Anesthesiology 2003; 99:259–69

Predictors of Survival following Cardiac Arrest in Patients Undergoing Noncardiac Surgery

A Study of 518,294 Patients at a Tertiary Referral Center

Juraj Sprung, M.D., Ph.D.,* Mary E. Warner, M.D.,† Michael G. Contreras, M.D.,‡ Darrell R. Schroeder, M.S.,§ Christopher M. Beighley, M.S.,§ Gregory A. Wilson, C.C.R.P.,‖ David O. Warner, M.D.*

Background: **The authors determined the incidence of cardiac arrest and predictors of survival following perioperative cardiac arrest in a large population of patients at a tertiary referral center.**

Methods: **Medical records of patients who experienced cardiac arrest in the perioperative period surrounding noncardiac surgery between January 1, 1990, and December 31, 2000, were reviewed. Logistic regression identified characteristics associated with immediate (≥ 1 h) and hospital survival, with $P \leq 0.01$ considered statistically significant.**

Results: **Cardiac arrest occurred in 223 of 518,294 anesthetics (4.3 per 10,000) during the study period. Frequency of arrest for patients receiving general anesthesia decreased over time (7.8 per 10,000 during 1990–1992; 3.2 per 10,000 during 1998–2000). The frequency of arrest during regional anesthesia (1.5 per 10,000) and monitored anesthesia care (0.7 per 10,000) remained consistent. Immediate survival after arrest was 46.6%, and hospital survival was 34.5%. Twenty-four patients (0.5 per 10,000) had cardiac arrest related primarily to anesthesia. From multivariate analysis, patients who experienced arrest due to bleeding were less likely to survive hospitalization (P = 0.001). Survival was also lower for patients who experienced arrest during nonstandard working hours (P = 0.006) and for patients who had protracted hypotension before arrest (P < 0.001).**

Conclusions: **The overall frequency of arrest for patients receiving anesthesia decreased during the study period. Most arrests were not due to anesthesia-related causes, and most patients experiencing anesthesia-related arrest survived to hospital discharge. Although many factors determining survival may not be amenable to modification, the fact that arrests during nonregular working hours had worse outcomes may indicate that the availability of human resources influences survival.**

IN 1954, the first comprehensive study of anesthesia-related mortality and anesthesia-related cardiac arrests in the United States was reported.[1] Numerous subsequent studies examined perioperative cardiac arrest,[2–19] with the incidence depending on the study period reported, on how the perioperative period was defined (intraoperative only,[5,8] intraoperative and recovery from anesthesia,[15] first 24 postoperative hours,[4,18] first 2 postoperative days,[19] 7 postoperative days,[3] or 30 postoperative days)[11] and whether cardiac arrest was a direct complication of anesthesia[8,18] or whether anesthesia was just a contributing factor.[18,19] Furthermore, incidence of cardiac arrest and mortality may depend on the surgical population; some studies examine all types of surgery,[5,7,17] while others exclude cardiac surgery[12] or obstetrical surgery.[9] Many authors believe that the frequency of anesthesia-related cardiac arrest has declined over recent decades. However, trends in both the frequency of perioperative cardiac arrest and anesthesia-related mortality remain controversial, with a recent review questioning whether in fact these rates have changed over the past five decades.[19]

> This article is accompanied by an Editorial View. Please see: Lagasse RS: Apples and oranges: The fruits of labor in anesthesia care. ANESTHESIOLOGY 2003; 99:248–9.

Although much attention has rightly been focused on issues surrounding the frequency of perioperative cardiac arrest, there is relatively little information regarding factors that determine its outcome. Factors such as the American Society of Anesthesiologists physical status (ASA PS) and age have been individually examined in univariate analysis,[18,20] but most studies have insufficient numbers of cases to perform multivariate analysis that would identify independent factors predicting outcome.

The primary aim of this study was to determine, in a large population of patients undergoing noncardiac surgery at a tertiary referral center, independent risk factors for immediate (within 1 h) and in-hospital mortality following perioperative cardiac arrest. The perioperative period was defined as the time from the induction of anesthesia to postanesthesia care unit discharge or intensive care unit admission. While pursuing this objective, we also generated data regarding trends in the frequency of perioperative cardiac arrest over the 11-yr study period, from 1990 to 2000 (inclusive). In a secondary analysis, cardiac arrests were classified as being either primarily attributable to anesthesia or not, so that mortality following each could be determined.

