■ CLINICAL INVESTIGATIONS

Anesthesia-related Cardiac Arrest in Children

Initial Findings of the Pediatric Perioperative Cardiac Arrest (POCA) Registry

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Background: The Pediatric Perioperative Cardiac Arrest (POCA) Registry was formed in 1994 in an attempt to determine

> This article is accompanied by an Editorial View. Please see: Rothstein P: Bringing light to the dark side. ANESTHESIOLOGY 2000; 93:1–3.

the clinical factors and outcomes associated with cardiac arrest in anesthetized children.

Methods: Institutions that provide anesthesia for children are voluntarily enrolled in the POCA Registry. A representative from each institution provides annual institutional demographic information and submits anonymously a standardized data form for each cardiac arrest (defined as the need for chest compressions or as death) in anesthetized children 18 yr of age or younger. Causes and factors associated with cardiac arrest are analyzed.

Results: In the first 4 yr of the POCA Registry, 63 institutions enrolled and submitted 289 cases of cardiac arrest. Of these, 150 arrests were judged to be related to anesthesia. Cardiac arrest related to anesthesia had an incidence of 1.4 ± 0.45 (mean ± SD) per 10,000 instances of anesthesia and a mortality rate of 26%. Medication-related (37%) and cardiovascular (32%) causes of cardiac arrest were most common, together accounting for 69% of all arrests. Cardiovascular depression from halothane, alone or in combination with other drugs, was responsible for two thirds of all medication-related arrests. Thirty-three percent of the patients were American Society of Anesthesiologists physical status 1–2; in this group, 64% of arrests were medication-related, compared with 23% in American Society of Anesthesiologists physical status 3–5 patients (P < 0.01). Infants younger than 1 yr of age accounted for 55% of all anesthesia-related arrests. Multivariate analysis demonstrated two predictors of mortality: American Society of Anesthesiologists physical status 3–5 (odds ratio, 12.99; 95% confidence interval, 2.9–57.7), and emergency status (odds ratio, 3.88; 95% confidence interval, 1.6–9.6).

Conclusions: Anesthesia-related cardiac arrest occurred most often in patients younger than 1 yr of age and in patients with severe underlying disease. Patients in the latter group, as well as patients having emergency surgery, were most likely to have a fatal outcome. The identification of medication-related problems as the most frequent cause of anesthesia-related cardiac arrest has important implications for preventive strategies. (Key words: Anesthetic complications; outcomes; pediatric.)

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INCREASED risk of perioperative cardiac arrest in children compared with adults has been recognized since the seminal study of Beecher and Todd.[1] A number of factors associated with perioperative cardiac arrest have been identified, including young age,[2-5] comorbid con-

ditions, and emergency surgery,[6] although the immediate cause of cardiac arrest has at times been after to identify.[7] Because anesthesia-related cardiac arrest is uncommon, a multiinstitutional database is required to more fully understand the mechanisms of cardiac arrest and to develop preventive strategies. To this end, the Pediatric Perioperative Cardiac Arrest (POCA) Registry was formed in 1994 under the combined auspices of the Committee on Professional Liability of the American Society of Anesthesiologists (ASA) and the American Academy of Pediatrics Section on Anesthesiology to investigate the causes of cardiac arrest in anesthetized children. The purpose of this report is to provide an analysis of the first 150 anesthesia-related cardiac arrests reported to the POCA Registry, with emphasis on etiology and outcome of cardiac arrest in the pediatric population.

Methods

Following project approval by the Human Subjects Review Board of the University of Washington, voluntary enrollment of cases began in 1994 from institutions in the United States and Canada that provide anesthetic care to children. From 1994 through 1997, 63 institutions were enrolled; 75% were university affiliated and 40% were children's hospitals. The majority of participating institutions were involved in training of fellows in pediatric anesthesia (40%) and/or residents in anesthesiology (76%) and served as tertiary referral centers for subspecialty surgical care.

Each institution was asked to designate a representative responsible for submitting demographic information, including type of institution, number and training of anesthesia providers, and number and types of cases. The institutional representatives were also asked to complete and submit a standardized data form for all cases of cardiac arrest (defined as the administration of chest compressions or as death) that occurred in children 18 yr of age or younger during administration of or recovery from anesthesia. Neonatal resuscitations and resuscitations in the pediatric intensive care unit or on the ward were excluded.

