

## RESEARCH REPORT

### Pediatric anaphylaxis in the operating room for anesthesia residents: a simulation study

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#### What is already known

- Pediatric anaphylaxis is a life-threatening, rapid-onset hypersensitive reaction and is one of the most common emergencies, although it is often under-recognized and under-treated.
- Simulation has helped characterize cognitive and technical skills in anesthesia residents and fully trained anesthesiologists for decades and remains a part of the Maintenance of Certification in Anesthesiology program.

#### What this article adds

- Anesthesia simulation efforts demonstrated areas for improvement in the recognition and management of pediatric intraoperative anaphylaxis.

#### Keywords

anaphylaxis; anesthesia; child; simulation; treatment; anaphylaxis

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Section Editor: Mark Thomas

Accepted 9 October 2016

doi:10.1111/pan.13052

#### Summary

**Background:** Pediatric intraoperative emergencies are rare but it is crucial for an anesthesia resident to be proficient in their management. Even the more common emergencies like anaphylaxis may not happen frequently for this proficiency to occur. Simulation increases exposure to these rare events in a safe learning environment to improve skills and build confidence while standardizing curriculum.

**Objective:** Anesthesia residents participated in a simulated case of intraoperative pediatric anaphylaxis to evaluate knowledge and performance gaps. The study also sought to determine whether a difference exists between second- (CA2) and third-year (CA3) anesthesia residents when managing pediatric anaphylaxis and cardiopulmonary arrest.

**Methods:** Anesthesia residents completed a standardized programmed simulation of intraoperative anaphylaxis in a 5-year old undergoing tonsillectomy and adenoidectomy. Anaphylaxis presented and progressed to bradycardia and pulseless electrical activity if anaphylaxis went unnoticed or untreated. Key time points were recorded. A scripted debriefing and written evaluation followed.

**Results:** Average time to diagnose anaphylaxis was 7.6 min, and time to give epinephrine was 6.5 min. Thirty-five percent of residents started epinephrine infusion following initial bolus. Average time calling for help between CA3 and CA2 residents was 2.5 min vs 5 min ( $P = 0.01$ ). CA3 residents verbalized a broader differential, including malignant hyperthermia and pneumothorax. Progression to pulseless electrical activity occurred in 65% of sessions prior

to epinephrine being administered. No resident initiated chest compressions for bradycardia.

**Conclusions:** Important performance deficits were seen in senior anesthesia residents during a simulated case of pediatric intraoperative anaphylaxis. Although CA3 performed better, deficits still existed. Anesthesia residents and training programs should partner in developing additional training recognizing anaphylaxis, pulseless electrical activity, and indication for chest compressions in a child.

## Introduction

Anesthesiologists are the designated leader for intraoperative emergencies. Management of emergencies is a core competency of anesthesia residency training programs, though emergencies and cardiac arrest under anesthesia are rare (1). Exposure to these critical events is partly dependent upon the case exposure of the residency program and varies among trainees (2). Therefore, residency programs must provide alternative exposure to practice management of these rare events.

One of the more common emergencies is anaphylaxis which is a life-threatening, rapid-onset hypersensitive reaction, often under-recognized and under-treated. Clinical manifestations of anaphylaxis fall on spectrums of severity and systemic involvement of multiple organ systems (3). Bronchospasm and upper airway symptoms are the most telling and concerning symptoms of anaphylaxis. Hypotension, tachycardia, and shock may follow but less reliably manifest as anaphylaxis (4). Draping and sedation further compound detection of broad presentations of anaphylaxis and thus contribute to under-recognition, shock, and death. Literature reports the incidence of anaphylaxis under anesthesia is grossly estimated between 1 in 3500 and 1 in 20 000, with a mortality rate of 3–6% (5–8). Muscle relaxants, antibiotics, and latex remain the most common causes of intraoperative anaphylaxis. Though the diagnosis of anaphylaxis during anesthesia is likely not the first consideration of the anesthesiologist, timely recognition and treatment with epinephrine best ensures cardiovascular, respiratory, and neurological recovery. All other interventions are adjuvant (9).

