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ORIGINAL RESEARCH

Evidence-Based Emergency Medicine

Randomized controlled trial comparing pit crew resuscitation model against standard advanced life support training

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This trial did not meet the definition of an applicable clinical trial (ACT) and thus, it was not registered in the Clinical Trials initially. During the conduction of the study, the authors however, saw for the best to conduct the Clinical trial registration anyway. The registration was done after the enrollment and ALS education but before analyzing the collected data.

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Abstract

Objectives: Pit crew models are designed to improve teamwork in critical medical situations, like advanced life support (ALS). We investigated if a pit crew model training improves performance assessment and ALS skills retention when compared to standard ALS education.

Methods: This was a prospective, blinded, randomized, and controlled, parallel-group trial. We recruited students to 4-person resuscitation teams. We video recorded simulated ALS-situations after the ALS education and after 6-month follow-up. We analyzed technical skills (TS) and non-technical skills (NTS) demonstrated in them with an instrument measuring TS and NTS, and used a linear mixed model to model the difference between the groups in the TS and NTS. Another linear model was used to explore the difference between the groups in hands-on ratio and hands-free time. The difference in the total assessment score was analyzed with the Mann-Whitney U-test. The primary outcome was the difference in the total assessment score between the groups at follow-up. ALS skills were considered to be a secondary outcome.

Results: Twenty-six teams underwent randomization. Twenty-two teams received the allocated education. Fifteen teams were evaluated at 6-month follow-up: 7 in the intervention group and 8 in the control group. At 6-month follow-up, the median (Q_1–Q_3) total assessment score for the control group was 6.5 (6–8) and 7 (6.25–8) for the intervention group but the difference was not significant ($U = 133$, $P = 0.373$). The

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intervention group performed better in terms of chest compression quality (interaction term, $\beta 3 = 0.23$; 95% confidence interval, 0.01–0.50; $P = 0.043$) at follow-up.

Conclusion: We found no difference in overall performance between the study arms. However, trends indicate that the pit crew model may help to retain ALS skills in different areas like chest compression quality.

KEYWORDS

advanced life support, clinical education, non-technical skills, pit crew model, RCT, resuscitation, simulation

1 | INTRODUCTION

1.1 | Background

Advanced life support (ALS) is a set of life-saving protocols and skills to provide urgent treatment to cardiac arrest.[1] It is a time-critical medical crisis where incorrect actions are associated with decreased survival rates.[2,3] A number of training techniques have been used as an effort to minimize these errors.[4–8] Simulation-based education in ALS is widely used, well-established,[8] and effective,[9,10] however, ALS skills deteriorate fast over time.[11,12] Additionally, drawbacks in resuscitation team organization and communication are frequent problems in true ALS.[13,14]

1.2 | Importance

Because unclear roles can cause errors during ALS,[1,15–17] more emphasis should be placed on educating specific roles and responsibilities to resuscitation team members. Pit crew models have been developed to respond to these problems: in these models all team members have their pre-assigned positions, roles, and tasks.[18–24]

Ideally, the management of ALS resembles a highly orchestrated formula 1 pit stop situation where the fast and well-coordinated teamwork is emphasized for a favorable result. This is called a pit crew model because the resuscitation team organizes themselves in 360° access to the patient that allows team members to immediately assume their pre-assigned positions, roles, and tasks. The model enables a highly choreographed approach for team members to initiate therapeutic tasks to the patient without specific instructions from the team leader.[18–24]

The pit crew model might be effective for in-hospital medical emergency teams[23] and in out-of-hospital cardiac arrest situations.[18,22] The aim of this approach is to minimize time delays in chest compression and defibrillation[17] and to perform the most important life-saving actions simultaneously according to the resuscitation algorithm.[1,25] It may clarify the crisis management by increasing the communication between the resuscitators. Further, the pit crew model may help the team physician to increase hands-free time from the ALS situation to maintain an overall perspective of the situation and only be involved in hands-on tasks, if required. This may help the physician to fully concentrate on the underlying pathologies that have led to the cardiac arrest (ie, H's and T's) and the decision making regarding treatment.

Predefined roles and tasks were first noticed as beneficial during patient hand-over.[26] Since then, several studies have demonstrated the benefits of a pit crew approach in a medical crisis like ALS.[18–23,27] However, a long-term benefit of pit crew training approach on ALS skills is yet unknown.

1.3 | Goals of this investigation

The aim of this study was to compare the long-term benefit of 2 different ALS training methods. We hypothesized that the pit crew approach would help maintain better ALS skills when compared to standard ALS education. Additionally, we explored if the model helps the team physician to increase hands-free time for other tasks and whether it contributed to the chest compression hands-on time.

2 | MATERIALS AND METHODS

2.1 | Study design and setting

We conducted this prospective, blinded, randomized controlled parallel-group study in a standardized simulation laboratory at the University of Turku, Faculty of Medicine in Finland. The trial conforms to the standards of the Declaration of Helsinki and was approved by the Ethics Committee of the Hospital District (31/2016), the hospital research authorities (T212/2016 and PA2/009/17), and the University of Applied Sciences Turku, Finland. The study was registered in ClinicalTrials.gov (NCT04364529). Informed written consent was obtained and the participants had a continuous option of withdrawing. No compensation was paid to participants. Data was treated confidentially. Reporting was done following the CONSORT guidelines.

2.2 | Selection of participants

We recruited volunteer 4th- to 5th-year medical students, 3rd to 4th-year paramedic students, and 4th-year nursing students (Figure 1).

The Bottom Line

Pit crew models of teamwork during critical resuscitations have been shown to clearly establish roles for more seamless care. When evaluated in advanced life support education, systemic evaluation found that the pit crew approach resulted in no clinically important differences to achieve key resuscitation goals at 6 months. Further application and clinical benefit of pit crew models in medical education needs to be pursued.

