Simulation and education

Pediatric resident resuscitation skills improve after "Rapid Cycle Deliberate Practice" training☆

Elizabeth A. Hunt [a,b,c,d,e,*], Jordan M. Duval-Arnould [a,b,d,e],
Kristen L. Nelson-McMillan [a,b,c,e], Jamie Haggerty Bradshaw [f], Marie Diener-West [g,h],
Julianne S. Perretta [e], Nicole A. Shilkofski [a,b,c,e,i]

[a] Johns Hopkins University School of Medicine, Baltimore, MD, USA
[b] Department of Anesthesiology and Critical Care Medicine, USA
[c] Department of Pediatrics, USA
[d] Division of Health Sciences Informatics, USA
[e] Johns Hopkins Medicine Simulation Center, Baltimore, MD, USA
[f] Uniformed Services of the Health Sciences, Bethesda, MD, USA
[g] Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, USA
[h] Department of Biostatistics, USA
[i] Perdana University Graduate School of Medicine, Kuala Lumpur, Malaysia

ARTICLE INFO

ABSTRACT

Introduction: Previous studies reveal pediatric resident resuscitation skills are inadequate, with little improvement during residency. The Accreditation Council for Graduate Medical Education highlights the need for documenting incremental acquisition of skills, i.e. "Milestones". We developed a simulation-based teaching approach "Rapid Cycle Deliberate Practice" (RCDP) focused on rapid acquisition of procedural and teamwork skills (i.e. "first-five minutes" (FFM) resuscitation skills). This novel method utilizes direct feedback and prioritizes opportunities for learners to "try again" over lengthy debriefing.
Participants: Pediatric residents from an academic medical center.
Methods: Prospective pre-post interventional study of residents managing a simulated cardiopulmonary arrest. Main outcome measures include: (1) interval between onset of pulseless ventricular tachycardia to initiation of compressions and (2) defibrillation.
Results: Seventy pediatric residents participated in the pre-intervention and fifty-one in the post-intervention period. Baseline characteristics were similar. The RCDP-FFM intervention was associated with a decrease in: *no-flow fraction*: [pre: 74% (5–100%) vs. post: 34% (26–53%); $p < 0.001$)], *no-blow fraction*: [pre: 39% (22–64%) median (IQR) vs. post: 30% (22–41%); $p = 0.01$], and *pre-shock pause*: [pre: 84 s (26–162) vs. post: 8 s (4–18); $p < 0.001$]. Survival analysis revealed RCDP-FFM was associated with starting compressions within 1 min of loss of pulse: [Adjusted Hazard Ratio (HR): 3.8 (95% CI: 2.0–7.2)] and defibrillating within 2 min: [HR: 1.7 (95% CI: 1.03–2.65)]. Third year residents were significantly more likely than first years to defibrillate within 2 min: [HR: 2.8 (95% CI: 1.5–5.1)].
Conclusions: Implementation of the RCDP-FFM was associated with improvement in performance of key measures of quality life support and progressive acquisition of resuscitation skills during pediatric residency.

1. Introduction

Over 5800 children will have an in-hospital cardiac arrest (IHCA) in the United States each year.[1] An exciting trend reveals survival to discharge from pediatric IHCA improving from 14.3% in 2000 to 43.9% in 2009, however, the majority of children will still not survive.[2] Deviance from American Heart Association (AHA) resuscitation guidelines is associated with decreased likelihood of survival from IHCA.[3,4] AHA recommends pulseless individuals receive chest compressions immediately, defibrillation within 2 min of a shockable rhythm and no pauses in chest compressions >10 s.[5,6]

In an initial "pre-intervention" study of simulated cardiopulmonary arrests (sCPAs), only 1/3 of pediatric residents started compressions within 1 min from onset of pulseless ventricular tachycardia (PVT), and less than half defibrillated within 2 min. There was no difference between first-year and third-year residents, suggesting Basic Life Support (BLS), Pediatric Advanced Life Support (PALS) and residency were not preparing them to manage IHCAs.[7] At our institution, we have now augmented BLS and PALS courses with curricula focused on acquisition of procedural and teamwork skills. As described below, this novel competency-based curriculum style is referred to as "Rapid Cycle Deliberate Practice" (RCDP).