For each case meeting POCA Registry entry criteria, the following data were requested: patient demographic information, surgical procedure, personnel involved in anesthetic care, anesthetic agents, and techniques and monitors used. In addition, the report asked for specific information about the cardiac arrest, including prearrest status, antecedent events, and the immediate cause of arrest. Possible causes for cardiac arrest were defined as shown in Appendix A. The institutional representatives were asked to assess the contribution to and outcome after cardiac arrest of anesthesia, surgery, and underlying patient disease as none, minor, major, or total.

Outcome was assessed using a modification of a 10-point severity of injury scale[8] applied 24 h after the arrest and at the last clinical evaluation (median, 7 days; range, 1–448 days) if the patient survived more than 24 h (Appendix B). Autopsy findings, if available, were also included.

A narrative summary was requested from the institutional representative to specify the sequence of events and causal relations associated with the cardiac arrest and to provide any relevant information not previously included.

All cases were submitted anonymously, identified only by a one- to five-digit number assigned by the institutional representative, thereby precluding identification of the patient, health care provider or providers, or submitting institution. Following submission, each data form was entered into a database maintained at the University of Washington School of Medicine Department of Anesthesiology and managed by the ASA Closed Claims Project staff. All data forms were reviewed by one member of the POCA Registry Steering Committee for consistency and completion. Demographic data (e.g., ASA physical status) were not edited. If data were missing from the data form, an alert was sent out to all POCA Registry institutional representatives requesting information for the case as identified by the one- to five-digit number.

Three members of the POCA Registry Steering Committee independently reviewed all data forms and categorized each cardiac arrest as anesthesia-related, not anesthesia-related, or unknown according to the definitions shown in Appendix C. Cases of inability to wean from cardiopulmonary bypass or early postbypass heart failure were categorized as not related to anesthesia; none of these cases had anesthesia-related problems in the prebypass period that influenced the subsequent failure to wean from bypass. Cases of arrest due to hemorrhage were classified as anesthesia-related if anesthesia personnel could have adequately replaced blood loss or if arrest was due to metabolic consequences of massive transfusion (e.g., hyperkalemia, hypocalcemia).

Disagreements among the three members of the Steering Committee Subgroup concerning whether or not a case was anesthesia-related were resolved by discussion; unanimity was required. Cases in which agreement

could not be reached or cause of arrest could not be determined were classified as unknown. Final committee assignments were compared with institutional reviewer assessments; major or total anesthesia responsibility were classified as "anesthesia-related," and minor, none, or unknown anesthesia responsibility were classified as "unrelated to anesthesia."

The POCA Registry Steering Committee Subgroup also independently reviewed etiology of arrest when the institutional assignment was ambiguous (*i.e.*, presumed cardiovascular cause, unclear etiology; presumed respiratory cause, unclear etiology; multiple events; and unknown). Agreement by two of three reviewers was required to change the institutional assignment of etiology of arrest.

Statistical Analysis

Reliability of POCA Registry Steering Committee members' assessments of whether cases were anesthetic related was measured by the κ statistic.[9] The κ statistic was also used to measure agreement between POCA Registry Steering Committee assignments and assignments by the submitting institution. A κ value greater than 0.40 at $P <$ 0.05 was established as an acceptable level of agreement.

All statistical analysis was restricted to cases designated by the Steering Committee as anesthesia related. The rate of perioperative cardiac arrest was calculated by dividing the total number of anesthesia-related cardiac arrests reported during each calendar year by the total number of instances of anesthetic administration by all participating institutions during that calendar year. Missing caseload data were estimated from the most recent data available. The overall 4-yr rate of arrest was calculated as the mean ± SD of the 4 yearly rates. Compliance with case reporting requirements was not measured. Categorical data were analyzed using Fisher exact test. Factors predicting mortality following cardiac arrest were analyzed with multivariate forward stepwise logistic regression with odds ratios and 95% confidence intervals reported. Variables with univariate likelihood ratio chi-square values significant at $P \leq$ 0.05 were included in the multivariate analysis. Significance was defined as values of $P \leq 0.05$.

