Pediatric Cardiopulmonary Arrest in the Postanesthesia Care Unit, Rare but Preventable: Analysis of Data From Wake Up Safe, The Pediatric Anesthesia Quality Improvement Initiative

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BACKGROUND: Nearly 20% of anesthesia-related pediatric cardiac arrests (CAs) occur during emergence or recovery. The aims of this case series were to use the Wake Up Safe database to describe the following: (1) the nature of pediatric postanesthesia care unit (PACU) CA and subsequent outcomes and (2) factors associated with harm after pediatric PACU CA.
METHODS: Pediatric CAs in the PACU were identified from the Wake Up Safe Pediatric Anesthesia Quality Improvement Initiative, a multicenter registry of adverse events in pediatric anesthesia. Demographics, underlying conditions, cause of CA, and outcomes were extracted. Descriptive statistics were used to characterize data and to assess risk of harm in those suffering CA.
RESULTS: A total of 26 CA events were included: 67% in children <5 years, and 30% in infants (<1 year); 18 (69%) were deemed likely or almost certainly preventable. All preventable CAs were respiratory in nature and most (67%) had purported root causes that included provider judgment or inexperience, inadequate supervision, and competing priorities. CAs of cardiac origin were associated with increased level of harm (temporary or greater), whereas those of respiratory origin were associated more often with no harm.
CONCLUSIONS: PACU CA events are rare and generally survivable, with better outcomes for respiratory-based events, but most were deemed preventable, suggesting a need for further vigilance in the early postoperative period. Maintenance of monitoring during patient transport to PACU and continuing care by anesthesia care providers until emergence from anesthesia may further reduce the preventable arrest rate. The root cause analyses conducted by individual institutions reporting these data to the Wake Up Safe provided only limited insight, so multicenter collaborative approaches may allow for greater insight into effective CA-prevention strategies. (Anesth Analg 2017;124:1231–6)

Nearly 20% of anesthesia-related pediatric cardiac arrests (CAs) occur during emergence or recovery from anesthesia, according to the Pediatric Perioperative Cardiac Arrest Registry.[1] Patients recovering from anesthesia are at risk for serious physiologic compromise because of the proximity to the surgical procedure, residual effects of anesthetic and analgesic medications, and underlying or unknown risk factors. Fortunately, CA has become a rare event, with less than 1 event per 10,000 children undergoing anesthesia for noncardiac procedures.[2–4] A recent study that used data from the American Heart Association's Get with the Guidelines-Resuscitation registry (formerly, National Registry of Cardiopulmonary Resuscitation) identified only 27 pediatric postanesthesia care unit (PACU) arrests among 2.3 million arrest records in nearly 1500 hospitals. This study was able to describe child- and setting-related factors associated with mortality after arrest but lacked essential information to allow examination of perioperative risks.[5]

Despite recent successes in reducing pediatric CA,[6] data regarding the nature and management of pediatric PACU CA and factors associated with favorable outcomes are needed to improve management and outcomes after these rare but critical events. The aim of this study was to describe the nature of pediatric PACU CA events and subsequent outcomes by the use of a series of cases identified from the Wake Up Safe: The Pediatric Anesthesia Quality Improvement Initiative database, which includes a multisite, voluntary registry of pediatric perioperative serious adverse events. A secondary aim was to describe factors related to the reported greater degree of harm from CA.

METHODS

This study was deemed exempt by the institutional review board at the University of Michigan and requirement for informed consent waived. This manuscript adheres to the CARE guidelines, as indicated by the EQUATOR Network. In 2006, the Quality and Safety Committee of the Society for Pediatric Anesthesia initiated a quality improvement project for the specialty of pediatric anesthesiology that ultimately resulted in the development of Wake Up Safe, a patient safety organization that maintains a national registry of deidentified serious adverse events.[7,8] The ultimate goal of Wake Up Safe is to implement change in processes of care that improve the quality and safety of anesthetic care provided to pediatric patients

