Improve Cardiac Emergency Preparedness by Building a Team-Based Cardiopulmonary Resuscitation Educational Plan

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Objective: To design an innovative team-based cardiopulmonary resuscitation (CPR) educational plan for multiple bystanders and evaluate whether it was associated with better teamwork and higher quality of resuscitation.

Methods: The team-based CPR plan defined the process for a three-person team, emphasize task allocation, leadership, and closed-loop communication. Participants qualified for single-rescuer CPR skills were randomized into teams of 3. The teamwork performance and CPR operation skills were evaluated in one simulated cardiac arrest scenario before and after training on the team-based CPR plan. The primary outcomes were measured by the Team Emergency Assessment Measure (TEAM) scale and chest compression fraction (CCF).

Results: Forty-three teams were included in the analysis. The team-based CPR plan significantly improved the team performance (global rating 6.7 ± 1.3 vs. 9.0 ± 0.7, corrected $p < 0.001$ after Bonferroni's correction). After implementing the team-based CPR plan, CCF increased [median 59 (IQR 48–69) vs. 64 (IQR 57–71%)%, corrected $p = 0.002$], while hands-off time decreased [median 233.2 (IQR 181.0–264.0) vs. 207 (IQR 174–222.9) s, corrected $p = 0.02$]. We found the average compression depth was significantly improved through the team-based CPR training [median 5.1 (IQR 4.7–5.6) vs. 5.3 (IQR 4.9–5.5) cm, $p = 0.03$] but no more significantly after applying the Bonferroni's correction (corrected $p = 0.35$). The compression depths were significantly improved by collaborating and exchanging the role of compression among the participants after the 6th min.

Conclusion: The team-based CPR plan is feasible for improving bystanders teamwork performance and effective for improving resuscitation quality in prearrival care. We suggest a wide application of the team-based CPR plan in the educational program for better resuscitation performance in real rescue events.

Keywords: out-of-hospital cardiac arrest, cardiopulmonary resuscitation, bystander, teamwork, emergency preparedness

INTRODUCTION

Health literacy is widely regarded as essential for achieving health and well-being (1, 2). As an essential part of health literacy, governments worldwide have adopted national strategies and targets to improve emergency preparedness (3, 4). It is noted that out-of-hospital cardiac arrest (OHCA) is one of the most critical medical emergencies. Prompt and effective cardiopulmonary resuscitation (CPR) by community first responders is essential for a better prognosis for patients with OHCA (5). To achieve high-quality CPR, China has proposed to have 3% and upper of its personnel certified in CPR training by 2030.

On account of complex procedures in resuscitation, the engagement of multiple rescuers is indispensable to guarantee high-quality CPR for patients with OHCA. It has been revealed that the presence of multiple bystanders is an independent factor positively correlated with high-performance CPR (6). Notably, 43.1% of OHCA rescue events are with multiple bystanders on the scene, which enables the implementation of the resuscitation procedures by teams of responders instead of isolated rescuers (7). Under these circumstances, a better prognosis for patients with OHCA is not only achieved by the high-quality CPR skills of every single rescuer but also by the cooperation of multiple bystanders to provide early defibrillation and avoid interruptions in resuscitation (8, 9). What is more, in prolonged resuscitation which is time-consuming and labor-intensive, team cooperation could enhance the quality of CPR while relieving the fatigue of individual rescuers (10).

Despite the high likelihood and feasibility of the resuscitation by multiple rescuers, it was rare to find standardized team educational plans and training programs for bystanders. Most of the established CPR educational plans for bystanders mainly emphasizing single-rescuer skills but neglect training in cooperation with others to implement better prearrival care (11). In advanced cardiovascular life support (ACLS), team-based resuscitation has been emphasized to improve survival and neurologic outcomes among cardiac arrest patients in the updated 2020 American Heart Association (AHA) and 2021 European Resuscitation Council (ERC) guidelines (12, 13). There is a lack of consolidated educational plans to provide effective and efficient methods of cooperation and communication for bystanders in a resuscitation team. Hence, we aimed to design an innovative educational plan for team-based CPR to influence the CPR operation skills and the cooperation among multiple bystanders. Furthermore, we hoped it could be widely applied in the educational program for better emergency preparedness about OHCA in real rescue events.

MATERIALS AND METHODS

Study Design and Ethics

We innovatively designed a team-based CPR educational plan for bystanders according to the updated AHA and ERC guidelines. Implemented quantitative analysis to evaluate the effectiveness and feasibility of the team-based CPR plan in a before-after intervention simulation study. Participants were randomly allocated to teams of 3 people to perform resuscitation in

a controlled simulated scenario and then tested in the same scenario after receiving the training of our designed team-based CPR educational plan. Ethics approval has been obtained from the Joint Research Ethics Board of the Shanghai Jiao Tong University Schools of Public Health and Nursing (SJUPN-201913).

