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Anesthestic-related Cardiac Arrest and Its Mortality

A Report Covering 72,959 Anesthetics over 10 Years from a US Teaching Hospital

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Background: **A prospective and retrospective case analysis study of all perioperative cardiac arrests occurring during a 10-yr period from 1989 to 1999 was done to determine the incidence, cause, and outcome of cardiac arrests attributable to anesthesia.**

Methods: **One hundred forty-four cases of cardiac arrest within 24 h of surgery were identified over a 10-yr period from an anesthesia database of 72,959 anesthetics. Case abstracts were reviewed by a Study Commission composed of external and internal members in order to judge which cardiac arrests were anesthesia-attributable and which were anesthesia-contributory. The rates of anesthesia-attributable and anesthesia-contributory cardiac arrest were estimated.**

Results: **Fifteen cardiac arrests out of a total number of 144 were judged to be related to anesthesia. Five cardiac arrests were anesthesia-attributable, resulting in an anesthesia-attributable cardiac arrest rate of 0.69 per 10,000 anesthetics (95% confidence interval, 0.085–1.29). Ten cardiac arrests were found to be anesthesia-contributory, resulting in an anesthesia-contributory rate of 1.37 per 10,000 anesthetics (95% confidence interval, 0.52–2.22). Causes of the cardiac arrests included medication-related events (40%), complications associated with central venous access (20%), problems in airway management (20%), unknown or possible vagal reaction in (13%), and one perioperative myocardial infarction. The risk of death related to anesthesia-attributable perioperative cardiac arrest was 0.55 per 10,000 anesthetics (95% confidence interval, 0.011–1.09).**

Conclusions: **Most perioperative cardiac arrests were related to medication administration, airway management, and technical problems of central venous access. Improvements focused on these three areas may result in better outcomes.**

DEATHS related to anesthesia in the perioperative period have been studied in the United States for over 60 yr. Details of the identified cases were reviewed by commissions composed of surgeons, internists, and anesthetists.[1] In 1954 Beecher and Todd[2] published what was then by far the most extensive study of anesthesia mortality in the United States. Concerns over the numbers of deaths attributable to anesthesia in the United States were shared by the international community and resulted in a number of publications from South Africa,[3] Australia,[4] France,[5] Canada,[6] and England, including the voluntary Confidential Enquiry into Perioperative Deaths in 1987.[7] A comprehensive study of cardiac arrest related to anesthesia at an academic institution was reported by Keenan and Boyan[8] in 1985. This was followed in 1993 by an analysis of 87 cases of cardiac arrest from the first 2,000 incidents reported to the Australian Incident Monitoring Study.[9] In this report, details of each cardiac arrest were reviewed, including identifying the main factors in the arrest and giving clinical summaries of preexisting conditions. In the United States, Morray *et al.*[10] recently reported on data from the Pediatric Perioperative Cardiac Arrest Registry from over 60 contributing institutions. In 2001, Biboulet *et al.*[11] reported on fatal and nonfatal cardiac arrests related to anesthesia in France.

Because there has been no recently reported study in the United States of cardiac arrest related to anesthesia in a general surgical population, this study was undertaken to report on all cardiac arrests occurring in the 24-h perioperative period from August 15, 1989 to August 14, 1999, at our institution, and to determine the incidence, cause, and outcome of cardiac arrests attributable to anesthesia.

This article is featured in "This Month in Anesthesiology." Please see this issue of ANESTHESIOLOGY, page 5A.

