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RESEARCH

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Impact of blended learning on manual defibrillator's use: A simulation-based randomized trial

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Abstract

Background: Blended learning, defined as the combination of traditional face-to-face instructor-led learning and e-learning course, has never been validated as a teaching method for the effective use of manual defibrillators in cardiopulmonary resuscitation.

Aim: To evaluate whether paediatric emergency and critical care providers exposed to a blended learning session performed better and recalled more defibrillator skills than those exposed to face-to-face learning only.

Study design: A two-period prospective, stratified, single-centre, simulation-based, randomized, controlled trial.

Methods: Registered nurses and postgraduate residents from either a paediatric emergency department or an intensive care unit were randomly assigned to a blended learning or face-to-face learning sessions on the recommended use of a manual defibrillator. Participants' adherence to recommendations was assessed by testing defibrillator skills in three consecutive paediatric cardiopulmonary scenarios performed on the day of the training and once again 2 months later. The primary endpoint was the number of errors observed during defibrillation, cardioversion, and transcutaneous pacing at the time of the initial intervention.

Results: Fifty participants were randomized to receive the intervention and 51 to the control group. When pooling all three procedures, the median total errors per participant was lower (2 [IQR: 1-4]) in providers exposed to blended learning than in those exposed to face-to-face learning only (3 [IQR: 2-5]; $P = .06$). The median of total errors per procedure was also lower. However, both training methods appeared insufficient to maintain appropriate skill retention over time as a repetition of procedures 2 months later without any refresher learning session yielded more errors in both groups.

Conclusions: Learners exposed to blended learning showed a reduced number in the total amount of errors compared with those exposed to face-to-face learning alone, with waning of skills over time.

Relevance to clinical practice: Proficiently teaching the use of a manual defibrillator can be performed through blended learning.

KEYWORDS
blended learning, defibrillator, education, educational technology, emergency medicine, nursing, paediatrics

1 | INTRODUCTION

Primary cardiac arrhythmias are relatively common among children, even without any underlying structural heart disease, and account for 55.1 per 100 000 paediatric emergency department (PED) visits.[1] However, those requiring prompt electrical therapy to terminate rhythm disturbances and restore adequate perfusion in poorly perfused patients are rare. They include supraventricular and ventricular tachycardia with a pulse requiring immediate synchronized cardioversion and symptomatic bradycardia requiring transcutaneous pacing for patients unresponsive to pharmacological therapy. Despite the low frequency of these events, doctors and nurses working in PED and paediatric intensive care units (PICUs) should be prepared to manage them without delay as they may rapidly lead to cardiopulmonary compromise and cardiac arrest when left unrecognized or untreated. In addition, arrhythmias like pulseless ventricular tachycardia or ventricular fibrillation, accounting for 27% of paediatric arrhythmia-related in-hospital cardiac arrests[2] and 7.8% of out-of-hospital,[3] require immediate defibrillation.

Automatic external defibrillators (AEDs) are extensively deployed to rapidly manage sudden cardiac arrest in adults. Within paediatric hospital settings, however, unless an AED with energy attenuation is provided, manual defibrillators are still preferred.[4] Because AEDs do not deliver synchronized shocks, they cannot be used for cardioversion or pacing. The American Heart Association (AHA) thus recommends that PED and PICU should have manual external defibrillators and skilled health care providers available to promptly and proficiently perform defibrillation, synchronized cardioversion, or pacing.[4,5] It is therefore mandatory that in-hospital first responders, mostly nurses and residents, are adequately trained for these procedures.[6] Low retention of cardiopulmonary resuscitation (CPR) skills over time[7] reinforces the need for providers to be repeatedly trained to and supervised for the use of manual defibrillators in order to maintain a high level of competence.[8-11] In 2018, the AHA highlighted the evidence supporting the best educational and knowledge translation strategies in resuscitation.[12] While the amount of literature investigating and promoting AED training is large, evidence regarding educational methods to operate manual defibrillators is scarce, especially in the paediatric population. Instructor-led and face-to-face sessions probably remain the standard teaching methods in most hospitals.

What is Known About the Topic

- The American Heart Association recommends that hospital-based health care providers with a duty to perform cardiopulmonary resuscitation and emergency electrical therapy be trained to use manual defibrillators.
- Blended learning, in which traditional face-to-face learning is combined with online e-learning, has been widely used in nursing and medical education in recent years.
- While the amount of literature investigating and promoting automatic external defibrillator training is large, blended learning has not been evaluated as an educational tool for learning manual defibrillator skills in paediatric emergency situations.

