Effect of Repetitive Simulation Training on Emergency Medical Services Team Performance in Simulated Pediatric Medical Emergencies

Kathryn Kothari, MD^{1,2}, Chelsea Zuger, MD¹, Neil Desai, MD³, Jan Leonard, MSPH¹, Michelle Alletag, MD¹, Ashley Balakas, CPEN⁴, Mike Binney, NRP⁵, Sean Caffrey, MBA, CESMO, NRP⁶, Jason Kotas, NREMT⁴, Patrick Mahar, MD¹, Kelley Roswell, MD¹, and Kathleen M. Adelgais, MD, MPH¹

ABSTRACT

Objective: Emergency medical services (EMS) professionals infrequently transport children leading to difficulty in recognition and management of pediatric critical illness. Simulation provides an opportunity to train EMS professionals on pediatric emergencies. The objective of this study was to examine the effect of serial simulation training over 6 months on EMS psychomotor and cognitive performance during team-based care.

Methods: This was a longitudinal prospective study of a simulation curriculum enrolling EMS professionals over a 6-month period during which they performed three high-fidelity simulations at 3-month intervals. The simulation scenarios included a 15-month-old seizure (T₀), 1-month-old with hypoglycemia (T₁), and 4-year-old clonidine ingestion (T₂). All scenarios were standardized and required recognition and management of respiratory failure and decompensated shock. Scenarios were videotaped and two investigators scored EMS team interventions during simulations using a standardized scoring tool. Inter-rater reliability was assessed on 30% of videos using kappa analysis. Volumes of administered intravenous fluid (IVF) and medications were measured to assess for errors in administration. The primary outcome was the change in scenario score from T₀ to T₂.

Results: A total of 135 team-based simulations were conducted over the study period (48, 40, and 47 at T₀, T₁, and T₂, respectively). Inter-rater reliability between reviewers was very good ($\kappa = 0.7$). Median simulation score improved from T₀ to T₂ (24 vs 31, $p < 0.001$, maximum score possible = 42). The proportion of completed tasks increased across multiple categories including improved recognition of respiratory decompensation (19% vs. 56%), management of the pediatric airway (44% vs. 88%), and timeliness of vascular access (10% vs. 38%). Correct IVF administration varied by scenario (25% vs. 52% vs. 30%, $p = 0.02$).

From the ¹Department of Pediatrics, Section of Pediatric Emergency Medicine, University of Colorado School of Medicine, Aurora, CO; the ²Denver Health and Hospital Authority, Denver, CO; the ³Emergency Department, British Columbia Children's Hospital, Vancouver, British Columbia, Canada; the ⁴Emergency Medical Services Education and Outreach Program, Children's Hospital Colorado, Aurora, CO; the ⁵West Metro Fire Protection District, Lakewood, CO; and the ⁶EMS Division, Crested Butte Fire Protection Authority, Crested Butte, CO.

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Address for correspondence and reprints: Kathryn Kothari, MD; e-mail: Kathryn.Kothari@gmail.com.

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Conclusion: Serial simulation improved EMS team-based care in both recognition and management of pediatric emergencies. A standardized pediatric simulation curriculum can be used to train EMS professionals on pediatric emergencies and improve performance.

Simulation training is an important and effective means of improving patient safety.¹ In the prehospital setting, simulation-based education is used to create high-stakes scenarios that are infrequently encountered by emergency medical services (EMS) professionals.^{2,3} This is particularly relevant to the management of children, because they represent only 5% to 10% of all EMS encounters.^{4,5}

Previous retrospective and simulation-based research studies demonstrate challenges in illness recognition and management in pediatric prehospital emergencies as well as high rates of medication administration errors.^{3,6–8} Specifically, in simulation studies of pediatric emergencies by Lammers et al.,^{6,9} there were significant deficiencies identified in the management of pediatric sepsis, seizures, respiratory distress, and cardiac arrest, including a failure to complete all expected actions or administer intravenous fluids (IVFs) in the setting of hypotension.