Inclusion criteria were as follows: (1) previous participation in simulated ALS training, (2) educational background as mentioned above, and (3) not more than 2 earlier participations in real-life ALS. The recruitment process included information e-mails, presentations, and promotion posters on the students' information board.

2.3 | Sample size calculation

We hypothesized that the pit crew model would show superiority to standard ALS training and used a 2-grade difference in the total assessment score of performance (scale 0-10)[28] providing an α level of 0.05, a power of 0.8, and a balanced setting in our sample size calculation. Based on our calculation, a total of 26 teams (104 students) were found to be a sufficient sample size to detect the defined difference.

2.4 | Educational interventions

The participants independently chose a date for the ALS simulation training to form 4-person training teams, including 1 medical student, 1 paramedic student, and 2 nursing students. We randomized the teams by a random-number generator into 2 parallel groups (intervention and control) with 1:1 ratio. We told participants that they would have ALS education in 2 ways, but participants did not know if they were in the intervention or control groups.

The education consisted of training of both technical skills (TS) and non-technical skills (NTS). TS are procedural based psychomotor techniques, which are needed in the application of the resuscitation algorithm (including chest compressions, rhythm identification and defibrillation, securing the airway and ventilation, and medication and fluid management). In contrast to TS, NTS are non-manual behavioral elements including cognitive or mental skills (eg, decision making, planning, and situation awareness) and social or interpersonal skills (eg, team-working, communication, and leadership) that contribute to safe and efficient team performance.[29–31]

One week before the ALS training day, the participants got the e-learning materials (Table S1). The overall content of the e-learning materials for both groups were similar, except that the intervention group received information about the pit crew model (standard operational procedure [SOP]) that described the roles and tasks of each participant in the team. The used pit crew model is a modified version of a previous project of the author (J.S).[32]

We arranged the first ALS-simulation training days in October 2017. The training of the TS and the resuscitation algorithm were the same in both groups. The difference in the NTS education between the groups was the pit crew model, which was taught only to the intervention group (Figure 2; Table 1). The details of the individual SOPs' are presented in the Supporting Information. The control groups were advised to organize themselves as they saw best: team members were advised to perform the division of labor by taking advantage of the skills of team members (Table 1).

Both groups first simulated 2 training simulations where after a third simulation, the ALS baseline simulation (Table S2), was video recorded. The scenarios were the same for both groups. ALS training was based on the European Resuscitation Guidelines.[8] The full content of the ALS training is presented in Table 1.

During the following 6 months, the participants were asked to study the given e-learning material and perform mental practice monthly. After 6 months from the training and baseline simulation, participants independently chose a date for ALS test simulation within the intervention and control groups to assemble new 4-person resuscitation teams. We ensured that the composition of the new resuscitation teams was completely new. In this way, we wanted to mimic real life situations, where the composition of the resuscitation team may differ from day to day. Then the new teams performed the ALS test simulation, which was video recorded (Table S2). We arranged a structured debriefing after each simulation scenario (Table S3). If a team member did not participate in their allocated ALS-session, the team would not be eligible, and we omitted the team from the study.

The trained simulation instructors were authors; V.P. (specializing physician in anesthesiology) in ALS-simulation training day and J.K. (registered nurse, paramedic) in the ALS test simulation.

2.5 | Measurements

Two blinded authors (M.R. and O.V.), both senior anesthetists and trained simulation instructors, evaluated the video-recorded ALS performances in random order. Both raters evaluated every video.

For the evaluation, the raters used the Instrument for the evaluation of ALS performance, which has been developed and published for research purposes.[28] The first section of the instrument, adherence to guidelines is devoted to the measurement of technical skills ($TS_{\text{total score}}$), whereas the rest measure non-technical skills ($NTS_{\text{total score}}$). Patient integrity and consideration of layman, and work routines were not evaluated. A rating scale from +2 to −2, and zero (0) was used for each item in the instrument. Zero was used only if the item could not be evaluated. Additionally, raters gave a total assessment score of performance on a scale from 0 to 10 (0 = poor, 10 = excellent) at the end of the instrument. The total assessment score was a subjective rating of the overall performance. The dimensions of the instrument and the evaluation scale are presented in the Table S4.