Materials and Methods

Study Population

After Mayo Foundation Institutional Review Board approval, we ascertained all perioperative cardiac arrests

* Professor of Anesthesiology, † Associate Professor of Anesthesiology, ‡ Resident in Anesthesiology, ‖ Study Coordinator, Department of Anesthesiology, § Staff Statistician, Division of Biostatistics.

Received from the Department of Anesthesiology and Division of Biostatistics, Mayo Clinic, Rochester, Minnesota. Submitted for publication November 18, 2002. Accepted for publication March 11, 2003. Support was provided from the Department of Anesthesiology, Mayo Clinic, Rochester, Minnesota.

Address reprint requests to Dr. Sprung: Department of Anesthesiology, Mayo Clinic, 200 First Street Southwest, Rochester, Minnesota 55905. Address electronic mail to: sprung.juraj@mayo.edu. Individual article reprints may be purchased through the Journal Web site, www.anesthesiology.org.

that occurred in patients undergoing noncardiac surgery at Mayo Clinic, Rochester, Minnesota, between January 1, 1990, and December 31, 2000. Only patients who had records of anesthesia were included in this review, which included both inpatients and outpatients. The Mayo Clinic Rochester Department of Anesthesiology maintains a database of all patients who experience perioperative cardiac arrest, information that is part of the department's Performance Improvement effort. As part of this initiative, reporting of all critical incidents by anesthesia providers is mandatory. A Performance Improvement Committee, consisting of staff anesthesiologists, anesthesia chief residents, certified nurse anesthetists, and recovery room nurses meets monthly to review all incidents. One of the authors (M. E. W.) has been either the Vice-Chair or Chair of the Committee for the entire period covered by this study. For each patient who experienced cardiac arrest, the Performance Improvement Committee gathers anesthesia records, physicians' notes, laboratory findings, and description and outcome of resuscitation. As part of this process, the participants in the resuscitation are interviewed shortly after the event to ensure the completeness and accuracy of the information. To ensure that all incidents were included, we also reviewed the Mayo Clinic medical records database for patients who were coded as experiencing postoperative "death," "unexplained intensive care unit admission," or "unexpected intubation"; this review did not disclose any additional perioperative cardiac arrests or mortality not contained within the Performance Improvement database.

For the purpose of this study, we defined cardiac arrest as an event that required resuscitation with either closed-chest compressions or open cardiac massage. Only cardiac arrests that occurred after anesthesia had been initiated were included (course of regional block, induction agent for general anesthesia given, or sedation prior to local anesthetic infiltration given). We included also cardiac arrests that occurred during transport to the recovery room or intensive care unit and during recovery room stay. Cardiac arrests that happened after the anesthesiologist transferred care of the patient to the intensive care unit personnel were not counted. No case was counted if the anesthesia team became involved only during resuscitation efforts. Cardiac arrests that occurred during cardiac surgery as well as during cardiac catheterization or cardioversion, even if the anesthesia team was involved in patient care, were not included. The numbers of anesthesia cases (and numbers of specific types of anesthesia) were extracted from the Mayo Clinic anesthesia database, and these numbers were used as denominators for calculation of incidence of cardiac arrest both for the entire study period and for each year.

For all the patients who were identified of having a cardiac arrest, we reviewed their Mayo Clinic medical records in addition to the Performance Committee report. To assess interrater reliability, three individual reviewers (J. S., M. G. C., and G. A. W.) collected data from the first 10 charts and confirmed uniformity of data extraction. The rest of medical records were reviewed by two authors (M. G. C. and G. A. W.). All unclear data entries from the source records were left open, and the final judgment of its significance was made by consensus with other authors.

The two main outcome variables were survival at least 1 h after initial resuscitation (immediate survival [IS]) and survival to discharge from the hospital (hospital survival [HS]).

Factors Analyzed

We studied several potential predictors of mortality following cardiac arrest. Patient-related factors included age, sex, ASA PS score (for the purpose of this analysis we grouped patients by ASA PS scores I–III or IV–V). Primary comorbid conditions were defined by the diagnostic criteria described by Hosking *et al.*[21] These criteria have been used repeatedly for epidemiologic studies conducted in our department.[22] Diagnostic categories analyzed included cardiovascular disease, hypertension, end-stage organ failure, systemic disease, infectious disease or sepsis, cerebrovascular disease, and diabetes mellitus.