Emergency medical services professionals identify the lack of high-quality pediatric education as a barrier to improving care for children.¹⁰ EMS professionals typically receive routine education to fulfill state licensure and national registry educational requirements and, overall, there is limited focus on pediatrics.¹¹ Studies demonstrate that simple prehospital protocol changes with training do not necessarily result in changes in care.^{7,12} Additionally, Su et al.¹³ demonstrated that EMS professionals lose knowledge and skills quickly after Pediatric Advanced Life Support (PALS) training, which only requires recertification every 2 years. Overall, there is limited evidence regarding best approaches to educate and promote retention and competency.¹⁴ Research on educational theory in emergency medicine residency training suggests that longitudinal simulation curriculum may improve learner competency.¹⁵ In addition, repeated simulation among EMS professionals and has demonstrated efficacy in the area of prehospital accuracy in disaster triage.¹⁶ To date, there are no longitudinal studies of repeated simulation training for prehospital professionals to promote retention of knowledge and team-based competency in pediatric medical emergencies.

The objective of this study was to examine the effect of serial simulation training over a 6-month period on EMS psychomotor and cognitive performance during

team-based care. We hypothesized that after three simulations, teams of EMS professionals would have a measurable improvement from baseline.

METHODS

Study Design and Setting

This was a longitudinal, prospective study of a simulation-based curriculum conducted over 6 months in a single urban fire-based EMS system. The simulations were conducted in a mobile simulation laboratory resembling the back of an ambulance equipped with audiovisual recording capabilities. The simulations utilized three different high-fidelity mannequins (Gau-mard), a 1-month-old, 15-month-old, and 5-year-old, allowing for continuous cardiorespiratory monitoring and real-time physiologic response to performed interventions. The local institutional review board reviewed and approved the study.

Simulation Scenario Development

Scenarios were developed by four study investigators: an expert in simulation, a training officer associated with the agency, the principal investigator, and an EMS researcher. Scenarios were reviewed by the agency to ensure clinical content aligned with protocols and expected interventions. The scenarios were pilot tested with a separate EMS agency unrelated to the study agency to provide an opportunity to train simulation facilitators and to assess construct validity. Based on feedback and observations from the pilot agency and study facilitators, the study investigators chose the three scenarios: a 15-month-old seizure and septic shock, a 1-month-old with hypoglycemia and hypovolemic shock, and a 4-year-old clonidine ingestion with distributive shock (Figure 1). To ensure that an assessment of performance could be standardized, all scenarios featured a pediatric patient with uncompensated shock and respiratory failure requiring airway management and crystalloid fluid resuscitation. The scenarios were programmed with vital sign trends for expected actions. A single facilitator ran the program for every scenario in the study. The clinical decompensation occurred at the same time during each case; thus the interventions for resuscitation were matched across all scenarios. Providers were required to think

T₀ Scenario: 15-month-old with septic shock and seizure

T₁ Scenario: 1-month-old with hypoglycemia, hypovolemic shock

T₂ Scenario: 4-year-old clonidine ingestion

Figure 1. Scenario timelines with vital sign progression and task expectation.

about the etiology of the shock and intervene on additional clinical factors per their agency protocols. The scenarios varied in patient age, weight, and clinical condition to avoid memorization of medication doses and fluid volume.

Selection of Participants

Licensed EMS professionals from one local fire-based EMS agency were recruited for the study. The agency serves a population of 280,000 over 130 square miles and is comprised of combined advanced life support (ALS) and basic life support (BLS) response. Subjects

were eligible for inclusion if they were emergency medical technicians (EMTs), advanced EMTs (AEMTs), or paramedics who met local and state authority requirements for staffing an ALS ambulance. Typical 911 response by this agency includes both a fire engine and an ambulance all staffed by EMS professionals employed by the agency. All personnel attend mandatory quarterly education designed to train on updated protocols and new clinical initiatives undertaken by the agency. Agency ALS professionals are required to obtain initial certification in pediatric advanced life support or pediatric education for prehospital

professionals, but at the time of the study, only field trainers were required to maintain PALS certification. The agency utilizes the Handtevy system for pediatric medication doses, equipment size, and resuscitation parameters. This system provides the calculated volume for each medication based on the agency formula and the estimated weight of the patient based on age or length. Participation in this study was the only pediatric education during the calendar year for this agency.

