Can J Anesth/J Can Anesth (2020) 67:674–684
https://doi.org/10.1007/s12630-020-01665-w

REPORTS OF ORIGINAL INVESTIGATIONS

Quality of clinical care provided during simulated pediatric cardiac arrest: a simulation-based study

Qualité des soins cliniques prodigués pendant un arrêt cardiaque pédiatrique simulé : une étude basée sur de la simulation

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Received: 16 September 2019 / Revised: 2 December 2019 / Accepted: 6 December 2019 / Published online: 28 April 2020

Abstract

Purpose *We sought to assess compliance to resuscitation guidelines during pediatric simulated cardiac arrests in a pediatric intensive care unit (PICU) and to identify performance gaps to target with future training.*

Methods *In a prospective observational study in a PICU, ten cardiac arrest scenarios were developed for resuscitation training and video recorded. The video recordings were examined for times to start cardiopulmonary resuscitation (CPR), delivery of first shock, CPR quality (rate, depth), length of pauses, chest compression fraction (CCF), ventilation, pulse/rhythm assessment, compressors' rotation, and leader's behaviours. The primary outcome was percentage of events compliant to Pediatric Advance Life Support guidelines.*

Results *Compliance to guidelines was poor in the 23 simulation events studied. The median [interquartile range] time to start CPR was 29 [16–76] sec and 320 [245–421] sec to deliver the first shock. A total of 306 30-sec epochs of CPR were analyzed; excellent CPR (≥ 90% compressions in target for rate and depth) was achieved in 22 (7%) epochs. More than a quarter of the CPR pauses lasted > 10 seconds (33/127, 26%) with just one task performed in most of them; CCF was ≥ 80% in 19/23 (82.6%) events. Ventilation rate for intubated patients was greater than 10 breaths·min^{-1} in 15/27 (56%) of one-minute epochs observed.*

Conclusions *Review of simulated resuscitation events found suboptimal compliance with resuscitation guidelines, particularly the times to starting CPR and delivering the first shock, as well as compression rate and depth.*

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s12630-020-01665-w) contains supplementary material, which is available to authorized users.

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Résumé

Objectif *Nous avons tenté d'évaluer l'observance des directives de réanimation pendant les arrêts cardiaques pédiatriques simulés dans une unité de soins intensifs pédiatriques (USIP) et d'identifier les écarts de performance afin d'aiguiller la formation future.*

Méthode *Dans une étude observationnelle prospective réalisée au sein d'une USIP, dix scénarios d'arrêt cardiaque ont été élaborés à des fins de formation en réanimation et enregistrés sur vidéo. Les enregistrements vidéo ont été étudiés pour évaluer le délai d'initiation de la réanimation cardiorespiratoire (RCR) et d'administration du premier choc, ainsi que la qualité de la RCR (fréquence,* *profondeur), la durée des pauses, la fraction des compressions thoraciques (FCT), la ventilation, l'évaluation du pouls/rythme, la rotation des compresseurs et les comportements du leader. Le critère d'évaluation principal était le pourcentage d'événements conformes aux directives de Soins avancés en réanimation pédiatrique (SARP).*

Résultats *L'observance des directives était faible dans les 23 sessions étudiées. Le temps médian [écart interquartile] était de 29 [16–76] sec avant d'amorcer la RCR et de 320 [245–421] sec avant d'administrer le premier choc. Au total, 306 séquences de 30 sec de RCR ont été analysées; une RCR excellente (≥ 90 % des compressions situées dans la cible de fréquence et de profondeur) a été réalisée dans 22 (7 %) séquences. Plus d'un quart des pauses de RCR ont duré > dix secondes (33/127, 26 %), avec une seule tâche réalisée dans la plupart; la FCT était de ≥ 80 % dans 19/23 (82,6 %) sessions. Chez les patients intubés, la fréquence de ventilation était supérieure à 10 respirations·min^{-1} dans 15/27 (56 %) des séquences d'une minute observées.*

Conclusion *Le passage en revue des événements de réanimation simulés a décelé une observance sous-optimale des directives de réanimation, particulièrement en ce qui touche au délai de l'initiation de la RCR et du premier choc, ainsi qu'à la fréquence et à la profondeur des compressions.*

The emphasis on high-quality cardiopulmonary resuscitation (CPR) has improved survival to hospital discharge from pediatric in-hospital cardiac arrest.[1] Yet CPR provided to patients in cardiac arrest frequently does not comply with current American Heart Association (AHA) guidelines.[2–5]

Maximizing survival from cardiac arrest requires improvement in resuscitation education and implementation of systems that support delivery of high-quality resuscitation.[6] High-fidelity simulations, where learning takes place in real clinical environments[7,8] are recommended, since they enhance skill performance and staff engagement.[8–10] In addition, effective teamwork and leadership behaviours are important factors in improving team performance, which may translate into better cardiac arrest outcomes.[11,12]

There is a paucity of literature describing adherence to guidelines by pediatric intensive care unit (PICU) teams across a spectrum of different cardiac arrest scenarios. Further, little is known about the impact of leadership and leader behaviours on team adherence to resuscitation guidelines.