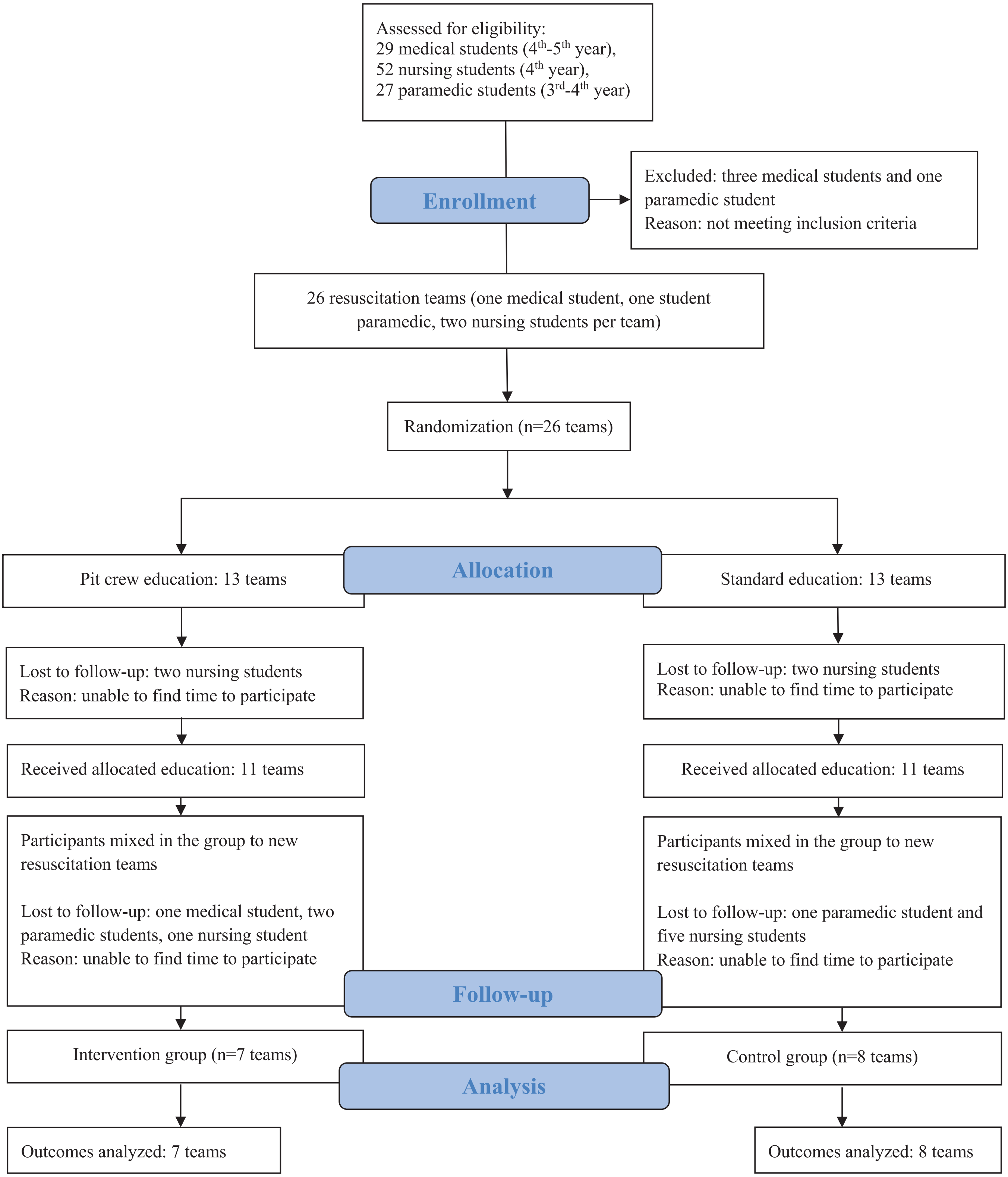

FIGURE 1 CONSORT flow diagram of study design and sample sizes

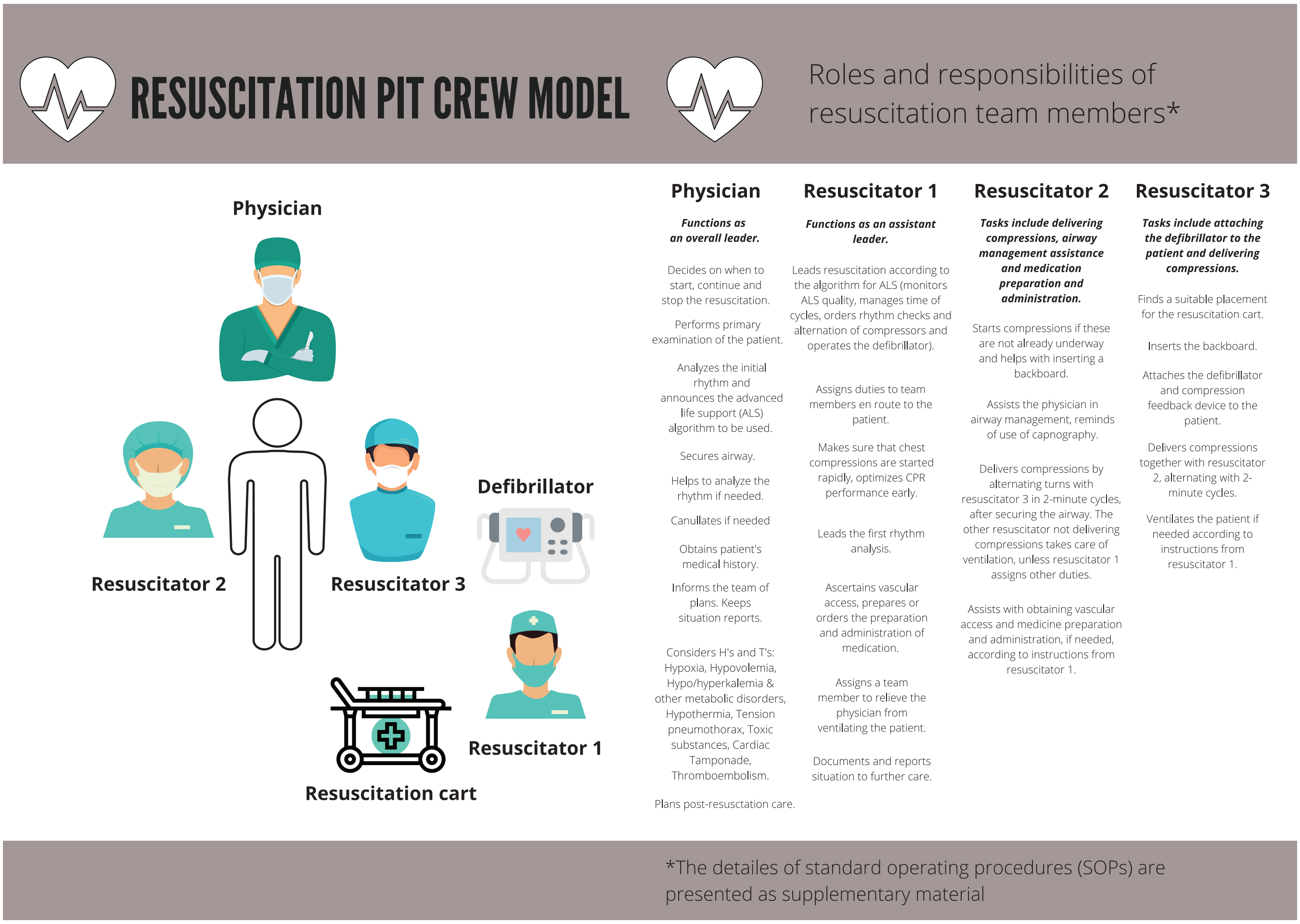

FIGURE 2 Resuscitation pit crew model with summarized responsibilities

The raters underwent 2 instruction sessions on how to use the instrument to ensure a consistent evaluation process. The raters were told not to make any judgments and only evaluate what really happened on the videos to avoid a bias. The raters discussed the evaluation criteria to standardize their grading during the evaluation process, but they made their evaluations independently. V.P. determined visually from the videos the hands-on time (time with chest compressions) and the time point when the team physician was hands-free from patient care.

2.6 | Outcome measures

The primary outcome was the difference in the total assessment score between the intervention and control groups after 6-month follow-up. The secondary outcome was the difference in ALS skills after 6-month follow-up. Additionally, we explored if the pit crew resuscitation model helped the team physician to take hands-free from the hands-on work and whether it contributed to the chest compression hands-on ratio (hands-on time divided by the total ALS time) between the groups.

2.7 | Statistical analysis

The items of the evaluation instrument were used to represent different ALS-metrics. The mean scores of each item evaluating TS and NTS were calculated for both raters and used as outcome variables. Zero values (0) were rescaled to missing values because 0 was used only when the item could not be evaluated. The pattern and frequencies of missing values (N/A) were inspected to assess the quality and representativeness of the data. No pattern was found, and all available data were used without imputation in the analyses. The hands-on ratio was calculated by dividing the hands-on time with the total length of the video.

Analyses were conducted with the R software version 3.6.3.[33] A linear mixed model (LMM) was used to model the difference between the groups in the TS and NTS. A linear model (LM) was used to explore the difference between the groups in hands-on ratio and hands-free time within the study period. In the models, group (β_1) and time (β_2) were used as fixed factors and reference levels were set to control group and baseline (β_0), respectively. The interaction term of the fixed factors (β_3) was included in the model to study if the change was different between the groups. The influence of raters on outcome variables

TABLE 1 Characteristics of study participants and the content of the ALS simulation training days

Characteristic	Participants All (*n* = 88)	Control (*n* = 44)	Intervention (*n* = 44)
Age, y			
Mean (SD)	26.6 (8.3)	27.2 (9.3)	26.1 (7.2)
Range	20 to 60	21 to 60	20 to 57
Female, No. (%)	71 (81%)	36 (82%)	35 (80%)
Male, No. (%)	17 (19%)	8 (18%)	9 (20%)

ALS-training day (baseline simulation)

The course of training	**Time to spend**
Pre-simulation[a] Information, consent Pre-simulation questionnaire	20 min