The first principle of RCDP is to maximize the time learners spend in deliberate practice. We give them multiple opportunities to "do it right", applying the concepts of overlearning and automatization, creating muscle memory for the "right way".[8–10] The second is for faculty to efficiently provide specific evidence-based or expert-derived solutions for common problems seen during IHCAs. This is more efficient than encouraging residents to explore new solutions. The third principle is to explicitly foster "psychological safety" so learners embrace our direct feedback without becoming defensive.[11,12] We create an environment where residents understand our goal is coaching them akin to world-class athletes, with high standards and even higher stakes, i.e. saving lives. They transition from being nervous about making mistakes to being enthusiastic about the opportunity for dedicated coaching and practice time. We rapidly cycle between deliberate practice and directed feedback until skill mastery is achieved, thus the rationale for referencing K. Anders Ericsson's work on deliberate practice as the inspiration for the term "Rapid Cycle Deliberate Practice".[13]

The objective of this study was to measure if implementation of an intervention, i.e. RCDP curriculum, was associated with: (1) improved performance on key resuscitation quality markers when compared to a baseline cohort from our initial pre-intervention study and (2) a measurable improvement between first and third-year pediatric residents.[7]

2. Methods

2.1. Pre-intervention baseline resuscitation curriculum

The pre-intervention resuscitation curriculum consisted of BLS during intern orientation, PALS at the beginning of second year, monthly in situ mock-codes on the wards described previously and sporadic mock codes on other rotations.[14] Greater detail regarding the pre-intervention cohort baseline characteristics was reported previously.[7,14,15]

2.2. Intervention

The post-intervention resuscitation training was identical to pre-intervention except: (1) PALS was moved from beginning of second-year to the end of first-year of residency and (2) introduction of the new curriculum.

2.3. Curriculum development

We designed curriculum that includes high-fidelity simulation and debriefing, both associated with improved resuscitation efforts.[16–18] We focus on management of the first 5 min of respiratory failure and cardiac arrest, thus we refer to this curriculum as RCDP-FFM. Along with practicing resuscitation technical skills we emphasize communication and teamwork principles. All teaching is consistent with AHA 2005 and 2010 pediatric BLS and PALS guidelines since initial curriculum development overlapped those periods. A summary of training objectives is available in Appendix 1.

Training is held each month in the Johns Hopkins Simulation Center for first and third-year pediatric residents that will carry Pediatric Rapid Response Team (PRRT) pagers that month (8 residents/session). The two-hour sessions are held at the beginning of the month in a "just-in-time" manner. They have this training prior to a surprise in situ mock code that occurs later that month, and before any true medical emergencies they might have to manage.[19] The curriculum is intended to be complementary to BLS and PALS and prepare them to manage a deteriorating child on the wards during the first 5 min of a crisis, while waiting for the pediatric intensive care unit (PICU) staff and remaining members of the PRRT to arrive.
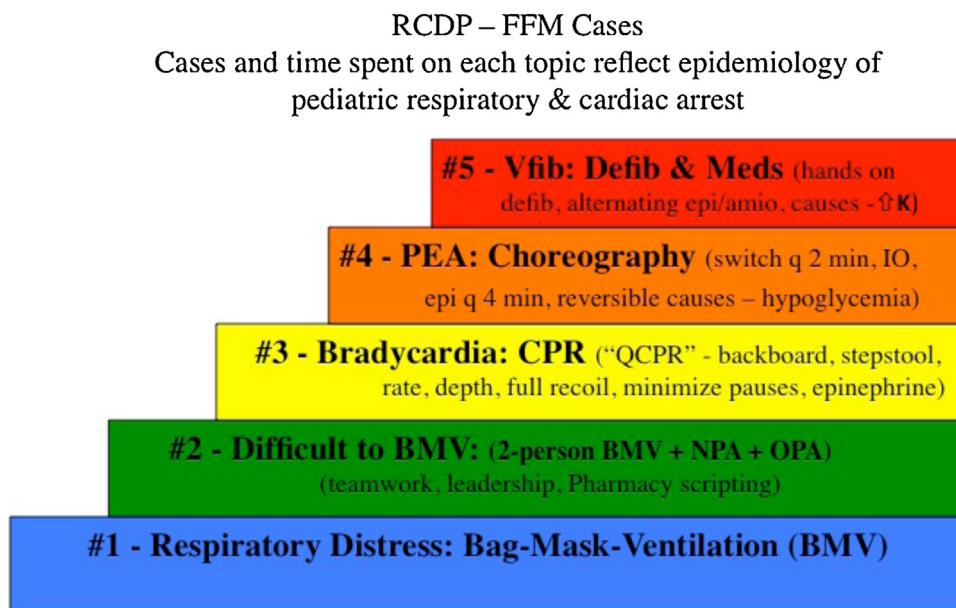
2.4. Defining key principles of RCDP training method