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Methods

After obtaining approval from our institutional review board, we analyzed all reported cardiac arrests in 72,959 consecutive anesthetics given to all patients who required anesthesia services at the University of Nebraska Medical Center in Omaha, NE, from August 15, 1989 through August 14, 1999. Cardiac arrests were identified from an anesthesia database, which was developed from a quality assessment form that was included with each anesthesia record as mandatory documentation of every anesthetic. The forms were completed by anesthesia staff, residents, and nurse anesthetists responsible for the anesthetic. The form consists of patient demographics, anesthesia provider information, date and location, American Society of Anesthesiologists (ASA) physical status classification,[12] and a 60-item checklist of airway, cardiovascular, respiratory, neurologic, regional, and miscellaneous events, with space for description of the event, treatment, and outcome, and a page for comments as to the putative cause or causes. Cardiac arrest was defined as an event requiring cardiopulmonary resuscitation, which may include closed-chest cardiac compressions. The quality assessment forms were collected along with a copy of the anesthesia record by billing personnel on a daily basis and reviewed for completeness by one of the authors on an ongoing basis throughout the period covered by this report. Capture of all eligible cases into the database was supplemented for the last 6 yr of the study (1995–1999) by monthly review of all hospital deaths, which included surgical deaths. Death was defined as demise of the patient for any cause. A daily hospital discharge list was compared with the daily surgical schedule by billing personnel to identify all cases who died within 48 h of anesthesia and surgery. The faculty anesthesiologist responsible for the case was asked to review the case and provide a written summary for peer review. Cases meeting autopsy quality review criteria, including any unanticipated or unexplained death, any death associated with a new therapeutic regimen, drug reaction, or blood transfusion, any intraoperative or intraprocedural death, and any death within 48 h related to a specific procedure or medical therapy, were referred to the hospital mortality review committee for further analysis. Although these sources additional to the anesthesia database were not designed to identify cardiac arrests, they did identify deaths that could have been related to anesthesia.

From August 15, 1989 to August 14, 1999, 72,959 anesthetics were administered in the main operating suite and the outpatient surgical center of the University of Nebraska Hospital. A total of 144 cardiac arrests were identified in the 24-h perioperative period. In order to have a comparison group of cases that underwent anesthesia but that did not suffer a cardiac arrest, each case with cardiac arrest was matched by a "proximal convenience" method to four other cases that underwent anesthesia on the same day and in the same operating suite (inpatient or outpatient). All anesthesia records are preserved in paper copy in files maintained by the Department of Anesthesia. The two cases randomly filed by billing clerks immediately preceding and immediately following the case of cardiac arrest were called "case controls." For all cases and controls, data were obtained on patient demographics, ASA physical status classification,[12] operation performed, date and time of operation, emergency or elective status, length of operation, anesthetic technique, and outcome. A case was considered "emergency" when it was so designated as part of the ASA physical status classification even when it was done during usual working hours of 7 AM to 3 PM. All cases begun after 3 PM were considered "emergency" for this study even though some were part of the regular schedule. Anesthetic technique refers to the primary method of anesthesia delivery and was broken down into general, regional, combined general and regional, and monitored anesthesia care. Local anesthesia only was given by the surgeon in certain terminally ill cases in which anesthesia staff were present for resuscitation and support. The surgical procedures performed on these patients were classified by major categories according to the *Physician's Current Procedural Terminology*, 4th Edition, as found in the ASA 1997 Relative Value Guide.[13]

The medical and anesthesia records of each patient who suffered a cardiac arrest while undergoing anesthesia were reviewed by at least one of the authors who are faculty members in the Department of Anesthesiology. A case abstract was prepared by one of these faculty after collecting data from the medical records using a standardized data form. There was no identification of the patient or healthcare provider or providers, and the abstracts were prepared without assigning responsibility for the cardiac arrest. Abstracts were identified by a three-digit number assigned by one of the authors and submitted anonymously to an Anesthesia Study Commission recruited for the project. The Commission was composed of experts from outside institutions as well as our own, who had no prior information about any of the cases. We believe that this approach produced as unbiased an assessment of the role of anesthesia as possible and is a more valid way of evaluating these cases for causation than would be possible by using faculty exclusively from within the institution.

The Study Commission was composed of three nationally recognized chairpersons of academic anesthesia departments, a surgeon who is chair of a department of surgery, and a senior faculty internist and pulmonologist, certified in critical care medicine. Commission members were blinded to patient identity and on the first review were asked to provide their "assessment of the primary cause of cardiac arrest or death" as due to (1) anesthesia, (2) surgery, (3) patient disease or condition, (4) other (*e.g.*, chance, electrical malfunction, fall, catastrophic failure of equipment), or (5) unable to decide from the information provided. In addition, Study Commission members were asked to determine which factor played a contributory role in the cardiac arrest or death, *i.e.*, anesthesia, surgery, patient disease or condition, or other contributing cause, and give a short explanation. They also had the option of requesting additional information about the cases. Agreement of opinion or consensus was determined when at least three of the five commission members agreed on the cause of event.