What this Paper Adds

- Blended learning is as effective as traditional face-to-face learning for paediatric emergency care skills in the field of emergency electrical therapy using a manual defibrillator by nurses and physicians.
- The results of this randomized trial provide valuable information for making blended learning a promising educational medium for training health care providers in the use of manual defibrillators.
- This suggests that blended learning may be a feasible alternative to face-to-face learning for hands-on manual defibrillator skill acquisition in paediatric emergency departments.

Computer-based e-learning offers the advantage for the learner to complete the course at an optimal timeframe and shifts the paradigm from a constraining instructor-led model to one that is on-demand, interactive, flexible, readily available at any time, resource-sparing without the need for local faculty assistance, and learner-centred. Moule et al have suggested that e-learning courses could improve CPR skills and the use of AED more effectively than classroom training for nurses.[13] However, a Cochrane systematic review has highlighted that e-learning alone is associated with only a small positive effect in terms of licensed health professionals' behaviours,

skills, or knowledge when compared with traditional learning methods with no access to e-learning.[14] Blending e-learning with traditional learning methods (blended learning, BL) might be more suitable for health care training than courses relying only on e-learning methods because of the need to acquire practical skills.[15,16]

To our knowledge, no study has investigated whether the exposure of paediatric health care providers to BL vs traditional learning methods (ie, face-to-face instructor-led learning course, FFL) may result in a reduction in error rates when using a manual defibrillator for emergency electrical therapies (ie, defibrillation, cardioversion, and transcutaneous pacing). The aim of this study was to test whether exposure to BL composed of a computer-based manual defibrillator e-learning course and face-to-face instruction would improve residents and nurses' manual defibrillator skills compared with FFL.

2 | METHODS

2.1 | Design

This was a two-period prospective, stratified, randomized, controlled trial (Figure 1) led among nurses and residents, to compare the effect of exposure to a BL session comprising an asynchronous e-learning course and face-to-face standardized instruction on the recommended use of a manual defibrillator to a traditional standardized didactic FFL session. Immediately after training, participants' adherence to recommendations was assessed by testing manual defibrillator skills in three consecutive standardized simulation-based paediatric CPR scenarios performed on the day of the training (first period) and once again 2 months later (second period). No changes were made to the course content over the study period. The trial was conducted according to the CONSORT[17] and the Reporting Guidelines for Health Care Simulation Research.[18] The resuscitation guidelines and specifications defined by the AHA are those followed and applied in Switzerland and throughout this study.

2.2 | Participants

PED and PICU nurses with registered Basic Life Support certification, renewed on an annual basis, were eligible for inclusion. Postgraduate year-1 to year-5 residents actively training in the department of paediatrics were also eligible. At our institution, all residents participate in a simulation-based continuing CPR education programme with several 2-hour sessions per year, including hands-on practice and debriefing using the AHA guidelines. The formative curriculum is intended to be complementary to AHA BLS and PALS courses. Nurses and residents were randomly selected on the day of the study from a list of staff on duty. Written informed consent was obtained before their involvement. Lack of past previous use of a defibrillator was not an exclusion