We systematically analyzed iterations of our curriculum (assessing for improvements in time to compressions, no-flow fractions and time to defibrillation), continuously updating our approach until learners consistently achieved curricular goals. Observation revealed learner-centered debriefing did not result in measurable improvement in the two-hour period. We shifted to a directed feedback or "coaching" style. The first scenario of each session is allowed to flow uninterrupted, acting as a needs assessment. We then progressively raise our expectations and interrupt for errors, addressing each by: (1) sharing performance data, quantifying any breeched standards (e.g. start compressions within 10 s of cardiac arrest, defibrillate within 2 min, no-flow fraction < 80%),[20] (2) solution oriented debriefing including "gold standard choreography", (3) scripted language to improve team communication and (4) use of what we call "action linked phrases"; (e.g. "There's no pulse, I'm starting chest compressions.") When residents repeat an error, whether it is related to a skill (i.e. delay to starting chest compressions) or a teamwork issue (i.e. not utilizing closed-loop communication), we ask them to "pause, rewind 10 s and try it again."

During the RCDP-FFM sessions, residents are exposed to a series of five clinical scenarios. The scenarios require residents to work as a team and allows for hands-on experience with a progression of resuscitation psychomotor skills (Fig. 1). Each scenario builds on skills taught in the previous scenario such that skills most frequently needed in pediatrics, e.g. bag-valve-mask ventilation (BVM) will be practiced the most. The case progression was designed to reflect the epidemiology of pediatric cardiac arrests, i.e. time spent on respiratory failure > bradycardia > pulseless electrical activity (PEA) > shockable rhythms. Similarly, teamwork skills including team choreography during resuscitation (i.e. switching compressors seamlessly) and communication skills progress throughout all five cases as well.

2.5. Study design

The participants consisted of two cohorts of pediatric residents separated by two years. We evaluated performance for residents who received RCDP-FFM ("post-intervention") against that of the

RCDP – FFM Cases
Cases and time spent on each topic reflect epidemiology of pediatric respiratory & cardiac arrest

#5 - Vfib: Defib & Meds (hands on defib, alternating epi/amio, causes - ⇧K)

#4 - PEA: Choreography (switch q 2 min, IO, epi q 4 min, reversible causes – hypoglycemia)

#3 - Bradycardia: CPR ("QCPR" - backboard, stepstool, rate, depth, full recoil, minimize pauses, epinephrine)

#2 - Difficult to BMV: (2-person BMV + NPA + OPA) (teamwork, leadership, Pharmacy scripting)

#1 - Respiratory Distress: Bag-Mask-Ventilation (BMV)

Fig. 1. Rapid Cycle Deliberate Practice – First Five Minutes (RCDP-FFM). Summary of 5 simulation cases and key objectives

historical control in our initial study ("pre-intervention").[7] The resuscitation skills of individual pediatric residents were assessed at the end of their academic year. This study was part of our institutional educational and quality assurance efforts. Primary data analysis was at the group level and deemed exempt by the Johns Hopkins University Institutional Review Board.

The primary outcome measure was the time interval between onset of PVT and defibrillation. Secondary outcome measures included: time interval between onset of PVT and (1) initiation of chest compressions, (2) no-flow fraction (proportion of time a pulseless patient received no compressions, defined as periods > 3 s), (3) initiation of BVM, (4) no-blow faction (proportion of time a pulseless patient received no respiratory support, defined as periods with no BVM > 10 s), and (5) pre-shock pause (interval between when chest compressions are paused and shock is delivered).

2.5.1. Post-intervention assessments: simulated cardiopulmonary arrests

Residents participated in individual sCPAs during their annual resuscitation competency assessment. Laerdal SimMan® was used to simulate an adolescent-sized patient who developed PVT in their presence. The resident was the team leader and two study personnel functioned as nurses. The sCPA started with one of three vignettes, but progression of vital signs were identical for all simulations. The details of how the sCPAs were conducted are described elsewhere and were identical for both cohorts.[7]

2.6. Data collection

2.6.1. Baseline characteristics

Residents completed an 18-item survey on gender, level of residency training, resuscitation education and experience. The survey development methods and results of the pre-intervention cohort are previously reported.[7]

2.6.2. Simulation performance data management and statistical analysis

Data for the pre-intervention cohort were reported previously.[7] Software was specifically designed, developed, and tested for

reliability for data abstraction from post-intervention video-taped sCPAs and stored in a Microsoft (Redmond, Washington) SQL CE database. Data from both cohorts were then combined and analyzed with STATA I/C 10.0 statistical software (College Station, TX). Proportions were calculated for categorical data and compared using the chi-square statistic. Continuous data were first assessed for distribution and based on the non-normal distribution median values and interquartile ranges were reported. Comparison of continuous data between the cohorts was made using the Wilcoxon rank-sum test.