Simulation increases exposure to these rare events in a safe learning environment to improve skills and build confidence while further standardizing the curriculum. The primary aim of the study was to determine the time taken to recognize and treat anaphylaxis, thereby identifying knowledge and performance gaps. The secondary aim was to determine whether a difference existed between second (CA2) and third (CA3) anesthesia residents when managing anaphylaxis and cardiopulmonary arrest.

## Methods

The Institutional Review Board at the University of Alabama at Birmingham approved this study. The scenario was designed by experts in the fields of simulation and pediatric anesthesia. To improve consistency of each session, the case was programmed using Laerdal simulation software (Laerdal, Wappingers Falls, NY, USA), allowing for identical timing in each session and the initial scenario stem given to participants, and debriefing points were scripted and Advocacy-Inquiry debriefing methodology was used. A data recording form was developed using the Society of Pediatric Anesthesia PediCrisis Checklist along with pediatric anesthesiology experts, and times were recorded via closed circuit video in an adjacent room (10). Any event times not captured in real time were documented using the video recording immediately following the session. All cases were performed using SimJunior (Laerdal, Wappingers Falls, NY, USA).

The scenario involved a 5-year-old male, weighing 20 kg, undergoing a tonsillectomy/adenoidectomy for chronic tonsillitis. His medical history was read to participants notable for 37-week delivery complicated by pneumothorax secondary to delivery trauma. He suffers from mild asthma. His Grade 1 airway was intubated appropriately and connected to an anesthesia machine. Participants viewed a cardiopulmonary monitor displaying standard vital signs, including capnography, ECG, pulse oximetry, cuff blood pressure, and core temperature. The patient was supine with sterile drapes covering eyes and face above the nose and covering from chin to feet. The otolaryngologist and nurses donned surgical attire and used appropriate instruments. The scenario lasted 10 min, immediately followed by a 20–30 min of debriefing.

The scenario began when the participant arrived in the operating room to relieve a confederate nurse anesthetist. The anesthetist performed a time-out immediately prior to case start to confirm details and ask the participant if antibiotics have been given. If not, the surgeon requested cefazolin 25 mg·kg<sup>-1</sup>. The anesthetist thanked the participant for the relief and asks, “Any

more questions?” The scripted, timed scenario began after the participant’s last question. After 2 min, the patient developed an obstructed pattern to their endtidal carbon dioxide monitor and the numerical value slowly increased. At this time, if the simulator’s breath sounds were re-examined, they had changed from normal to bilateral wheezing. In addition, at the 2-min time period, the child developed increasing tachycardia and hypotension. The reaction progressed to bradycardia and pulseless electric activity (PEA) if anaphylaxis went unrecognized and untreated. Time to key events was recorded on a standard form developed from the PediCrisis Checklists (10). A scripted debriefing followed, and each participant completed evaluations. A pilot session was done to evaluate the scenario and further prepare the confederate nurses. No data from the pilot session were used in data analysis.

Simulation sessions were conducted monthly from August 2014 through March 2015. Participants were CA2 and CA3 at Children’s of Alabama, Birmingham, AL, for a 2-month pediatric rotation. All learners had participated in previous pediatric and adult simulation sessions. One resident participated per session. No resident participated more than once. Participation was voluntary. There were no exclusion criteria. Videotaped, scripted debriefing of teams followed the conclusion of each case.

Times to critical events including time to recognition and time to treat were recorded on a data recording form and entered into a spreadsheet. Unaccomplished actions were left blank and not assigned a time. Descriptive statistics were calculated using Microsoft Excel (Microsoft, Redmond, WA, USA). Statistical analysis used SPSS software (Chicago, IL). An unpaired Student’s *t*-test and chi-square test was used to compare different level of learners. Postdebriefing evaluations were analyzed to provide qualitative data about satisfaction with the course, learning themes, and ability to apply learning to practice.

## Results

Eleven CA2 and six CA3 anesthesia residents participated individually in this study. Average time to diagnose anaphylaxis was  $7.6 \pm 2.4$  min, and time to give epinephrine was  $6.5 \pm 2.1$  min. Only six of 17 residents started an epinephrine infusion following the initial bolus. Only one gave the recommended dose of epinephrine; all others gave a code dose. Less than half of the residents verbalized hypotension, called for help, or administered steroids, diphenhydramine, or ranitidine. All residents eventually administered epinephrine.