Results

In the first 4 yr of operation, 289 cases were submitted to the POCA Registry. Of these, 150 (52%) were anes-

Table 1. Anesthesia-related *Versus* Unrelated Cardiac Arrest Groups

	Anesthesia-related	Not anesthesia-related	Unknown
Total number	150 (52%)	115 (40%)	24 (8%)
ASA physical status			
1	23 (15%)	2 (2%)	1 (4%)
2	27 (18%)	5 (4%)	0 (0%)
3	56 (37%)	22 (19%)	9 (38%)
4	41 (27%)	64 (56%)	12 (50%)
5	3 (2%)	22 (19%)	2 (8%)
Age			
<1 months	22 (15%)	48 (42%)	5 (21%)
1–5 months	42 (28%)	16 (14%)	7 (29%)
6–11 months	19 (13%)	8 (7%)	2 (8%)
12 months–5 yr	47 (31%)	23 (20%)	4 (17%)
6–18 yr	20 (13%)	20 (17%)	6 (25%)
Emergency surgery	31 (21%)	51 (45%)	5 (22%)
Type of surgery			
Airway	16 (11%)	0 (0%)	0 (0%)
Cardiac	26 (17%)	46 (40%)	8 (33%)
General/urology	59 (39%)	38 (33%)	5 (21%)
Central line	7 (5%)	8 (7%)	4 (17%)
Craniotomy	5 (3%)	11 (10%)	5 (21%)
Thoracic	5 (3%)	8 (7%)	0 (0%)
Miscellaneous	32 (21%)	4 (3%)	2 (8%)

thesia related, and the remainder were related to underlying patient disease or to the surgical process (nonanesthesia related; n = 115), or were of an undetermined cause (n = 24; table 1). POCA Steering Committee members initially agreed on their independent assignments in 69% of cases (κ = 0.64). Final POCA Steering Committee assignments agreed with the original submitting institution report 85% of the time (κ = 0.71). In the non-anesthesia-related group, 25 (22%) were cardiac surgery patients who failed to wean from cardiopulmonary bypass or had early postbypass heart failure, 20 (17%) arrested as a result of uncontrollable surgical bleeding, 25 (22%) had miscellaneous cardiovascular events, 14 (12%) had presumed cardiovascular events with unknown etiology, 5 (4%) had air embolism, 5 (4%) had complications of central venous pressure lines, and 21 (18%) had other miscellaneous causes of arrest. The remaining analysis focuses on the 150 anesthesia-related cases.

During the study period, participating institutions administered anesthesia to children younger than 18 yr of age an estimated 1,089,200 times. The mean overall incidence of anesthesia-related cardiac arrest was 1.4 ± 0.45 per 10,000 instances of anesthesia per year (range, 1.1–2.1 per 10,000 instances of anesthesia per yr). The profile of the 150 cases of anesthesia-related cardiac arrest is detailed below and in tables 1 and 2. Infants

Table 2. Mechanism of Cardiac Arrest

Mechanism	Number of Arrests
Medication-related	55 (37%)
Inhalation agents	
Halothane alone	26 (46%)
Halothane plus an intravenous medication	11 (20%)
Sevoflurane alone	2 (4%)
Intravenous medications	
Single	5 (9%)
Combination	5 (9%)
Intravenous injection of local anesthetic	5 (9%)
Succinylcholine-induced hyperkalemia	1 (2%)
Cardiovascular	48 (32%)
Presumed CV, unclear etiology	18 (38%)
Hemorrhage, transfusion-related	8 (17%)
Inadequate/Inappropriate fluid therapy	6 (13%)
Arrhythmia	5 (10%)
Hyperkalemia	4 (8%)
Air embolism	2 (4%)
Pacemaker-related	2 (4%)
Vagal response	1 (2%)
Pulmonary hypertension	1 (2%)
Tetralogy hypercyanotic spell	1 (2%)
Respiratory	30 (20%)
Laryngospasm	9 (30%)
Airway obstruction	8 (27%)
Difficult intubation	4 (13%)
Inadequate oxygenation	3 (10%)
Inadvertent extubation	2 (7%)
Presumed respiratory, unclear etiology	2 (7%)
Inadequate ventilation	1 (3%)
Bronchospasm	1 (3%)
Equipment-related	10 (7%)
Central line	4 (40%)
Breathing circuit	2 (20%)
Peripheral intravenous catheter	1 (10%)
Other	3 (30%)
Multiple events	5 (3%)
Hypothermia	1 (<1%)
Unclear etiology	1 (<1%)

CV = cardiovascular.

younger than 1 yr of age accounted for 55% of anesthesia-related cardiac arrests (table 1). Thirty-three percent of arrests occurred in ASA physical status 1–2 patients, and 67% occurred in ASA physical status 3–5 patients. Twenty-one percent of arrests occurred during emergency surgery. General surgery (including urology) was the most common surgical category (39%); hernia repair (n = 10) and exploratory laparotomy (n = 7) were the most common procedures in this group.