Study Participants and Randomization

From 1 January 2020 to 15 June 2021, 135 medical school students over 18 years old were recruited for the current study. Participants were chosen from among students who had not participated in the clinical practice or CPR training experiment. First, individuals were taken the basic life support training hosted by WeCan CPR training program (14). Through the WeCan CPR training, participants mastered skills including calling the emergency dispatch number of China's mainland (1-2-0), performing chest compression, mouth-to-mouth ventilation, and using an automated external defibrillator (AED).

Then the team-based CPR training was conducted for the participants, who worked in groups of three allocated by a simple random sampling method. All participants were informed about the intention of the present study and provided written informed consent to participate in the study.

Team-Based CPR Educational Plan

The innovative team-based CPR educational protocol was designed for teams consisting of three bystanders. The protocol referred to the Team Strategies and Tools to Enhance Performance and Patient Safety (TeamSTEPPS) and ACLS guidelines. TeamSTEPPS is a teamwork and communication systems model that has the potential to increase the effectiveness of team members with regard to leadership, communication, situation monitoring, and mutual support (15). As shown in **Figure 1**, the team-based CPR protocol divided the team-based CPR process into five parts, namely, (1) identification of cardiac arrest, (2) organization of a team (role distribution), (3) resuscitation before the AED arrives (Role A and Role B), (4) resuscitation after the AED arrives (Role A, Role B, and Role C), and (5) arrival of the ambulance. It concisely defined the roles and responsibilities of each member and emphasized the methods and importance of reasonable task allocation, leadership, and closed-loop communication within the resuscitation team. The protocol still highlights the critical elements of communication skills (call-out and check-back), cooperation skills (mutual support and knowledge sharing), and leadership skills (maintenance of a global perspective and task management).

The team-based CPR educational training contained a 10-min video course and a 20-min exercise. The 10-min video course strictly referenced the team-based CPR protocol and included an example demonstrating each step of it.

Effectiveness Assessment of the Team-Based CPR Educational Plan

We designed a before-after intervention simulation study for lay rescuers. Each group of three individuals was asked to operate

Team-based CPR protocol

This team-based cardiopulmonary resuscitation (CPR) protocol is designed for teams consisting of three bystanders. Roles of each member in the three-person teams during team-based CPR are demonstrated as Role A, Role B and Role C.

Importantly, within each step in the protocol, the actions of different roles are always simultaneous.

Throughout the team education process, all team members should be encouraged to:

- **Allocate roles and tasks directly to named individuals in a clear, loud and comprehensible way.**
- **Accept the conveyed orders quickly and provide instant feedback of confirmation.**
- **Question unclear instructions, non-optimal interventions and observable mistakes in a friendly and confident manner.**
- **Monitor the surrounding environment, the patient's clinical conditions, and resuscitation quality.**
- **Call for essential assistance and constructive advice early when knowing self-limitations in completing the allocated tasks.**
- **Encourage a calm environment of information sharing, mutual trust and respect, and collective efforts.**

The CPR procedure can be initiated as soon as someone falls down with unconscious and abnormal breath.

Key point: Early resuscitation, reduced hands-off time and early automated external defibrillator (AED) use through teamwork.

Step I Identification of cardiac arrest

The first arriving rescuer

- Verify scene safety.
- Check for conscience and breathing.
- Call for possible help loudly as soon as cardiac arrest is identified.

Step II Organization of a team

Role A

- Immediately start chest compression.
- Assign Role B and Role C to team members as they have negotiated before the simulation scenario.

Step III Resuscitation before the AED arrives

Role B

- Make an emergency call and give essential information. Join Role A after having hung up the call.

Role A

- Keep performing chest compression.
- After Role B has joined, perform the 30:2 compression-ventilation coordination. They should perform the chest compression in turn (e.g. every 3 cycles).

Attention: when there are two rescuers performing CPR, it's recommended that one rescuer performs chest compression while the other performs ventilation, which can reduce the intervals between compression-ventilation cycles. They should regularly exchange their tasks so that the rescuer performing chest compression will not be exhausted, which may greatly reduce the quality of CPR.

Role C

- Retrieve an AED.

Step IV Resuscitation after the AED arrives

Role C

- Operate the defibrillator.
- After the defibrillation, join Role A and Role B.

Role A and Role B

- Keep performing chest compression and ventilation. It's worth noting that during preparation of AED, chest compression and ventilation should not be interrupted.
- Only during rhythm analysis and defibrillation by the AED, chest compression and ventilation can be paused.

Role A, Role B and Role C

- After Role C has joined, chest compression should be performed in turns of three people.
- Continuing this cycle of 30 compression followed by 2 breaths until professional rescuers arrive.