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nationwide. Member institutions of Wake Up Safe submit annual data regarding the types and numbers of anesthetics performed, including American Society of Anesthesiologists physical status, surgical billing codes, age, and sex, as well as more detailed case information pertaining to specific serious adverse events as defined by Wake Up Safe guidelines. CA is defined by Wake Up Safe as "Cessation of cardiac mechanical activity as confirmed by the absence of signs of circulation (Use of cardiac compressions with or without defibrillation)."[9] Appendix 1 (Supplemental Digital Content, http://links.lww.com/AA/B579) lists the member institutions and when they joined Wake Up Safe. Before each case submission, 3 anesthesiologists who were not involved in the event must analyze the event using a standardized root cause analysis method to identify the causal or contributing factor(s).[9] Representatives from each member institution received education on root cause analysis methodology before participation in an effort to standardize case evaluation across sites.

For the purpose of this case series, the database was queried for all events reported between March 25, 2008, and December 11, 2015 to obtain all CA events that occurred in children (<18 years of age) in the PACU setting or during transport to the PACU. All reported data were extracted, including demographics, pre-CA comorbid conditions, reported contributors of CA (primary and secondary), management details, and outcomes, including survival and extent of harm.

Cases were described as anesthesia-related when anesthesia was indicated as a primary or secondary cause and as not anesthesia-related when cases were reported as "anesthesia not a contributing factor." Surgical procedures were reported with the use of Current Procedural Terminology codes, and were, for the purpose of this study, classified as low, medium, or high surgical severity according to these definitions: low severity surgery = noninvasive diagnostic or superficial surgery with minimal blood loss; moderate = invasive, anticipated moderate blood loss, emergent, or airway procedure; high = major procedure, anticipated excessive blood loss.[10]

Nighttime was defined as 7 PM to 7 AM and weekend as 12 AM Saturday to 12 AM Monday. Narrative data were edited for typographical errors, brevity, and clarity. The outcome of the CA was assessed by the original institutions as no harm, temporary harm, permanent harm, severe permanent harm, or death. Institutions were instructed to select the greatest appropriate level. We further coded these levels of harm as No harm versus Harm for the purpose only to compare the primary cause and subsequent outcome.

Statistical Analysis

Data were analyzed with SPSS Software, version 22 (IBM Corp, Armonk, NY). Data are described as n (%) or mean ± standard deviation as appropriate. The χ^2 with Fisher's exact tests were used to compare the reported degree of harm experienced (defined immediately above) between the reported cause (ie, respiratory or cardiac). P values <.05 were considered statistically significant for this univariate comparison.

RESULTS

The data query of the Wake Up Safe database as of December 11, 2015 yielded 26 cases of pediatric PACU CA from 552 CA events reported. Table 1 lists cases in which the PACU CA was deemed likely or definitely preventable, whereas Table 2 lists cases that were deemed unlikely or not preventable. Twelve of 26 (46.2%) patients were scheduled for hospital admission after surgery, 2 (cases 2 and 15, 7.7%) arrests occurred at a free-standing surgery center, and the remainder were outpatients in a larger hospital setting. Eleven (42.3%) surgeries were of low severity (ie, diagnostic or superficial), whereas the rest (15 [57.7%]) were of medium severity. Only 1 CA (case 17, 3.8%) occurred on a weekend and 3 (cases 17, 18, and 21, 11.5%) at night.

The reported preventability of the arrests varied with 1 (case 19, 3.8%) reporting that it almost certainly could not have been prevented, 6 (23.1%) reporting that it likely could not have been prevented, 1 (case 26, 3.8%) having no opinion, 13 (50%) reporting that it likely could have been prevented, and 5 (19.2%) reporting that it almost certainly could have been prevented.