Another set of factors concerned variables related to the surgical procedure and probable cause of arrest. Surgical procedures were grouped into three categories according to a subjective assessment of the level of surgical insult and associated risk for poor outcome: (1) general, orthopedic, neurosurgical, and urologic procedures; (2) vascular, thoracic, and trauma procedures; and (3) transplant surgery (liver, kidney, and pancreas). Although the level of surgical stress in these three types of transplant procedures may vary, all have altered homeostatic mechanisms, and therefore, for the purposes of this study, we considered them a special category. The urgency of surgery was defined by the ASA PS designation of "emergency" by anesthesia providers. The probable cause of arrest was in most instances determined a short time after the event by the Performance Improvement Committee and noted in their report. In cases when the cause was not clear from these records, the authors reexamined the original medical records and made a consensual decision. For the purpose of this analysis, we grouped all probable causes into three categories: (1) primary bleeding (intraoperative hemorrhage regardless of etiology, such as that resulting from coagulopathy, trauma, surgical, or ruptured vessels); (2) primary cardiac causes (including myocardial infarction, high-degree blocks, or dysrhythmias due to any etiology, such as electrolyte abnormalities, placement of pacemaker wires, and medication-related asystole); and (3) "other causes," including pulmonary embolic events (thromboembolism, air, fat, or carbon dioxide embolism), anaphylactic or other drug reactions, and hypoxia (*e.g.*, primary pulmonary pathology, postextubation hypoxia or respiratory depression, upper airway obstruction, and unrecognized tracheal extubation). The primary electrocardiographic rhythm recorded (asystole, ventricular fibrillation, or pulseless electrical activity) was noted. If several rhythms were present, for the purpose of this analysis, we used only the first one recorded. The duration of surgery at the time of arrest (< 1.0, 1.0–1.9, 2.0–2.9, and ≥ 3.0 h) was also determined. Other factors analyzed included the patient's hemodynamic stability before arrest (defined as the need for infusion of vasopressors before arrest), the occurrence of more than a 10-min period of tachycardia (> 120 beats/min), and hypotension (systolic blood pressure < 80 mmHg), or hypertension (systolic blood pressure > 160 mmHg) that preceded the arrest.

A final set of factors examined anesthesia-related parameters. At Mayo Clinic Rochester, consultant physicians supervise anesthesia providers. The primary anesthesia provider at the time of cardiac arrest was noted as being a resident, certified registered nurse anesthetist, or student nurse anesthetist. The type of anesthesia was recorded as the primary type of anesthetic being used at the time of arrest: general, regional (all types of peripheral regional blocks or neuraxial anesthesia), or monitored anesthesia care (MAC). If the patient received a combined general and regional technique, we considered that arrest occurred during general anesthesia. The type of invasive monitoring present at the time of arrest (arterial line, central venous pressure monitor, or pulmonary artery catheter) was also noted. Finally, arrests were classified as occurring during anesthesia induction, during maintenance of anesthesia, or during emergence and recovery from anesthesia. The time of arrest was also noted as occurring during regular working hours (07:00–20:00, Monday through Friday) or during the night (20:01–06:59, Monday through Friday) and weekends (Friday 20:01 through Monday 06:59). The rationale for this time division is that in our practice, the call team takes over call duty at 20:01 (Monday through Friday), such that in general, the number of personnel available to respond to cardiac arrest is reduced.

As a secondary, separate analysis, cardiac arrests that could be attributed primarily to anesthesia management were identified according to the judgment of the Performance Improvement Committee, as confirmed by the consensus of two authors (J. S. and D. O. W.). Unstable patients (*e.g.*, those with bleeding aortic aneurysm) whose arrest occurred after an anesthetic induction agent was given were not considered as having had primarily an anesthesia-attributable cardiac arrest (regardless of fact that anesthesia may have contributed). Any cardiac arrest that occurred after an anesthetic drug (*e.g.*, narcotic, muscle relaxant, induction agent) was given to a stable patient who had either immediate arrest or depression of ventilation leading to hypoxemic cardiac arrest was considered as primarily attributable to anesthesia. All obvious mishaps in airway management (*e.g.*, inability to intubate the trachea, unrecognized accidental extubation, and lost airway during tracheotomy) were also considered as primarily attributable to anesthesia.