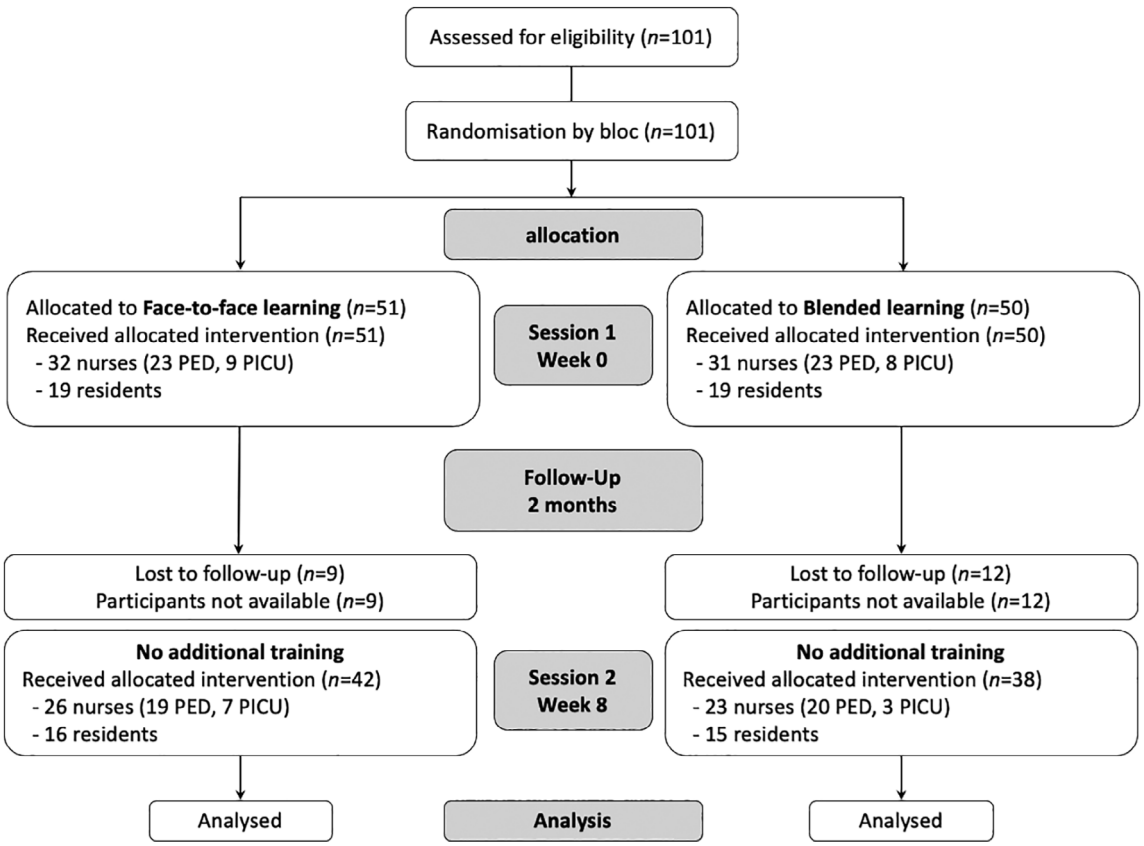

FIGURE 1 CONSORT flow chart

criterion. Participants were instructed that they would have to use a manual defibrillator.

2.3 | Educational intervention

The education session invariably began with a 20-minute FFL course provided to each participant in a similar manner in terms of educational content and flow. Each function of the manual defibrillator Philips HeartStart MRx biphasic defibrillator (Koninklijke Philips N.V., The Netherlands) and manipulations was explained and demonstrated on the machine itself. The same was true for the associated equipment (ie, ECG cables, pads, etc). In particular, as recommended at our institution, participants were taught that once electrical and mechanical capture had been achieved during transcutaneous pacing, the mA current intensity should be set 10% above the capture threshold as a safety margin. The defibrillator pads were taught to be placed on the child's chest in an anteroposterior configuration. The course was provided once per participant. Participants allocated to the blended learning arm did the FFL course and immediately after had an additional training with a tailored and gamified 20- to 30-minute e-learning course (Supplementary Appendix and Figures S1-S3). Those allocated to the face-to-face learning arm only followed the FFL course. The content of the e-learning was exactly the same as that taught in the FFL. The FFL and e-learning content was taught exactly as it was tested during the intervention.

2.4 | Setting

The study was conducted in a tertiary hospital in Switzerland (Geneva University Hospitals). Two sets of three standardized scenarios each (Appendix) were created to be run on a high-fidelity manikin (Laerdal SimJunior, Laerdal Medical, Norway). The scenarios were conducted in situ in the PED shock room to increase realism. The content of the scenario was not revealed before the intervention started to avoid preparation bias.

2.5 | Outcome measures

The primary outcome was the total number of errors observed during the three scenarios (defibrillation, cardioversion, and transcutaneous pacing) in each study arm during the first study period. This outcome immediately relates to the correct use of the defibrillator and proper delivery of electrical procedures. The following error-prone dichotomic variables were measured in each study arm and for each scenario: (a) correct paediatric pad size and anterior-posterior placement in the centre of the exposed child's chest $+/-1$ cm; (b) correct defibrillator operating mode; (c) adequate choice of energy dose according to AHA recommendations[4,5] for the arrhythmia being treated; (d) load of energy dose; (e) verbalization of the safety precaution measures before shock delivery; and (f) delivery of electric current.

Secondary outcomes were (a) the total number of errors made during a second study period testing the same electrical procedures on three new scenarios showing the same rhythm disorders, (b) the delay (in seconds) required to complete the electrical procedures in each of the two study periods. For pacing, the time from the verbal order to set the stimulation rate at the desired pacing frequency, as well as the time to achieve 100% capture with a 10% safety margin, was assessed.

2.6 | Measurement and data collection

Primary and secondary outcomes were collected through direct, standardized observations to be completed during the scenarios. Three standardized skills checklists (Appendix) were developed for this purpose. They were constructed by two Paediatric Advanced Life Support (PALS) instructor-certified emergency doctors (JNS and LL) through a detailed review of the AHA guidelines for CPR and emergency cardiovascular care.[5] They were also tailored according to the AHA rhythm disturbance/electrical therapy skills station competency checklist[19] and the manufacturer's instructions[20] to ensure content validity. By using standardized checklists, we aimed to reduce assessment bias. We defined the error as an incomplete or incorrect completion of any of the aforementioned items. To assess the reproducibility of the scoring procedure, two experienced and trained investigators (JNS and LL) independently scored the first 10 participants (10%) using a dichotomous (correct/not correct) scale for each item of the primary outcome during the first study period. Both investigators were blinded to each other's scores. A single observer (JNS) scored and timed the remaining participants during both study periods. Data were then manually retrieved and entered into a Microsoft Excel spreadsheet (version 2011). Unaccomplished actions were left blank and not assigned to any corresponding time.

