

Anesthesiology Residents' Performance of Pediatric Resuscitation during a Simulated Hyperkalemic Cardiac Arrest

Kimberly J. Howard-Quijano, M.D.,* Marjorie A. Stiegler, M.D.,† Yue Ming Huang, Ed.D., M.H.S.,‡ Cecilia Canales, M.P.H.,§ Randolph H. Steadman, M.D.||

ABSTRACT

Background: Anesthesiologists are responsible for the management of perioperative cardiopulmonary arrest in children. This study used simulation to assess the pediatric resuscitation skills of experienced anesthesia residents.

Methods: Nineteen anesthesia residents were evaluated using a pediatric pulseless electrical activity scenario. The authors used a standardized checklist to evaluate the residents' diagnostic and therapeutic interventions.

Results: After the onset of pulseless electrical activity, 79% of residents initiated cardiopulmonary resuscitation within 1 min. Approximately one third (31%) performed chest compressions at the recommended rate. Epinephrine was administered by 95% of residents, but only one third used the correct pediatric dose. All residents administered fluid boluses, but only 16% administered the recommended volume. Only one fourth of the residents considered hyperkalemia as a cause of pulseless electrical activity. None of the residents asked for dosing aids.

Conclusion: During this simulated pediatric emergency, anesthesia residents demonstrated an acceptable knowledge of general resuscitation maneuvers. However, a subset of resuscitation skills was incorrectly performed, mostly related to age or weight. Importantly, many residents did not consider the full differential diagnosis of pulseless electrical activity. Anesthesia residents may benefit from additional pediatric resuscitation training and practice using cognitive aids to access dosages and complicated diagnostic algorithms.

* Resident Physician, † Assistant Clinical Professor, ‡ Assistant Adjunct Professor, § Staff Research Associate, || Professor of Clinical Anesthesiology, Department of Anesthesiology, David Geffen School of Medicine at the University of California, Los Angeles, Los Angeles, California.

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Address correspondence to Dr. Steadman: Department of Anesthesiology, David Geffen School of Medicine at UCLA, Box 957403, 757 Westwood Plaza, Suite 2331E, Los Angeles, California 90095-7403. rsteadman@mednet.ucla.edu. Information on purchasing reprints may be found at www.anesthesiology.org or on the masthead page at the beginning of this issue. ANESTHESIOLOGY's articles are made freely accessible to all readers, for personal use only, 6 months from the cover date of the issue.

What We Already Know about This Topic

- ❖ Pediatric cardiac arrests occurs rarely, although more commonly in sick patients at tertiary medical centers, where residents are likely involved in patient care

What This Article Tells Us That Is New

- ❖ In a high-fidelity simulation with 20 residents of pediatric cardiac arrest with pulseless electrical activity, general resuscitation was well performed
- ❖ A subset of skills, primarily related to patient age and weight, including doses of epinephrine and intravenous fluids and rate of chest compression, were performed incorrectly by a majority of residents

PEDIATRIC perioperative cardiac arrest is a devastating event. Neonatal perioperative cardiac arrest occurs more frequently than adult cardiac arrest, and it is associated with a high mortality.¹⁻⁴ The reported incidence varies from 1.4 cardiac arrests per 10,000 pediatric anesthetics performed, in the Pediatric Perioperative Cardiac Arrest registry, to 3.3-4.6 cardiac arrests per 10,000 cases reported by various single-institution studies.³⁻⁵ Perioperative cardiac arrest in children is more likely to occur in American Society of Anesthesiologists physical status 3-5 patients and in emergency cases.⁶ These high-acuity cases are often seen at tertiary teaching hospitals where anesthesiology residents routinely take care of pediatric patients and are responsible for the management of perioperative cardiac arrests.⁶ As pediatric in-hospital cardiac arrest occurs infrequently, resuscitation skills in the residency curriculum are often taught and tested through simulator-based evaluations and mock codes.⁷⁻¹⁰ With the advent of pediatric simulators during the last decade, this technology is an ideal modality to evaluate and prepare the residents for actual occurrences.⁸

As a part of our usual protocol for incorporating challenging clinical cases into our simulation-based resident education curriculum, we scripted and piloted a scenario involving a pediatric craniotomy complicated by intraoperative hyperkalemic cardiac

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arrest. During this piloting, we observed some trends indicating possible knowledge gaps. We decided to formally evaluate these skills using a modified version of a previously validated checklist for the assessment of pediatric resuscitation skills using simulated scenarios.⁸