General anesthesia alone was administered in most cases (88%); regional techniques were used alone or in combination with general anesthesia in 1% and 9% of cases, respectively. Monitoring devices in use at the time of cardiac arrest included pulse oximeter (99%), electro-

cardiograph (97%), blood pressure cuff (95%), capnograph (86%), and an inspired O_2 monitoring device (86%). Most cardiac arrests occurred during induction (37%) or maintenance (45%) of anesthesia, usually following one or more of the following antecedent events: bradycardia (54%), hypotension (49%), abnormality of oxygen saturation as measured by pulse oximetry (46%), inability to measure blood pressure (25%), abnormality of end-tidal CO_2 (21%), cyanosis (21%), or arrhythmia (16%). In 11% of cases, cardiac arrest occurred without recognized warning.

The causes of anesthesia-related cardiac arrest are shown in table 2. Medication-related problems were most common, accounting for 37% of all arrests. Cardiovascular depression from the administration of halothane (n = 26), halothane plus an intravenous medication (fentanyl [n = 3], bupivacaine [n = 3], lidocaine [n = 2], propranolol [n = 1], sufentanil [n = 1], or thiopental [n = 1]), or sevoflurane (n = 2) was regarded by reviewers as the primary cause in 71% of all medication cases. Median age for the 37 cardiac arrests related to halothane (either alone or in combination with an intravenous medication) was 6 months (range, 5 days–7 yr). Twenty-three of these patients were ASA physical status 1–2, and 14 were ASA physical status 3–5 (eight because of congenital heart disease). Three patients had an unrecognized cardiomyopathy. The median halothane concentration was 2%; five patients received halothane 3–3.9%, and nine received 4% or more halothane just prior to arrest. Sixty-six percent of halothane-related arrests occurred during induction, and 34% occurred during the maintenance phase. The most common antecedent events were bradycardia (n = 25) and hypotension (n = 25). An abnormality in oxygen saturation as measured by pulse oximetry was seen in 17 patients; loss of signal was the most common type of abnormality (n = 12). The most common associated factors were assisted or controlled ventilation (n = 18) and difficult intravenous access requiring multiple attempts (n = 4). Three of the 37 patients died, and two survived with permanent injury. All other cases were successfully resuscitated and recovered without permanent injury. Epinephrine alone (n = 10), atropine alone (n = 7), or epinephrine plus atropine (n = 15) were the drug treatments usually associated with return of adequate circulation.

The two arrests relating to cardiovascular depression from sevoflurane occurred during induction of anesthesia in ASA physical status 3 children and were preceded by hypotension and bradycardia. Both children were successfully resuscitated and survived without sequelae.

Five cases of arrest following intravascular injection of local anesthetic were reported. Four of these occurred during caudal injections (following induction of general anesthesia with halothane) of 0.25% bupivacaine with 1:200,000 epinephrine (0.5-1 ml/kg) through either a 23-gauge needle (n = 3), or a catheter (n = 1), despite negative aspiration and a negative test dose. All patients displayed ventricular arrhythmias. One patient was given intravenous phenytoin, and two were defibrillated. One other patient returned to sinus rhythm with only chest massage and ventilation with 100% oxygen. All four of these patients recovered without injury. The fifth case occurred following intranasal injection by the surgeon of 5 ml of 1% lidocaine with 1:100,000 epinephrine prior to endoscopic sinus surgery in a 4-yr-old boy. The administration of 4% cocaine pledgets, as well as 1% halothane, may also have contributed to this child's pulseless ventricular tachycardia. Conversion to normal sinus rhythm was achieved *via* a precordial thump, and the child recovered without sequelae.

Cardiovascular causes of cardiac arrest were found in 48 cases; in 18 of these, an exact cause of cardiac arrest could not be determined. Ten of these 18 patients had underlying congenital heart disease and were ASA physical status 3-5. The most common cardiovascular category in which an exact etiology could be determined was cardiac arrest as a consequence of hemorrhage or its therapy (n = 8). In three of these cases, the arrest was at least in part caused by hyperkalemia resulting from massive transfusion.