Following the Study Commission's initial review, 45 of the original 144 cases were submitted for a second review because the case either had been coded as primarily caused by anesthesia by at least one Study Commission member or had been coded with anesthesia as a contributing cause by two or more members. Commission members were asked to not refer to previous notes or any other materials at the time of second review and to make only one choice of the role of anesthesia in this subset of cases using the following scale:

1. I am certain, far beyond a reasonable degree of medical certainty, that anesthesia was the primary cause of the adverse event (certainty > 90%).
2. I am certain beyond a reasonable degree of medical certainty, meaning, it is more likely than not that anesthesia was the primary cause of the adverse event (certainty 51–90%).
3. Anesthesia was not the primary cause of the adverse event, but I am certain, far beyond a reasonable degree of medical certainty, that anesthesia was an important contributing cause of the adverse event (certainty > 90%).
4. Anesthesia was not the primary cause of the adverse event. I am certain, beyond a reasonable degree of medical certainty, that it is more likely than not that anesthesia was an important contributing cause of the adverse event (certainty 51–90%).
5. Anesthesia was neither the primary nor an important contributing cause of the adverse event.

Statistical Analysis

Simple comparisons of cases and controls were performed using a combination of chi-square (for comparison of categorical data) and Wilcoxon rank-sum (for comparison of continuous data) statistics. Logistic regression was used to determine factors that independently predict the risk of cardiac arrest in the perioperative period. The probability of cardiac arrest in the perioperative period was modeled as a function of various patient characteristics, including ASA physical status, age, sex, operation type (emergency *vs.* scheduled), and surgical procedure.

Results

There were 72,959 anesthetics administered during the 10 yr of this study, including both inpatient and outpatient surgical locations. A total of 144 cardiac arrests were identified within a 24-h perioperative period from an anesthesia quality assessment database. There were no additions to this database from 6 yr of monthly review of all hospital deaths or from other sources, including referrals from autopsy review or anesthesia case comparisons with the surgical schedule. Overall incidence of cardiac arrest from all causes was 19.7 per 10,000 anesthetics (95% confidence interval [CI], 16.52–22.96). Each cardiac arrest was matched using a "proximal convenience" method with four other cases undergoing anesthesia on the same day and in the same operating suite in order to have a comparison group. The characteristics of cases and the comparison group (controls) are displayed in table 1.

As compared to controls, patients experiencing cardiac arrest were older (odds ratio [OR], 1.01; 95% CI, 1.01–1.02; $P = 0.0002$), more likely male (OR 0.71; 95% CI, 0.49–1.02; $P = 0.07$), more likely to have a greater ASA physical status ($P < 0.0001$; 68% ASA IV or V *vs.* 14% for controls), more likely to have emergency surgery (OR, 5.14; 95% CI, 3.49–7.56; $P < 0.0001$), thoracic (including cardiac)–spine or upper abdominal surgery ($P < 0.0001$), longer operations (OR, 1.00; 95% CI, 1.003–1.00; $P = 0002$), and surgery after 3 PM (OR, 0.45; 95% CI, 0.30–0.66; $P < 0.0001$). Nearly 60% percent of all cases with cardiac arrest were classified as "emergency" in their ASA physical status classification, but only 36.8% of the arrests occurred from 3 PM to 7 AM.

A total of 22 (15.3%) cardiac arrests were reported out of 16,051 cases 20 yr of age or younger, for an overall incidence of arrest in this age group of 13.7 per 10,000 anesthetics (95% CI, 7.98–19.43). Twenty-seven percent of arrests occurred in patients aged less than 1 yr, with only one patient ASA physical status III. The remainder of patients in this age group were ASA physical status IV or V. Only one patient was successfully resuscitated. There were 5 children in each of three age groups: 1–6 yr, 6–12 yr, and 13–20 yr. Out of the entire group of 22, there were only 4 (18%) patients with ASA physical status II–III. Eleven (50%) were ASA physical status IV, and 7 (32%) were ASA physical status V. Thirteen (59%) were emergency cases. Operative procedures included 7 (32%) exploratory laparotomies, 5 (23%) liver transplants, and 2 (9%) each of diaphragmatic hernia repair, cardiac with cardiopulmonary bypass, intracranial procedures, thoracotomies, and 1 (4.5%) each tonsillectomy and central line.