We performed time-to-event analysis for the interval between onset of PVT and first defibrillation, as well as time to initiation of chest compressions. The assumption of proportional hazards was assessed using graphical log–log plots of survival probability against analysis time; this assumption held sufficiently to use time-to-event methodology. Kaplan–Meier survival curves were estimated and compared using the log-rank test. Cox proportional hazards regression models were fit to estimate hazard ratios using a stepwise process of inclusion of independent variables; both unadjusted and adjusted hazard ratios were calculated. Potential collinearity/multicollinearity of independent variables was evaluated using several methods including evaluation of the mean variance inflation factor (mVIF) value for each model using ordinary least squares regression and a series of sensitivity analyses.

3. Results

3.1. Baseline characteristics

Seventy pediatric residents participated in the pre-intervention period and fifty-one in the post-intervention period. Baseline characteristics are stratified by cohort and reported in Table 1. Resuscitation training was similar between the two cohorts except fewer of the post-intervention cohort had training in advanced cardiopulmonary life support and more had exposure to simulators during medical school. As expected, more post-intervention than pre-intervention residents had taken PALS since one of the

Table 1
Baseline characteristics.

Baseline Characteristics	Pre-RCDP, $n = 70n$ (%)	Post-RCDP, $n = 51n$ (%)	p-Value
PGY			
1	27 (39%)	19 (37%)	0.975
2	22 (31%)	17 (33%)	
3	21 (30%)	15 (29%)	
Gender			
Males	28 (40%)	19 (37%)	0.760
Females	42 (60%)	32 (63%)	
Resuscitation training in medical school			
BLS	57 (81%)	41 (82%)	0.936
ACLS	33 (47%)	14 (28%)	**0.034**
PALS	3 (4%)	2 (4%)	0.938
Code team training	23 (33%)	12 (24%)	0.293
Simulator exposure	17 (24%)	13 (26%)	0.831
Resuscitation using simulator	8 (11%)	10 (50%)	**<0.001**
Resuscitation training in residency			
Mock code this year	46 (66%)	37 (79%)	0.129
Mock code during residency	65 (93%)	46 (92%)	0.860
Simulator training during test year	37 (53%)	22 (45%)	0.393
Resuscitation training ever			
BLS	64 (91%)	44 (94%)	0.663
PALS	40 (57%)	46 (98%)	**<0.001**
Resuscitation experience			
Attended real code in medical school	53 (76%)	37 (73%)	0.694
# codes in medical school[a]	2 (1–3)	1 (0–2)	0.2767
Attended real code in residency	67 (96%)	45 (88%)	0.122
# codes in residency[a]	4 (3–8)	5 (2–7)	0.4208
Codes as Team Leader	0 (0–0)	0 (0–0)	0.6125
Ever defibrillated a patient	11 (16%)	6 (12%)	0.595
Ever defibrillated a patient or manikin	46 (66%)	41 (80%)	0.076

The bold values indicate a p value < 0.05.

[a] Median (interquartile range).

recommendations from the initial study was to move PALS into the internship year.

3.2. Airway management

More than 90% of residents in both cohorts requested team members perform BVM or initiated it themselves. There was a significant reduction in the median (interquartile range–IQR) no-blow fraction for the post-intervention cohort, [pre: 39% (22–64%) vs. post: 30% (22–42%), $p = 0.01$], see Table 2.
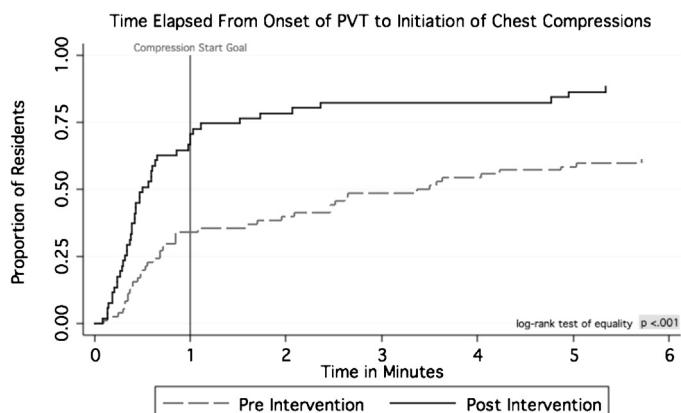
3.3. Compressions