Training of TS and resuscitation algorithm[a] Presentation on high-fidelity manikin Presentation of devices and materials (contents of the resuscitation trolley, airway equipment, medicines, cannulation equipment, timer, documenting, etc) Hands-on test on devices in use • Starting patient monitoring (oxygen saturation, blood pressure, 3-lead ECG, capnography) • Performing cardiopulmonary resuscitation and using of CPR feedback device (Laerdal CPRmeter) • Mask ventilation and securing airway with supraglottic device • Using manual external defibrillator (ZOLL R Series Monitor/Defibrillator) Adult cardiac arrest algorithm. Recognition of the rhythm and management of underlying pathologies for example, H's and T's (hypoxia, hypovolemia, hypo/hyperkalemia and other metabolic disorders, hypothermia, tension pneumothorax, toxic substances, cardiac tamponade, thromboembolism)	70 min
Training of NTS Intervention group • Training presentation: an overview of the pit crew approach and potential value of it • Laminated SOP are given to each participant • The team organizes themselves in 360° access to the high-fidelity mannequin and each member assumes a position and role based on the pit crew model • Team practices the predetermined tasks of the pit crew model • The team organizes themselves and starts to perform ALS as "dry run" for 3 times to assume the roles Control group • The team organizes themselves as they see best: team members are advised to perform the division of labor (leadership, compressions, ventilation, airway management, cannulation, medicines, situation reports, clinical management, etc) based on skills of individual team members • Participants were advised to communicate effectively and to use closed-loop communication • The team organizes themselves and starts to perform ALS as "dry run" 3 times to make appropriate division of labor and find suitable positions	30 minutes
Simulation scenario 1: myocardial infarction (non-STEMI), VF Debriefing 1	10 min 20 min
Simulation scenario 2: pulmonary embolism, PEA Debriefing 2	10 min 20 min
Lunch break	20 min
Simulation scenario 3: myocardial infarction (STEMI), VF Debriefing 3	10 min 20 min
Post-simulation Final feedback	10 min

(Continues)

TABLE 1 (Continued)

Characteristic	Participants All (*n* = 88)	Control (*n* = 44)	Intervention (*n* = 44)
6-mo follow-up (test simulation)			
The course of training			**Time to spend**
Information Familiarization with high-fidelity manikin and the equipment in use			20 min
Simulation scenario 4: myocardial infarction (STEMI), VF Debriefing 4			10 min 20 min
Final feedback			up to 30 min

Abbreviations: ALS, advance life support; NTS, non-technical skills; PEA, pulseless electrical activity; SOP, standard operational procedures; TS, technical skills; VF, ventricular fibrillation.
[a]Same intervention for both groups.

was considered by adding the rater as a random factor in LMM. The difference in the total assessment score was analyzed with the Mann-Whitney U-test.