Table 2 gives additional information about the 129 cases of cardiac arrest that were attributable either to patient disease–condition or surgery. The largest category, trauma, had 28 (21.7%) cases, followed by end-stage liver disease and complications associated with liver transplantation, with 25 (19.4%) cases. Twenty-one (16.3%) cases were unable to be weaned from cardiopulmonary bypass. Smaller numbers included ruptured aneurysms, technical problems, exsanguinating hemorrhage, and perioperative myocardial infarction.

We used logistic regression to identify factors that appeared to independently predict for risk of arrest in the perioperative period. ASA physical status was most strongly predictive, and emergency surgery was associated with an elevated risk. Patients with ASA physical status V had a risk of arrest more than 300 times that of those with ASA physical status I or II (table 3). Patients with ASA physical status III were at significantly higher risk than those with ASA physical status I or II. Among this patient group, those undergoing thoracic (including cardiac) or spine surgery and those undergoing other

Table 1. Characteristics of Cases and Comparison Group for Cardiac Arrest

Characteristics	Cases (N = 144)	Controls (N = 576)	*P*	OR	95% CI
Age (yr)	49.9 ± 23.8	41.5 ± 24.9	0.0002	1.01*	1.01–1.02
< 1	6 (4.2%)	27 (4.7%)			
1–10	10 (6.9%)	63 (10.9%)			
11–20	6 (4.2%)	51 (8.9%)			
21–30	10 (6.9%)	69 (12.0%)			
31–50	25 (17.4%)	135 (23.4%)			
51–70	58 (40.3%)	153 (26.6%)			
71–90	29 (20.1%)	78 (13.5%)			
Sex					
Female	65 (45.1%)	309 (53.6%)	0.0683	0.71	0.49–1.02
Male	79 (54.9%)	267 (46.4%)			
ASA physical status					
I	1 (0.7%)	79 (13.7%)	< 0.0001	0.00	0.00–0.14
II	5 (3.5%)	185 (32.1%)		0.00	0.00–0.01
III	40 (27.8%)	230 (39.9%)		0.02	0.01–0.06
IV	59 (41.0%)	77 (13.4%)		0.01	0.04–0.26
V	39 (27.1%)	5 (0.9%)			
Emergency *versus* scheduled†	86 (59.7%)	129 (22.4%)	< 0.0001	5.14	3.49–7.56
Surgical procedures					
Head/neck	13 (9.0%)	111 (19.3%)	< 0.0001	0.12	0.05–0.28
Thoracic/spine	56 (38.9%)	106 (18.4%)		0.22	0.10–0.45
Upper abdomen	26 (18.1%)	48 (8.3%)		0.60	0.33–1.08
Extremity	7 (4.9%)	112 (19.4%)		0.049	0.01–0.21
Other	2 (1.4%)	75 (13.0%)		0.98	0.55–1.73
Lower abdomen	40 (27.8%)	124 (21.5%)			
Length of operation (min)	301.8 ± 227.3	172.9 ± 133.9	0.0002	1.00*	1.00–1.00
≤ 90	35 (24.3%)	213 (37%)			
91–180	25 (17.4%)	177 (30.7%)			
> 180	84 (58.3%)	186 (32.3%)			
Time of day (24-h clock)					
Day (0700–1500)	91 (63.2%)	457 (79.3%)	< 0.0001	0.45	0.30–0.66
Evening/night (1500–0700)	53 (36.8%)	119 (20.7%)			
Anesthetic technique, general *versus* other	118 (81.9%)	484 (84%)	0.5461	0.86	0.53–1.39

$P < 0.05$ significant.

* Odds ratio (OR) computed considering variable as continuous. † See text for definition of emergency.

95% CI = 95% confidence interval; ASA = American Society of Anesthesiologists.

operative procedures but on an emergency basis were at elevated risk. The risk for patients classified as ASA physical status IV was greater than that for those classified as ASA physical status III. Emergency surgery in patients with ASA physical status IV increased the risk of cardiac arrest. After accounting for the effects of ASA physical status, emergency surgery, and surgical site, none of the other factors were predictive for cardiac arrest risk. The focus that follows is on the 15 cardiac arrests related to anesthesia.