2.7 | Sample size

In a previous unpublished pilot study among 30 participants (PED and PICU nurses, and paediatric residents), based on a similar intervention, the mean difference in the total number of pooled errors for the three scenarios between the BL (40 errors) and FFL groups (57 errors) was 1.13 (30% error reduction), with a pooled standard deviation (SD) of 2.0. Based on these results and in order to detect a similar absolute difference of at least 30% in the proportion of errors between both groups in the first study period with 80% power and 95% confidence interval (CI), the calculated sample size was 50 participants per study arm.

2.8 | Randomization, blinding, and allocation concealment

Once written consent was obtained and baseline assessments completed, participants were stratified by occupational category (resident;

PED nurse; PICU nurse). Blinding to the purpose of the study during recruitment was maintained to minimize preparation bias. Allocation concealment was performed using www.sealedenvelope.com to generate the randomization list and was not released until participants completed the FFL training session. Participants were then randomly allocated to one of the two arms in a 1:1 ratio by drawing lots (Figure 1). Participants and investigators were unblinded after randomization.

2.9 | Statistical analysis

2.9.1 | Primary outcome

We first evaluated the total number of errors concerning the use of the defibrillator for each of the three scenarios during the first study period. The number of errors was expressed as absolute frequencies (n) and percentages (%) with 95% CIs. Non-normally distributed variables were analysed using the Mann-Whitney test. The percentage of participants completing each procedure appropriately (ie, without error) was documented. Detailed errors for each of the six key actions per scenario were numbered and computed in contingency tables and Chi-squared or Fisher's exact tests were used to assess the relationship among variables. A Mann-Whitney test for unpaired data was used to compare interventions. Differences were reported by allocation group.

2.9.2 | Secondary outcome

The total number of errors concerning the use of the defibrillator for each of the three new scenarios during the second study period was evaluated similarly than in the first study period. For each scenario in both study periods, we evaluated the time in seconds (continuous variable) elapsed between the task order and subsequent defibrillation, cardioversion, and pacing attempts. Continuous variables were expressed as means with 95% CIs or median and interquartile ranges when analysing large disparity data in the subjects. A Mann-Whitney test was performed for quantitative variables. Paired data were compared between both study periods using McNemar's test or Wilcoxon tests, depending on whether the data were categorical or continuous. Kaplan-Meier curves for time elapsed between the task order and defibrillation, cardioversion, and pacing were estimated and compared using the log-rank (Mantel-Cox) test for bivariate survival analysis.

Finally, a comparison of the average total number of errors was performed using Wilcoxon rank-sum test to determine any effect by the following variables: "PALS training" (previous AHA PALS certification or no previous AHA PALS certification); "years of experience" (<3 or ≥3 years); and "occupation category" (resident or nurse). SPSS, version 22 (IBM Corporation, New York) was used for analyses, and GraphPad Prism, version 9.0 (GraphPad Software, Inc., California) for graphics. A P value <.05 was considered significant.

2.9.3 | Ethics approval

The study received a declaration of no objection by Swissethics and the Geneva Ethics Committee (Req-2019-00080) as the purpose of the study was to examine the effect of the intervention on health care providers. For the same reason and according to the International Committee of Medical Journal Editors, a trial registration number was not required. Confidentiality was ensured during the entire study process, and participants were anonymized by assigning them an ID. Data were safely stored in duplicate on secured hard disk drives and kept in a locked cabinet in a secure location at the Geneva Children's Hospital. The study was undertaken with the understanding and written consent of each subject and according to the principles of the Declaration of Helsinki, the standards of Good Clinical Practice, and Swiss regulatory requirements.

3 | RESULTS

3.1 | Participants' characteristics

From 1 March 2016 to 30 September 2017, 101 nurses and residents were included and randomized (50 in the BL group and 51 in the FFL group) (Figure 1). Randomization was adequate with balanced baseline characteristics between the two groups (Table 1). All participants accessed and successfully completed the e-learning without assistance. There was no crash of the online connection. We observed excellent inter-rater reliability scores using Cohen's kappa coefficients for the primary outcome (Kappa coefficients = 1), and excellent inter-rater agreement scores using intra-class correlation coefficients (ICC) for the secondary outcome (ICC = 1).