In this study, we video reviewed simulations to identify gaps in clinical performance during cardiac arrest care in our PICU across different scenarios. Our overall objectives were to assess compliance to resuscitation guidelines and to identify performance issues amenable to improvement through better training.

Methods

Study design and setting

The University of Calgary Research Ethics Board approved this prospective, observational study on May 8, 2015. All participants provided informed consent. A one-year four-part CPR quality educational bundle was implemented in the PICU at Alberta Children's Hospital in Calgary, AB, Canada from September 3, 2015 to November 22, 2016. This bundle included: 1) replacement of our defibrillator with the Zoll R Series® with CPR feedback technology embedded (Zoll Medical Corporation, MA, USA), 2) bi-weekly simulated cardiac arrest events in the PICU, 3) real cardiac arrest event debriefing sessions, and 4) brief CPR retraining sessions ("rolling refreshers") for PICU resuscitation team members. We had previously found that bedside chest compression skills decayed over time despite two refresher sessions with feedback.[13] This paper describes the simulated cardiac arrest events conducted.

Participants

All ten PICU attending physicians, two nurse practitioners, approximately 150 registered nurses, 45 respiratory therapists, and 50 rotating medical residents were eligible for inclusion. All PICU clinical staff underwent training on how to use the Zoll R Series defibrillator over a two-month period prior to its implementation for clinical use. This training occurred before this study began. Participants were working their regular shifts and attended the simulations if they did not have clinical responsibilities at the time. They were able to abandon the simulation if called to the bedside or to attend their clinical duties. Our 15-bed PICU admits approximately 900 patients per year and has approximately 15–20 cardiac arrest events per year.

Data collection and analysis

Simulated CPR events took place in a PICU patient room. We used ten scenario scripts relevant to PICU developed by the senior author (E.G.) (eAppendix, available as Electronic Supplementary Material [ESM]); these varied from ten to 30 min in duration. Depending on the scenario, a bedside nurse and a physician or respiratory therapist received the patient history from a researcher acting as either a transport team member or a physician from the emergency department (ED). The PICU team either took over the resuscitative care if already started by the research team or had to recognize cardiac arrest and act upon it. A member of the research team provided laboratory results or radiologic reports if requested or available during case progression. The simulations progressed until return of spontaneous circulation (ROSC) was achieved, extracorporeal life support was called for, or CPR had run for 30 min, whichever came first. We used a high-fidelity human mannequin, SimJunior® (Laerdal Medical); the "crash cart" and all standard resuscitation equipment and medications, including the Zoll defibrillator, were available in the room or where usually located in the PICU.

All scenarios were facilitated by trained clinician simulation educators, who are physicians or nurses from either the PICU or ED. All scenarios were debriefed immediately following the end of the scenario and lasted approximately 20–30 min. During these debriefings, emphasis was placed on CPR quality and the application of the Zoll defibrillator.

Events were video recorded, transcribed, and data collected from review of the transcripts and observation of videos. To analyze transcripts and videos, we used an observation guide (eAppendix, available as ESM) developed by two of the authors (D.G.J., E.G.) and content-validated using two videos and their transcripts by other authors (D.A.M., W.B.), who were expert simulation educators. The guide included key resuscitation processes that were based on AHA Pediatric Advance Life Support (PALS) guidelines,[1,14] a clinical performance tool (CPT), a pediatric resuscitation guideline-adherence tool, published evidence of validity,[15] and coded team member behaviours.

Quantitative CPR data were measured and recorded during resuscitations with the Zoll defibrillator and extracted using Zoll Rescue Net Code Review v5.7 (Zoll Medical Corporation). Data included chest compression (CC) rate (CC/min) and depth (cm) and were evaluated per 30-sec epochs.

The total event time was from receiving the patient history and starting care to the end of the simulation. The total CPR time was from initiation of CPR by a PICU team member to the end of compressions.

Outcome measures

The primary outcomes were the compliance to guidelines of key clinical tasks, including time to start CPR and to delivering the first shock, CPR quality, ventilation, pauses, pulse and rhythm checks, and rotation of compressors, as described in Table 1.