Results of the first review identified six cases of cardiac arrest attributable to anesthesia. Since an additional 15 cases received at least one vote for anesthesia-attributable and an additional 24 cases had at least two votes for anesthesia-contributory, it was decided to resubmit all 45 of these cases to the Study Commission for a rigorously defined second review as described in the Methods section. After the more restrictive conditions imposed for the second review, 30 of the 45 cases were judged not attributable to or contributory to anesthesia. Five of the six original cases of cardiac arrest attributed to anesthesia were so identified on the second review as anesthesia-attributable. The sixth case moved to the anesthesia-contributory group along with nine remaining cases from the second review group of 45. The five cardiac arrests attributable to anesthesia gave a cardiac arrest rate due to anesthesia of 0.69 per 10,000 anesthetics (95% CI, 0.085–1.29). Four of these five patients died (80%), for an observed mortality rate due to anesthesia of 0.55 per 10,000 anesthetics (95% CI, 0.011–1.09). The 10 cases in which anesthesia was assessed to be a contributory cause of event gave an anesthesia-contributory cardiac arrest rate of 1.37 per 10,000 anesthetics (95% CI, 0.52–2.22). Mortality in this group was markedly less (30%).

There were no anesthesia-attributable cardiac arrests reported in the database in the 16,051 cases aged 20 yr or younger. Three cardiac arrests in patients aged 7 yr and younger were judged to be in the anesthesia-contributory group, for an incidence of 1.9 per 10,000 anesthetics (95% CI, 0–3.98). None of these patients died.

In order to have a group large enough to perform statistical calculations, the 5 anesthesia-attributable and 10 anesthesia-contributory cases were combined into a

Table 2. Cardiac Arrests Attributable to Patient Disease/Condition, or Surgical Factors

Causes of Arrest	Number N (%)	Mortality (%)
	129	75
Trauma: motor vehicle, gunshot wound, stabbing, fall, electrocution	28 (21.7)	100
End stage liver disease and complications associated with liver transplantation	25 (19.4)	76
Unable to wean from cardiopulmonary bypass	21 (16.3)	100
Complications associated with cardiac surgery	9 (7.0)	44
Ruptured aneurysm; abdominal or thoracic	9 (7.0)	100
Technical complications: surgical and special procedures, central venous access	9 (7.0)	44
Complications associated with automatic implantable cardiac defibrillator placement	5 (3.9)	20
Exsanguinating hemorrhage at operation associated with primary disease process	5 (3.9)	40
Complications associated with small bowel transplantation	4 (3.1)	75
Complications associated with radical cancer surgery	4 (3.1)	50
Sepsis and multiple organ failure	3 (2.3)	100
Pulmonary embolus	3 (2.3)	100
Perioperative myocardial infarction	2 (1.6)	100
Complications associated with congenital heart defect	2 (1.6)	100

single group and compared to their 60 time-related case controls. There were no statistically significant differences between the 15 cases experiencing anesthesia-related cardiac arrest and their 60 controls in age, sex, ASA physical status, emergency *versus* scheduled operations, surgical procedures, length of operation, time of day, or anesthetic technique.

Table 4 summarizes the adverse events in anesthesia-related cardiac arrests. The five anesthesia-attributable cases are listed as numbers 1–5, and anesthesia-contributory cases are 6–15. Age, ASA physical status, and emergency listing, location of event, presumed cause of the arrest, and outcome are noted. All anesthesia-attributable cardiac arrests that resulted in death were in patients with ASA physical status III, for a mortality rate of 80%. In addition to each patient's underlying serious medical problems, causes leading to cardiac arrest included medication-related events. Two cases of respiratory arrest followed by cardiac arrest occurred in patients given morphine intravenously for postoperative pain control. One patient with ASA physical status II was successfully resuscitated with no permanent sequelae, but the second, with ASA physical status III, was temporarily resuscitated but died with permanent injuries. A relative overdose of induction agent resulted in three cardiac arrests in patients with ASA physical status ranging from I to V, but all were successfully resuscitated and went on to complete recovery. A patient with ASA physical status I was found to have an undiagnosed peripartum cardiomyopathy but made a full recovery. One patient with ASA physical status III was given a single 1-mg intravenous dose of midazolam that resulted in cardiac arrest. The patient initially responded well to resuscitation efforts but died several hours later after further treatment was withdrawn because of a "do not resuscitate" status. Other causes of arrest included loss of airway–unable to ventilate, unknown or probable vagal reaction, complications associated with central venous access resulting in induction of dysrhythmia or bleeding resulting in hemothorax, and one case each of pulmonary aspiration and perioperative myocardial infarction. Mortality in the anesthesia-contributory group was 30%, and ASA physical status ranged from I to V. No anesthetic was administered in two cases. The only case of aspiration occurred during regional anesthesia. Five events occurred during induction and two occurred prior to induction of anesthesia. Three events occurred during the recovery period in an intensive care unit, and one event occurred in the patient's room. Four events occurred during the maintenance period.