Table 1 shows the number of participants who performed or verbalized different actions and differential diagnoses. Third-years called for help earlier ( $2.5 \text{ min} \pm 41 \text{ s}$  vs  $\pm 5 \text{ min} \pm 41 \text{ s}$ ,  $P = 0.014$ ), but only 6 of 17 participants called for help. No other time differences were statistically significant between training years. Four residents initiated chest compressions during PEA, but no resident initiated compressions upon initial bradycardia.

Table 2 shows the number of residents who verbalized pharmacologic interventions, and actions. Third-years were more likely to initiate chest compressions (75% CA3 vs 14% CA2,  $P = 0.044$ ) and call for the crash cart (50% vs 18%,  $P = 0.17$ ). Furthermore, CA3 were more likely to mention malignant hyperthermia (83% vs 45%,  $P = 0.13$ ) and pneumothorax (50% vs 27%,  $P = 0.35$ ). The scenario progressed to a cardiac rhythm of PEA in 11 of 17 simulations prior to epinephrine administration.

The course was well rated by participants. Using a 5-point Likert scale, the scores for “I think this course was a helpful learning experience” was  $4.8 \pm 0.6$ ; “I was satisfied with the content and quality of the course”,  $4.8 \pm 0.4$ ; “I will be able to apply concepts, knowledge and skills I have learned to other clinical experiences”,  $4.9 \pm 0.3$ . Learning themes included, “Learning about a common emergency; anaphylaxis”, “immediate learner centered debriefing following simulation”, and “practicing teamwork/crisis management skills.”

## Discussion

Our study found deviations from treatment guidelines among anesthesia residents in the management of severe anaphylaxis in a pediatric intraoperative simulated patient (10,11). The most important deviation was lack

**Table 1** Number of participants who gave or mentioned items during case

| Actions                | Yes | No | Verbalized | Performed |
|------------------------|-----|----|------------|-----------|
| Fluid bolus            | 3   | 14 |            | x         |
| Steroids               | 6   | 11 |            | x         |
| Diphenhydramine        | 2   | 15 |            | x         |
| Ranitidine             | 3   | 14 |            | x         |
| Albuterol              | 10  | 7  |            | x         |
| Tryptase               | 0   | 17 | x          |           |
| Malignant Hyperthermia | 10  | 7  | x          |           |
| Pneumothorax           | 6   | 11 | x          |           |
| Code                   | 11  | 6  | x          |           |
| Chest compressions     | 4   | 13 |            | x         |
| Beta blocker           | 3   | 14 |            | x         |
| Atropine               | 4   | 17 |            | x         |
| Crash cart             | 5   | 12 | x          |           |

**Table 2** Number (%) of participants by training year completing action with mean time and standard deviation in seconds. [ETCO<sub>2</sub> – endtidal carbon dioxide, confidence intervals – CI, FiO<sub>2</sub> – fraction of inspired oxygen, epi – epinephrine, CA – anesthesia training year, sd – standard deviation]

| Action                                | CA Year | Number | % Of class | Mean | STD | P value | 95% CI around difference in means |
|---------------------------------------|---------|--------|------------|------|-----|---------|-----------------------------------|
| Verbalize bronchospasm                | 2       | 7      | 64         | 205  | 248 | 0.868   | –377 to 324                       |
|                                       | 3       | 4      | 67         | 232  | 245 |         |                                   |
| Verbalize tachycardia                 | 2       | 8      | 73         | 197  | 94  | 0.164   | –29 to 156                        |
|                                       | 3       | 6      | 100        | 134  | 50  |         |                                   |
| Verbalize hypotension                 | 2       | 6      | 55         | 303  | 118 | 0.449   | –373 to 188                       |
|                                       | 3       | 2      | 33         | 396  | 220 |         |                                   |
| Verbalize increased ETCO <sub>2</sub> | 2       | 10     | 90         | 148  | 27  | 0.437   | –26 to 56                         |
|                                       | 3       | 6      | 100        | 133  | 50  |         |                                   |
| Call for help                         | 2       | 4      | 36         | 300  | 41  | 0.014   | 51–249                            |
|                                       | 3       | 2      | 33         | 150  | 41  |         |                                   |
| Give 100% FiO <sub>2</sub>            | 2       | 7      | 64         | 253  | 53  | 0.758   | –104 to 138                       |
|                                       | 3       | 6      | 100        | 236  | 134 |         |                                   |
| Time to ask for epinephrine bolus     | 2       | 11     | 100        | 384  | 138 | 0.87    | –148 to 126                       |
|                                       | 3       | 6      | 100        | 394  | 100 |         |                                   |
| Second epinephrine bolus              | 2       | 10     | 90         | 602  | 128 | 0.884   | –168 to 146                       |
|                                       | 3       | 6      | 100        | 614  | 164 |         |                                   |
| Time to start epinephrine infusion    | 2       | 3      | 27         | 544  | 27  | 0.28    | –574 to 276                       |
|                                       | 3       | 3      | 50         | 693  | 177 |         |                                   |
| Time to give a fluid bolus            | 2       | 6      | 55         | 318  | 115 | 0.731   | –149 to 203                       |
|                                       | 3       | 5      | 83         | 290  | 143 |         |                                   |
| Accurate anaphylaxis                  | 2       | 9      | 82         | 450  | 163 | 0.829   | –205 to 167                       |
|                                       | 3       | 5      | 83         | 469  | 132 |         |                                   |