Post-intervention residents were faster to start chest compressions than the pre-intervention cohort [pre: 51 s (27–210) vs. post: 27 s (18–60), $p < 0.002$.] The no-flow fraction was also significantly reduced [pre: 74% (5–100%) vs. post: 34% (26–53%), $p < 0.001$], see Table 2. More of the post-intervention group started compressions within 1 min of pulselessness: [pre: 34% vs. post: 71%, $p < 0.001$] demonstrated in Fig. 2. In a Cox regression controlling for level of training, gender and prior participation in a PALS course, the post-intervention group was 3.8 times more likely to start compressions within 1 min than the pre-intervention group [HR: 3.82, 95% CI: 2.03–7.17, $p < 0.001$], see Table 3. PALS was not independently associated with starting compressions within 1 min of PVT: [HR: 0.92, 95% CI: 0.34–2.45, $p = 0.86$]. Unlike in our initial study cohort, there was successive improvement by year of post-graduate training; i.e. second-year residents were 3.3 times more likely and third-years were 4.3 times more likely to start compressions within 1 min of PVT than first-years.

3.4. Defibrillation

There was no difference in the proportion of each group that successfully defibrillated at some point during the sCPA. However, there was a significant decrease in median time from onset of PVT to defibrillation after the intervention: [pre: 163 s (120–300) vs. post: 128 s (101–209), $p = 0.03$]. The median pre-shock pause time was improved for the post-intervention group by a factor of 10 [pre: 84 s (26–162) vs. post: 8 s (4–18), $p < 0.001$], see Fig. 3.

Although there was not a significant difference in the proportion of residents in each group successfully delivering a shock within 2 min in bi-variate analysis, the multivariable Cox proportional hazard analysis indicated residents in the intervention group were 65%

Fig. 2. Kaplan–Meier: onset of PVT to Initiation of Chest Compressions.

Table 2
Resuscitation performance.

Resuscitation performance	Pre-RCDP, n = 70	Post-RCDP, n = 51	p-Value
Airway and breathing			
Ordered or used BVM	64 (91%)	50 (98%)	0.12
Time to ordering BVM (s)[a]	23 (13–88)	19 (11–30)	0.09
Min–max (s)[a]	[5–515]	[2–192]	
Total time respirations not performed (s)	196 (144–265)	148 (98–189)	**0.004**
"No-Blow" fraction	39% (22–64%)	30% (22–41%)	**0.013**
Circulation			
Ordered or performed compressions	47 (67%)	46 (90%)	**0.003**
Started compressions with-in 1 min	24 (34%)	36 (71%)	**<0.001**
Time to first compression (s)[a]	51 (27–210)	27 (18–60)	**<0.002**
Min–max (s)[a]	[6–736]	[5–461]	
Total time compressions not performed (s)	357 (242–573)	141 (92–250)	**<0.001**
"No-Flow" fraction	74% (5–100%)	34% (26–53%)	**<0.001**
Defibrillation			
Successfully delivered a shock	65 (94%)	46 (90%)	0.410
Successfully delivered shock with-in 3 min	38 (54%)	33 (65%)	0.250
Time to successfully delivering shock (s)[a]	163 (120–300)	128 (101–209)	**0.03**
Min–max (s)[a]	[67–668]	[53–759]	
Pre-shock pause time (s)[a]	84 (26–162)	8 (4–18)	**<.001**
At least one failed defibrillation attempt	34 (49%)	14 (28%)	**0.02**

The bold values indicate a p value < 0.05.

[a] Median (inter-quartile range).

more likely to defibrillate within 2 min than the pre-intervention group [HR: 1.65, 95% CI: 1.03–2.65, p = 0.04]. Second and third-year residents were significantly more likely to defibrillate within 2 min than the first-year residents, see Table 3. The mVIF for this model was 1.14 indicating collinearity of independent variables was not a substantive concern.

It was recognized there could be intra-person correlation given 15 participants in the pre-intervention cohort were also included in the post-intervention cohort. We performed a sensitivity analysis by repeating the same analyses after excluding these 15 observations. The findings were not significantly changed, suggesting little or no intra-person correlation.

4. Discussion

We present the results of a prospective pre-post interventional study of pediatric resident performance during simulated sCPAs.

Our analysis revealed an association between the RCDP-FFM curriculum and marked improvement in quality measures of BLS and defibrillation. This manuscript introduces an innovative teaching style we call "Rapid Cycle Deliberate Practice", which enables rapid attainment of competence in resuscitation performance skills.

4.1. Clinical significance

The quality of resuscitation efforts delivered to a patient matters. Ornato et al. demonstrated adults who suffer an IHCA are less likely to survive when errors in resuscitation occurred.[3] Chan et al. demonstrated a 52% decrease in odds of survival from IHCA if an adult patient with VF/PVT was not defibrillated within 2 min.[4] Edelson et al. demonstrated each five second increment in pre-shock pause decreases the likelihood of successful defibrillation.[21] These data are relevant to those caring for children as Samson et al. demonstrated 10% of children who suffer an IHCA will have VF/PVT

Table 3
Cox multivariable regression analysis of time to compressions and time to defibrillation.