Attention: Every 2 minutes, the AED will automatically re-analyze the rhythm of the patient and perform a defibrillation. Only during rhythm analysis and defibrillation by the AED, pause chest compression and ventilation.

Step V Arrival of ambulance

FIGURE 1 | Team-based cardiopulmonary resuscitation protocol. CPR, cardiopulmonary resuscitation; AED, automated external defibrillator.
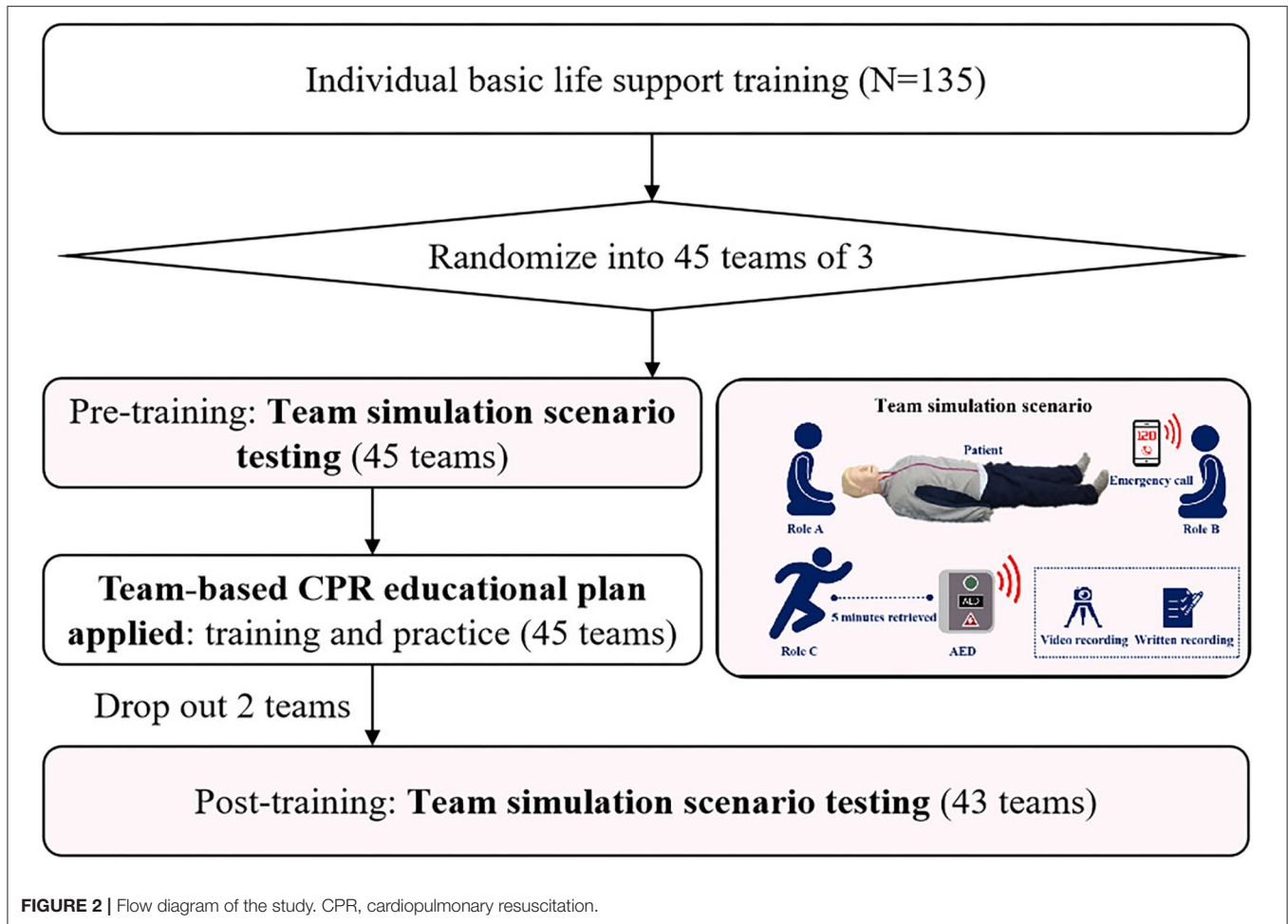
FIGURE 2 | Flow diagram of the study. CPR, cardiopulmonary resuscitation.

the OHCA resuscitation twice before and after the team-based CPR educational plan was applied in the simulated scenario. We evaluated whether the training with the team-based CPR protocol was associated with improving resuscitation quality and better-organized teamwork.