Respiratory events accounted for 20% of all cardiac arrests; the most common etiology was airway obstruction, due either to laryngospasm or anatomic obstruction. The laryngospasm group (n = 9) tended to be previously healthy; all but three were ASA physical status 1-2. Nonetheless, all developed severe bradycardia, hypotension, or both requiring initiation of chest compression. In most cases (n = 8), laryngospasm occurred during induction with halothane and nitrous oxide. Five of the cases required succinylcholine, and all were intubated successfully. Epinephrine was required in only one patient. One patient developed aspiration pneumonia, and one patient subsequently died of massive blood loss from a sagittal sinus tear. All other patients recovered without injury.

Most of the patients who arrested from anatomic airway obstruction had significant underlying disease: two had airway compression during repair of tracheoesophageal fistula; two had severe macroglossia; one had cystic fibrosis associated with mucous plugging; one had se-
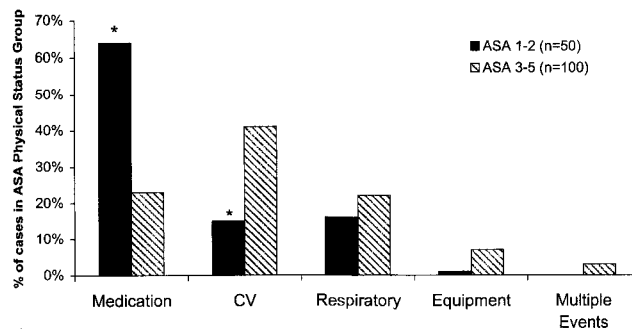

Fig. 1. Primary cause of anesthesia-related cardiac arrest in American Society of Anesthesiologists (ASA) physical status 1–2 and 3–5 patients. *P < 0.01 compared with ASA physical status 3–5 patients.

vere papillomatosis; and one had micrognathia. Similarly, the patients who arrested because of difficult intubation had significant underlying disease, and all were 4 months of age or younger: two had congenital heart disease; one had trisomy 18; and one had Pierre-Robin-related micrognathia.

The most common equipment problems were complications of anesthesiologist-placed central lines, either from induction of an arrhythmia or from creation of tamponade, hemothorax, or pneumothorax.

Thirty-three percent (n = 50) of all cardiac arrests occurred in previously healthy (ASA physical status 1-2) patients. A comparison of mechanism of arrest for ASA physical status 1-2 and ASA physical status 3-5 patients is shown in figure 1. Medication-related arrests were more common (P < 0.001) and cardiovascular etiologies were less common (P < 0.001) in ASA physical status 1-2 patients than in ASA physical status 3-5 patients.

Twenty-six percent of patients died, 6% suffered permanent injury, and 68% had no injury or temporary injury. The profile of the 39 patients who died is shown in table 3. All of the patients who died had significant underlying disease. Of the two patients reported as ASA physical status 1-2 who died, one was a 15-month-old child who arrested during induction of anesthesia prior to adenoidectomy; autopsy revealed massive cardiomegaly secondary to an unsuspected cardiomyopathy. The other was a 1-yr-old child with ichthyosis, failure to thrive, and hypertonia who arrested for presumed cardiovascular reasons during induction of anesthesia prior to gastrostomy.

Congenital heart disease was present in 15 of the patients who died, including patients in the medication-related (n = 1), respiratory-related (n = 2) and equipment-related (n = 1) categories. Acquired cardiomyopa-

Table 3. Profile of Anesthetic-related Deaths

Associated Factor	Number of Deaths
Total number	39
ASA physical status	
I–II	2 (5%)
III–V	37 (95%)
Surgical Status	
Emergency	16 (41%)
Nonemergency	22 (56%)
Phase of anesthetic	
Induction	10 (26%)
Maintenance	21 (54%)
Other	8 (21%)
Cause of arrest	
Cardiovascular	
Presumed CV, unclear etiology	9
Hemorrhage, transfusion-related	4
Inadequate/inappropriate fluid therapy	3
Hyperkalemia	3
Arrhythmia	2
Pacer-related	1
Pulmonary hypertension	1
Medication-related	
Halothane-induced CV depression	3
Multiple medications	1
Respiratory	
Airway obstruction	2
Difficult intubation	1
Inadequate ventilation	1
Presumed respiratory, unclear etiology	1
Laryngospasm	1*
Equipment problems	
Breathing circuit pressurized	1
Other	
Multiple events	4
Hypothermia	1

* Patient recovered from laryngospasm-related arrest (anesthesia-related) but subsequently arrested and died from uncontrollable hemorrhage (not anesthesia-related).