	Unadjusted hazard ratio	95% CI	p-Value	Adjusted hazard ratio[a]	95% CI	p-Value
Compressions ≤ 1 min						
Pre intervention	1.0 (reference)	–	–	1.0 (reference)	–	–
Post intervention	2.94	1.75–4.94	<0.001	3.82	2.03–7.17	**<0.001**
Male	1.0 (reference)	–	–	1.0 (reference)	–	–
Female	.639	.383–1.06	.085	.57	0.31–0.89	**0.045**
PALS never	1.0 (reference)	–	–	1.0 (reference)	–	–
PALS ever	3.33	1.51–7.35	**0.003**	.92	0.34–2.45	.860
PGY 1	1.0 (reference)	–	–	1.0 (reference)	–	–
PGY 2	2.74	1.39–5.42	**.004**	3.33	1.56–7.08	**0.002**
PGY 3	3.47	1.77–6.83	**<0.001**	4.29	1.91–9.62	**<0.001**
Defibrillation ≤ 3 min						
Pre intervention	1.0 (reference)	–	–	1.0 (reference)	–	–
Post intervention	1.41	.88–2.25	0.149	1.65	1.03–2.65	**0.039**
Male	1.0 (reference)	–	–	1.0 (reference)	–	–
Female	.58	.36–.92	**0.02**	.57	0.36–0.92	**0.022**
PGY 1	1.0 (reference)	–	–	1.0 (reference)	–	–
PGY 2	1.91	1.04–3.51	**0.037**	2.03	1.11–3.74	**0.022**
PGY 3	2.76	1.52–5.00	**0.001**	2.80	1.53–5.11	**0.001**

The bold values indicate a p value < 0.05.

[a] Hazard ratio adjusted for the RCDP curriculum intervention, level of training, gender and prior participation in a PALS course.
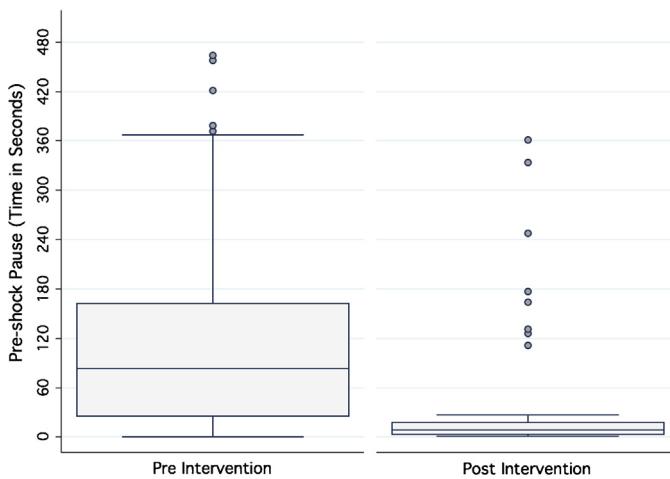
Fig. 3. Pre-shock pause decreased 10-fold after RCDP-FFM.

as their initial rhythm and 27% will have a shockable rhythm at some point during the event.[22] Our earlier study revealed residents who had previously discharged a defibrillator were 87% faster at defibrillating than those who had not done so.[7] Thus we now require *each* resident to operate the defibrillator in the middle of a VF scenario. After introduction of the RCDP-FFM curriculum, our residents were 1.7 times more likely to defibrillate within 2 min per AHA guidelines. There was a 10-fold reduction in the median pre-shock pause. Due to literature revealing the danger of hyperventilation in cardiac arrest, we now de-emphasize the no-blow fraction but highlight when the no-flow fraction is much higher than the no-blow fraction it is suggestive that more attention is being paid to ventilation than compressions. It is important to prevent hyperventilation.[23–25]

4.2. Resuscitation skill developmental milestones

In our initial study, third-year residents were equally unlikely to perform key resuscitation maneuvers as first-years. In response, we created a two-hour training session to address these deficits. Initially, we performed a 20-min simulation with a 40-min debriefing and then repeated that with a separate resuscitation topic. Unfortunately, we saw no improvement in performance. Neither the extra training time nor the repeated exposure to the traditional curriculum was associated with improvement. As described above, we ultimately discovered what we now call the RCDP method. After exposure to the RCDP-FFM curriculum, our third year residents' resuscitation skills were measurably better than the first year residents.

