicians to improve their clinical first-aid skills and there is value in promoting it for use in clinical skills training of physicians. However, the simulator cannot replace a real patient and the complex situations faced in the process of clinical patient resuscitation cannot be fully reflected in the simulator. Therefore, continuous clinical practice is necessary.

AUTHOR CONTRIBUTIONS

Ruirui Zhang: Conceptualization; data curation; methodology; project administration; writing—original draft. **Yu Liu**: Conceptualization; project administration; resources; supervision; writing—review and editing. **Mingming Zhang**: Investigation; methodology; project administration; writing—review and editing. **Kejuan Ning**: Data curation; project administration; writing—review and editing. **Hongliang Bai**: Conceptualization; methodology; project administration; supervision; writing—review and editing. **Litao Guo**: Data curation; formal analysis; funding acquisition; methodology; resources; writing—original draft; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

All data generated or analyzed during this study are included in this published article. All authors have read and approved the final version of the manuscript. All authors had full access to all of the data in this study and takes complete responsibility for the integrity of the data and the accuracy of the data analysis.

ETHICS STATEMENT

This study was approved by the Ethics Committee of the First Affiliated Hospital of Xi'an Jiaotong University (2018 G-178). All methods were performed in accordance with relevant guidelines and regulations. Informed consent was obtained from all the participants.

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