Statistical Analysis

The frequency of cardiac arrest was calculated for each year during the study period, both overall and by type of anesthesia (general, regional, or MAC). Logistic regression was used to determine characteristics associated with IS (≥ 1 h) and HS for patients who experienced cardiac arrest during anesthesia. For these analyses, patient age and duration of surgery were treated as continuous variables, and all other characteristics were treated as categorical variables. Separate analyses were performed for IS and HS outcomes. For each characteristic, a simple logistic regression model was used to assess the univariate association of the given characteristic with the survival outcome. Because of the large number of characteristics assessed as potential predictors, only P values less than or equal to 0.01 were considered statistically significant to reduce the likelihood of type I error. Multiple logistic regression with stepwise backward elimination of nonsignificant variables was then used to identify a set of independent predictors of survival. Because the attribution of arrest to anesthesia-related causes (a secondary analysis in our study) is to some degree open to interpretation, it was not included as a factor in this analysis. To reduce the number of characteristics included in the multivariate analyses, only those found to have some evidence ($P < 0.05$) of a univariate association with either IS or HS were included in the initial multiple logistic regression model. The multivariate analysis was also performed by using a stepwise forward approach to assess consistency of the variable selection procedure. All analyses were performed with use of SAS Software Release 8.2 (SAS Institute Inc., Cary, NC).

Results

Incidence of Cardiac Arrest

Between January 1, 1990, and December 31, 2000, a total of 518,294 anesthetics were administered to patients undergoing noncardiac surgical procedures at Mayo Clinic, Rochester, Minnesota. A total of 223 patients experienced cardiac arrest during the interval between the start of anesthesia (induction of general anesthesia or initiation of sedation or regional block) and the time the patient was discharged from the recovery room or the patient's care was transferred to the intensive care unit personnel. The overall incidence of cardiac arrest

Table 1. Frequency of Cardiac Arrest during Anesthesia by Calendar Year and Type of Anesthesia

	Type of Anesthesia											
	General			Regional			MAC			Total		
Year	Anesthetics, No.	Arrests, No.	Arrests per 10,000 Anesthetics	Anesthetics, No.	Arrests, No.	Arrests per 10,000 Anesthetics	Anesthetics, No.	Arrests, No.	Arrests per 10,000 Anesthetics	Anesthetics, No.	Arrests, No.	Arrests per 10,000 Anesthetics
1990	31,126	20	6.4	6,145	1	1.6	6,149	1	1.6	43,420	22	5.1
1991	30,500	32	10.5	6,834	2	2.9	6,305	0	0.0	43,639	34	7.8
1992	31,866	21	6.6	6,387	2	3.1	6,662	0	0.0	44,915	23	5.1
1993	32,326	29	9.0	6,744	1	1.5	6,813	0	0.0	45,883	30	6.5
1994	32,853	20	6.1	6,496	0	0.0	5,354	1	1.9	44,703	21	4.7
1995	33,665	20	5.9	6,662	0	0.0	5,696	1	1.8	46,023	21	4.6
1996	33,915	15	4.4	6,327	2	3.2	6,194	1	1.6	46,436	18	3.9
1997	35,742	13	3.6	6,788	1	1.5	6,610	0	0.0	49,140	14	2.8
1998	36,680	8	2.2	6,382	2	3.1	7,120	0	0.0	50,182	10	2.0
1999	37,936	16	4.2	6,410	0	0.0	6,990	1	1.4	51,336	17	3.3
2000	39,473	13	3.3	6,641	0	0.0	6,503	0	0.0	52,617	13	2.5
Total	376,082	207	5.5	71,816	11	1.5	70,396	5	0.7	518,294	223	4.3

MAC = monitored anesthesia care.

was thus 4.3 per 10,000 anesthetics. The incidence of cardiac arrest for patients receiving general anesthesia decreased over the 11-yr study period from a rate of 7.8 per 10,000 anesthetics during the first 3 yr (1990–1992) to a rate of 3.2 per 10,000 anesthetics during the final 3 yr (1998–2000) (table 1 and fig. 1). The incidence of cardiac arrest for patients receiving regional anesthesia and MAC remained low and relatively consistent over the study period; the overall frequency was 1.5 per 10,000 anesthetics for patients receiving regional anesthesia and 0.7 per 10,000 for patients receiving MAC. In addition to external cardiac massage (in all patients), resuscitation efforts included the use of epinephrine in 186 patients (83.4%), atropine in 122 patients (54.7%), and defibrillation in 91 patients (40.8%).

Twenty-four cardiac arrests were determined to be attributable to anesthesia (0.5 per 10,000 anesthetics; table 2). These arrests could be classified into two main categories: (1) medication-related (13 patients [54.2%]); and (2) airway/ventilation-related (11 patients [45.8%]). In the latter category, five had cardiac arrest related to loss of airway patency, and six had arrest due to inadequate ventilation (residual neuromuscular blockade, oversedation, premature tracheal extubation, high spinal anesthetic). Nine (37.5%) arrests were related to the use of neuromuscular blocking agents. Regarding the latter, arrest occurred after the administration of drugs to reverse neuromuscular blockade in six patients (25%) and as a consequence of hypoxia secondary to inadequate reversal of neuromuscular blockade in three patients (12.5%).