3.2 | Main results

Health care providers exposed to BL showed fewer median total errors per participant for the three electrical procedures pooled (2 [IQR: 1-4]) than those exposed to FFL only (3 [IQR: 2-5]), approaching statistical significance ($P = .06$) (Table 2). The distribution of the cumulative number of errors by study group for the three electrical procedures pooled during the first study period, as well as the cumulative number for each type of procedure considered separately, is shown in Figure 2. Defibrillation, cardioversion, and pacing errors stratified by participants committing 0 errors during the first study period are summarized in Table 2. Participants in the BL group performed more error-free procedures than those in the FFL group, although this was not statistically significant. Cardioversion was the procedure with the highest rate of errors. For defibrillation and cardioversion procedures, the most common errors were observed during pad placement, selection of energy, and recall of safety measures (Table S1). Whereas the defibrillation mode selection was error-free, the synchronized mode selection during cardioversion was problematic in both allocation groups. For the

TABLE 1 Participants' demographics and clinical characteristics

Demographics and clinical characteristics	Randomization arm	
	FFL (N = 51)	BL (N = 50)
Mean age in years	34.8 (±8.6)	35.0 (±8.3)
Nurses	37.9 (±9.3)	38.5 (±8.7)
Residents	29.4 (±3.1)	29.3 (±2.4)
Gender (female/ male)	45/6 (88.2)	47/3 (94)
Occupation		
PED nurses	23 (45.1)	23 (46.0)
PICU nurses	9 (17.6)	8 (16)
Residents	19 (37.3)	19 (38.0)
Clinical experience since registration in years		
PED nurses	14.7 (±11.3)	14.3 (±9.6)
PICU nurses	14.3 (±6.1)	10.8 (±3.5)
Residents	3.5 (±2.2)	4.2 (±3.7)
PALS training		
Nurses	9/32 (28.1)	10/31 (32.3)
Residents	12/19 (63.2)	10/19 (52.6)
Previous PALS certification in years		
Nurses	2.1 (±5.5)	1.7 (±2.8)
Residents	2.5 (±2.1)	2.6 (±2.5)
Simulation scenarios performed in the last past 6 years		
PED nurses	5.0 (±3.6)	7.1 (±5.7)
PICU nurses	2.6 (±2.0)	4.3 (±2.5)
Residents	4.4 (±2.8)	4.7 (±3.6)
Previous use of a manual defibrillator since registration		
PED nurses	5.5 (±14.2)	6.5 (±15.3)
PICU nurses	3.8 (±2.2)	3.0 (±3.5)
Residents	2.1 (±3.6)	1.6 (±2.7)
Level of self-confidence in the use of a manual defibrillator		
PED nurses	2.3 (±0.69)	2.3 (±0.5)
confident	3/23 (13.0)	1/23 (4.3)
knows theory, not confident	11/23 (47.8)	15/23 (65.2)
needs theory reinforcement	9/23 (39.1)	7/23 (30.4)
PICU nurses	1.7 (±0.5)	1.8 (±0.7)
confident	3/9 (33.3)	3/8 (37.5)
knows theory, not confident	6/9 (66.7)	4/8 (50.0)
needs theory reinforcement	0/9 (0)	1/8 (12.5)
Residents	2.4 (±0.7)	2.0 (±0.7)
confident	2/19 (10.5)	5/19 (26.3)
knows theory, not confident	7/19 (36.8)	9/19 (47.4)
needs theory reinforcement	10/19 (52.6)	5/19 (26.3)

Note: Data are means (SD) or numbers (%).
Abbreviations: BL, blended learning; FFL, face-to-face learning; PALS, Paediatric Advanced Life Support; PED, paediatric emergency department; PICU, paediatric intensive care unit.

TABLE 2 Errors and time to emergency electrical therapies during the first study period

Procedure	FFL (N = 51)	BL (N = 50)	Hazard ratio (95% CI)	*P* value
	Median [interquartile range (IQR)] errors per participant			
Defibrillation	1 [0-1]	1 [0-1]		.56
Cardioversion	1 [1-2]	1 [0-1.75]		.11
Pacing	1 [0.5-2]	1 [0-1]		.11
Total for three procedures	3 [2-5]	2 [1-4]		.06
	Number (%) of participants performing error-free manipulations			
Defibrillation	21 (41.2)	24 (48.0)		.50[a]
Cardioversion	10 (19.6)	15 (30.0)		.14[a]
Pacing	13 (25.5)	17 (34.0)		.62[a]
All three procedures	3 (5.9)	5 (10)		.19[a]
	Median [IQR] time to electrical procedure in seconds			
Defibrillation	55 [42-70]	51 [45-62]	0.91 (0.62-1.35)	.66[b]
Cardioversion	62 [54-106]	62 [52-89]	0.82 (0.55-1.21)	.46[b]
Setting the pacing rate at 90 bpm	103 [72-142]	90 [69-140]	0.89 (0.60-1.32)	.46[b]
Setting mA (achieving 100% capture)	170 [128-212]	160 [115-244]	1.15 (0.78-1.70)	.91[b]