The secondary outcomes included the proportion of events where expected roles of leaders in the key clinical tasks were observed. The expected roles were coded by content analysis of the transcripts and based on leaders' behaviours that may affect the adherence to guideline recommendations, including CPR quality targets, defibrillation, ventilation, rhythm and pulse check, and task coordination to avoid pauses.

Statistical analysis

Sample size was not calculated, but rather a convenience sample of available PICU staff was used. Data were summarized as frequencies and percentages for categorical variables and medians [interquartile ranges (IQR)] for numeric variables given the skewness. Time intervals were expressed as median [range and IQR]. Non- parametric tests used included Kruskal–Wallis test and Kendall's tau correlation. A $P < 0.05$ indicated statistical significance. Analyses were conducted with SPSS version 25.0 for Mac (IBM, Armonk NY, USA).

Results

Over one year, 28 simulated cardiac arrest events of ten clinical scenarios were video recorded. and data were drawn from 23 of these (Fig. 1). The median [IQR] duration of each event was 13.9 [9.8–14.8] min (range, 5.8–24.2 min), and the median [IQR] time providing CPR was 11.4 [7.6–13.2] min (range, 5.8–24.2 min).

Teams were *in situ* activated and comprised attending physicians who led most of the events, nurse practitioners, nurses, residents, and respiratory therapists, totaling 104 participants over one year; 35 of them attended two or more events where they took on different roles. We focused our analysis on the teams' and not individual providers' performances, which not only depend on training but also on the roles of and integration with other team members. Therefore, an individual-level analysis was not possible. A median [IQR] of 6 [5–7] providers participated in each event. Table 2 shows characteristics of participants by discipline. Additional demographic and professional characteristics of participants in the educational bundle are reported elsewhere.[13]

Times to completion of tasks

Six teams took over care from an ED team and 17 recognized cardiac arrest themselves at the beginning of the scenario. Compliance with the recommended time to start CPR was low (Table 3); five of 17 teams (29.4%) delayed starting CPR for longer than one minute. The median [IQR] time elapsed from the earliest recognition of

Table 1 Outcome measures

Clinical task	Measure	Description
Time to start CPR	- Percentage of simulated events that started CPR in less than 30 sec; - Median [IQR] of time elapsed to starting CPR.	Measured from the earliest recognition of cardiac arrest, either pulse lost or onset of a shockable rhythm displayed on the monitor.
Time to first shock	- Percentage of shockable simulated events that delivered the first shock in less than 2 min; - Median [IQR] of time elapsed to delivering the first shock.	Measured from the earliest recognition of cardiac arrest, either pulse lost or onset of a shockable rhythm displayed.
CPR quality	- Percentage of 30-sec epochs with 90% or higher of chest compressions in target for rate and depth; - Percentage of 30-sec epochs with excellent CPR	Rate: 100–120/min, depth: 5 cm Excellent CPR defined as 90% or higher of chest compressions in target for both rate and depth.
Ventilation	- For intubated patients, percentage of 1-min epochs where 10 breaths·min^{-1} are counted. - For non-intubated patients, percentage of events where a compression to ventilation ratio of 15:2 was observed.	Breaths·min^{-1} were observed over 1-min epochs, with no interruptions, up to three times per bagger if an advanced airway was placed and whenever possible (i.e., bagger was in sight on recording for a full minute).
Pauses	- Percentage of interruptions of 10 sec or less in duration; - Median [IQR] duration of pauses; - Proportion of coordinated pauses; - Median [IQR] of duration of perishock pauses; - percentage of events with chest compression fraction (CCF) of 80% or higher - Median [IQR] of CCF.	Coordinated pauses were defined as pauses having multiple tasks or activities done. Perishock pauses defined as the interval from the last chest compression before the shock to the first one after the shock Pauses shorter than 2 sec for rotating compressors and ventilation (in non-intubated patients) were excluded.
Pulse and rhythm checks	- Percentage of events where pulse/rhythm checks were performed regularly after each 2-min cycles of chest compressions; - Proportion of perishock pauses that included a pulse check; - Proportion of events where checking for pulses was done simultaneously with compressions; - Proportion of events where a pulse check was performed after ROSC was achieved.	
Rotating compressors	- Percentage of compressing cycles of length of 2 min ±10 sec; - Median [IQR] of compressing cycles.	Compressing cycles defined as the time compressing by a single provider.

CCF = chest compression fraction; CPR = cardiopulmonary resuscitation; IQR = interquartile range

cardiac arrest to starting compressions was 29 [16–76] sec (range, 4–127 sec).