Materials and Methods

Clinical anesthesia year-2 and 3 (CA-2 and CA-3) residents from a tertiary teaching hospital who had completed at least 2 months of formal pediatric anesthesia training were eligible for enrollment in the study. A total of 20 of 26 eligible anesthesiology residents participated in the Institutional Review Board (The UCLA Office of the Human Research Protection Program, Los Angeles, CA) approved the study. We used an infant simulator (SimBaby, software version 1.3; Laerdal Medical Corporation, Wappingers Falls, NY) for the simulation sessions. After participant consent was obtained, 19 of the sessions were videotaped for review. One session was not videotaped because of technical reasons. All participants had previously participated in at least three previous simulation sessions as a part of the standard anesthesiology residency curriculum. Participants were oriented to the infant simulator features and were given the opportunity to familiarize themselves with the simulated patient and operating room environment before the start of the scenario.

Our scenario, modeled after an actual case, was that of a craniotomy for tumor excision in a 1-yr-old patient weighing 10 kg. The intraoperative course was notable for substantial blood loss, massive blood transfusion requirements, and subsequent hyperkalemic cardiac arrest (appendix). Laboratory studies were available to the participants in a way that mirrored their availability during the actual event. We developed a standardized scenario algorithm and script, actor roles, prompts, and a checklist for evaluating resident's interventions. The standardized scenario was preprogrammed using simulation software and run each time by the same simulator operator. Additional simulation staff members served as actors, playing the role of circulating nurse and surgeon. At least one member of the participating staff was an attending anesthesiologist.

The evaluation checklist was modeled after the 2008 Tool for Resuscitation Assessment using Computerized Simulation checklist developed to assess pediatric residents' competency in pediatric resuscitation.⁸ The checklist was modified to be more specific to anesthesia residents and our simulation scenario. We chose not to assess participants in the areas of intravenous access, mask ventilation, or tracheal intubation because the subjects had considerable experience in these skills. The checklist consisted of yes or no evaluations in the areas of behavioral skills (establishing leadership for the code, communicating with operating room personnel, and calling for assistance), clinical skills (age-appropriate chest compressions, fluid volumes, and medication dosing), and diagnostic skills (identification and consideration of differential diagnosis of pulseless electrical activity [PEA], and recognition of hyperkalemia related to massive blood transfusion as the etiology of PEA).

The videotaped sessions were independently reviewed by two reviewers (K.H.Q. and Y.M.H.) and scored using the checklist. A "yes" or "no" answer for each intervention and the specific intervention or medication dose was documented on the checklist. Participants were asked to announce aloud what medication, fluid, or blood product they were administering, and the dose. If a participant failed to specify a dosage, the "nurse" asked for clarification. During cardiopulmonary resuscitation (CPR), the "nurse" would offer to perform CPR and then elicit the desired chest compression rate from the resident participant. Checklist calibration was performed between the two raters before reviewing the videotaped sessions. Videotaped sessions were reviewed independently, any differences were discussed after viewing, and a final checklist answer was agreed on. All video data were entered into an Excel database (Microsoft Corporation, Redmond, WA). Descriptive statistics and frequencies for each checklist intervention were calculated using Statistical Package for the Social Sciences version 16.0 (SPSS Inc., Chicago, IL).

Results

The percentage of participants who performed each checklist item is shown in figure 1. After the onset of cardiac arrest (PEA), 88% (15/17) of participants palpated for the presence of a pulse. Data for pulse palpation could not be collected on two of the participants because a staff member inadvertently announced pulselessness before the participant completed their assessment of the pulse. Approximately four fifths (15/19) of the participants initiated CPR within 1 min of recognition of pulselessness, and 31% (5/16) instructed the "nurse" to perform the Pediatric Advanced Life Support (PALS) recommended chest compression rate (CPR rate) of 100 compressions per minute. The announced CPR rate for one participant was inaudible during video feedback, and the data for two participants could not be collected because the staff member did not inquire about the desired CPR rate during the scenario. Eight participants instructed chest compressions to be performed at a rate of 120–150 per minute, two at a rate faster than 120 (instructing the "nurse" to perform compressions "as fast as you can"), and two instructed compressions at a rate less than 100 per minute. One participant instructed the "nurse" to perform compressions at a rate less than recommended, but later instructed the "nurse" to perform compressions "as fast as you can" (table 1). The pulse was reassessed during resuscitation by 63% (12/19) of participants.