of chest compressions for pediatric bradycardia. In addition, although anesthesia guidelines allow for either a small intravenous (IV) dose of epinephrine followed by its infusion or intramuscular injection, no resident gave the smaller IV dose, and only six asked for an epinephrine infusion following the bolus. Because IV epinephrine has only a 3–5-min half-life and the course of anaphylaxis is longer, a follow-up infusion is necessary.

Our study builds upon literature evaluating anesthesia residents during intraoperative emergencies. Broadly, older studies have surveyed and assessed anesthesiologists' knowledge base and management of these emergencies. International surveys of anesthesiologists at each level of training reveal that knowledge of perioperative resuscitation protocols is inadequate (11,12).

Further literature describes simulated intraoperative diagnosis and treatment of anaphylaxis by anesthesia teams. The most notable reports employed anesthesia teams operating full-scale anesthesia simulators. A 2001 Scandinavian study reported none of the 21 teams diagnosed anaphylaxis within 10 min of onset (13). In a more recent study, anesthesia trainees and fully trained staff interacted with a high fidelity human patient simulator presenting with intraoperative anaphylaxis, either with or without a novel expert clinical decision support system. Times to diagnosis and treatment of anaphylaxis when using the support system were compared to those without

access to the expert system. The best-case decrease in time to diagnosis for anaphylaxis was 97 s, but overall, the observed differences were not statistically significant (14). Lastly, times to treatment with epinephrine during high fidelity simulation have been shown to discriminate novice and experienced anesthesia residents (15).

Gaps in emergency care are also found in simulation studies in other training programs, such as pediatrics (16–18). Simulation aids discovery of such gaps and may help close them. An exemplary study by Shilkofski *et al.* (19) exposes pediatric residents to a simulation of unstable supraventricular tachycardia (SVT) to assess recognition and treatment times. Deficiencies in cognitive knowledge and technical skills were apparent. Median time to electrical cardioversion was 8.9 min, far exceeded the American Heart Association's (AHA's) recommendation of “immediate cardioversion.”

Additionally, simulation has helped characterize cognitive and technical skills in anesthesia residents and fully trained anesthesiologists for decades and remains a part of the Maintenance of Certification in Anesthesiology program. Recent studies concluded that simulation can “stimulate active learning and motivate personal and collaborative practice improvement changes” (20). Early simulations of the anesthesiologist's task environment sought to define and refine scripts and methodologies (21). An early study determining whether anesthesia

simulators improved performance chose the setting of intraoperative anaphylaxis, as we did, and scored performance by times to action and a standardized scoring scheme by video-recording (22). Video-recording became an accepted medium of analysis within a decade of anesthesia simulation adoption to assess behavioral and technical skill, as well as trainee progress (23). Furthermore, a similarly notable study assessed diagnosis and time to events during simulated intraoperative anaphylaxis among resident, faculty, and private practice anesthesiologists. Overall, 40% of subjects correctly diagnosed anaphylaxis, and only 30% managed cardiac arrest according to Advanced Cardiac Life Support guidelines. No pediatric scenarios were included (24). Specific to trainees, early simulation comparing first- and second-year anesthesia residents reported no statistical difference between classes, based on incidence of simple and critical errors (25). Our study demonstrated additional comparisons between residency classes lacking statistical significance. A further study reported that senior residents out-performed junior residents in simulated acute intraoperative scenarios. Remarkably, however, both junior and senior trainees equally failed to diagnose and manage perioperative anaphylaxis (26). Early anesthesia simulation efforts demonstrated inherent value while exposing domains for improvement, regardless of training level, and current efforts continue to expose under-recognition of anaphylaxis.