CV = cardiovascular.

Table 4. Multivariate Analysis of Predictors of Mortality

Factor	Odds Ratio	95% Confidence Interval	Estimated Coefficient	P
ASA physical status III–V	12.99	2.9–57.7	2.56	0.007
Emergency surgery	3.88	1.6–9.6	1.35	0.0036

ASA = American Society of Anesthesiologists.

ASA physical status 3–5 patients was 37%, compared with 4% in ASA physical status 1-2 patients (P < 0.001). Emergency surgery (mortality rate 52 vs. 13% in non-emergency surgery; P < 0.001), was also predictive (table 4). Age group and type of surgery were not predictive of mortality.

Discussion

This report provides insight into the origins and outcomes of anesthesia-related cardiac arrest in children under conditions of contemporary practice in North American hospitals. Patients younger than 1 yr of age accounted for more than one half of all arrests. Medication-related and cardiovascular causes of arrest were most common, together accounting for 69% of all arrests. Severe underlying patient disease and emergency surgery were the factors most strongly associated with poor outcome following cardiac arrest in anesthetized children.

Previous authors have reported an increased incidence of perioperative cardiac arrest in infants. Rackow et al.,[2] and subsequently Tiret et al.[4] and Ollson et al.,[3] suggested that infants younger than 1 yr of age were at increased risk. Cohen et al.[5] found that the largest number of perioperative complications occurred in infants younger than 1 month of age. POCA Registry data also suggest that infants are at increased risk, although the denominators necessary to calculate age-based risk are not yet available. Severe underlying patient disease such as prematurity, congenital heart disease, and other congenital defects place the infant at higher anesthetic risk than the older child or the adult. Interestingly, age as a factor independent of underlying disease was not predictive of mortality following cardiac arrest.

Medication-related problems accounted for 37% of all arrests and 64% of arrests in previously healthy (ASA physical status 1-2) patients. The predominant mechanism of arrest in this category was cardiovascular depression from the inhalation agents, usually halothane, either alone or in combination with an intravenous medication.

thies were present in three patients, all of whom arrested from halothane-induced cardiovascular depression and could not be resuscitated. Sepsis was the underlying problem in all three patients who died because of inadequate fluid replacement. Four patients died because of massive blood loss during tumor resection; two of these patients arrested because of hyperkalemia associated with massive transfusion. Hyperkalemia played a role in the death of three other patients. Two were liver transplant patients who developed wide complex tachyarrhythmias after reperfusion and could not be resuscitated. The other was a complex patient with renal insufficiency and severe metabolic acidosis.

By multivariate analysis, ASA physical status 3-5 was the strongest predictor of death. The mortality rate in

Of the children who arrested due to cardiovascular depression from halothane, 50% were 6 months of age or younger, and 50% had a reported inspired halothane concentration of 2% or less. This finding is consistent with the observation that young children may be vulnerable to cardiovascular depression from even conventional concentrations of halothane.[10,11] In some cases, associated factors may have contributed to cardiovascular depression by halothane. For example, the use of assisted or controlled ventilation may have accelerated the rise of halothane concentration in the blood and myocardium or may have reduced cardiac output by impeding venous return. Similarly, difficulty in gaining intravenous access may have resulted in prolonged exposure to high inspired halothane concentrations. Patients with significant underlying disease such as congenital heart disease may tolerate poorly any compromise in cardiac output caused by halothane-induced reductions in heart rate or myocardial contractility. The same is true for acquired heart disease, as illustrated by the three patients who arrested and died during induction with halothane and were found to have cardiomyopathies.

It is unclear at this time whether the increasing popularity of sevoflurane as an induction agent in children will have an impact on the number of reports of cardiac arrest attributed to inhalation agents. Sevoflurane has been reported to have less potential for producing bradycardia[12,13] and myocardial depression[14,15] than does halothane. Because denominators are not available, the incidences for halothane- and sevoflurane-related cardiac arrests cannot be calculated.

Most cases of intravascular injection of local anesthetic occurred during attempts at caudal injection despite negative aspiration and absence of response to a test dose. Incremental dosing of local anesthetic into the epidural space has been recommended over bolus injection to allow earlier detection of intravascular injection,[16] although this has not been systematically studied. Alternatively, use of local anesthetics with less myocardial toxicity than that associated with bupivacaine might be preventive.