All participants (19/19) administered intravenous fluid boluses for the treatment of hypotension, but only 16% (3/19) administered the recommended volume of 20 ml/kg. An unspecified volume, likely to result in a bolus more than 20 ml/kg ("intravenous fluids wide open"), was administered by 58% (11/19) of participants, and 26% (5/19) administered less than the recommended bolus (table 1).

PEA as the cause of cardiac arrest was recognized by 79% (15/19) of participants without a prompt from a staff member. At least 3 of the 10 items in the differential diagnosis of PEA were considered by 79% (15/19) of the participants.

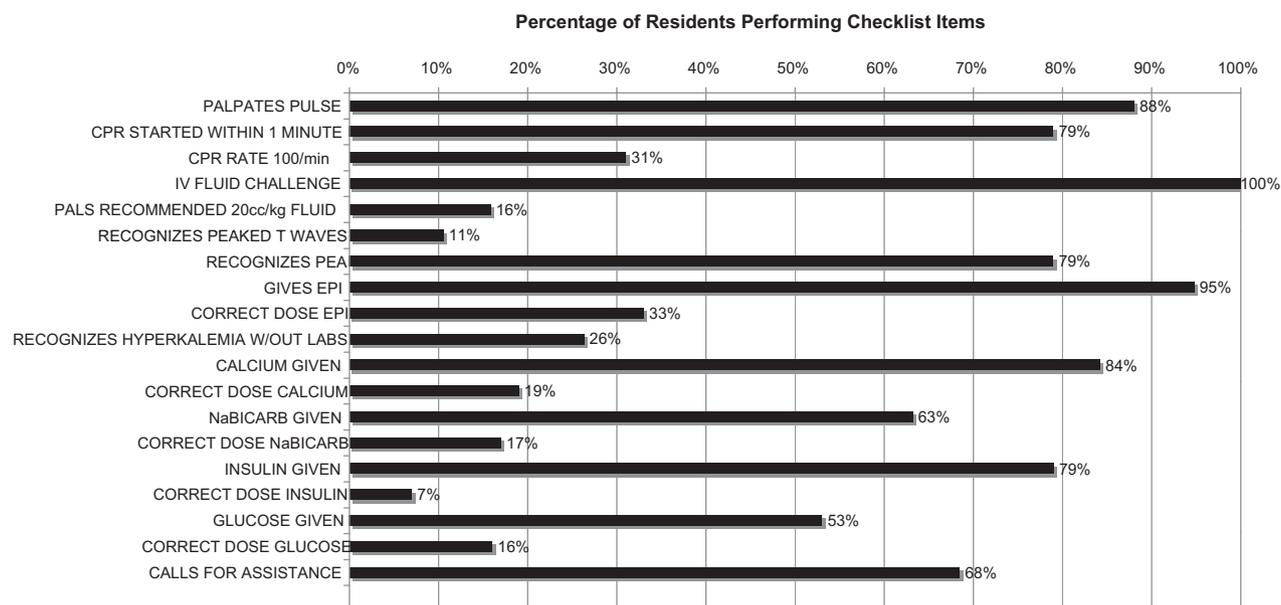


Fig. 1. Percentage of anesthesiology residents performing pediatric resuscitation interventions. CPR = cardiopulmonary resuscitation; Epi = epinephrine; IV = intravenous; NaBicarb = sodium bicarbonate; PALS = Pediatric Advanced Life Support; PEA = pulseless electrical activity; w/out = without.

During the scenario, 26% (5/19) of participants diagnosed hyperkalemia as a cause of PEA, without a staff prompt or laboratory values, and 11% (2/19) recognized the presence of peaked T waves on the monitor.

Table 1. Pediatric Resuscitation Interventions

Intervention	No. Participants (%)
CPR rate* (n = 16)	
"as fast as you can"	2 (13)
Rate of 120–150	8 (50)
PALS recommended rate of 100	5 (31)
Rate of 30†	2 (13)
Fluid bolus for treatment of hypotension (n = 19)	
Greater than PALS ("fluids wide open")	11 (58)
PALS recommended (20 ml/kg)	3 (16)
Less than PALS (ml/kg)	
10	3 (16)
5	1 (5)
2	1 (5)
Epinephrine for treatment of PEA‡ (n = 18)	
Adult dose (1 mg)	2 (11)
PALS recommended dose (10 µg/kg)	6 (33)
Less than PALS (µg)	
10	6 (33)
1	1 (6)

* One participant directed "nurse" to perform cardiopulmonary resuscitation (CPR) first at a rate of 30 and then subsequently "as fast as you can." † During debriefing, participants indicated rate of 30 was intended to mean the chest compression to ventilation ratio of 30:2. ‡ Three participants stated that they did not know the correct dose of epinephrine.