Simulation Session

The teams of EMS professionals participated in three high-fidelity simulations at 3-month intervals over 6 months and were consistent with their typical composition when responding on scene. In general, teams were comprised of 3 or fewer paramedics and one to three EMTs and AEMTs. Participation in simulation training took place at a central training center during the professionals' scheduled shifts as part of their mandatory quarterly education. Individual stations went out of service to participate with their crews. For the purposes of this study, we chose not control for team composition. During each simulation, teams used their own agency's field guide for pediatric dosing (Handtevy) and pediatric supplies organized according to their own pediatric equipment kits. Based on the clinical presentation of each scenario and agency protocol, expected tasks included airway management, fluid resuscitation, and medication administration. Expected actions included the administration of midazolam for seizure activity and 10% dextrose for hypoglycemia. A trial of naloxone was optional for the

clonidine ingestion and not considered an expected action. Simulations were programmed for clinical decompensation with associated improvement based when expected actions were completed. Simulations were 10 minutes each. There were two facilitators in the room with the participants. One facilitator was an actor/parent and could answer limited historical questions. The second facilitator ran the simulation program.

Simulation Orientation

Prior to participating in the simulation, all study participants were oriented to the mobile simulation laboratory and the high-fidelity mannequin by a single study investigator. Over 10 minutes, they were given the opportunity to feel location of pulses, listen to breath sounds, and observe different motor aspects of the mannequin including pupillary constriction, seizure activity, and chest wall rise.

Simulation Debrief

Participants did not receive any education or feedback during the simulation, but instead underwent a 20- to 30-minute multimodal structured debriefing guided by a standardized debriefing tool adapted from Eppich and Cheng¹⁷ for the purposes of this study (Figure 2). A total of nine simulation facilitators were trained in study procedures and use of the standardized debriefing tool. During the debriefing, study participants were educated on pediatric assessment and resuscitation skills with a focus on airway, breathing, and circulation (ABCs) as well as team skills such as closed-loop communication. During the debriefing, video playback

<p><i>Setting the scene:</i> I'll spend about 20 minutes debriefing the case with you. Ask about feelings then have someone describe the case. Look at how the case was managed and how it could be changed in the future. End by focusing on case specific tasks and how it can be applied to practice.</p>							
<p><i>Reaction:</i> <i>How did it make you feel?</i></p>			<p><i>Description:</i> Ask for summary of case</p>				
<p>Initial assessment: Focused SAMPLE history, Vital signs (RR, HR, BP, oxygen saturations), Patient weight Review: length-based tape for weight estimate</p>	<p><i>Airway and Breathing:</i> Airway assessment, RR for age, signs of respiratory distress, O₂ saturations, supplemental O₂, BMV, review technique including mask size, airway repositioning, rate, assessment of quality</p>	<p>Circulation: Identify signs of perfusion, HR for age, BP for age, capillary refill, manage poor perfusion (IV/IO placement), timely access, IV fluid administration and volume of boluses, pull-push technique</p>	<p>Disability: Pupils Evaluate responsiveness</p>	<p><i>Case specific medical management (example for seizure):</i> Seizure recognition, treatment (benzodiazepine, dosing, routes of administration)</p>			
<p><i>Closing remarks:</i> What went well? What didn't go well? If not already addressed: discuss roles, closed loop communication. Discuss any outstanding questions or concerns. This was a challenging case and meant simulate the stress of a pediatric emergency. Thank you for participating!</p>							
<p>RR: respiratory rate, HR: heart rate, BP: blood pressure. O₂: oxygen, BMV: bag mask ventilation IV: Intravenous, IO: intraosseous</p>							