Compliance to the PALS guideline for the time to deliver the first shock was poor (Table 3). The teams delivered the first shock in a median [IQR] time of 320 [245–421] sec (range, 48–520 sec).

Cardiopulmonary resuscitation quality

Quantitative CPR data were available for 16 of 22 events where Zoll was used and yielded 306 30-sec epochs of CPR. Data from six events were lost because of technical issues with data transfer from the defibrillator. Overall, the target for CC rate was achieved in more epochs (172 of 306, 56.2%) than the target for depth was (56 of 306, 19%). Excellent CPR (as defined by 90% or more of compressions in target for rate and depth) was rarely achieved with only 22 of 306 epochs (7.2%) meeting guideline recommendations for both parameters (Table 3).

Ventilation

Ventilation rate of non-intubated patients (measured as either breath·min^{-1}; 15 events) or compression-ventilation ratio of non-intubated patients (eight events) was reported for 17 out of 23 (73.9%) simulations. Breaths·min^{-1} were counted for nine of 15 events with an intubated patient. Six scenarios were excluded from this analysis for the following reasons: three scenarios of hyperventilation (i.e., high intracranial pressure), one scenario of tension

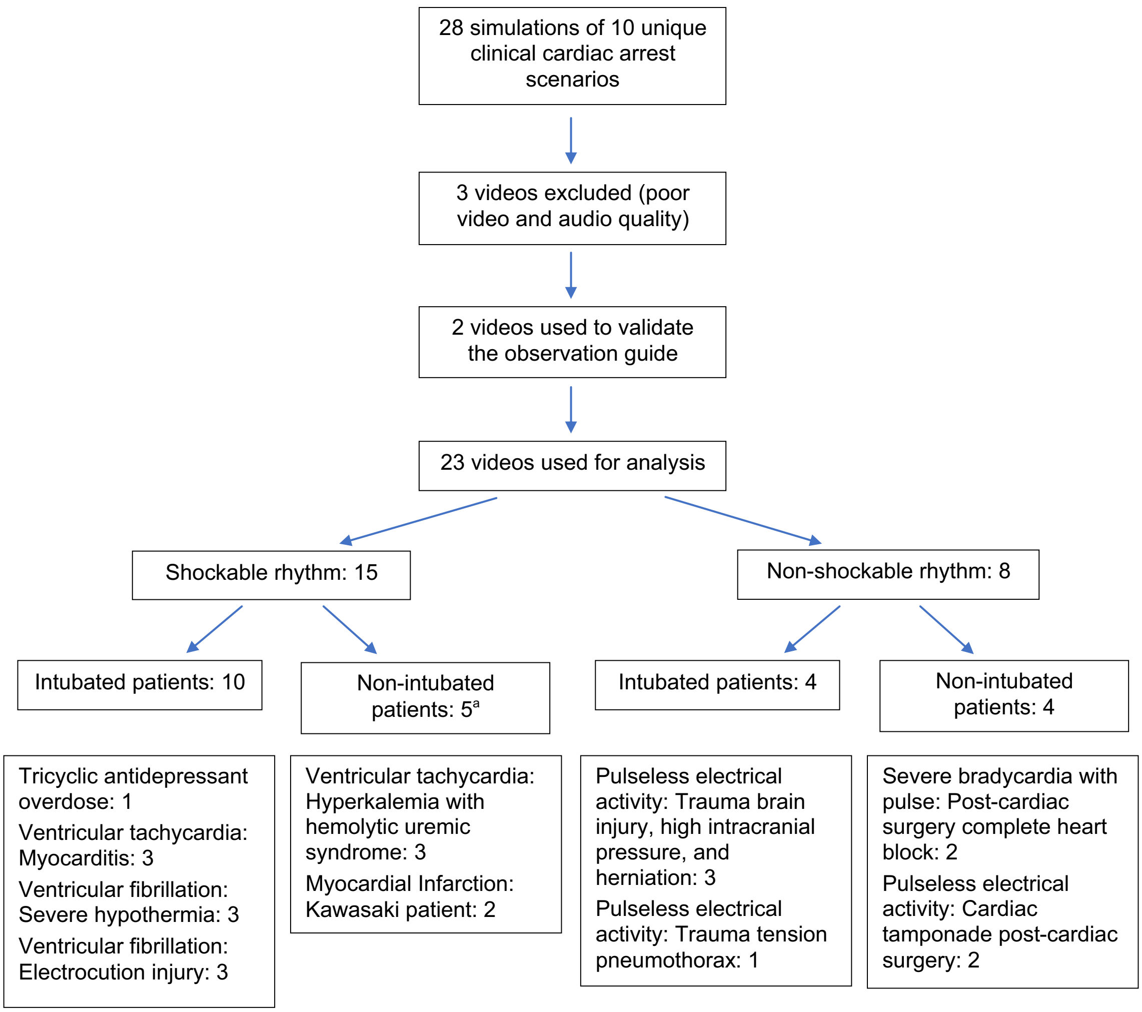

Fig. 1 Flow chart of video recordings and video review of clinical scenarios. [a]In one scenario of "ventricular tachycardia: hyperkalemia with hemolytic uremic syndrome", the patient was intubated in the course of the event

pneumothorax where ventilation was scripted to be difficult, and two events where the bagging was not in sight of the camera (Fig. 1).

Twenty-seven one-minute epochs of ventilation were registered for analysis; in all the epochs, respiratory therapists were bagging. The median [IQR] ventilation rate in most epochs of 11 [10–13] breaths·min^{-1} was greater than what PALS guidelines required (Table 3). The difference was likely not clinically significant, given that only three of 27 (11.1%) were greater than 20 breaths·min^{-1}. Bagging rate was significantly affected by whether providers of ventilation were also responsible for other tasks (P = 0.04) (Fig. 2). Step-down follow-up analysis showed that if the bagger also provided compressions during the event, the bagging rate increased.

Compression-ventilation ratio was assessed for the eight simulations with non-intubated patients. Four of those met the recommended rate of 15:2 (Table 3). A ratio of 30:2 was observed in three events: in one, it was fixed to 15:2 after three minutes; in another, breaths were given simultaneously with compressions. In the remaining event, 10 breath·min^{-1} were given as if the patient was intubated.