The residents participate in the RCDP curriculum each time they are on the general wards, i.e. several times per year for both first and third-years. These results suggest a positive dose response, which we did not see with our traditional mock codes or with the initial drafts of our curriculum. Of interest, second-years were noted to be better than first-years even though they had not had further RCDP curriculum exposure. Anecdotally, second-year residents reported after being exposed to RCDP several times during their first-year, they were prompted to do more self-directed learning, i.e. review the defibrillator, and take better advantage of training opportunities during in situ mock codes. The implication is these components are synergistic. Resuscitation skills can and should be measured with a requirement of incremental acquisition of competency, as advocated by the ACGME's Milestones Project.[26] It is also important that we use our limited resources (i.e. health care dollars and trainee time) effectively, by measuring the efficacy of curricular efforts. Future discussion is warranted regarding which

resuscitation skills should be mastered by each stage of training, as well as exploration of necessary retraining intervals.

4.3. BLS and PALS as pre-requisites for RCDP-FFM

Consistent with our previous analysis, PALS was not independently associated with time-to-defibrillation performance. While PALS has a clear impact on "knowing" what to do algorithmically, as is evidenced by cognitive assessment during certification, this is not sufficient to operationalize the content into actions during clinical scenarios.[27] However, it is possible our residents quickly improved their skills during our RCDP-FFM curriculum because they had already taken BLS and PALS; we hypothesize that these courses are synergistic in achieving our results.

Therefore the key principles of RCDP described above (maximal deliberate practice opportunities, overlearning and automatization to create muscle memory, expert derived solutions with directed feedback and fostering a psychologically safe environment) were inherent in the design and implementation of the curriculum.

4.4. Limitations

First, we used high-fidelity simulators, which not all residency programs have. There are conflicting data on whether high and low-fidelity simulators have equivalent impact on learning.[28,29] Our design does not allow us to say high-fidelity simulation was integral to our success. Second, more residents in the pre-intervention group participated in the assessment. While quasi-selection bias may have been induced (high-performers being more likely to participate), non-participation was due to scheduling conflicts, and should not have systematically skewed our results. Third, baseline characteristics were assessed using cross-sectional data, thus potential for recall bias exists. Fourth, while we describe a positive dose-response we did not gather attendance data sufficient to recommend a specific number of exposures or to define decay. However, these issues are somewhat obviated given we teach in a "just-in-time" manner. Residents carrying PRRT beepers have this training when they are most likely to need the skills, i.e. repeated booster shots. We have not yet identified a "saturation" curve that would imply they no longer need repeated exposure. Finally, this was a single site study and results may not be generalizable to other institutions or other subject matter.

5. Conclusion

This study revealed the RCDP-FFM curriculum was associated with improved performance by pediatric residents during sCPAs in nearly all measures of resuscitation. Future investigation is needed to see if RCDP-FFM is effective when implemented at other institutions and with other topic areas. Additionally, research is needed to determine if the benefits observed in simulation associated with our intervention translate to clinical practice, thus reducing error, improving performance, and ultimately saving lives of children who require and deserve high quality resuscitation.

Contributor's statement

All authors have made substantial contributions to all of the following: (1) the conception and design of the study, or acquisition of data, or analysis and interpretation of data, (2) drafting the article or revising it critically for important intellectual content, (3) final approval of the version to be submitted.

Conflict of interest statement

The authors have no conflict of interest to report.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.resuscitation.2014.02.025.