Figure 2. Simulation debrief.

of the simulation session was available for review to highlight execution and timing of tasks. Multiple camera angles provided participants the opportunity to see the manner in which their hands were positioned on the mannequin and how fast they provided breaths during bag-mask ventilation (BMV). Study participants were taught airway management, the recognition and management of compensated and decompensated shock, and the administration of fluids including a demonstration of the pull-push method for rapid fluid administration.¹⁸ All study participants were given the opportunity to practice using a stopcock for this method of fluid administration. Finally, errors of omission and commission around fluid resuscitation and medication administration were discussed.

Methods of Measurement

All simulations were videotaped and team-based care was scored using an adapted version of the Simulation Team Assessment Tool¹⁹ (see Data Supplement S1, available as supporting information in the online version of this paper, which is available at <http://online.library.wiley.com/doi/10.1002/aet2.10537/full>). Since all scenarios matched in timing of clinical decompensation and type of resuscitation, this tool was appropriate for each clinical vignette. The STAT tool scores expected actions on a scale from 0 to 2 based on timing and degree of completion. In addition to taking a SAMPLE (signs/symptoms, allergies, medications, past illness, last meal, events preceding) history, participants needed to obtain vital signs, perform airway maneuvers (towel roll, jaw thrust, oral airway), listen for bilateral breath sounds, apply oxygen via nonrebreather, perform BMV, administer isotonic fluid with a 20 mL/kg bolus, and reexamine the patient and reassess the vital signs after interventions. We removed the scored tasks in the original tool that are out of scope for prehospital care providers for the purposes of the study. Certain items related to human factor tasks were also removed as the focus of the training was basic resuscitation skills (ABCs) and an in-depth analysis of human factors was outside the scope of the study. Our adaptation included 21 expected actions for each scenario over five categories including general assessment, airway assessment, breathing assessment, circulation assessment, and leadership and team-based skills. The maximum number of points for each scenario was 42.

Two investigators, with clinical training in pediatric emergencies, trained on the STAT scoring tool,

reviewed and scored the videos. The investigators utilized a data dictionary to score each task. Participants were required to physically perform all tasks on the mannequin to receive credit (i.e., had to reposition the airway with a jaw thrust, towel roll, or oral airway to get credit for airway maneuvers). One-third of the videos were reviewed by both investigators and these scores were used to establish inter-rater reliability via a kappa statistic.

To assess accuracy of fluid and medication administration, the volume of administered isotonic fluid and medication was collected in a reservoir attached to the mannequin and subsequently measured after each scenario. For the purposes of the study, intravenous (IV) and intraosseous (IO) access were successful if participants cannulated the vein of the mannequin and fluid was collected in the reservoir. If unsuccessful, participants were verbally told that their IV was not successful. During the second simulation (infant), IO was the only means of vascular access. Per the agency field guide and protocol, seizures are treated with midazolam, hypoglycemia is treated with premixed 10% dextrose, and a trial of naloxone is recommended for a suspected ingestion in a pediatric patient. The recognition of etiology of shock and medication administration are not included in the STAT tool and were scored separately.

Outcomes

For the purpose of our study and reporting, scenarios are referred to by the time point at which they were conducted (T_0 = first scenario, T_1 = second scenario, T_2 = last scenario). The primary outcome was the change in team-based score as measured by the scoring tool between T_0 , T_1 , and T_2 . Secondary outcomes included the comparison of the proportion of scenarios with medication and fluid errors as well as the completion of expected individual tasks (as defined by a score of 2) across the three scenarios. Errors in medication and fluid administration were defined as errors of omission (failure to administer medications and fluids when indicated) and errors of commission (administration of greater or less than 20% of the indicated dose of medication or fluids or administration of a medication not indicated by the protocol). Of note, given that the agency protocol did not mandate use of any medications as part of the management of ingestions, all medications administered during the T_2 scenario other than naloxone were considered errors of commission.