Cardiopulmonary resuscitation pauses

A total of 128 CPR pauses were registered, most of them met the recommended duration but just 30.4% were coordinated, as defined by two or more tasks completed during the interruption (Table 3). The median [IQR] duration of each pause was seven [5–10] seconds (range, 2–59 sec), with a median [IQR] of five [3–7] pauses per event. In 39 pauses, a shock was delivered, with a median [IQR] duration of peri-shock pause of six [5–8] seconds (range, 3–26 sec).

Most events complied with PALS guidelines for chest compression fraction (CCF) (Table 3) with a median [IQR]

Table 2 Participants in simulated events

Participants (*n*=104)	
Participants by discipline	
Attending physicians	8/104 (7.7)
Nurse practitioner	2/104 (1.9)
Registered nurse	57/104 (54.8)
Respiratory therapist	24/104 (23.1)
Residents[a]	13/104 (12.5)
Leaders by discipline	
Attending physician	18/23 (78.3)
Nurse practitioner	4/23 (17.4)
Resident	1/23 (4.3)
Number of compressors per event	
2	5/23 (21.7)
3	15/23 (65.2)
4	2/23 (8.7)
5	1/23 (4.3)
Discipline of compressors (*n*=61)	
Registered nurse	36/61 (59)
Respiratory therapist	16/61 (26)
Resident	9/61 (15)

[a] Comprised of residents from Pediatrics, Anesthesia, Emergency, Respirology, Neurology, and Pediatric Emergency Medicine

of 88.3 [83.0–93.2]%. The time to start CPR was significantly related to the CCF ($P < 0.001$).

Pulse and rhythm assessment

Table 3 summarizes compliance to guideline recommendations for pulse check. Over the course of the study, just 36 pulse/rhythm assessments were performed. Most of the teams did not follow the recommended two-minute mark for this process. These were mostly coordinated with other tasks (25 of 36; 69.4%). Five of those were combined pulse check and rhythm assessments. Feeling for pulses with compressions was registered in eight out of 23 simulations (34.8%).

Alternating compressors

A total of 151 compression cycles were recorded with a median [IQR] of six [4–8] cycles in each simulation. The median [IQR] duration of these cycles was 1.5 [0.9–2.1] min (range, 0.2–6.2 min). Compliance to guidelines was suboptimal for rotating compressors (Table 3). Just 40 (26.5%) compression cycles were longer than two minutes but 45 (29.8%) lasted one minute or less. Length of compression cycles was not affected by the leader behaviour ($P = 0.39$) but was significantly affected by the number of compressors ($P = 0.02$). Step-down follow-up analysis showed that having four compressors was associated with a significantly shorter length of compression cycles compared with having two compressors (Table 4).

Leader's behaviours

Table 4 presents a summary of the main leader behaviours related to key clinical tasks.