[a]Fisher's Exact test.
[b]Mann-Whitney test.
Abbreviations: 95% CI, 95% confidence interval; BL, blended learning; bpm, beats per minute; FFL, face-to-face learning; N, total number of participants.

pacing procedure, pad placement and setting the adequate pacing rate and energy were the most frequently encountered types of errors. Finally, we observed that PALS training and years of experience did not modify the intervention's effect in terms of errors, whereas occupation category favoured a reduction in errors for residents exposed to BL vs nurses (Table S2).

3.3 | Secondary outcomes

Repetition of the three procedures 2 months later without any refresher learning course in between yielded less participants with no error in their scenarios than in the first study period in both allocation groups (Table S3). Also, median defibrillation and pacing errors per procedure, as well as median total errors involving all three procedures, increased significantly from the first to the second study period in both groups (Table S4), suggesting that the loss of performance was independent of the intervention. Regarding cardioversion, we did not observe significant increase in the second study period. The most common areas for increased error rates were selection of the correct defibrillation energy dose, safety measures, and the setting of the correct mA dose in the pacing scenario (Table S1).

Median times between rhythm recognition by the study investigator to defibrillation, cardioversion, and pacing during the first and second study periods are summarized in Table 2 and Table S3, respectively. No differences were observed between participants exposed to BL or FFL, irrespective of the study period (Figure S4). In both groups, the defibrillation attempt was performed within a minute. It took more time for all participants to defibrillate, cardiovert, and pace in the second study period than in the first period.

4 | DISCUSSION

We report the first randomized controlled trial comparing the effect of traditional FFL vs BL in nurses and residents on the adequate use of a manual defibrillator and subsequent skill acquisition and retention over time for defibrillation, cardioversion, and transcutaneous pacing. Overall, BL was as effective as traditional FFL. Median error per provider for the overall recommended procedures showed a trend towards a lower number of errors after exposure to a unique BL course (ie, FFL + e-learning) than to a traditional FFL course. This trend was noticeable for cardioversion and pacing, but not for defibrillation, with a sample size that did not allow significance to be reached at the procedure level. This error reduction was observed with the same magnitude and direction regardless of AHA PALS training and years of experience, thus suggesting a worthwhile benefit of its use by caregivers with different experience levels. In addition, it can be argued that not making any errors at all when using a defibrillator in critical situations is probably more clinically relevant than just reducing them. Although our findings did not reach significance, we observed that the number of error-free manipulations was higher in the BL group for all procedures. Our findings suggest that BL holds promise as an educational tool for teaching the use of manual defibrillators in paediatrics.

Residents and nurses working in PED and PICU often serve as front-line responders to inpatient resuscitations. Among essential CPR