The team-based CPR simulated scenario was set in a quiet and isolated room with a manikin (Resusci Anne QCPR, Laerdal Medical, Stavanger, Norway) laid on the floor. Each team was required to assign and finish tasks including calling the emergency dispatcher, chest compressions, mouth-to-mouth ventilation, and retrieving and using an AED. The scenario started when each team walked into the room and stopped 10-min after they started the first chest compression. When Role C left and fetched the AED (Laerdal AED trainer 2, Laerdal Medical, Stavanger, Norway), he/she was required to return to the room after 5 min.

Before the simulated scenario started, researchers explained to the participants the tasks they needed to complete. No feedback was provided to the participants once the scenario started. The performance of each team throughout the entire scenario was recorded by three cameras from different angles: the head, the side, and the above.

Data Collection and Outcome Measures

Data were collected from manikin feedback, video recordings, and the evaluation of researchers to measure the resuscitation quality and teamwork of each team. Outcomes were collected before and after the training and submitted to a blind assessor.

The primary outcomes were the Team Emergency Assessment Measure (TEAM) scale and chest compression fraction (CCF) (16). The TEAM scale consists of 11 items measuring the teamwork behaviors of medical teams dealing with critical situations. It has been used in several clinical and simulation-based studies with comparable outcomes and has been proven to be the most appropriate and valid tool for evaluating teamwork in emergency teams (17, 18). The TEAM scale involves three categories: leadership (two items), teamwork (7 items), and task management (two items). Each item is rated on a five-point Likert scale. And then, a final global rating scale of 1 to 10 was used as an overall comprehensive review of performance (19). Researchers were previously instructed about how to use the scale and provided with specific training on the scoring criteria. Two researchers evaluated the TEAM scale by watching video recordings of each team independently and discussed it to reach a consensus on the evaluation. CCF was calculated using the equation: 1—(real hands-off time/total scenario time), in which

TABLE 1 | Comparison of the team-based CPR performance using Team Emergency Assessment Measure scale.

Team performance	Pre-training (n = 43)	Post-training (n = 43)	P-value[c]	P[d]corrected
Leadership[a]				
1. The team leader let the team know what was expected of them through direction and command	2.2 ± 1.5	3.6 ± 1.0	<0.001	<0.001
2. The team leader maintained a global perspective	2.4 ± 1.3	3.3 ± 1.0	<0.001	0.001
Teamwork[a]				
3. The team communicated effectively	2.9 ± 1.1	3.8 ± 0.4	<0.001	<0.001
4. The team worked together to complete tasks in a timely manner	2.6 ± 1.1	3.7 ± 0.6	<0.001	<0.001
5. The team acted with composure and control	2.9 ± 0.9	3.5 ± 0.7	0.003	0.04
6. The team morale was positive	1.8 ± 0.9	2.7 ± 0.6	<0.001	<0.001
7. The team adapted to changing situations	3.0 ± 1.1	3.9 ± 0.4	<0.001	<0.001
8. The team monitored and reassessed the situation	3.3 ± 1.5	3.9 ± 0.6	0.01	0.15
9. The team anticipated potential actions	2.3 ± 1.0	2.7 ± 1.0	0.03	0.37
Task management[a]				
10. The team prioritized tasks	2.9 ± 1.0	3.8 ± 0.6	<0.001	<0.001
11. The team followed approved standards/guidelines	2.9 ± 0.9	3.7 ± 0.4	<0.001	<0.001
Overall[b]				
12. Global rating	6.7 ± 1.3	9.0 ± 0.7	<0.001	<0.001

Values were shown as mean ± SD.
[a] Task management items are rated on a 5-point Likert scale.
[b] The overall performance is rated on a global rating scale of 1–10.
[c] p-Values were derived by paired sample t-test.
[d] Bonferroni's correction for multiple testing.

the hands-off time, including the delay at the beginning and all pauses, was measured in seconds using SimPad PLUS (Laerdal Medical, Stavanger, Norway).

Secondary outcomes included the quality of chest compressions, ventilation, AED performances, and time intervals during the resuscitation. The quality of chest compressions and ventilations were recorded using SimPad PLUS. AED performances were assessed by researchers using a dichotomous (yes/no) format. Time intervals during the resuscitation were measured using a stopwatch from the beginning of the simulated scenario. Participants' age, sex, and self-reported body weight were also documented.

Sample Size and Power Analysis

The study sample size was calculated based on a pilot study of six teams, in addition to participant availability considerations. A 5% change in CCF was considered a relevant difference. With statistical power of 90% and a two-sided alpha level of 0.05, the minimum number of teams was found to be 35. We recruited 45 teams (135 participants), considering the possibility of loss to the post-training and the participants' availability. Those six teams in the pilot period were included in the final analysis as the data were homogeneity.

Statistical Analysis

Data were presented as frequencies with percentages for categorical variables and means with SDs or median (interquartile range) for continuous variables. Differences in categorical outcomes were assessed using McNemar's test.