Discussion

This study demonstrated that CPR in our PICU failed to meet guidelines for most parameters studied. Teams delayed starting CPR and delivering the first shock. The CCF was consistently above 80%, and most pauses were shorter than ten seconds, but just a third of those were coordinated. Ventilation above target rate for intubated patients was common and good coordination of compression and breathing in non-intubated patients was met by just half of the teams. Meeting rate and depth targets for CPR was poor even when CPR feedback followed. Most of the teams showed poor time-management regarding rotating compressors and checking for pulses. Interestingly, our study showed poorer adherence to CPR quality metrics than others who have published in this area.[16] Possible explanations for this difference include different learners (pediatric *vs* general emergency medicine) and the use of a single standardized scenario *vs* many different ones.

Delaying CPR and first shock has been reported in other studies.[17–19] This is a major concern as these delays are associated with lower rates of survival after cardiac arrest in adults.[20–22] In our study, the delay starting CPR significantly reduced the overall CCF, which is also associated with decreased ROSC and survival to hospital discharge.[23,24] Two recent qualitative studies reported uncertainty of nurses and junior doctors in recognizing cardiac arrest and properly initiating management of arrested patients.[25,26] Considering the impact on patient survival, delays by bedside staff in recognizing cardiac arrest, calling for help, starting compressions, and having the defibrillator ready all constitute important targets for improvement.

Another important finding was that CPR quality targets were not often met even with feedback from our defibrillator and coaching from other team members during most events. Similarly, others have reported that even with feedback, compression rate and depth are still suboptimal, but suggest that feedback allows teams to perform closer to guidelines.[3–5,10,27–29] In contrast, Cheng

Table 3 Compliance to guideline recommendations of resuscitation parameters studied

CPR parameter (*n*)	Measured by	Target (source)	Compliance frequency (%)
Time to start CPR (*n*=17 teams)	Time elapsed since the earliest recognition of cardiac arrest	≤ 30 sec (CPT)	9/17 (52.9)
Time to first shock Scenarios with a shockable rhythm (*n*=14[a])	Time elapsed since the earliest recognition of cardiac arrest	≤ 2 min (AHA)	1/14 (7.1)
CPR quality targets			
CPR quality targets achieved (*n*=306[b] 30 sec-epochs)	Percentage of epochs with ≥ 90% of chest compressions in target for rate, depth, and rate and depth	Rate: 100 – 120/min Depth: 5 cm (AHA)	172/306 (56.2), 58/306 (19), and 22/306 (7.2), respectively
Ventilation			
Breaths·min^{-1} in intubated patients (*n*=27 1-min epochs from 9 events)	Observed breaths·min^{-1}	10 breaths·min^{-1} (AHA)	6/27 (22.2)
Compression-ventilation ratio in non-intubated patients (*n*=8 events)	Compression-ventilation ratio	15:2 (AHA)	4/8 (50)
Pauses			
Interruptions longer than 2 sec (*n*=128)	Duration	≤ 10 sec (AHA)	95/128 (74.2)
	Coordinated	(AHA)	39/128 (30.4)
CCF (*n*=23)	Time on-chest/cardiac arrest length	≥ 80% (AHA)	19/23 (82.6)
Pulse and rhythm check			
Regularly performed (*n*=23)	Times when they are performed	After each 2-min cycle of CPR (AHA, CPT)	5/23 (21.7)
Performed immediately after or before a shock (*n*=39 shocks delivered)	Pulse check performed	Avoid perishock pauses (AHA)	3/39 (7.7)
Performed after a rhythm changed on monitor (*n*=15 scenarios with ROSC)	A reason related to ROSC is mentioned as the reason to check for pulses	Check for pulses after ROSC achieved (AHA)	12/15 (80)
Alternating compressors			
Compressing cycles (*n*=151)	Length of compressing cycles	2 min (AHA)	23[c]/151 (27.2)

AHA = American Heart Association; CPR = cardiopulmonary resuscitation; CPT = clinical performance tool; IQR = interquartile range; ROSC = return of spontaneous circulation

[a] One scenario of ventricular tachycardia (hyperkalemia) was excluded as no shock was delivered

[b] One scenario was excluded from this analysis because defibrillator pads were not placed accurately

[c] Included cycles of length of 2 min ± 10 sec

et al. found that having a trained CPR coach as part of the resuscitation team when a CPR feedback defibrillator is in use significantly improves CPR quality during simulated cardiac arrest.[30] The coaches in our study were selected ad hoc and were not specifically trained in this role, which may explain our different findings.