The increased frequency of cardiovascular causes and the decreased incidence of respiratory causes of arrests differ from previous studies of anesthesia-related cardiac arrest in children. In the 1975 study of Salem *et al.*,[17] an equal proportion of cardiac arrests was ascribed to respiratory and cardiovascular causes. In a 1985 report from Keenan and Boyan,[6] cardiac arrest in children was most commonly ascribed either to failure to ventilate or to anesthetic overdose. In the Pediatric Closed Claims

Project report, respiratory causes of adverse events (including cardiac arrest) were most common, accounting for 43% of all claims, compared with only 13% in which cardiovascular causes were implicated.[7]

The frequency of cardiovascular events in the POCA Registry may relate to the entry criteria: *i.e.*, the need for chest compression. Arrests due to adverse respiratory events would not be included unless chest compressions were required. The predominance of cardiovascular events may also have some relation to the frequent use of pulse oximetry and capnography, monitors that may be more effective in preventing respiratory rather than cardiovascular events. Compared with the current report, the relative frequency of respiratory events was higher and that of cardiovascular events was lower in claims in the Pediatric Closed Claims Project report,[7] in which pulse oximetry was used in only 7% of cases. It is also possible that some events previously categorized as respiratory in the absence of pulse oximetry and capnography were actually cardiovascular in origin.

Several diagnoses are notable by their absence from the POCA Registry, including cardiac arrest from malignant hyperthermia or latex anaphylaxis. The reasons for this are unclear, but perhaps widespread recognition of these entities has reduced the routine use of triggering agents for malignant hyperthermia or the use of latex-containing products in potentially susceptible patients.

The only factors predictive of mortality following cardiac arrest were ASA physical status and emergency surgery. Although both have been reported as risk factors for anesthesia-related cardiac arrest in children,[4,6] this is the first study to identify them as factors predicting outcome from arrest. Emergency surgery as a predictor of mortality may be related to either patient factors (*e.g.*, cause of arrest, severity of underlying disease) or environmental factors (*e.g.*, availability of support staff or ancillary services). In our study, all deaths during emergency surgery occurred in ASA physical status 3–5 patients. There were no differences in distribution of age or cause of arrest between the emergency surgery patients who survived arrest and those that did not.

The POCA Registry has some important methodologic weaknesses. First, it depends on voluntary reporting from institutional representatives who must collate a large amount of data to report even a single case. Underreporting is likely in this situation. For example, the annual incidence-of-arrest figure may be negatively biased (*i.e.*, lower than the actual rate of arrest). Selection bias is also possible, such that unexpected cardiac arrests or highly sensitive cases might not get reported.

Although underreporting would decrease the calculated incidence of cardiac arrest, our figure of 1.4 per 10,000 incidences of anesthesia is similar to that reported by others.[4,6] Self-reporting may also lead to inaccuracies in the data, such as underestimates of the anesthetic concentration at the time of arrest.

Second, the institutions participating in the POCA Registry may not be representative of all institutions providing surgical care to children. Despite the best efforts of the authors, the POCA Registry remains heavily skewed toward university-affiliated institutions and pediatric referral centers, although it is likely that a majority of instances of pediatric anesthesia in North America and elsewhere are delivered in community hospitals. At the same time, it is reasonable to expect that the lessons learned from patterns and profiles of cardiac arrest could be applied to all institutions caring for children.

A final weakness is that the demographic data submitted by participating institutions do not yet include distributions for age and ASA physical status of all patients in the pediatric age group who underwent anesthesia. Without these denominators, incidence figures for age and ASA physical status groups cannot be calculated.

In its first 4 yr of operation, the POCA Registry has gathered 150 cases of anesthesia-related cardiac arrest from a total of 289 cases submitted from 63 North American institutions. Medication-related and cardiovascular causes of arrest were most common. Fifty-five percent of arrests occurred in children younger than 1 yr of age. Severe underlying disease and emergency surgery were the factors most strongly associated with mortality following cardiac arrest. ASA physical status 1–2 patients accounted for one third of all anesthesia-related cardiac arrests. Reviewers regarded cardiovascular depression by halothane to be a frequent cause of arrest in this group.