Root Cause Analyses

In events deemed preventable, individual provider factors were most commonly identified as the primary root cause (12 of 18 [66.7%]) and of these, 11 were related to decision making and one to human factors. Inadequate supervision, characterized as an organizational factor, was the primary cause for 1 CA, whereas the patient disease was the primary factor in the remaining 5 CA. Of the remaining preventable cases, 4 had organizational factors, being either inadequate supervision or competing priorities; 1 had a verbal miscommunication, and 1 had a team factor defined as "no clear leader during the event." In the 8 cases deemed to be not preventable, the primary root cause was universally the patient's disease. In 3 of these cases, however, a second contributing case of provider decision-making was identified.

Degree of Harm From the CA

The degree of harm suffered by the children who experienced CA is described in the last column of Tables 1 and 2. Univariate comparisons revealed that CA with a cardiac origin, such as hypovolemia, hemorrhage, arrhythmia, or cardiac failure, were significantly more likely to be associated with patient harm (66.7% vs 10%; $P = .013$). Conversely, CA with a respiratory origin were less likely to be associated with patient harm (10.5% vs 57.1%, $P = .028$). Twenty (76.9%) of the children required admission to the intensive care unit (ICU) post-CA, 17 of which were unplanned admissions.

DISCUSSION

This study describes the pediatric PACU CA events as reported to the Wake Up Safe: The Pediatric Anesthesia Quality Improvement Initiative and provides an analysis of factors associated with harm from these rare events. On the basis of this database, 4.7% of pediatric perioperative CA events occur in the PACU. Despite the relatively small fraction of PACU CA events, these represent an opportunity for significant improvement because 69% of PACU CA events were judged by institutional review to have been preventable.

The outcomes of these early postoperative arrests were remarkably good, with only 1 death (case 25, 3.8%). This finding is significantly better than the mortality rates previously reported for pediatric PACU CA[5] and for pediatric CA

Table 1. Preventable Cardiac Arrests in PACU

Case	Cause	Narrative	Comorbidities	Anesthesia Related	1° Root Cause	2° Root Cause	Harm
1	Respiratory	4 y M ASA 3 with craniofacial abnormalities for ABR under propofol sedation. Airway obstruction on emergence leading to bradycardic arrest	Genetic, neurologic, pulmonary	Yes	**Provider/Decision:** judgment	**Disease** **Organizational:** inadequate supervision	No harm
2	Respiratory	15 mo F ASA 2 for BMT; laryngospasm after anesthesia providers left in PACU leading to bradycardic arrest	None		**Organizational:** competing priorities	**Provider/HF:** time pressure	Emotional distress or inconvenience
3	Respiratory	6 y M ASA 3 for hand surgery, awake extubation in OR, hypoventilation on transport leading to bradycardic arrest	None	Yes	**Provider/Decision:** judgment		Additional treatment (admission)
4	Respiratory	5 mo M ASA 3 for cardiac catheterization under general anesthesia; on arrival to PACU, severe hypoxemia; CPR initiated	Cardiac		**Disease**		Additional treatment (reintubation)
5	Respiratory	7 mo M ASA 3 s/p bidirectional Glenn procedure for cleft palate repair, extubated awake with progressive respiratory distress in PACU	Cardiac		**Disease**		Additional treatment (reintubation)
6	Respiratory	13 y M ASA 3 with repaired ASD for dental restoration; apnea and airway obstruction; significant blood/clot suctioned from airway when reintubated	Cardiac	Yes	**Disease**		Additional treatment (reintubation, 5 d on mechanical ventilation)
7	Respiratory	18 mo F ASA 3 for BMT, T&A, and DL&B, extubated awake, progressive PACU airway obstruction	Pulmonary		**Provider/decision:** inexperience	**Provider/Decision:** failure to call for assistance, **Miscommunication** (verbal): information not communicated **Team:** no clear leader	Additional treatment (reintubation, 6 d on mechanical ventilation)
8	Respiratory	20 mo M ASA 3 for rectal EUA, apnea on PACU arrival	Pulmonary		**Provider/Decision:** judgment	**Disease** **Provider/Decision:** Inexperience **Provider/HF:** cognitive bias	Additional treatment
9	Respiratory	4 y F former premature infant ASA 2E for T&A; received 5 mg morphine; deep extubation in OR; on PACU arrival, bradycardia and marked hypoxemia	Pulmonary	Yes	**Provider/HF:** cognitive bias	**Disease** **Provider/Decision:** judgment **Provider/Decision:** knowledge	Temporary harm (reintubation, 3 d of mechanical ventilation, neurological injury which resolved)
10	Respiratory	16 y F ASA 3 with complex airway history for DL&B under spontaneous ventilation; laryngospasm on transport	Neurologic, pulmonary	Yes	**Provider/Decision:** judgment	**Disease**	Additional treatment (reintubation)
11	Respiratory	Term 1 mo M ASA 3 for DL&B, in PACU had seizure with bradycardia, muscular rigidity with inability to ventilate	Genetic, neurologic, pulmonary		**Disease**		Additional treatment (reintubation)
12	Respiratory	6 mo F ASA 3 with micrognathia for anoplasty, after deep extubation in OR developed laryngospasm in PACU	Genetic, neurologic, renal	Yes	**Provider/Decision:** judgment		Additional treatment
13	Respiratory	2 y F ASA 2 for T&A, deep extubation in OR, within 10 min of arrival to PACU developed hypoxemia and bradycardia	Obstructive sleep apnea	Yes	**Disease**	**Organizational:** competing priorities	Additional treatment (ICU admission)
14	Medication error	4 mo M ASA 1 for cleft lip repair and BMT, received accidental overdose of fentanyl by student nurse anesthetist	None	Yes	**Provider/HF:** distraction	**Organizational:** inadequate supervision	Additional treatment
15	Respiratory	8 mo F ASA 2 for MRI under deep sedation, developed apnea and cyanosis in PACU	Nystagmus	Yes	**Provider/Decision:** judgment		Additional treatment