PALS = Pediatric Advanced Life Support; PEA = pulseless electrical activity.

For the treatment of PEA, 95% (18/19) of participants administered epinephrine; 33% (6/18) administered the correct pediatric dose (0.01 mg/kg or 10 µg/kg). Of the 12 participants administering an incorrect dose of epinephrine, two participants administered the recommended adult dose (1 mg), seven participants administered significantly less than the recommended dose (six administered 10 µg and one administered 1 µg), and three participants stated that they did not know the correct dose. After the diagnosis of hyperkalemia (with or without a prompt), 84% (16/19) administered calcium, whereas 19% (3/16) administered the correct pediatric dose (20 mg/kg). Nearly two third (63%, 12/19) of participants administered bicarbonate for hyperkalemia treatment; 17% (2/12) administered the correct pediatric dose (1 mEq/kg). Insulin was administered by 79% (15/19) of participants, but only 7% (1/15) knew the correct pediatric dose (0.1 U/kg). Glucose was administered with insulin by 53% (10/19) of participants, with 16% (3/10) ordering the correct pediatric dose (0.5 g/kg). Furosemide was administered by 11% (2/19) of participants, but none knew the pediatric dose (1 mg/kg). Hyperventilation and albuterol were provided for the treatment of hyperkalemia by 21% (4/19) of participants. Three participants incorrectly chose to defibrillate in an effort to treat PEA. No one referred to treatment guidelines.

All 19 of the participants took leadership for the code and communicated effectively with the surgeon and operating room staff. Sixty-eight percent (13/19) of participants called for additional anesthesiology assistance during the code.

Discussion

We observed generally acceptable resuscitation performance among the anesthesiology residents. For instance, the majority assessed for the presence of a pulse, and chest compressions were initiated promptly. The commendable leadership

and communication skills exhibited by the residents may have resulted from previous simulation-based training where leadership and communication with the operating team is emphasized. However, a subset of pediatric-specific actions was performed incorrectly by a significant number of residents. These actions include age-appropriate chest compression rate and weight-appropriate fluid resuscitation volume and medication dosages.

Pediatric resuscitation skills are important for pediatric anesthesiologists. They are also crucial for anesthesiologists who do not typically care for pediatric patients, as they may be called on to do so postoperatively or during emergencies. It is reassuring that the majority of residents recognized the presence of PEA, but the underlying cause was not fully explored. The ability to individually consider the numerous diagnoses that can lead to PEA may be particularly challenging during stressful clinical encounters. The use of reference materials such as code algorithms (cognitive aids) should be encouraged for this purpose. Whether this would have increased the likelihood that hyperkalemia was considered, or treated earlier, is unknown but one would presume so.

Most of the remaining knowledge gaps were related to age and weight-specific guidelines, which can also be remedied by reference material such as patient-specific dosing charts. These are in common use in many pediatric care areas but may not stay with the patient when they leave the ward for diagnostic tests or procedures. Why none of the residents attempted to access dosing charts is unclear; it could be due to a lack of experience using them or due to their perception that their innate knowledge was being assessed during the simulated encounter and such aids would, therefore, not be available to them.

Although the case we used is complex, and may typically be encountered only by subspecialists in pediatric anesthesiology, the knowledge gaps we identified are of value in planning educational curricula for general anesthesiology residents. PEA could occur in any case, and embedding it in a simulation scenario helps to differentiate the residents' ability to recognize this type of cardiac arrest and initiate appropriate clinical management, including identification of possible causes. The Pediatric Perioperative Cardiac Arrest Registry found that cardiac causes now outnumber respiratory causes of cardiopulmonary arrest, and the single most common cardiac cause of arrest is hypovolemia due to blood loss.⁶ Hyperkalemia-induced cardiac arrest is a predictable and reversible complication of massive blood transfusion that anesthesiologists should anticipate and treat in an age appropriate manner.^{11,12} The majority of case reports of transfusion-related hyperkalemia leading to cardiac arrest have been in pediatric patients. One fifth of perioperative pediatric cardiac arrests during noncardiac surgery were associated with hyperkalemia during blood transfusions.^{9,12}

The survival rate of hyperkalemic cardiac arrests during rapid blood transfusion is 12.5%, half that of pediatric cardiac arrest overall (26%).¹² This highlights the importance of preemptive education. Although extensive blood loss may be more common in orthopedic, cardiac, or transplant cases, unexpected blood loss can occur in any case, and the resulting PEA requires standard management.