The American Heart Association (AHA) Pediatric Advanced Life Support (PALS) training is not currently required of anesthesia residents. However, pediatric resuscitation competency and practice of PALS guidelines are not only essential for pediatric anesthesiologists but also for anesthesia residents and adult anesthesiologists who assist or cover pediatric patients. We specifically chose a 5-year-old healthy child undergoing tonsillectomy/adenoidectomy because anesthesiologists will commonly encounter this setting in the community. Recent study of anesthesia resident performance during a simulated resuscitation of hyperkalemic cardiac arrest concludes that while CA-2 and CA-3 residents demonstrated adequate basic resuscitation skills, pediatric-specific skills, such as weight-appropriate dosing and age-appropriate chest compressions indicated for pediatric bradycardia, were lacking. Investigators did not compare CA-2 and CA-3 performance (27).

A 2008 study surveyed anesthesia residents, fellows, and attending physicians concerning their knowledge of the PALS resuscitation guidelines on cardiac management, medication sequence, and epinephrine dosing. Investigators found that only experience correlates positively with correct answers. Only two of five questions based on PALS were answered correctly >50% of the

time. Similar knowledge gaps were also seen therein, and the investigators suggested tailoring PALS instruction to anesthesiologists might improve survey results, simulation performance and, most important, patient outcome (28).

Two other studies indicate additional pediatric resuscitation training for anesthesia residents improves pediatric resident resuscitation skills, but postcertification knowledge decays rapidly (29,30). Broadening anesthesia residents' exposure to intraoperative cardiopulmonary emergencies using simulation may help to close cognitive gaps better than PALS certification alone, while keeping in mind their brief exposure to pediatrics during training. However, specific reinforcing measures are needed to decrease knowledge decay. To this end, rapid cycle deliberate practice (RCDP), a relatively new training methodology for algorithmic learning shows continuing progress (31).

Our study has important limitations. It was conducted at a single institution and therefore these results cannot be generalizable for other anesthesia training programs. Moreover, although most senior residents took part, participation was voluntary, and thus, the sample size for a single institution remains relatively small and likely non-random. It is unknown whether participating residents were stronger or weaker trainees. Despite their high fidelity, reliability, and advanced features, simulators do not completely capture the clinical context and are themselves a source of systematic error. We did not make the Society of Pediatric Anesthesiologist Pediatric Crisis Checklist available during the scenario as this is not readily available in our operating rooms. Results may have improved if this was easily available during the case and this may be an important measure implemented to improve intraoperative patient care. Lastly, no current evidence directly shows that simulation training improves operational performance in clinical settings, though there is clear evidence suggesting that simulation improves competence, teamwork, and self-efficacy (32).

In conclusion, important actions were often missed in a simulated case of pediatric intraoperative anaphylaxis by senior anesthesia residents. One of the more common mistakes was the failure to start chest compressions when the heart rate of a child fell below 60 beats per minute as PALS guidelines recommend. Therefore, this study allowed us to identify the knowledge and performance gaps that are present in second- and third-year anesthesia residents. However, there was not a significant difference between the two groups. It is unknown whether requiring PALS training or new training methods such as RCDP will improve performance. Although challenging, it will be important for anesthesia residents and training programs to work together along with hospital systems to close these important performance gaps.

## Ethical approval

This study was approved by the Institutional Review Board of the University of Alabama at Birmingham.

## Funding

Departmental resources funded this study.

## Conflict of interest

The authors have no conflicts of interest. Dr Tofil has spoken without pay at a Laerdal conference based on self-developed material and was reimbursed only for travel.

## Acknowledgment

None.

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