(*Continued*)

Table 1. Continued

Case	Cause	Narrative	Comorbidities	Anesthesia Related	1° Root Cause	2° Root Cause	Harm
16	Respiratory	9 mo M ASA 1E for I&D of a neck abscess, on PACU arrival, airway obstruction noted with bradycardia and cyanosis	None	Yes	**Provider/Decision:** judgment	**Provider/Decision:** inexperience, **Provider/HF:** cognitive bias	Additional treatment
17	Respiratory	15 mo M ASA 1 for circumcision, deep extubation of LMA in OR, during PACU handover developed progressive hypoxemia then bradycardia	None	Yes	**Provider/Decision:** judgment		Temporary harm (ICU admission)
18	Respiratory	3 y M ASA 2E for humerus fracture, deep LMA extubation in OR; hypoxia/cyanosis on PACU arrival.	None	Yes	**Provider/Decision:** judgment		Temporary harm

Key: **BOLD** indicates categories of root causes:
- **Disease**, attributable to patient disease
- **Provider**, attributable to individual/provider factors, with subcategories: **Decision**, clinical decision making; **Limitations**, provider limitations; **HF**, human factors
- **Organizational** factors
- **Team**/Interpersonal factors
- **Miscommunication**

Abbreviations: 1°, primary; 2°, secondary; ABR, auditory brainstem–evoked responses; ASA, American Society of Anesthesiologists Physical Status; ASD, atrial septal defect; BMT, bilateral myringotomy and tube placement; CPR, cardiopulmonary resuscitation; DL&B, direct laryngoscopy and rigid bronchoscopy; EUA, exam under anesthesia; F, female; ICU, intensive care unit; I&D, incision and drainage; LMA, laryngeal mask airway; M, male; mo, month-old; MRI, magnetic resonance imaging; OR, operating room; PACU, postanesthesia care unit; s/p, status post; T&A, tonsillectomy and adenoidectomy; y, year-old.