Discussion

This report describes the findings of an independent Study Commission review of 144 cardiac arrests in 72,959 anesthetics at a single academic medical center over 10 yr from August 15, 1989 to August 14, 1999. The Study Commission found that 15 cases of cardiac arrest were related to anesthesia. Causes of the cardiac arrests were medication-related in 40%, complications associated with central venous access in 20%, airway-related complications in 20%, unknown or possible vagal reaction in 13%, and perioperative myocardial infarction in a single case.

In a report on anesthesia-related cardiac arrest in children, Morray *et al.*[10] found that medication-related problems were responsible for 37% of all cardiac arrests, and the current study found a similar incidence of 40%. None of our medication-related events involved the use of a wrong drug, but rather a relative overdose administered to the patient or an unusual response by the patient to a standard dose. Using a small dose of drug initially (test

Table 3. Factors Predictive of Cardiac Arrest (n = 144)

Patient Group	Estimated Odds Ratio
ASA physical status I or II, elective surgery	1.0 (baseline)
ASA physical status III, other surgery,* elective	3.89
ASA physical status III, other surgery, emergency	9.4
ASA physical status III, thoracic (including cardiac); spine	17.6
ASA physical status IV, elective surgery	19.6
ASA physical status IV, emergency surgery	53.6
ASA physical status V	343

* Other surgery = any operation except intrathoracic, cardiac, or spine.
ASA = American Society of Anesthesiologists.

Table 4. Adverse Events in Cardiac Arrests Related to Anesthesia (n = 15)

No.	Age (yr)	ASA PS	Location	Event leading to arrest	Period	Outcome	Anesthetic Technique
1*	24	III	IP	Adverse drug event: narcotic overdose	PACU	Death	General
2*	45	III	IP	Loss of airway/unable to ventilate	Induction	Death	General
3*	59	III	IP	Bleeding/complications related to central venous access	Maintenance	Death	General
4*	66	III	IP	Loss of airway/unable to ventilate	Induction	Death	General
5*	80	II	OP	Adverse drug event: overdose of induction agent	Induction	Recovered	General
6†	1	IV	IP	Probable vagal reaction	PICU	Recovered	General
7†	2	II	IP	Adverse drug event: narcotic overdose	Patient room	Recovered	General
8†	7	IVE	IP	Probable vagal reaction	Maintenance	Recovered	General
9†	34	I	OP	Adverse drug event: overdose of induction agent	Induction	Recovered	General
10†	57	IIIE	IP	Aspiration of stomach contents	Maintenance	Recovered	Regional
11†	57	III	IP	Perioperative myocardial infarction	AICU	Death	General
12†	58	VE	IP	Adverse drug event: overdose of induction agent	Induction	Recovered	General
13†	61	IVE	IP	Dysrhythmia/complication related to central venous access	Before induction	Death	None
14†	62	3	IP	Dysrhythmia associated with AICD placement	Maintenance	Recovered	General
15†	65	3	OP	Adverse drug event: response to premedication	Before induction	Death	None

* Anesthesia attributable. † Anesthesia contributory.

ASA PS = American Society of Anesthesiologists physical status; E = emergency; IP = inpatient operating suite; OP = outpatient operating suite; PACU = postanesthetic care unit; PICU = pediatric intensive care unit; AICU = adult intensive care unit.

dose) and observing the patient's response to this dose before proceeding with further increments of drug may prevent some of these complications. Morray *et al.*[10] also reported three patients with cardiac arrest who were found to have had an unrecognized cardiomyopathy, while we had a single patient with this diagnosis.