Data Analysis

Univariable analysis was used to generate descriptive statistics. We reported the individual components of the team scores and the median total session score and interquartile range (IQR) across the three simulations (T_0 , T_1 , T_2) using the Kruskal-Wallis test. Differences between the fluid and medication data were analyzed using chi-square and Kruskal-Wallis tests for categorical and continuous variables, respectively, and stratified between errors of omission and errors of commission. Statistical analyses were performed using SAS (version 9.4, SAS Institute, Cary, NC). Statistical significance was set at $p < 0.05$.

Prior unpublished data from utilization of the adapted STAT tool had a mean score of 30 with a standard deviation of 5. Using this information, we planned to enroll a minimum of 16 teams per time period to detect a 5-point change between two simulations.

RESULTS

During the study period, there were 313 participants who participated in 135 team-based simulations: 48, 40, and 47 at T_0 , T_1 , and T_2 , respectively. The interrater reliability for video review was very good ($\kappa = 0.7$, 95% confidence interval [CI] = 0.66 to 0.74). Table 1 demonstrates the characteristics of the study participants. Overall, the majority of the study participants were male with paramedic certification training; 52% reporting they had access to simulation training and 57% stating that they felt their pediatric training was adequate.

Simulation Performance

During the 6-month study period, the overall median team-based simulation scores improved from 24 (IQR = 21–27) at T_0 to 27 (IQR = 23–29) at T_1 , and 31 (IQR = 27–33) at T_2 ($p < 0.001$). The proportion of completed tasks at T_2 compared with T_0 increased across multiple categories (Figure 3). Teams completed more steps in the primary survey and initial assessment with 36% completing a primary survey within 2 minutes at T_2 compared to 10% at T_0 . In addition, 62% of teams obtained a full set of vital signs at T_2 compared with 29% at T_0 . With regard to improvements managing respiratory failure between T_0 and T_2 , the proportion of teams recognizing respiratory decompensation within 30 seconds increased (19% vs 56%). During this same period, the proportion of

Table 1
Demographics of Participants

	<i>n</i> = 313 (%)
Age (years) [#]	
<25	6 (2)
26–30	24 (8)
31–35	42 (14)
35–40	54 (18)
>41	179 (59)
Sex ^Y	
Male	292 (98)
Female	7 (2)
Race ^Ψ	
White	283 (93)
Native Hawaiian/other Pacific Islander	1 (<1)
Hispanic or Latino	7 (2%)
Black or African American	1 (<1)
Indian or Alaska Native	4 (1)
Other*	8 (3)
Parent ^{&}	
Yes	235 (77)
Employment status ^ω	
Full-time	298 (99)
Certification Level ^{##}	
EMT-basic	101 (33)
EMT-intermediate	8 (3)
EMT-paramedic	198 (65)
Training type ^{ΥΥ}	
Basic Life Support	109 (36)
Advanced Life Support	198 (64)
Feel pediatric training is adequate ^{ΨΨ}	
Yes	171 (57)
No	128 (43)
Current exposure to simulation ^{&&}	
Yes	156 (52)
No	143 (48)

*Other identifies as multiracial missing responses: $\#(n = 8)$, $Y(n = 14)$, $\Psi(n = 9)$, $\&(n = 6)$, $\omega(n = 12)$, $\##(n = 6)$, $ΥΥ(n = 6)$, $ΨΨ(n = 14)$, $\&\&(n = 14)$.

teams initiating BMV also increased (8% to 42%). Teams demonstrated improvement in use of the BVM with 87% of teams using proper fit and technique during the T_2 scenario compared to 44% at T_0 . Teams obtained early vascular access more often (10% at T_0 vs. 38% at T_2) and initiated fluid resuscitation within 6 minutes more frequently (33% at T_0 vs. 51% at T_2). However, overall, less than 10% of teams initiated a fluid bolus within 6 minutes across all scenarios. Task prioritization improved across scenarios (4% at T_0 to 33% at T_2) as well as leadership direction (27% at T_0 to 47% at T_2).