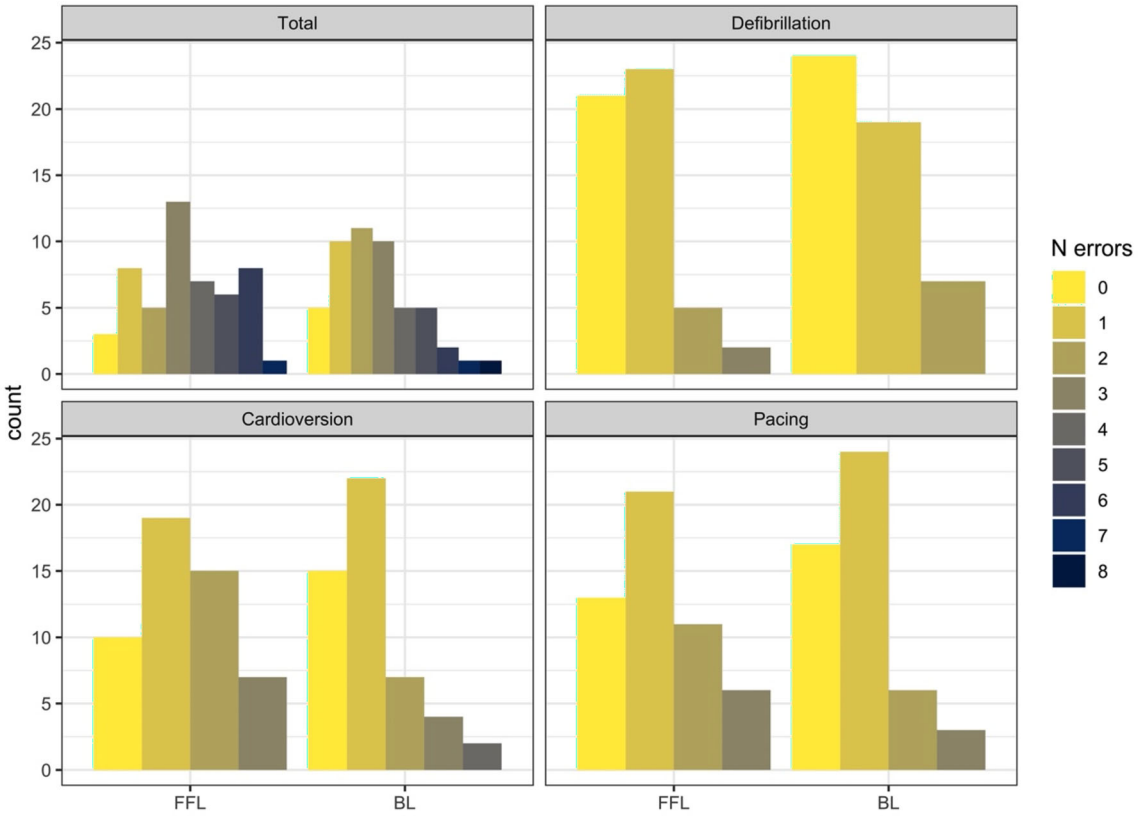

FIGURE 2 Number of errors per participants (count), electrical procedure, and study arm. The upper left panel shows the overall number of errors for the three electrical procedures pooled. The upper right, lower left, and lower right panels show the number of errors for defibrillation, cardioversion, and transcutaneous pacing, respectively. The axes represent the number of errors per study arm (x-axis) and the count of participants delivering the electrical therapies (y-axis). FFL, face-to-face learning study arm; BL, blended learning study arm. A trend towards a reduction in the number of errors per participant can be visualized in this figure for cardioversion and pacing procedures as well as for the three electrical procedures pooled

skills, the proficient and fast use of manual defibrillators is an essential competency. This is typically accomplished by exposure to real-life resuscitations requiring electrical therapies and educational courses. As the former is uncommon in paediatric care for a single health care provider, it is well recognized that resuscitation skills are often sub-optimal with retention decays over time, despite conventional educational programmes.[2,21]

An alternative educational strategy is to prefer BL.[14,22,23] By allowing time for self-directed acquisition of theoretical knowledge during e-learning sessions,[14,24] BL allows more time for practical activities during FFL classroom training sessions, such as instructor-led CPR hands-on skills.[25] To the best of our knowledge, our study findings suggest for the first time that exposing providers to BL for the appropriate use of a manual defibrillator in emergency paediatric resuscitation could be a valuable method. However, the lack of a significant difference between both educational methods observed at the level of each electrical procedure prompts us to be cautious and not too hastily conclude to such an impact.

Furthermore, similar to other studies that assessed various resuscitation skills,[26,27] we observed that providing 40-minute BL (ie, 20 minutes of FFL + 20 minutes of e-learning sessions) and 20-minute FFL only once did not prevent a rapid decay in defibrillator skills in as little as 2 months after initial training. As the optimal duration for resuscitation skills' training has not been defined definitively,[7] it remains to be established whether this relates to an insufficient time devoted to each learning course or the need for repeated training. BL was shown to provide opportunities for reinforcement through repeatable learning and a simulated experience.[28] Sullivan et al well described that once technical skills competency is achieved, maintenance training prevents skill deterioration through low-dose high-frequency training.[29] In any case, adding an e-learning course to FFL seems relevant because after an initial BL course, e-learning is designed to be used as a low-dose, high-frequency skill maintenance tool. Future studies will need to assess the frequency and related extent to which this availability and use of e-learning enable participants to maintain the acquired skills.

Overall, providers exposed to BL in this study did not deliver electrical therapies faster than those exposed to traditional FFL. Similar to the error rates, we also observed deterioration in the time spent to deliver them 2 months after initial training. Unlike Fidler et al who noted average times of between 20 and 45 seconds for manual

defibrillation, cardioversion, or pacing[30] in adults, we observed time to defibrillation of 55 seconds, in agreement with AHA guidelines,[31] but inconsistent time to cardioversion and pacing. An explanation could be that our scenarios were closer to reality. First, participants had to adjust weight-based electrical energy doses. In adult emergency care, this step is skipped as these variables are more uniformly set. Moreover, while participants in Fidler's study were instructed by clinical vignettes to the correct energy doses and electrical modes, these time-consuming decisions were left to the appreciation of the providers in our study, as would be the case in real life. Second, the scenarios in our study included several tasks leading to additional delays in the entire electrical therapy delivery procedure. Whereas participants in Fidler's study used a defibrillator already connected to a rhythm simulator, providers in our study needed time to select and place the correct electrode pads and electrocardiogram cables on the manikin and to connect them to the monitor before delivering shocks.