Complications associated with central venous access accounted for 20% of cardiac arrests in the current study compared to 4% in the report by Morray *et al.*[10] Complications included bleeding resulting in hemothorax and induction of dysrhythmias that progressed to ventricular fibrillation. ASA physical status was III–IV in this subset of patients with a mortality of 67%. Since patients who have central lines placed are likely to be those undergoing more serious operations or those with at least ASA physical status III, they do represent a higher risk group of patients. Both surgeons and anesthesia providers need to be aware of the possibility of life-threatening complications and be prepared to treat them.

Airway-related problems included the loss of airway with difficulty ventilating and subsequent complications resulting in temporary recovery only. The single case of aspiration occurred in a patient who was sedated under regional anesthesia. Since all of these patients had other associated medical problems, reflected by their ASA physical status III, they may have had fewer reserves and been less able to recover after loss of airway or aspiration.

In two patients, a definite cause for the cardiac arrest was undetermined, although a vagal reaction could not be ruled out. They had ASA physical status III–IV, and both made a full recovery after treatment. A single case of perioperative myocardial infarction resulted in patient demise several hours after operation despite aggressive treatment.

In the entire group of 144 perioperative cardiac arrests compared to their controls, the current study found that patients experiencing cardiac arrests were older, male, had a greater ASA physical status, had operations of greater length, emergency operations, surgery later in the day, and were likely to undergo thoracic, cardiac, spine, or upper abdominal surgery. Comparing the 15 anesthesia-related perioperative cardiac arrests to their 60 time-related case controls resulted in no statistically significant differences in age, sex, ASA physical status, emergency *versus* scheduled operations, surgical procedures, length of operation, time of day, or anesthetic technique.

Cardiac arrest associated with anesthesia was studied in 1985 by Keenan and Boyan,[8] who reviewed all cardiac arrests in a university hospital over a 15-yr period. They found that risk for emergency patients was six times that for elective patients. Although 60% of cardiac arrests in the current study were emergency cases, none of five cardiac arrests attributable to anesthesia was an emergency case. Sixty percent of anesthesia-attributable cardiac arrests occurred during the induction phase, with only one (20%) during maintenance and one (20%) during the recovery period.

In 1988, Olsson and Hallen[14] reported on cardiac arrest during anesthesia using a computer-based anesthesia record system totaling 250,543 anesthetics. In contrast to the current study, where 40% of anesthesia-related cardiac arrests were medication-related, they found the most frequent problems to be ventilatory, then postsuccinylcholine asystole, and hypotension following induction. They retrieved all cases from an anesthesia form in which "circulatory arrest" was noted. They found a total of 170 cardiac arrests, of which 115 were considered caused by anesthesia, for an overall incidence of 6.8 cardiac arrests per 10,000 anesthetics. There were nine deaths attributed to anesthesia, resulting in a mortality caused by anesthesia of 0.3 per 10,000 anesthetics.

An analysis of 87 cardiac arrests reported in the first 2,000 incidents in the Australian Incident Monitoring Study was reported by Morgan *et al.*[9] in 1993. The cases were divided into groups according to most common primary cause of the arrest. In this more recent study, they too found that drug related events were most common. Other causes were vagal stimulation, hypoventilation, bleeding, anaphylaxis, and direct cardiac stimulation. Forty-six percent of the cardiac arrests had an anesthetic cause, with preventable factors present in 58% of these cases. A study from France reported by Biboulet *et al.*[11] in 2001 found 11 cardiac arrests in 101,769 anesthetics, a somewhat larger database than the current study, with a frequency of 1.1 per 10,000 (95% CI, 0.44–1.72). Mortality was 0.6 per 10,000 (95% CI, 0.12–1.06). Three of the arrests were totally related to anesthesia, and eight were partly related to anesthesia. In contrast to the current study, with only 13.7% of patients ASA physical status I, 90% of their cases were considered to be ASA physical status I–II.

Possible methodological weaknesses associated with the current study include its representation of the experience from only a single institution. The University of Nebraska Hospital is a 300-bed tertiary care referral center with approximately 12,000 patient discharges per year and is a metropolitan trauma center. It provides care for the population of Nebraska and surrounding areas. Patient mix includes high-risk obstetric patients, and there is a 30-bed neonatal intensive care unit and a pediatric intensive care unit. During the period of this study, an active pediatric and adult liver transplant program was in place with 100–150 transplants per year and a developing small bowel transplantation program. Transplant patients come from the region as well as the United States with some international patients. Anesthesia care is provided by full-time academic faculty, residents, and certified registered nurse anesthetists. Obtaining meaningful data requires compilation of information covering a relatively long time period; access to 10 yr of data gave us a denominator of nearly 73,000 anesthetics upon which to base our calculations. The single-institution database offered a reporting consistency that would not be available from a multicenter study. On the other hand, peculiarities of our particular practice might have influenced our statistics.