The Normal distribution was confirmed using the Kolmogorov–Smirnov test. Differences between pre-training and post-training were compared using the Wilcoxon matched-pairs signed-rank test for continuous variables with non-parametric distribution and the paired sample t-test for continuous variables with normal distribution. We use the Bonferroni correction to control the type I error rate when multiple testing is performed (20). All statistics were managed by Office Excel 2010 and analyzed using SPSS 24.0. Two-sided p-values < 0.05 were considered significant.

RESULTS

We recruited 135 medical students and randomly divided them into 45 resuscitation teams. Two teams were excluded from analyses due to loss after pre-training simulation assessment for urgent business (**Figure 2**). A total of 43 three bystanders' teams consisting of 129 participants were included for analysis with a mean age of 20.86 years (SD = 2.54) and a mean weight of 58.39 kg (SD = 12.22). In total, twenty-eight (21.7%) of them were men. The demographic characteristics of participants such as age, weight, and gender, did not differ between those who completed the post-training and those who did not.

After the plan was applied, the global rating of teamwork performance was significantly improved (6.7 ± 1.3 vs. 9.0 ± 0.7, $p < 0.001$) with all team performance dimensions significantly improved ($p < 0.05$) (**Table 1**). After applying Bonferroni's correction, the global rating of teamwork performance was

TABLE 2 | Team-based CPR operation assessment by three bystanders.

Parameters	Pre-training (n = 43)	Post-training (n = 43)	P-value[b]	P[c]corrected
Overall				
CCF (%)	59.0 (48.0–69.0)	64.0 (57.0-71.0)	<0.001	0.002
Hands-off time (s)	233.2 (181.0–264.0)	207.0 (174.0-222.9)	0.001	0.02
Overall score (%, 100 in total)	27.0 (18.0–47.0)	49.0 (34.0-64.0)	<0.001	<0.001
Chest compression				
Average compression depth (cm)	5.1 (4.7–5.6)	5.3 (4.9–5.5)	0.03	0.35
Deep enough compression (5-6 cm) (%)	65.0 (36.0–82.0)	72.0 (50.0–86.0)	0.02	0.24
Average compression rate (min^{-1})	112.0 (107.0–118.0)	121.0 (116.0–124.0)	<0.001	0.001
Compression with adequate rate (100–120 min^{-1}) (%)	75.0 (44.0–88.0)	51.0 (23.0–84.0)	0.02	0.24
Compression score (%, 100 in total)	76.0 (58.0–84.0)	82.0 (71.0–87.0)	0.005	0.06
Ventilation				
Average ventilation volume (ml)	518.0 (438.0–584.0)	570.0 (513.0–644.0)	0.02	0.26
Perform circles of 30 compressions and 2 breaths (%)[a]	31 (72.1)	38 (88.4)	<0.001	<0.001
Ventilation score (%, 100 in total)	55.0 (35.0–72.0)	65.0 (50.0–78.0)	0.06	0.79
AED support				
Placing the electrodes without flow time (%)[a]	31 (72.1)	41 (95.3)	<0.001	<0.001
Clear while AED delivers the shock (%)[a]	11 (25.6)	21 (48.8)	0.11	1.43

Values were shown as median (interquartile range).
[a]*Values were shown as n (%). p-Values were derived by McNemar's tests.*
[b]*p-Values were derived by Wilcoxon matched-pairs signed rank test.*
[c]*Bonferroni's correction for multiple testing.*
CPR, cardiopulmonary resuscitation; CCF, chest compression fraction; AED, automated external defibrillator.

still significantly improved (corrected $p < 0.001$). The team-based CPR plan still significantly improved participants' abilities in all the leadership dimensions (2/2) and task management dimensions (2/2), and parts of the teamwork dimensions (5/7) by adjusting Bonferroni's correction (corrected $p < 0.05$).

After the team-based CPR training, the CCF has significantly improved [median 59 (IQR 48–69) vs. 64 (IQR 57–71) %, $p < 0.001$] as hands-off time has decreased [median 233.2 (IQR 181.0–264.0) vs. 207 (IQR 174–222.9) s, $p = 0.001$] (**Table 2**). After applying Bonferroni's correction, the CCF and hands-off time remained significant (corrected $p = 0.002$ and corrected $p = 0.02$, respectively). The overall score for resuscitation performance was significantly improved [median 27 (IQR 18–47) vs. 49 (IQR 34–64)%, corrected $p < 0.001$]. We found the average compression depth was significantly improved through the team-based CPR training [median 5.1 (IQR 4.7–5.6) vs. 5.3 (IQR 4.9–5.5) cm, $p = 0.03$] but no more significantly by applying Bonferroni's correction (corrected $p = 0.35$). We found the compression depths were significantly improved by collaborating and exchanging the role of compression among the participants after the 6th min (**Figure 3**). The time points of compression depth were significantly improved at the 7th min (4.93 ± 0.57 vs. 5.22 ± 0.57 cm, $p = 0.02$), 8th min (4.83 ± 0.63 vs. 5.22 ± 0.55 cm, $p = 0.003$) and 9th min (4.86 ± 0.59 vs. 5.18 ± 0.57 cm, $p = 0.01$).