5 | LIMITATIONS

This study has several potential limitations. First, it was a single-centre study with findings that may not be transposable to other centres. An external validation with the conduct of studies similar to ours in other centres would be valuable.

Second, we only assessed hands-on defibrillator skills on a Philips MRx device. A comparative study evaluating human-device usability of the Philips MRx and two other popular manual defibrillators demonstrated no clear superiority of the defibrillator's usability,[30] but as it is the model of defibrillator used in our institution, it made sense to study the Philips MRx model.

Third, as our study scenarios were designed as single-rescuer resuscitations focusing on electrical skills without any other provider participating to the resuscitation, this might have contributed to bias some of the results, such as the safety measures that might have not been taken seriously enough.

Fourth, to avoid preparation bias, there was no baseline assessment showing equal or difference in performance between groups prior to the intervention. In addition, we did not have reliable records of previous defibrillator use and number of resuscitations learners had participated in. The randomized design of the study should have balanced these potential uncontrolled confounders.

Fifth, the checklist used to assess the outcomes was not validated, which could lead to some misclassification bias. Nevertheless, it was designed by two experts based on official documentation for the device used.

Sixth, although participants were explicitly asked to maintain confidentiality regarding the purpose of the study and the content of the scenario towards other participants to avoid preparation bias, we cannot assure that this instruction was followed by everyone. However, we did not notice any improvement in performance during the course of the study or during the second part of the study, which seems to show a good preservation of the confidentiality to which the participants had committed themselves.

Finally, although the sample size met our pre-study power calculation, the number of participants enrolled was modest, and this might limit the generalizability of our findings. It remains to be examined whether our findings translate into real life to be clinically significant.

6 | IMPLICATION AND RECOMMENDATIONS FOR PRACTICE

A paradigm shift from traditional instructor-led FFL classroom teaching to BL that integrates learner-centred content and technologies used for online learning can be implemented in hospitals to enhance the performance of health care providers in manual defibrillation skills.

7 | CONCLUSIONS

This randomized trial showed improvements in paediatric emergency care skills in the field of emergency electrical therapy using a manual defibrillator by health care providers exposed to BL compared with FFL. Although the same number of errors regarding individual procedure items was observed, irrespective of the learning method used, a trend towards a reduction in the total amount of errors was observed in providers exposed to BL when the performances over the three electrical procedures were pooled. BL or FFL performed only once appeared insufficient to maintain skills over time. Further studies to assess the impact of frequent retraining courses on long-term skills retention should be conducted.

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[Correction added on 12 April 2022, after first online publication: CSAL funding statement has been added.]

AUTHOR'S CONTRIBUTION

Johan N. Siebert was responsible for the literature search and reading articles, analysed the data, created the figures, and drafted the manuscript. Laurence Lacroix was responsible for the concept and design of the study. Johan N. Siebert and Laurence Lacroix were responsible for data acquisition. Delphine S. Courvoisier performed data analyses and created the Figures. Alban Glangetas provided assistance for data analyses. Kevin Haddad was responsible for the development of the project software, provided technical and material support and operated the manikin. Alban Glangetas, Marine Grange, Kevin Haddad, Delphine S. Courvoisier and Laurence

Lacroix were responsible for the critical review of manuscript content. Laurence Lacroix was the trial coordinator and responsible for the overall conduct of this study and oversaw the writing of this manuscript. All authors have contributed to, seen, and approved the final submitted version of the manuscript; had full access to all the data, including statistical reports and tables, in the study; and can take responsibility for the integrity of the data and the accuracy of the data analysis. The corresponding author (Johan N. Siebert) confirms that he had full access to the participants' data and endorsed the final responsibility for the submission. He further affirms that the manuscript is an honest, accurate, and transparent account of the study being reported, that no important aspects of the study have been omitted, and that any deviations from the study plan have been explained.

DATA AVAILABILITY STATEMENT

Individual participant data that underlie the results reported in this article, after deidentification (text, tables, figures, and appendices), will be made available from the corresponding author upon reasonable and approved request at johan.siebert@hcuge.ch, beginning 6 months and ending 5 years following article publication. Data will be made available to researchers whose proposed use of the data has been approved by an independent review committee identified for this purpose. Data requestors will need to sign a data access agreement.

ETHICS STATEMENT

The study received a declaration of no objection by Swissethics and the Geneva Ethics Committee (Req-2019-00080) as the purpose of the study was to examine the effect of the intervention on health care providers. For the same reason and according to the International Committee of Medical Journal Editors, a trial registration number was not required. The study was conducted in accordance with the principles of the Declaration of Helsinki, the standards of Good Clinical Practice, and Swiss regulatory requirements.

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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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