Appendix A

Definitions of Mechanisms of Cardiac Arrest

1. Cardiovascular events
   - Transfusion reaction: Administration of appropriately matched blood followed by a transfusion reaction to the blood.
   - Wrong blood administered: Administration of blood not intended for the patient.
   - Hemorrhage: Inability to adequately replace blood loss or arrest due to metabolic consequence of rapid or massive transfusion (e.g., hyperkalemia, hypocalcemia).
   - Other possible causes not explicitly defined: Inadequate or inappropriate fluid therapy, electrolyte imbalance, pulmonary embolism, arrhythmia, septic shock, air embolus, failure to wean from cardiopulmonary bypass, and early postbypass cardiac failure.
   - Presumed cardiovascular cause, unclear etiology: Cause of event could not be determined, but appeared to be cardiovascular.

2. Medication-related events
   - Administration of a drug that was not prescribed, indicated or intended; administration of inappropriate dose of a drug that was intended; syringe or vial swaps; administration of. appropriate drug and dose followed by abnormal response in the patient
   - Cardiac arrest as a response to an inhaled anesthetic agent was defined as arrest preceded by evidence of cardiovascular depression during administration of a potent inhaled agent in the absence of hypoxemia, airway obstruction, or equipment problems.
   - Intravenous injection of local anesthetic was defined as signs of local anesthetic toxicity (arrhythmia, cardiovascular collapse, or seizures) occurring within 1–2 min of injection of local anesthetic medication.

3. Respiratory events
   - Airway obstruction: Obstruction of the patient's airway from physiologic conditions such as tumors, tracheal stenosis, or laryngospasm diagnosed by physical examination or capnography. Kinking of the endotracheal tube was listed under Equipment Problems.
   - Esophageal intubation: Placement of endotracheal tube in esophagus that was not detected within 6 breaths.
   - Inadvertent extubation: Inadvertent removal or dislodgment of endotracheal tube.
   - Premature extubation: Purposeful removal of endotracheal tube, with subsequent loss of airway patency, regardless of whether appropriate indications for extubation were present.
   - Pneumothorax: Pneumothorax specified as the initial event leading to cardiac arrest rather than as a complication of resuscitation.
   - Inadequate ventilation: Clinically excessive hypercarbia with respiratory acidosis.
   - Inadequate oxygenation: Hypoxemia resulting from failure of the respiratory system.
   - Difficult intubation: Difficulty encountered in attempting to place endotracheal tube into the patient's airway, without specification of number of attempts.
   - Aspiration: Passage of gastric contents or other fluids or solid materials into the airway.
   - Inadequate fraction of inspired oxygen: Inadequate fraction of inspired oxygen for the maintenance of systemic oxygenation.
   - Bronchospasm: Wheezing with need for increased airway pressure, inspired oxygen concentration, or both.
   - Presumed respiratory cause, unclear etiology: Cause of event could not be determined, but appeared to be respiratory.

4. Equipment problems
   - Equipment misuse (human fault or error associated with preparation, maintenance, or deployment of a medical device) and equipment malfunction despite appropriate maintenance and previous uneventful use.

5. Unknown
   - Cause of arrest could not be determined.

Appendix B

Severity of Injury Score[8]

Score	Injury
0	No obvious injury
1	Emotional injury only (*e.g.*, fright, awake during anesthetic, pain during anesthetic)
	Temporary
2	Insignificant (*e.g.*, lacerations, contusions); no delay in recovery.
3	Minor (*e.g.*, decrease in hospital); recovery delayed; extra time in recovery room or hospital
4	Major (*e.g.*, brain damage, nerve damage); prolonged hospitalization
	Permanent
5	Minor (*e.g.*, damage to organs, nondisabling injuries)
6	Significant (*e.g.*, loss of eye, deafness, loss of one kidney or lung)
7	Major (*e.g.*, paraplegia, loss of use of limb, blindness, brain damage)
8	Grave (*e.g.*, severe brain damage, quadriplegia, lifelong care, fatal prognosis)
9	Death

Appendix C

Definitions for Categories of Impact of Anesthesia on Genesis of Cardiac Arrest

Anesthesia-related: Anesthesia personnel or the anesthetic process played at least some role (ranging from minor to total) in the genesis of cardiac arrest. A single cause for arrest might or might not be known. Cases in which cardiac arrest might have resulted from the failure of anesthesia personnel to provide appropriate consultative advice were included in this category.

Not anesthesia-related: The cause of arrest was known and related entirely to underlying patient disease or to the surgical process. Anesthesia personnel or the anesthetic process did not contribute, even to a minor degree.

Unknown: The cause of the arrest could not be determined or the role of anesthesia personnel or the anesthetic process could not be assessed in the genesis of cardiac arrest.

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