The emergency response time, including time to cardiac arrest identification [median 10 (IQR 7–16.3) vs. 7.0 (IQR 6–12) s, $p = 0.001$], time to open the airway [median 45.0 (IQR 36.0–63.0) vs. 39.0 (IQR 31–49) s, $p = 0.01$] and time to resume CPR

aftershock [median 5.8 (IQR 3.9–8) vs. 3.5 (IQR 3–4.1) s, $p < 0.001$] were significantly shortened after the educational plan was applied (**Table 3**). After Bonferroni's correction, the indicators above remained significant (corrected $p < 0.05$).

DISCUSSION

Optimal role assignment and effective cooperation in resuscitation are required when there are multiple bystanders on the scene of an OHCA. However, most of the established CPR training plans for bystanders only emphasize the technical skills of individual rescuers (21). As resuscitation effort is a time-consuming and labor-intensive task, it's indispensable to propose an educational plan to distribute the roles optimally and maximize the effectiveness of multiple bystanders, to guarantee the implementation of high-quality CPR for patients with OHCA. To our knowledge, this is the first study to innovatively design a team-based CPR educational plan for bystanders and implement quantitative analysis to evaluate its effectiveness and feasibility in a cardiac arrest simulated scenario. Our study demonstrated that team-based CPR training could significantly improve teamwork performance and resuscitation quality through positive and valid communication and cooperation. It increased the proportion of adequate compression depth, reduced hands-off time, avoided excessive ventilation, and ensured early defibrillation. The optimization of all these indicators would be theoretically associated with improved survival and neurological outcomes for patients with OHCA (7, 22, 23).

FIGURE 3 | Trends of chest compression depths in team-based cardiopulmonary resuscitation scenario.
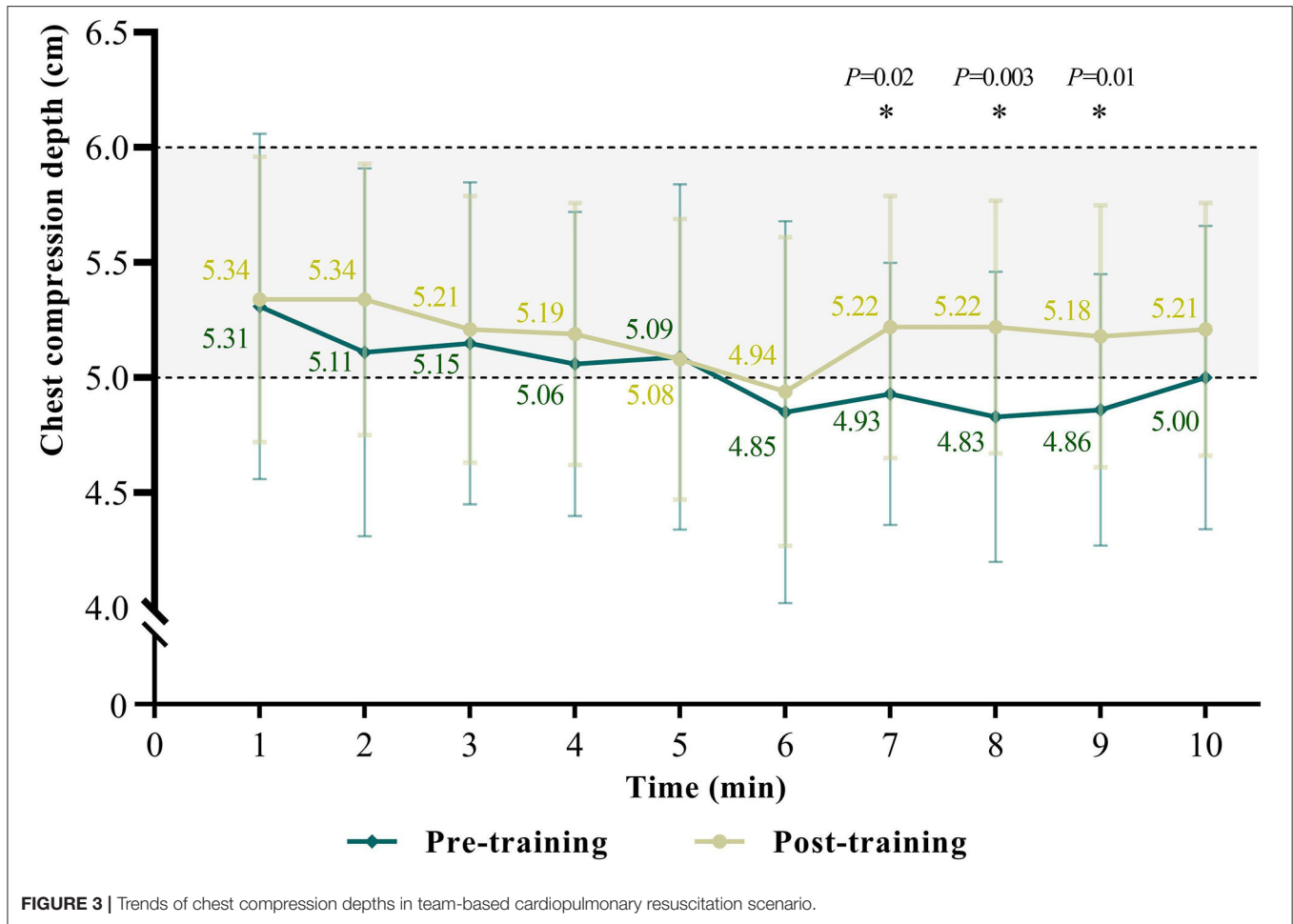
It was noted that, without team educational protocol, a group of three participants could not achieve ideal teamwork performance even though they had mastered the single-rescuer CPR skill. Poor performance was widespread in task allocation, leadership, and communication. Previous studies have revealed that not only technical skills of individuals but also professional teamwork is required to implement successful resuscitation for patients with OHCA with multiple bystanders on the scene (24). A good resuscitation team should possess skills in leadership, task management, effective communication, mutual supervision, and maintenance of guidelines (25). Consequently, it's necessary to emphasize team-based intervention in the CPR educational plan. Our team-based CPR plan emphasizes mutual support and cooperation throughout the resuscitation, ensuring high-quality CPR through properly allocating and shifting team member roles and providing defibrillation without interfering with basic chest compression and breathing. It has been proved to be effective to improve teamwork performance in this before-after intervention study.