We depended on reporting of adverse events by faculty, residents, and nurse anesthetists. Although filling out the form for each case was mandatory, it is still possible that some events were missed. If so, our figures may be slightly optimistic. Our institution is relatively small, with a core of faculty that had a low rate of turnover during the collection period. Adverse events are reviewed weekly as part of our quality control program. In addition, one of the authors served as chair of the institutional mortality review committee for the last 6 yr of this study database, during which time members of the committee reviewed every death from the entire institution monthly. We feel that the results of our study most likely give a realistic assessment of perioperative cardiac arrest.

Although events related to anesthesia may not be discovered immediately but make themselves apparent several days later, we chose a time period of 24 h following the completion of anesthesia since we were primarily interested in cardiac arrests occurring in the operating room or soon after administration of anesthesia. Most patients had a postoperative visit by an anesthesia provider within 24 h following surgery, so any problems discovered at that time would be found and added to our database. Our goal is to have all patients seen by their anesthesia provider within 48 h of anesthesia for a postanesthetic visit. In those complex cases requiring longer hospitalizations or frequent trips to the operating room, the patients may be seen on a daily basis for many days. Because of the smaller size of our institution and close working relationships with the surgeons, it is unlikely that an event such as a perioperative cardiac arrest occurring in the first 24 h of anesthesia and surgery would have failed to come to our attention, or, if so, the surgeon would fail to inform one of the anesthesia providers. Outpatients received a follow-up telephone call the day following surgery or, in cases done on Friday, the following Monday.

Information on each case was written as an abstract by one of four faculty members on the research team, and although members may have had some awareness of events surrounding certain cases, information for the abstract was obtained following a standardized data form, and the abstract was prepared in such a way that responsibility was not assigned by the member who wrote it. The fact that the Commissioners reviewed abstracts and not original data are an additional weakness of the current study. However, no member of the Study Commission had prior knowledge of any of these cases.

Fifteen cases of anesthesia-related cardiac arrest were identified from a total of 72,959 anesthetics over a 10-yr period in a tertiary care university hospital. Medication-related events, airway management, and complications related to central venous access accounted for 80% of the cardiac arrests. The risk of cardiac arrest attributable to anesthesia was 0.69 per 10,000 anesthetics (95% CI, 0.085–1.29), and the risk of anesthesia contributory to cardiac arrest was 1.37 per 10,000 anesthetics (95% CI, 0.52–2.22). Risk of death due to anesthesia-attributable perioperative cardiac arrest was 0.55 per 10,000 anesthetics (95% CI, 0.011–1.09). Our results differ by at least 10-fold from a commonly quoted study[7] reporting the risk of death from anesthesia as 1 per 185,000 anesthetics. We believe that with mandatory reporting and use of an independent Study Commission, our results more accurately reflect the risk of perioperative cardiac arrest and the real risk of anesthesia.

The Study Commission was composed of five members: Joanne Conroy, M.D., then Professor and Chair, Department of Anesthesiology and Perioperative Medicine, Medical University of South Carolina; Alden Harken, M.D., Professor and Chairman, Department of Surgery, University of Colorado Health Sciences Center; Debra J. Romberger, M.D., Associate Professor, Internal Medicine and Pulmonology, University of Nebraska Medical Center; John Tinker, M.D., Professor and Chairman, Department of Anesthesiology, University of Nebraska Medical Center; and Mark Warner, M.D., now Professor and Chairman, Department of Anesthesiology, Mayo Clinic and Mayo Medical School. The authors thank all of the members for their willingness to serve on the Study Commission. Without their time and efforts this study would not have been possible. The authors also thank Tamim Wafa, now a senior medical student, Creighton University Medical School, Omaha, NE, for his able assistance with data entry, and James R. Newland, M.D., Professor, Pathology and Laboratory Medicine, University of Nebraska College of Medicine for his critical review of the manuscript.

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