in general.[2,11] This likely reflects several possible confounders. Children who were sicker and, thus, more likely to have a poor outcome may be more likely to bypass PACU in favor of direct transport to the ICU. This possibility is reflected in our finding that no child in this sample underwent major surgical procedures (ie, high severity), which would be more likely to have a planned ICU admission after surgery. In addition, the Wake Up Safe participants include only children's hospitals, whereas the American Heart Association CA database includes hospitals with a mixed adult and pediatric population. It is, therefore, possible that the lower mortality in our sample reflects an advantage in staff expertise and/or organizational support that has been advocated increasingly for children.[12] Alternatively, methodologic differences or a selection bias in reporting may have contributed to our findings. Wake Up Safe also had more limited follow-up than the American Heart Association, mostly less than 24 hours instead of to discharge. With longer follow-up, additional harm may have been detected. Finally, given the small sample sizes, the difference in outcomes may reflect simple chance variation.

Root Cause Analyses

Of interest, all CAs that were deemed preventable were respiratory in nature. Although some factors that may be contributory to these events remain unknown (eg, residual muscle relaxation, obstructive sleep apnea history), this finding has important implications for vigilance in monitoring during all aspects of postoperative recovery, when children are at the greatest risk for obstruction and respiratory depression. Despite identifying many cases with learning potential, the root cause analyses presented here typically identified provider error (decision making or judgment) or patient issues (disease process) as primary and/or secondary root causes (eg, cases 7–10). Ideally, the root cause analysis should focus on latent errors ("hidden problems within the health care system") and active errors ("those between humans and a complex system") rather than "concentrate on the individual" patient disease or provider error.[9]

We propose that systems-based root causes can be thoroughly considered for all CAs to ensure that preventable systems issues be addressed. Such reviews would include but not be limited to reducing the impact of production pressure; improving policies for defining the end of anesthesia care; educating providers to prevent the routine deviation ("workaround") of that policy because of production pressure, or a lack of an appropriate policy/protocol guiding PACU transfer and handover entirely. Unfortunately, robust discussions of deidentified patients are difficult, given the lack of context and understanding of local culture or policies that may have contributed to the case. Recently, however, the Wake Up Safe Committee has transitioned its focus to improving the quality improvement collaboration between member institutions with an aim to enhance case-based or problem-based discussions that may lead to broader benefit with more generalizable lessons and recommendations.

Prevention

Production pressure remains a factor in pediatric PACU CA. Recurring modifiable factors in these arrests included inadequate monitoring during transport to PACU, inadequate

Table 2. Nonpreventable Cardiac Arrests in PACU

Case	Cause	Narrative	Comorbidities	Anesthesia Related	1° Root Cause	2° Root Cause	Harm
19	Cardiac	2 y M ASA 2 with syncope for cardiac loop recorder placement. 20 min after PACU arrival, bradycardia, VT, PEA arrest requiring ECMO. Found to have coronary artery pathology	Cardiac		**Disease**		Severe permanent harm (neurologic injury)
20	Cardiac	9 y M ASA 3 for cardiac catheterization with symptomatic bradycardia and syncope after emergence from anesthesia	Cardiac		**Disease**		No harm
21	Respiratory	11 mo M ASA 2 for cleft palate repair; airway obstruction 45 min after PACU admission	None		**Disease**		Additional treatment (reintubation)
22	Cardiac	14 y F ASA 4 with SLE, lupus nephritis, pulmonary hypertension for thrombectomy in catheter lab, developed dyspnea, syncope; during airway management, had cardiac arrest	Cardiac, Renal, Lupus	No	**Disease**		Additional treatment (reintubation, iNO, inotropic support)
23	Cardiac	7 y F ASA 3 for liver biopsy, in PACU pallor, emesis, syncope then bradycardic arrest, due to hypovolemia from occult hemorrhage	Liver, Renal	No	**Disease**		Temporary harm
24	Cardiac	11 y M ASA 3 with sickle cell disease for laparoscopic splenectomy, cholecystectomy and appendectomy, with desaturation followed by refractory bradycardia in PACU	Hematologic		**Disease**	**Provider/Decision:** Clinical decision making	Severe permanent harm
25	Cardiac	6 mo M ASA 4 with HLHS with LV sinusoids for gastric tube placement, with cardiac arrest on PACU arrival requiring ECMO cannulation; support withdrawn shortly afterward	Cardiac	Yes	**Disease**	**Provider/Decision:** judgment	Death
26	Respiratory	9 mo F ASA 2 for BMT, T&A, taken to PACU intubated; desaturation followed by bradycardia. Returned to OR for DL&B	Pulmonary	Yes	**Disease**	**Provider/Decision:** Clinical decision making	Additional treatment (DL&B; PICU admission)