Leadership in a competent team is essential for providing high-quality CPR (26). As multiple bystanders may feel bewildered in such a critical situation, a strong leader is important to calm them down, assign tasks, and coordinate

each member during the resuscitation. People who have received education about the team-based CPR plan are strongly recommended to take the responsibility as a team leader, delegating various functions to other untrained bystanders during the resuscitation. To sum up, the educational plan is expected to improve health literacy about public willingness to participate in team-based resuscitation and optimize the effectiveness of multiple bystanders.

The median CCF increased from 58 to 64% after the application of a team-based CPR educational plan. The estimated adjusted linear effect on the odds ratio of survival for a 10% change in CCF was 1.11 (95% confidence interval 1.01 to 1.21) (27). In addition, the guidelines have emphasized that hands-off time during CPR should be as short as possible, and a CCF of at least 60% is associated with better resuscitation outcomes due to the time-sensitivity of OHCA (28). We found the median CCF in the pre-training group didn't reach the recommended standard. This unsatisfactory CCF can be contributed to delayed and intermittent resuscitation performed by multiple bystanders, because of ambiguous duty distribution and ineffective communication. And it is confirmed that effective collaboration of multiple bystanders can improve the CCF by reducing pause time for necessary manipulation,

Time intervals	Pre-training (n = 43)	Post-training (n = 43)	P-value[b]	P[c]corrected
Time to cardiac arrest identification (s)	10.0 (7.0–16.3)	7.0 (6.0–12.0)	0.001	0.01
Time to call 1-2-0 (s)	14.0 (9.5–22.5)	12.0 (9.0–18.0)	0.05	0.28
Time to first chest compression (s)	18.0 (15.0–25.0)	15.0 (12.0–21.0)	0.001	0.01
Time to open the airway (s)	45.0 (36.0–63.0)	39.0 (31.0–49.0)	0.01	0.08
Time to first shock (s)[a]	381.0 (370.0–394.5)	378.0 (366.0–389.0)	0.05	0.32
Time to resume CPR after shock (s)	5.8 (3.9–8.0)	3.5 (3.0–4.1)	<0.001	<0.001

Values were shown as median (interquartile range), p-Values were derived by Wilcoxon matched-pairs signed rank test.
[a]*Including 5 min spent for the retrieval of AED.*
[b]*p-Values were derived by Wilcoxon matched-pairs signed rank test.*
[c]*Bonferroni's correction for multiple testing.*
CPR, cardiopulmonary resuscitation; 1-2-0, emergency dispatch number of China's mainland; AED, automated external defibrillator.

such as identification of OHCA, ventilation, defibrillation, or compression exchange between team members (29). Thus, the cultivation of leadership, communication, and cooperation skills during team-based CPR is highly emphasized in the educational plan to reduce hands-off time as much as possible. Satisfactorily, the team-based CPR educational plan was proven to be effective because there was a significant improvement in CCF after the training of our plan.