Our finding of frequent ventilation above the target rate concurs with previous reports.[2,31–33] Clearly, the correct rate is difficult to achieve and based on our findings, baggers might become distracted by the resuscitation environment, especially if they have other tasks to perform during events. According to PALS guidelines, a simple rate of 10 breaths·min^{-1} rather than a range of breaths per minute may be easier to learn, remember, and perform,[14] yet more training is needed for providers to master this skill.

A compression to ventilation ratio of 30:2 was sometimes observed in our study when ventilating pediatric patients, which is the recommended rate for adult and adolescents.[34] This study does not provide enough evidence to suggest a lack of knowledge regarding this; the small sample size and the fact that providers were

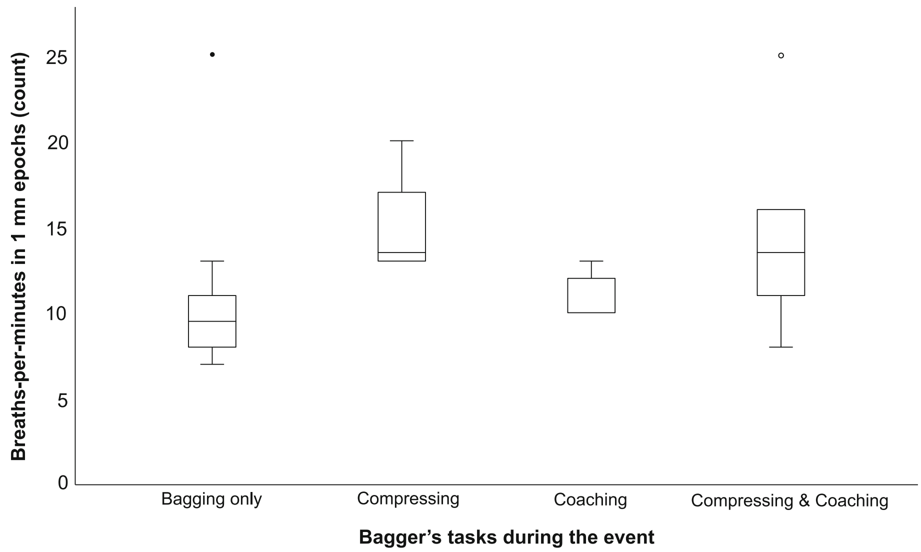

Fig. 2 Ventilation in non-intubated patients in relation to bagger's tasks in the event. Outliers are noted by an open circle and extreme cases are noted by a filled circle

Table 4 Leaders' roles or behaviours related to key processes described

Leader's behaviour observed	Frequency (%)
CPR quality	
Reminded CPR quality targets (22 events where Zoll defibrillator was used)	11/22 (50)
Designated someone to watch for CPR targets on Zoll defibrillator	12/22 (54.5)
Provided feedback on CPR quality	11/22 (50)
Defibrillation	
Checked times for shocks to be delivered and discussed pause in advance	14/23 (60.7)
Ventilation	
Stated or confirmed frequency of ventilation	11/23 (48)
- In the first 2 min of CPR	7/11 (64)
- After 5 min of CPR	2/11 (18.5)
- After ROSC	2/11 (18.5)
Confirmed ventilation was effective (i.e., asked for breathing effort, air entry, chest rise, breath sounds)	17/23 (73.9)
No discussion regarding ventilation	4/23 (17.4)
Pulse/rhythm check	
Indicated when to do it	15/23 (65.2)
Ordered to either follow $EtCO_2$ or see-through rhythm on defibrillator so no pauses for pulses/rhythm assessments were needed (7 simulations where no pulse check was done and 6 where just one was done)	2/13 (15.4)
Requested feeling for pulses with compressions	8/23 (34.8)
Alternating compressors	
Set the time to compress either at 2 min or alternated when compressors felt fatigue	12/23 (52.2)
Did not set time but eventually asked compressors to switch over or checked on them	4/23 (17.4)

CPR = cardiopulmonary resuscitation; $EtCO_2$ = end-tidal carbon dioxide; ROSC = return of spontaneous circulation

ventilating a mannequin may explain why they lost sense of patients' age, although the age of the patient was mentioned in the patient history.

The observed leaders' behaviours suggest they trust respiratory therapists' skills and knowledge and did not identify the deviated ventilation ratio. Therefore, leaders did not coach or follow up on baggers as long as they were able to bag and get a chest rise and end-tidal carbon dioxide. A paucity of findings and the importance for patient outcomes advocate for further investigations and training in this area to gain awareness and improve performance.