Although this study indicates a need for additional pediatric resuscitation practice or education among anesthesia residents, we did not investigate how to best implement this. Whether PALS training is sufficient is an important question. The results from studies looking at pediatric resuscitation skills in pediatric residents, who are required to be PALS certified, show increased resuscitation-specific knowledge after certification.¹³ However, the information decays quickly after the course, and some residents perform poorly on mock codes despite being PALS certified.^{7,9,13} Further, although pediatric residents had improved bag mask ventilation and tracheal intubation skills after PALS,⁷ anesthesiology residents have considerable experience in airway management, and it is unlikely that these skills will improve as a result of mannequin-based training. If the assumption that anesthesia residents are competent in pediatric airway management is valid, PALS training may be inappropriate to address the needs of anesthesia residents. Anesthesia residents may receive more benefit from an anesthesia-specific PALS course that emphasizes the rate and depth of the chest compression and weight-specific medication dosage and fluid volumes. However, no accrediting body or organization offers an anesthesia-focused pediatric resuscitation course. Recognizing that perioperative cardiac arrest is distinct from prehospital cardiac arrest, the American Society of Anesthesiologists has published a monograph that focuses on anesthesiology-centric Advanced Cardiac Life Support, but the focus is on adult, not pediatric, patients.[#] It is likely that the most effective approach would be increased exposure to simulated pediatric emergencies rather than a one-time course. The simulated emergency curriculum should focus on use of cognitive aids, and the emphasis should be placed on a variety of cardiac emergencies.

Our study has limitations related to the use of simulation. First, residents verbalized the medication dosages and fluid volumes they intended to give, and they were not evaluated on the actual amount of medication or fluids given. This design was used to assess knowledge rather than technical skills related to medication or fluid delivery. Recognition of the magnitude of the transfused blood (which qualified as a massive transfusion since one blood volume was administered) may have been difficult because blood was ordered, and the total volumes to be transfused were announced but not actually given. Similarly, blood loss estimates were verbalized by the "surgeon," but the absence of actual bleeding may affect residents' perception of the amount of blood lost and administered. It is unknown whether residents would have administered fluids or medications correctly in a real clinical setting or would have instructed others to administer

Anesthesia Advanced Circulatory Life Support. Available at: <http://www.asahq.org/clinical/Anesthesiology-CentricACLS.pdf>. Accessed August 31, 2009.

medication. Second, the autonomy the residents were given as a result of their role as subjects was artificial. In an actual clinical setting, residents would call an attending anesthesiologist to assist rather than manage the patient by themselves. During the study, resident participants were instructed to act independently as if they were attending physicians. This may be less important when considering that all residents had completed the minimum requirement of two 1-month pediatric anesthesia rotations, and two thirds were CA-3 residents who completed residency within several months of study participation. Third, this study was conducted with residents from a single residency program and, therefore, may not be generalized to residents from other programs. However, the residents in the study had completed a 2-month pediatric assignment at an affiliated children's hospital where several local anesthesia programs also send their residents, so the subjects' skills are likely to reflect the skills of the other programs' residents at the completion of the 2-month experience. In a recent study of general pediatric residents, errors and delays in diagnosis and treatment of a simulated cardiopulmonary arrest occurred, so it is unlikely that our findings are isolated to a single residency program or to anesthesiology residents.¹⁴

We used simulation to identify the skills and knowledge gaps of anesthesiology residents in the setting of pediatric resuscitation skills. Simulation is beneficial in this context because it allows experience in infrequent events, permits resident autonomy without risk to patients, and can be accompanied by a facilitated debriefing that encourages reflection on the experience. The knowledge gaps that were identified during the simulated encounters may be best addressed through a wider range of simulated encounters that are selected to address the most common etiologies of perioperative pediatric cardiac arrest. Training should concentrate on cardiac arrest rather than respiratory arrest and should include techniques that incorporate the use of patient-specific dosing guidelines and other cognitive aids. Future studies should be aimed at identifying best practices to educate and train anesthesia residents in pediatric resuscitation skills.