The results are presented by using medians with lower and upper quartiles (Q_1–Q_3). The estimated fixed coefficients of the model with 95% confidence intervals (95% CI) and *P*-values are reported. Visual inspection of model residuals was used for justification of the analyses. One group was excluded from the analyses of ventilation quality (−3.3 SD, intervention group, 6-month follow-up).

The inter-rater agreement (IRA) between the raters was assessed using the original instrument scale and Bangdiwala's B-statistic, a measurement for IRA for ordinal variables.[34] Visual inspection of overall and stratified agreement charts were used to evaluate if any bias was present. The overall B-statistic for both TS, NTS, and their subcategories are reported.

3 | RESULTS

3.1 | Characteristics of the evaluated videos

Twenty-six teams underwent randomization. Four students (2 students in each arm) retracted, and hence, 22 teams (88 study participants) received the allocated education. Ten students retracted during the 6-month follow-up (4 in the intervention arm, 6 in the control arm). Hence, 7 resuscitation teams in the intervention arm and 8 in the control arm were included in the analysis of ALS metrics after the 6-month follow-up. A total of 37 videos were evaluated (Figure 1): 11 videos of the control group (median length, 9:09 min; 8:54–9:26) and 11 videos of the intervention group (median length, 8:55 min; 8:43–9:13) at baseline, and 8 videos of the control group (median length, 9:40 min; 9:17–10:08) and 7 of the intervention group (median length, 9:40 min; 9:21–10:14) at 6-month follow-up. Table 1 presents the characteristics of participants.

3.2 | Consistency of raters

The IRA was slight for the total assessment score (B = 0.17). The IRA was substantial for $TS_{total\ score}$ (B = 0.77), chest compression quality (B = 0.62), and ventilation quality (B = 0.59) and perfect or almost perfect for the rest of TS subgroups (B ranging from 0.81 to 1.00). The IRA was substantial for $NTS_{total\ score}$ (B = 0.66) and for all NTS subgroups (B ranging from 0.61 to 0.74).

3.3 | Main results

At baseline, the median of the total assessment score was 8 for both the control (7–8.75) and intervention (8–9) group (U = 288, *P* = 0.260). There was no difference in ALS-metrics between the groups at the baseline (as represented by β_1). As represented by a negative β_2, $TS_{total\ score}$, recognition of the need for cardiopulmonary resuscitation, chest compression quality, rhythm control and defibrillation quality, $NTS_{total\ score}$, and division of labor, and information management deteriorated in both groups during the 6-month follow-up (Table 2; Figure 3).

At 6-month follow-up, the median total assessment score for the control group was 6.5 (6–8) and 7 (6.25–8) for the intervention group, but the difference was not significant (U = 133, *P* = 0.373). There were no differences in the ALS-metrics between the groups during the follow-up time (Table 2). The scatterplot of all the raw scores is presented in the Supporting Information.

However, the intervention group maintained somewhat better chest compression quality scores during the 6-month follow-up time (as represented by a positive interaction term, β_3 = 0.23; 95% CI 0.01–0.50, *P* = 0.043) (Table 2; Figure 3). The evaluation of chest compression quality consisted of 8 separately assessed items considering: correct compression quality, correct compression rate, correct compression-ventilation ratio, correct compression depth, complete chest recoil, minimizing the number of interruptions, minimizing the length of

TABLE 2 Scores for TS, NTS, physician hands-free times, and hands-on ratios at baseline and at 6-month follow-up