Figure 3. Percentage of teams receiving 2-point scores for each task by scenario. *Timed task-completion within a preordained timeframe to receive 2 points (see Data Supplement S1). BVM = bag-valve mask ventilation; ABCs = airway, breathing, circulation; IVF = intravenous fluid; Cap = capillary; 1° = primary.

Medication and Fluid Administration

At least 90% of teams administered IVFs at T₀, T₁, and T₂. At T₀ and T₁, 94 and 100% of teams, respectively, attempted IO as first attempt to access or after a missed IV attempt (Table 2). Overall, in 65% of simulations there was an error in the volume of fluid administered with a decrease in the number of scenarios with an error over course of the simulation curriculum (Table 2). Underdose and overdose of IVF was frequent with overdoses as high as four times the indicated fluid volume. When the administered volume was incorrect, there was a wide range of measured volume at all time points (Table 2). The method of fluid administration did change over the course of the simulations with an increased use of the pull-push method after the first scenario (44% vs. 73% vs. 65%, $p = 0.02$).

The medications administered during the scenarios are shown in Table 2. Study participants primarily administered the medications aligned to their protocols associated with each scenario, administering midazolam during the T₀ scenario, dextrose (10%) during the T₁ scenario, and naloxone during T₂ scenario. Accuracy of medication doses increased from T₀ to T₁ (72% vs. 85%; Table 2). Errors of omission occurred only during the T₁ scenario where dextrose was not administered to the mannequin in 7% of scenarios. In general, among scenarios in which we were able to measure the volume given, there were no errors of commission in 76 scenarios (76/97, 78%) with data stratified by scenario timepoint shown in Table 2. Among the remaining scenarios, there were a total of 21 errors of commission (70% incorrect dose, 30% incorrect medication; Table 2).

Table 2
IVF and Medication Administration and Errors by Teams in Each Simulation

	T ₀ [1-year-old, 10 kg] <i>n</i> = 48 (%)	T ₁ [1-month-old, 5 kg] <i>n</i> = 40 (%)	T ₂ [4-year-old, 20 kg] <i>n</i> = 47 (%)	p-value
IV attempt	10 (21)	10 (25)	40 (85)	
IO attempt	45 (94)	40 (100)	10 (21)	
IVF administered	43 (90)	37 (93)	46 (98)	0.45
Administration technique				
Pull-push	19 (44)	27 (73)	30 (65)	0.02†
Other [†]	24 (56)	10 (27)	16 (35)	
IVF volume administered correct*	12 (25)	21 (52)	14 (30)	0.02†
IVF overdoses [<i>n</i> (%)]	12 (25)	7 (18)	2 (4)	
(mL/kg) administered, med (range)	28 (25-70)	24 (12-80)	25 (25-25)	
IVF underdoses [<i>n</i> (%)]	15 (31)	5 (13)	15 (53)	
(mL/kg) administered, med (range)	5 (0-15)	4 (0-4.8)	7.5 (0-13.5)	
IVF volume stated correct* ^δ [<i>n</i> (%)]	38 (79)	29 (73)	43 (91)	0.06
Teams who gave medications	48 (100%)	40 (100%)	11 (24%)	
Number of medication given	50	49	12	
Name of medication				
Midazolam	48 (100)	9 (23)	0 (0)	
Dextrose (10%)	0 (0)	37 (93)	0 (0)	
Naloxone	0 (0)	0 (0)	10 (21) ^ψ	
Other	2 (4)	3 (8)	2 (4)	
Adenosine	1 (2)	0 (0)	0 (0)	
Albuterol	1 (2)	1 (3)	0 (0)	
Diazepam	0 (0)	2 (5)	0 (0)	
Epinephrine	0 (0)	0 (0)	2 (4)	
Scenarios with correct medications* ^δ	34/47 (72)	33/39 (85)	9/11 (82)	
Scenarios with errors in medication or dosing ^δ	13/47 (28)	6/39 (15)	2/11 (18)	

IO = intraosseous; IV = intravenous; IVF = intravenous fluid.