We found just a few compressing cycles by single providers that complied with PALS guidelines.[1] Previous studies have shown that two minutes of uninterrupted CCs are well tolerated by trained providers.[35] Despite performance differences between individuals, decay due to fatigue is rare in the first two minutes.[36] Nevertheless, Ashton *et al*. recommend rotating the rescuers after one minute.[37] Short cycles, as seen in this study, decrease CCF by the frequency of switching.[38] Yet, it is recommended that leaders monitor compressors for signs of fatigue and rotate them if their performance does not improve.[39] In our study, the disorganized pattern in changing compressors is not explicitly related to CPR quality targets, although the fact that leaders asked compressors to rotate in some events may suggest they had noticed a decay in skills by following CPR feedback when asked to do so.

The large discrepancies noted in length of compression cycles may have affected resuscitation dynamics. The recommended two-minute duration sets the time for coordinating compressor changes and pulse/rhythm assessments, which were infrequently coordinated in our study. Coordinating rotating compressors with rhythm analysis, defibrillation, and other tasks that require a pause can be effectively accomplished with clear communication between leaders and team members, allowing multiple tasks to be achieved by multiple providers.[39,40] Previous findings suggest that sharing a mental model by team members prior to shock delivery significantly decreases peri-shock pause duration.[40] These findings inform the importance of teaching coordinating tasks when training teams and leaders.

This study has several limitations. Our study was conducted in the PICU of a single centre and its findings may not be generalizable to other hospitals or units. Our study design and small sample size precludes us from analyzing differences between low and high-functioning teams, which could have potentially shown interesting differences. For this study, we deliberately used a large number of clinical scenarios that reduced the possibility of consistent evaluation between events but provided an opportunity for a portion of the staff to practice in the actual setting and assess clinical tasks in a variety of clinical scenarios they may encounter.

Further, the Zoll defibrillator was introduced at the beginning of the study so lack of familiarity with this new technology might have temporarily affected providers' performance. In addition, as part of the educational bundle described above, most of the providers participated in "rolling refreshers", which may account for some improvements in performance. This one-year bundle allowed us to identify gaps and targets for education and improvement, and also try different methods to teach providers. Nevertheless, we cannot confirm a trend towards performance improvement with this study. Participants were working their regular shifts and participated in the simulations only if they had no other clinical duties or responsibilities at the time, but fatigue or focus on their patients could have distracted them from their performance at the simulation. Most of the providers were exempt from AHA basic life support provider courses over the project length, but they may have been part of actual events.

Finally, the findings from simulated resuscitations may not be extrapolated to real-life events. Nevertheless, our study supports the value of video review to assess team performance and identify critical issues during resuscitation and gaps for training. We will soon begin evaluating team performance by video review of real events at our centre, allowing us to compare these data. Therefore, we will be able to determine the extent to which simulated data can be applied to study real-life events and patient outcomes.

Conclusions

Video review and defibrillator data of simulated resuscitation events showed that compliance with resuscitation guidelines was poor in a PICU, and identified targets for training and education of resuscitation team members. Times to start CPR and deliver the first shock, as well as compression rate and depth were notably unsatisfactory. Mastering coordinating key tasks and ventilation must be part of team and leadership training and quality improvement.

Author contributions *Dailys Garcia-Jorda* and *Elaine Gilfoyle* contributed to all aspects of this manuscript, including study conception and design; acquisition, analysis, and interpretation of data; and drafting the article. *Dori-Ann Martin* contributed to the acquisition and analysis of data. *Jenna Camphaug* contributed to the acquisition of data. *Wendy Bissett*, *Tanya Spence*, *Meagan Mahoney, Adam Cheng*, and *Yiqun Lin* contributed to the analysis and interpretation of data.

Acknowledgment Annemarie Silver, Ph.D., principal Scientist at Zoll Medical provided the extracts from Zoll defibrillator.

Conflicts of interest None.

Funding statement Dailys Garcia-Jorda received a postdoctoral fellowship from Alberta Children Hospital Research Institute. Elaine Gilfoyle received the University of Calgary Department of Pediatrics Innovation Grant for the project "Pilot evaluation of a novel CPR feedback device in PICU: Can we improve the quality of CPR we deliver to patients?" related to this study. Elaine Gilfoyle, Meagan Mahoney, Adam Cheng, Wendy Bissett, Tanya Spence, and Yiqun Lin received an in-kind donation of the Zoll R Series® defibrillator from Zoll® Corporation. The remaining authors report no disclosures related to this manuscript.

Editorial responsibility This submission was handled by Dr. Hilary P. Grocott, Editor-in-Chief, *Canadian Journal of Anesthesia.*

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