	Baseline		6-Months follow-up	
	Control (β_0) ($n = 11$)	Intervention (β_1) ($n = 11$)	Control (β_2) ($n = 8$)	Intervention (β_3) ($n = 7$)
$TS_{total\ score}$[a]				
EMM (95% CI)	1.81 (1.73, 1.90)	1.77 (1.70, 1.84)	1.57 (1.49, 1.65)	1.58 (1.47, 1.69)
Estimate (95% CI)	1.81 (1.73, 1.90)	−0.04 (−0.11, 0.03)	−0.24 (−0.32, −0.16)	0.05 (−0.06, 0.16)
P-value	$P < 0.001$	$P = 0.293$	$P < 0.001$	$P = 0.401$
Recognition of the need for cardiopulmonary resuscitation[a]				
EMM (95% CI)	2.00 (1.88, 2.12)	1.93 (1.76, 2.09)	1.60 (1.42, 1.78)	1.77 (1.52, 2.03)
Estimate (95% CI)	2.00 (1.88, 2.12)	−0.07 (−0.24, 0.09)	−0.40 (−0.58, −0.22)	0.24 (−0.01, 0.50)
P-value	$P < 0.001$	$P = 0.395$	$P < 0.001$	$P = 0.072$
Chest compression quality[a]				
EMM (95% CI)	1.73 (1.47, 1.98)	1.70 (1.57, 1.84)	1.48 (1.33, 1.63)	1.68 (1.46, 1.90)
Estimate (95% CI)	1.73 (1.47, 1.98)	−0.03 (−0.16, 0.11)	−0.25 (−0.40, −0.10)	0.23 (0.01, 0.45)
P-value	$P = 0.017$	$P = 0.724$	$P = 0.002$	$P = 0.043$
Ventilation quality[a]				
EMM (95% CI)	1.61 (1.43, 1.79)	1.69 (1.45, 1.72)	1.36 (1.21, 1.51)	1.67 (1.45, 1.89)
Estimate (95% CI)	1.61 (1.43, 1.79)	0.08 (−0.12, 0.28)	−0.14 (−0.36, 0.08)	−0.24 (−0.56, 0.08)
P-value	$P < 0.001$	$P = 0.444$	$P = 0.219$	$P = 0.153$
Rhythm control and defibrillation quality[a]				
EMM (95% CI)	1.91 (1.83, 1.99)	1.85 (1.73, 1.97)	1.70 (1.57, 1.83)	1.74 (1.56, 1.93)
Estimate (95% CI)	1.91 (1.83, 1.99)	−0.06 (−0.18, 0.06)	−0.21 (−0.34, −0.08)	0.10 (−0.08, 0.29)
P-value	$P < 0.001$	$P = 0.324$	$P = 0.002$	$P = 0.297$
Medication and fluid therapy[a]				
EMM (95% CI)	1.82 (1.66, 1.97)	1.71 (1.48, 1.93)	1.61 (1.37, 1.85)	1.34 (0.99, 1.69)
Estimate (95% CI)	1.82 (1.66, 1.97)	−0.11 (−0.34, 0.11)	−0.21 (−0.45, 0.03)	−0.16 (−0.51, 0.19)
P-value	$P < 0.001$	$P = 0.326$	$P = 0.100$	$P = 0.390$
$NTS_{total\ score}$[a]				
EMM (95% CI)	1.63 (1.44, 1.81)	1.56 (1.43, 1.70)	1.47 (1.32, 1.62)	1.42 (1.21, 1.64)
Estimate (95% CI)	1.63 (1.44, 1.81)	−0.07 (−0.20, 0.07)	−0.16 (−0.31, −0.01)	0.02 (−0.19, 0.24)
P-value	$P = 0.005$	$P = 0.334$	$P = 0.038$	$P = 0.833$
Decision making[a]				
EMM (95% CI)	0.90 (0.64, 1.16)	0.84 (0.47, 1.21)	0.77 (0.37, 1.18)	0.87 (0.28, 1.45)
Estimate (95% CI)	0.90 (0.64, 1.16)	−0.06 (−0.43, 0.31)	−0.13 (−0.53, 0.28)	0.16 (−0.43, 0.74)
P-value	$P < 0.001$	$P = 0.765$	$P = 0.542$	$P = 0.606$
Division of labor[a]				
EMM (95% CI)	1.75 (1.15, 1.99)	1.66 (1.50, 1.83)	1.55 (1.37, 1.72)	1.42 (1.16, 1.67)
Estimate (95% CI)	1.75 (1.51, 1.99)	−0.09 (−0.25, 0.08)	−0.20 (−0.38, −0.03)	−0.04 (−0.30, 0.21)
P-value	$P = 0.010$	$P = 0.300$	$P = 0.029$	$P = 0.744$
Team behavior[a]				
EMM (95% CI)	1.86 (1.59, 2.21)	1.81 (1.73, 1.90)	1.81 (1.71, 1.90)	1.74 (1.61, 1.88)
Estimate (95% CI)	1.86 (1.59, 2.12)	−0.05 (−0.13, 0.04)	−0.05 (−0.15, 0.04)	−0.02 (−0.15, 0.12)
P-value	$P = 0.028$	$P = 0.391$	$P = 0.274$	$P = 0.796$

(Continues)

TABLE 2 (Continued)

	Baseline		6-Months follow-up	
	Control (β_0) ($n = 11$)	**Intervention (β_1) ($n = 11$)**	**Control (β_2) ($n = 8$)**	**Intervention (β_3) ($n = 7$)**
Information management[a]				
EMM (95% CI)	1.64 (1.50, 1.79)	1.59 (1.39, 1.8)	1.41 (1.19, 1.63)	1.35 (1.03, 1.66)
Estimate (95% CI)	1.64 (1.50, 1.79)	−0.05 (−0.25, 0.16)	−0.23 (−0.45, −0.01)	−0.01 (−0.33, 0.30)
P-value	$P < 0.001$	$P = 0.664$	$P = 0.050$	$P = 0.932$
Physician hands-free time (s)[b]				
EMM (95% CI)	249 (194, 303)	202 (124, 279)	373 (285, 460)	314 (187, 440)
Estimate (95% CI)	249 (194, 303)	−46,9 (−123, 30.1)	124 (36.7, 211.3)	−12 (−138, 115)
P-value	$P < 0.001$	$P = 0.223$	$P = 0.007$	$P = 0.848$
Hands-on ratio[b]				
EMM (95% CI)	0.879 (0.866, 0.892)	0.880 (0.861, 0.898)	0.874 (0.854, 0.893)	0.892 (0.864, 0.921)
Estimate (95% CI)	0.879 (0.866, 0.892)	0.0002 (−0.018, 0.019)	−0.006 (−0.026, 0.014)	0.020 (−0.010, 0.047)
P-value	$P < 0.001$	$P = 0.979$	$P = 0.556$	$P = 0.197$

Note: The table presents the EMMs, the estimates, and *P*-values of linear model or LMM for each outcome together with 95% CI. The estimate of the intercept term, β_0, describes the expected mean of the control group at baseline, estimate of β_1 depicts how this mean differs from the control group, estimate of β_2 describes how the expected mean changed from the baseline to the end of the 6-month follow-up and the interaction term, β_3, indicates whether this change in time is different for the test group compared to the control group
Abbreviations: EMM, estimated marginal means; LMM, linear mixed model; NTS, non-technical skills; TS, technical skills.
[a]Scores could range from −2 to +2.
[b]Linear model.

necessary interruptions, and how the team evaluated cardiopulmonary resuscitation (CPR) quality.[28]