References

1. Knudson JD, Neish SR, Cabrera AG, et al. Prevalence and outcomes of pediatric in-hospital cardiopulmonary resuscitation in the United States: an analysis of the Kids' Inpatient Database. Crit Care Med 2012;40:2940–4.
2. Girotra S, Spertus JA, Li Y, et al. Survival trends in pediatric in-hospital cardiac arrests: an analysis from get with the guidelines – resuscitation. Circ Cardiovasc Qual Outcomes 2013;6:42–9.
3. Ornato JP, Peberdy MA, Reid RD, Feeser VR, Dhindsa HS. NRCPR investigators. Impact of resuscitation system errors on survival from in-hospital cardiac arrest. Resuscitation 2012;83:63–9.
4. Chan PS, Krumholz HM, Nichol G, Nallamothu BK, AHA NRCPR Investigators. Delayed time to defibrillation after in-hospital cardiac arrest. NEJM 2008;358:9–17.
5. American Heart Association et al. 2005. American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care of pediatric and neonatal patients: pediatric basic life support. Pediatrics 2006;117:e989–1004.
6. Kleinman ME, de Caen AR, Chameides L, et al. Part 10: pediatric basic and advanced life support: 2010 international consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. Circulation 2010;122:S466–515.
7. Hunt EA, Vera K, Diener-West M, et al. Delays and errors in cardiopulmonary resuscitation and defibrillation by pediatric residents during simulated cardiopulmonary arrests. Resuscitation 2009;80:819–25.
8. Puttemans V, Wenderoth N, Swinnen SP. Changes in brain activation during the acquisition of a multifrequency bimanual coordination task: from the cognitive stage to advanced levels of automaticity. J Neurosci 2005;25:4270–8.
9. Debaere F, Wenderoth N, Sunaert S, Van Hecke P, Swinnen SP. Changes in brain activation during the acquisition of a new bimanual coodination task. Neuropsychologia 2004;42:855–67.
10. Goff BA. Changing the paradigm in surgical education. Obstet Gynecol 2008;112:328–32.
11. Edmondson A. Psychological safety and learning behavior in work teams. Adm Sci Q 1999;44:350–83.
12. Kolbe M, Weiss M, Grote G, et al. TeamGAINS: a tool for structured debriefings for simulation-based team trainings. BMJ Qual Saf 2013:1–13.
13. Ericsson KA. Deliberate practice and the acquisition of expert performance: a general overview. Academic Emerg Med 2008;15:988–94.
14. Hunt EA, Patel S, Vera K, Shaffner DH, Pronovost PJ. Survey of pediatric resident experiences with resuscitation training and attendance at actual cardiopulmonary arrests. Pediatr Crit Care Med 2009;10:96–105.
15. Hunt EA, Walker AR, Shaffner DH, Miller MR, Pronovost PJ. Simulation of in-hospital pediatric medical emergencies and cardiopulmonary arrests: highlighting the importance of the first 5 min. Pediatrics 2008;121:e34–43.
16. Wayne DB, Butter J, Siddall VJ, et al. Graduating internal medicine residents' self-assessment and performance of advanced cardiac life support skills. Med Teach 2006;28:365–9.
17. Dine CJ, Gersh RE, Leary M, Riegel BJ, Bellini LM, Abella BS. Improving cardiopulmonary resuscitation quality and resuscitation training by combining audiovisual feedback and debriefing. Crit Care Med 2008;36:2817–22.
18. Andreatta P, Saxton E, Thompson M, Annich G. Simulation-based mock codes significantly correlate with improved pediatric patient cardiopulmonary arrest survival rates. Pediatr Crit Care Med 2011;12:33–8.
19. Barnes BE. Creating the Practice-Learning Environment: Using Information Technology to Support a New Model of Continuing Medical Education. Acad Emed 1998;73:278–81.
20. Meaney PA, Bobrow BJ, Mancini ME, et al. Cardiopulmonary resuscitation quality: improving cardiac resuscitation outcomes both inside and outside the hospital: a consensus statement from the American Heart Association. Circulation 2013;128:417–35.
21. Edelson DP, Abella BS, Kramer-Johansen J, et al. Effects of compression depth and pre-shock pauses predict defibrillation failure during cardiac arrest. Resuscitation 2006;71:137–45.
22. Samson RA, Nadkarni VM, Meaney PA, et al. Outcomes of in-hospital ventricular fibrillation in children. N Engl J Med 2006;354:2328–39.
23. Aufderheide TP, Sigurdsson G, Pirallo RG, et al. Hyperventilation-induced hypotension during cardiopulmonary resuscitation. Circulation 2004;109:1960–5.
24. Niebauer JM1, White ML, Zinkan JL, Youngblood AQ, Tofil NM. Hyperventilation in pediatric resuscitation: performance in simulated pediatric medical emergencies. Pediatrics 2011;128:e1195–200.
25. Park SO1, Shin DH, Baek KJ, et al. A clinical observational study analysing the factors associated with hyperventilation during actual cardiopulmonary resuscitation in the emergency department. Resuscitation 2013;84:298–303.
26. Hicks PJ, Schumacher DJ, Benson BJ, et al. The pediatrics milestones: conceptual framework, guiding principles, and approach to development. J Grad Med Educ 2010;2:410–8.
27. Grant EC, Marczinski CA, Menon K. Using pediatric advanced life support in pediatric residency training: does the curriculum need resuscitation. Pediatr Crit Care Med 2007;8:433–9.
28. Donoghue AJ, Durbin DR, Nadel FM, Stryjewski GR, Kost SI, Nadkarni VM. Effect of high-fidelity simulation on Pediatric Advanced Life Support training in pediatric house staff: a randomized trial. Pediatr Emerg Care 2009;25:139–44.
29. Cheng A, Hunt EA, Donoghue A, et al. Examining pediatric resuscitation education using simulation and scripted debriefing: a multicenter randomized trial. JAMA Pediatr 2013;22:1–9.