Key: **BOLD** indicates categories of Root Causes:

- **Disease**, attributable to patient disease
- **Provider**, attributable to individual/provider factors, with subcategories: **Decision**, clinical decision making; **Limitations**, provider limitations; **HF**, human factors
- **Organizational** factors
- **Team**/interpersonal factors
- **Miscommunication**

Abbreviations: 1°, primary; 2°, secondary; ASA, American Society of Anesthesiologists Physical Status; BMT, bilateral myringotomy and tube placement; DL&B, direct laryngoscopy and rigid bronchoscopy; ECMO, extracorporeal membrane oxygenation; F, female; HLHS, hypoplastic left heart syndrome; iNO, inhaled nitric oxide; LV, left ventricular; M, male; mo, month-old; PACU, postanesthesia care unit; PEA, pulseless electrical activity; PICU: pediatric intensive care unit; SLE, systemic lupus erythematosus, T&A, tonsillectomy and adenoidectomy; VT, ventricular tachycardia; y, year-old.

supervision, and transition of care from anesthesia providers to PACU nursing before patient emergence from anesthesia. Such factors suggest that, first and foremost, ensuring adequate supervision and monitoring of patients during this critical transition is a critical checkpoint. That provider judgment further contributed to preventable CA suggests a need for enhanced methods to identify high-risk patients based on known risk factors for airway or respiratory events. It is unclear from the details of these events whether anesthesia providers immediately were available in the PACU settings; however, the analyses do suggest that frequent, scheduled reassessment by anesthesia providers may reduce the frequency of precursor and actual PACU CA events. Finally, data suggest that better guidance is needed to help identify patients who are suitable for deep extubation and to ensure the attendant presence of anesthesia care through emergence.

Limitations

The voluntary, multicenter nature of the database used in this study poses the potential for selection and reporting biases, limiting the ability to generalize findings. The nature of reporting precludes our ability to estimate the prevalence of CA, because it is unknown how many children in each institution are admitted to the PACU setting after surgery. Furthermore, despite centralized training, specific guidelines, and definitions, preventability and the root cause analyses methodology may have differed between institutions. Certain factors associated with outcomes including CA management details such as timing of epinephrine administration[13] are not available in the reporting. The absence of PACU population information (ie, denominator) precludes calculation of incidence or analysis of predictors of CA. Erroneous data also may have been entered during the manual data entry process. These data must, therefore, be interpreted with caution. Lastly, the small sample size precluded the ability to conduct more rigorous analyses (such as adjustment for nonreported confounders) of risk factors and outcomes.

CONCLUSIONS

This study found that although PACU CA events are a small portion of perioperative arrests in children, most were deemed preventable, suggesting a need for further vigilance in the early postoperative period. Maintenance of monitoring during patient transport to PACU and continuing care by anesthesia care providers until emergence from anesthesia may further reduce the preventable arrest rate. The root cause analyses conducted by individual institutions reporting these data to the Wake Up Safe provides only limited insight into what may be broader systems-based contributors to PACU CA. Multicenter collaborative approaches that couple deidentified databases with workgroups that can freely discuss these events may allow for greater insight into effective CA prevention strategies.

DISCLOSURES

Name: Robert E. Christensen, MD.
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