4 | LIMITATIONS

This study has several limitations. First, there was loss in participants, limiting the sample size. The substantial drop-out from randomization (n = 26 teams) to 6 months (n = 15 teams) was a major limitation. This makes the study likely to be underpowered and might also have caused a selection bias. It is possible that the participants with less confidence in their resuscitation skills more easily retracted from the study, and this could have had an impact on what was evaluated. To prepare the drop-out rate in participants, we wanted to recruit more students. However, the number of students meeting inclusion criteria in our university was limited. Second, the simulation scenarios were fairly straight forward. A more complex approach could have led to more differences between the groups. Mimicking the true complexity of ALS management in the simulation laboratory is challenging,[35,36] and pit crew models can provide much advantage in the unpredictable clinical settings. Due to technical challenges, we could not use the recordings of the CPR-feedback device. Assessing chest compression quality (ie, compression depth and chest recoil) would have been more reliable if we had used data collected by the CPR-feedback device in addition to the visual evaluation.[37] Third, the primary outcome was a subjective rating of overall performance. There was only slight agreement between the raters. Future research could use the ALS mean score for primary outcome measure. The teams' knowledge of being observed might have affected performance. Different results might be found in other environments, cultures, and in participants with different educational background. Additionally, we did not have a system for scoring actual compliance to the pit crew approach during the evaluation. Results of simulations are not necessarily generalizable to clinical settings. Trials in clinical setting are needed to confirm our findings.

5 | DISCUSSION

We found no difference between the study arms in ALS skill retention after 6 months of the ALS education. Yet, the pit crew model seemed to help retain somewhat better chest compression quality. Nonetheless, this distinction was minor and barely clinically relevant. However, because high-quality chest compressions with minimal interruptions is a crucial element effecting patient outcomes during ALS,[1,25] even minor improvements in chest compression quality may be pivotal.

As expected, ALS skills deteriorated in both arms on many levels during the follow up. Although not statistically significant, there were many interesting trends toward better performance in the intervention arm. First, the hands-on-ratio seemed slightly better in the intervention arm. Second, analyses suggest that the pit crew model may help retain TS and NTS in different areas as the interaction term (β_3) was mostly positive in the analysis of $TS_{total\ score}$ and $NTS_{total\ score}$ and in most of the analyzed subgroups. Third, the team physician in the intervention arm had hands-free time from patient care earlier

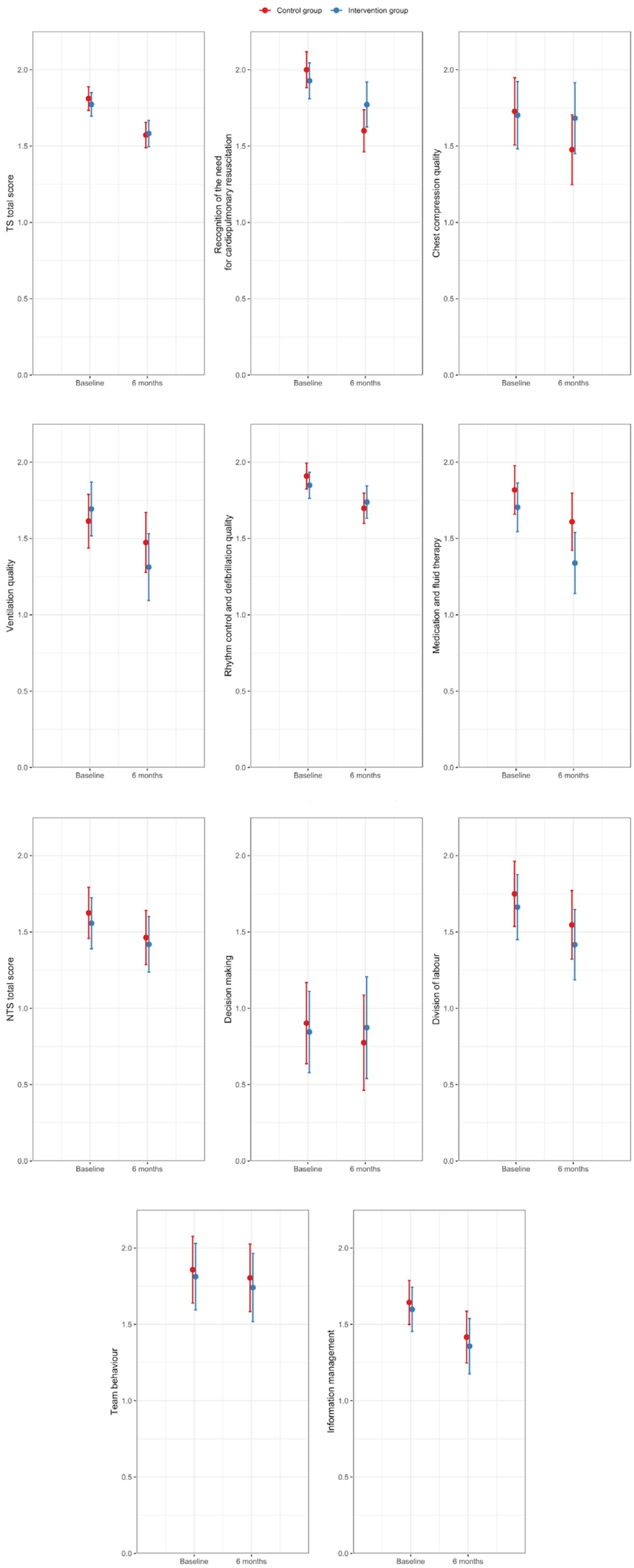

FIGURE 3 This figure illustrates the estimated marginal means with 95% CIs of control and intervention group at baseline and after 6-months follow-up according the linear mixed model

(12 s on average) than in the control arm. These findings indicate that the study could have been underpowered for these outcomes. Nonetheless, there seems to be an advantage with using the pit crew approach on chest compression quality even with this sample size.