References

1. Braz LG, Modolo NS, do Nascimento P Jr, Bruschi BA, Castiglia YM, Ganem EM, de Carvalho LR, Braz JR: Perioperative cardiac arrest: A study of 53,718 anaesthetics over 9 yr from a Brazilian teaching hospital. *Br J Anaesth* 2006; 96:569-75
2. Newland MC, Ellis SJ, Lydiatt CA, Peters KR, Tinker JH, Romberger DJ, Ullrich FA, Anderson JR: Anesthetic-related cardiac arrest and its mortality: A report covering 72,959 anaesthetics over 10 years from a US teaching hospital. *ANESTHESIOLOGY* 2002; 97:108-15
3. Flick RP, Sprung J, Harrison TE, Gleich SJ, Schroeder DR, Hanson AC, Buenvenida SL, Warner DO: Perioperative cardiac arrests in children between 1988 and 2005 at a tertiary referral center: A study of 92,881 patients. *ANESTHESIOLOGY* 2007; 106:226-37; quiz 413-4
4. Morray JP, Geiduschek JM, Ramamoorthy C, Haberkern CM, Hackel A, Caplan RA, Domino KB, Posner K, Cheney FW: Anesthesia-related cardiac arrest in children: Initial findings of the Pediatric Perioperative Cardiac Arrest (POCA) Registry. *ANESTHESIOLOGY* 2000; 93:6-14
5. Murat I, Constant I, Maud'huy H: Perioperative anaesthetic morbidity in children: A database of 24,165 anaesthetics over a 30-month period. *Paediatr Anaesth* 2004; 14:158-66
6. Bhananker SM, Ramamoorthy C, Geiduschek JM, Posner KL, Domino KB, Haberkern CM, Campos JS, Morray JP: Anesthesia-related cardiac arrest in children: Update from the Pediatric Perioperative Cardiac Arrest Registry. *Anesth Analg* 2007; 105:344-50
7. Quan L, Shugerman RP, Kunkel NC, Brownlee CJ: Evaluation of resuscitation skills in new residents before and after pediatric advanced life support course. *Pediatrics* 2001; 108:E110
8. Brett-Fleegler MB, Vinci RJ, Weiner DL, Harris SK, Shih MC, Kleinman ME: A simulator-based tool that assesses pediatric resident resuscitation competency. *Pediatrics* 2008; 121:e597-603
9. 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 minutes. *Pediatrics* 2008; 121:e34-43
10. White JR, Shugerman R, Brownlee C, Quan L: Performance of advanced resuscitation skills by pediatric housestaff. *Arch Pediatr Adolesc Med* 1998; 152:1232-5
11. Barcelona SL, Thompson AA, Cote CJ: Intraoperative pediatric blood transfusion therapy: A review of common issues. Part II: Transfusion therapy, special considerations, and reduction of allogenic blood transfusions. *Paediatr Anaesth* 2005; 15:814-30
12. Smith HM, Farrow SJ, Ackerman JD, Stubbs JR, Sprung J: Cardiac arrests associated with hyperkalemia during red blood cell transfusion: A case series. *Anesth Analg* 2008; 106:1062-9
13. Nadel FM, Lavelle JM, Fein JA, Giardino AP, Decker JM, Durbin DR: Assessing pediatric senior residents' training in resuscitation: fund of knowledge, technical skills, and perception of confidence. *Pediatr Emerg Care* 2000; 16: 73-6
14. Hunt EA, Vera K, Diener-West M, Haggerty JA, Nelson KL, Shaffner DH, Pronovost PJ: Delays and errors in cardiopulmonary resuscitation and defibrillation by pediatric residents during simulated cardiopulmonary arrests. *Resuscitation* 2009; 80:819-25

Appendix: Scenario Script and Key Events

The scenario is that of a 1-yr-old patient weighing 10 kg undergoing craniotomy for a tumor excision. The study begins as care is transferred from an actor anesthesiologist to the study participant. At this time, the patient is intubated, in lateral decubitus position, and the surgery is underway.

Shortly after the study participant assumes care, the patient develops hypotension, accompanied by substantial blood loss (800 ml total), necessitating massive blood transfusion. After participants transfuse the equivalent of one estimated blood volume of packed red blood cells, the patient develops hyperkalemia-associated peaked T waves and ultimately decompensates into pulseless electrical activity.

Participants identify and treat pulseless electrical activity, and if not done spontaneously, they are prompted by a staff member acting as the "surgeon" to explore the cause of pulseless electrical activity. If participants are unable to make the diagnosis of hyperkalemia despite actor prompts, they are presented with requested laboratory results showing grossly increased level of potassium. Scenario concludes with appropriate and successful treatment of hyperkalemia, or after 25 min of total scenario time.