[†]Other = IV drip, IO drip, manually squeezing fluid bag

^δVolume not measured (*n*): IVF—T₀ (7), T₁ (4), T₂ (5); Medications—T₀ (1), T₁ (1).

^ψField guide dictates titrate to effect.

*±20% length-based weight.

† $p < 0.05$

DISCUSSION

Improving and maintaining EMS professional skills in pediatric emergencies is a challenging but important endeavor. Recently, a national task force composed of a multidisciplinary group of EMS educators published recommendations for pediatric research with the goal of improving patient outcomes. Respiratory disease/failure, sepsis, and seizures were among the five clinical areas with critical outcomes for EMS care.²⁰ Additionally, the Emergency Medical Services for Children Program performance measures include measures requiring EMS professionals to demonstrate competency with pediatric equipment.²¹ Our objective was to determine if EMS professional performance during repeated simulations would result in improvements in team-based care and EMS professional psychomotor and cognitive skills. We found that after participation in three simulations over 6 months, there was a measurable improvement in team-based care with improvements in critical tasks including obtaining vital signs, recognizing respiratory decompensation, and appropriately managing a pediatric airway. Furthermore, teams improved time to vascular access and initiation of fluid resuscitation.

Respiratory illness is the most common reason for pediatric EMS transport.⁵ Cognitive and psychomotor proficiency in airway and breathing skills is paramount to patient safety. In a simulation of pediatric sepsis and seizure, Lammers et al.⁶ demonstrated that only 62% of teams performed BMV correctly. In our study, we found similar deficiencies. At baseline, 44% of teams performed BMV with correct technique with only 6% using the correct rate. However, after three simulated scenarios, the proportion of teams who performed BMV at an appropriate rate increased sevenfold and appropriate technique doubled. The improvement in these skills with repeat exposure suggests that repeated simulation leads to increased competence.

Emergency medical services professionals often have difficulty identifying illness in pediatric patients.^{3,6,7} Across the three scenarios, professionals were more timely with initiation of interventions including recognition of respiratory decompensation and initiation of BMV and obtaining peripheral access. The third scenario featured a pediatric patient in shock with bradycardia, and professionals still managed to recognize the need for fluid resuscitation in the setting of hypotension.

In this study, EMS professionals attempted to administer a fluid bolus for simulated shock. Although

administration of accurate IVF dosing varied, most groups verbalized the correct dose. A study of IVF administration demonstrated that rapid administration of fluid is not feasible via a gravity setup (wide-open), but a pressure bag or pull-push setup can allow administration of a 20 mL/kg bolus within 5 minutes. Given that the volume of fluid is small in young children and infants, a pressure bag setup may lead to significant operator error.¹⁸ Other studies demonstrate that IVF administration is uncommon and, therefore, EMS professionals have little practice in doing this during actual out-of-hospital encounters.²² In our study, we found frequent overdoses and underdoses with fluid administration. Although the local protocol for the agency indicates that fluid volume boluses should be administered using the pull-push method, many professionals in this study still utilized various methods to administer fluids including the use of bursters, manual squeezing of the bag, and in several instances, placing a blood pressure on the bag to administer the fluid quickly. Over the course of the curriculum, the use of the pull-push method did improve after participants were taught how to use a stopcock and were given the opportunity to practice during debriefing sessions. However, significant errors continued to occur with underdoses being more common. For this reason, further study is needed to examine ways to improve the accuracy of volume administration to children when indicated.