Our results revealed that compression depth was continuously deteriorating during 10 min CPR whether trained with the team educational plan or not. As noted, the proportion of adequate compression depth (5–6 cm) significantly improved after Role C took the AED back in the post-training group (**Figure 3**). Chest compression at an adequate depth has been recognized as an important aspect of high-quality CPR for a better prognosis patients with OHCA (30). It has been proved that compression depth begins to decrease after 90 to 120 s of CPR, and only 18% of the delivered chest compressions were at sufficient depth after 5 min of resuscitation in the previous study (31). The deterioration of compression depth during prolonged CPR can be mainly attributed to the progressive fatigue of bystanders (32). In terms of the substantial improvement following AED retrieval after our plan was applied, it is probably because role C joined in chest compressions instead of just operating AED in most of the pre-training teams, which relieved the fatigue of role A and B.

We portrayed a team-based CPR scenario to follow in a realistic environment. Although the high-fidelity manikin may not represent the diversity of patients' chests and changes in chest resistance during extended CPR (33), the information gained from our educational plan would help the participants perform proper CPR without unnecessary concerns. In the present team-based CPR plan, we educated the knowledge and attitudes toward safety in the resuscitation based on the AHA and ERC guidelines (12, 13). It has been reported that one of the common errors in CPR is failing to compress to an adequate depth (more than 5 cm but no more than 6 cm) (34). According to previous research (35), chest compression depth always decreased along with the time of performance due to fatigue. In the present study, the median depth after the training was 5.3 cm and none of the

delivered chest compressions were over 6 cm depth after the 1st min of resuscitation. We encourage the participants to push hard and deep during chest compressions and exchange the role of compression when they are physically tired in the team-based plan (36).

Team-based CPR plans for bystanders in resuscitation education are an important educational strategy with far-reaching application value. Studies about the effect of team-based CPR training on outcomes of patients with OHCA have mainly focused on ACLS so far, but it should extend to include bystanders in public as well (12). Limited health literacy prevents individuals from developing the knowledge, skills, and confidence necessary to engage in emergency preparedness. Although immediate bystander CPR has been shown to increase OHCA survival by two to threefold (37). Only a minority of bystanders are willing to attempt CPR for patients with OHCA because of lack of confidence, fear of harming the victim, and causing legal trouble. This highlights the importance of early bystander intervention and widespread education. Education of closed-loop communication and effective collaboration in resuscitation teams will reduce medical errors by individual rescuers, increase the willingness of trained bystanders to help patients in a life-threatening situation, and give participants the confidence to attempt resuscitation whenever needed (38). So far, a team-based CPR educational plan as an experimental unit has been applied in the WeCan CPR training program which is a thriving public BLS quality and basic CPR training program in China (33). The significant improvement in the teamwork performance and the resuscitation quality has proven the necessity to popularize the team-based CPR educational plan in the community and workplaces.

This study has several limitations. First, there may be selection bias because we recruited medical students aged 18–23 years. We recruited the participants without the clinical practice. Their CPR awareness and skill level were similar to the general students by questionnaire test. The young generation was considered the ideal population to improve health literacy. They are an important target group for CPR education because they are more likely to perform team-based CPR in practice. Second, this study was conducted in resuscitation teams of 3 people. In the real

action, there may be more than three laypersons on the scene. One of the critical elements of high-quality CPR for a team is the fluent cooperation among the rescuers to reduce the hands-off time. We suggest a team of more than 3 rescuers could also implement the team-based CPR protocol by shifting the roles of team members. Lastly, the design of the before-after study could reduce the impact of the confounding factors between groups, but we have to admit that the practice effect was present and could result in a motivational bias. For this reason, the skill retention potential of the team-based CPR plan was not evaluated in our present study. Further skill retention investigations are required in the future.

CONCLUSIONS

An innovative team-based CPR educational plan for lay rescuers could significantly improve the CPR quality and reduce the hands-off time of bystanders in terms of teamwork performance in a simulated scenario. This article verified the effectiveness and feasibility of an innovative team-based CPR educational plan for bystanders in the simulation study, which can be widely applied in the future educational program to increase health literacy and improve emergency preparedness for the public in real rescue events.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Joint Research Ethics Board of the Shanghai Jiao Tong University Schools of Public Health and Nursing (SJUPN-201913). The patients/participants provided their written informed consent to participate in this study.

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