We believe that a pit crew model diminishes unnecessary moving around, helping resuscitation team members to focus on performing high-quality CPR with minimally interruptions. This is considered to be a crucial element affecting outcomes during ALS.[1,25] Team members organized themselves around the patient according to this approach and assumed their roles and responsibilities. When following this approach, 2 team members (resuscitators 2 and 3) located themselves on both sides of the patient opposite to each other. In this manner, they can deliver shocks and perform chest compressions and ventilation by turns without a need to change their positions.

Human factors, like physical or mental pressure and other specific emotions, may be barriers to performing optimal ALS. Yet, little is known about perceived stress of health care professionals during ALS and whether stress is associated with ALS performance. In this pit crew model, the team leadership responsibilities are partly shared. After an airway is secured and an intravenous-access is verified, the assistant leader (resuscitator 1) is able to take control of the ALS algorithm so the physician can have hands free and focus on the clinical management and assessing the etiology of the cardiac arrest. This may relieve some of the cognitive load and stress. Altogether, the pit crew model is a part of high-quality cardiopulmonary resuscitation as it may balance the team TS and NTS performance. This also may help the team to follow the resuscitation algorithm, to perform chest compressions with minimally interruptions, and to defibrillate early.

The introduced pit crew model is adjustable according to local circumstances, requirements, and for resuscitation teams with different compositions. Because the tasks are predetermined, the configuration of the resuscitation team should not impact performance. It also seems to be easy to comprehend by people who rarely perform ALS. We believe that a pit crew model may reduce emotional and psychological post-resuscitation trauma, especially among less experienced rescuers like students and medical residents. A pit crew model may provide a cost-efficient method for resuscitation team members to rehearse ALS skills (eg, by mental practice). Very little research has been done about the effect of a pit crew model on trauma team performance.[38] The pit crew approach may help the trauma team leader to increase hands-free time for other important tasks. These could be a topic for future research.

Earlier studies have demonstrated the benefits of a pit crew approach. Spitzer and colleagues[23] implemented a pit crew model in their organization to provide in-hospital ALS. This intervention seemed to improve team communication and other ALS-metrics. In the study of Hopkins and colleagues,[22] the implementation of a pit crew approach and several other American Heart Association best practice recommendations improved patient survival and neurological outcome in the out-of-hospital setting. Further, the pit crew model reduces no-flow time and no-flow ratio of cardiac arrest teams that used a load-distributing band chest compression device.[21] Additionally, the pit crew models seem to encourage team members to adhere to guidelines[20] that are associated with improved outcomes.[39] Recently, to respond to the ongoing pandemic, Stinehart and colleagues[40] presented a modified pit crew model designed for management of cardiac arrest of patients with known or suspected COVID-19 infection. However, in 1 randomized controlled trial, the pit crew model did not have a positive effect on ALS performance.[41] In the study of Netherton,[24] implementation of a pit crew model was not associated with an improvement in survival to discharge after out-of-hospital cardiac arrest. Pit crew models have also been shown to be useful in other medical crises (eg, reducing time to start an endovascular stroke therapy).[27]

There are advantages with this study. First, we used a randomized, controlled, and blinded design for outcome evaluation. Second, the mean scores of the ALS skills directly after the educational ALS simulations were the same for both groups, which indicate that ALS skills of the both study arms were as equal as possible. ALS skills were generally rated to be on a high level indicating the high quality of ALS education in this study. Third, the structures of the resuscitation teams resembled real life: the participants had different educational backgrounds and they were mixed during the follow-up.

In this study, we present an in-hospital ALS pit crew model designed for resuscitation teams consisting of 4 members. We investigated if this pit crew model helps retain ALS skills in a simulation setting. We found no difference in overall performance between the study arms, however, there were trends indicating that the pit crew model may be to retain ALS skills in different areas like chest compression quality.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Ville Peltonen: Corresponding author, study design, conceptualization, methodology, validation, investigation, resources, data acquisition, data analysis, writing–original draft, writing–review & editing, final approval of the version to be submitted, visualization, project administration, and funding acquisition. **Laura-Maria Peltonen**: Study design, conceptualization, methodology, validation, investigation, writing–original draft, writing–review and editing, and final approval of the version to be submitted. **Matias Rantanen**: Investigation, data analysis, writing–original draft, writing–review & editing, and final approval of the version to be submitted. **Jaana Koskela**: Study design, conceptualization, methodology, resources, data acquisition, writing–review & editing, and final approval of the version to be submitted. **Olli Vänttinen**: Investigation, data acquisition, writing–review and editing, and final approval of the version to be submitted. **Katariina Perkonoja**: Study design, software, validation, formal analysis, data acquisition, data analysis, writing–original draft, writing–review and editing, visualization, and final approval of the version to be submitted. **Jari Säämänen**: Study design, conceptualization, resources, writing–review and editing, and final approval of the version to be submitted. **Sanna Salanterä**: Study design, conceptualization, methodology, validation, investigation, writing–review and editing, supervision, project administration, and final approval of the version to be submitted. **Miretta Tommila**: Study design, conceptualization, methodology, validation, investigation, resources, data acquisition, writing–original draft, writing–review and editing, supervision, project administration, and final approval of the version to be submitted.

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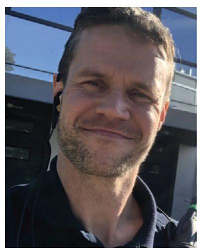

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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