In this study, we examined both errors of omission and errors of commission. Errors of omission were uncommon and only seen in the second scenario with a failure to administer dextrose in the setting of hypoglycemia. This is similar to the finding of Hoyle et al.⁸ who found that EMS professionals failed to check a blood sugar during simulation leading to errors of omission.^{21,22} When medications were administered, the error rate in the first scenario was 30% (15/50 total doses of medication). Prior studies demonstrate dosing errors between 35 and 49%.^{8,12} A study evaluating pediatric seizure management found that professionals who underwent a 1-day simulation training were only slightly more likely to administer proper medication dosing.¹² In this study, teams had access to their field guide which lists medication doses and volumes. Use of Handtevy may be associated with decreased cognitive errors compared to the traditional length-based tape.²³ However, in that study, there was no difference in the frequency of procedural errors. The ability to practice in simulation affords learners the opportunity to improve their procedural

skills hence the importance in evaluating the impact of simulation on this important outcome. The agency field guide may explain the improved baseline error rate of 24% but further study is needed for correlation with actual patient encounters where procedural errors may go undetected through review of EMS chart documentation alone. The frequency of errors went down further by the second simulation to 11% (6/52 total doses of medication), which is notable given that other than debriefing, there was no further training or practice after the first scenario prior to returning to the simulation laboratory.

In addition to medication volume errors, teams occasionally administered an incorrect medication for the clinical scenario. At T_0 , one team administered adenosine for tachycardia instead of the indicated IVF. During debriefing, we taught professionals about supraventricular tachycardia compared with tachycardia secondary to shock in the pediatric population and did not see that error reproduced. We also saw albuterol administered on more than one occasion without an indication. Finally, teams attempted to start or give epinephrine for blood pressure support prior to providing adequate fluid resuscitation. This highlights how the lack of recognition of the clinical condition serves as an important root cause of errors during prehospital care. In a survey of EMS professionals on medication errors, professionals reported that 33% of their medication errors were protocol errors.²⁴ Further study is needed to examine ways to promote recognition of clinical condition and reinforce protocol adherence among EMS professionals.

LIMITATIONS

This was a quasi-experimental study of an educational intervention among EMS professionals who were recruited while on service and did not have a separate control group that did not get the intervention. While the department had little turnover in personnel over the study time frame, our study participants may have rotated between stations or missed an intervention due to vacation or leave. Given the study design, it was not possible to control for team composition at each scenario, which likely varied across the course of the study. Although this was not optimal and the mix of individuals at each scenario was unavoidable, it does reflect the true nature of ambulance team staffing. We note that our study population is 98% male, higher than the reported national average of 72%,²⁵ and as such, this may limit the generalizability of our results.

We described teams who received 2 points for a given task. Teams were able to achieve partial task completion (or 1 point) for most rated tasks. For example, teams that obtained one to three vital signs received 1 point. The proportion of teams who received 1 point was high across most resuscitation skills at all time points. To detect a difference, we reported the proportion of teams who achieved task completion. Therefore, our analysis may not describe fully the change in clinical practice across simulations. Also, we examined EMS professional cognitive and psychomotor skills using a team-based scoring system and did not assess each study participant individually. Again, our study design likely reflects the true nature of EMS professional practice.

In this study, we analyzed medication and fluid volume errors as a secondary outcome. This was an exploratory analysis as a proxy for the psychomotor component of team-based care. While we did find improvement in error rates for both fluid and medication errors, this study was not powered to find a small change in these outcomes. Future study is needed to determine if multiple simulation decreases volume error rates in the prehospital setting.

Finally, implementation of an equally rigorous training program to other agencies may be limited by cost and time; however, we have demonstrated that there is a measurable improvement in pediatric resuscitation skills with repeated simulation as an educational intervention.

CONCLUSION

In summary, this study found that repeated simulation improves pediatric resuscitation skills among emergency medical services professionals. Further study is needed to examine the impact this type of training has on actual out-of-hospital encounters.

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Supporting Information

The following supporting information is available in the online version of this paper available at <http://onlinelibrary.wiley.com/doi/10.1002/aet2.10537/full>
Data Supplement S1. Scoring tool.