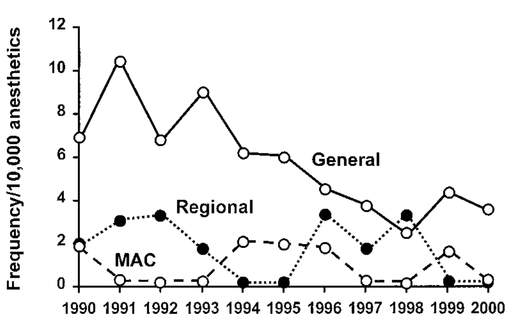

Fig. 1. Frequency of cardiac arrests by calendar year and type of anesthesia. MAC = monitored anesthesia care.

Univariate Analysis of Factors Associated with Survival after Arrest

The median age of the 223 patients (130 male, 93 female) who experienced perioperative cardiac arrest was 66 yr (range, 1–98 yr). Eight patients (3.6%) were younger than 18 yr, and 6 patients (2.7%) were older than 85 yr. Of the 223 patients, 104 (46.6%) survived at least 1 h (IS), and 77 (34.5%) survived to hospital discharge (HS). The percentage of patients who survived (both IS and HS) after perioperative cardiac arrest did not change significantly over the study period.

A considerable proportion of patients (43.5%) who experienced perioperative cardiac arrest were classified as ASA PS IV or V (table 3). Survival was significantly better for patients with ASA PS classification of III or lower (46%) compared with those with ASA PS classification of IV or higher (20%). Figure 2 illustrates distribution of IS and HS in regard to the patients' ASA PS. The majority (75%) of ASA PS I patients survived immediate resuscitation, and immediate survivors were discharged home. With increased ASA PS both IS and HS drastically decreased; only 11.8% of ASA PS V patients survived immediate resuscitation, although all these immediate survivors left the hospital.

Of the 223 patients who experienced perioperative cardiac arrest, 98 (43.9%) had undergone emergency procedures, and 207 (92.8%) had received general anesthesia (table 4). Patients who experienced cardiac

Table 2. Cardiac Arrests Attributed to Anesthesia (Listed According to the Timing of Arrest)

Age, yr	ASA PS Class	Arrest Type	Resuscitation Time, min	Probable Cause of Arrest	Hospital Survival
Arrests during anesthetic induction (25%)					
74	2	Asystole	1	Succinylcholine given just before arrest*	Yes
78	4E	Asystole	1	Unable to intubate trachea (hypoxia)	Yes
7	2	Asystole	3	Mivacurium given just before arrest*	Yes
70	3	Asystole	5	Nitroprusside given just before arrest for hypertension*	Yes
70	3	PEA	5	Thiopental given just before arrest*	Yes
67	3	VF	5	Thiopental given just before arrest*	Yes
Arrests during anesthetic course (20.8%)					
42	1	Asystole	3	Propofol given just before arrest*	Yes
62	3	Asystole	60	Accidental tracheal extubation in prone position (hypoxia)	No
72	3	Asystole	5	Fentanyl given just before arrest (vagal?)*	Yes
71	3	VF	30	Tracheostomy tube misplaced into false passage (hypoxia)	No
81	3	Asystole	5	Oversedation vs. high neuraxial block (3% chloroprocaine, 28 ml; midazolam, 6 mg; fentanyl, 100 μg for hemorrhoidectomy) (hypoxia)	Yes
Arrests during emergence (33.3%)					
70	2	Asystole	5	Neuromuscular reversal agents given just before arrest*	Yes
65	3	Asystole	2	Neuromuscular reversal agents given just before arrest*	Yes
83	4E	VF	10	Neuromuscular reversal agents given just before arrest*	Yes
61	3	Asystole	10	Neuromuscular reversal agents given just before arrest*	Yes
30	3	Asystole	5	Inadequate reversal of neuromuscular blockade (hypoxia)	Yes
66	2	Asystole	5	Inadequate reversal of neuromuscular blockade (hypoxia)	Yes
66	2	Asystole	10	Neuromuscular reversal agents given just before arrest*	Yes
60	3	Asystole	3	Neuromuscular reversal agents given just before arrest*	Yes
Arrests during postoperative transport (12.5%)					
31	3	Asystole	5	Respiratory distress after tracheal extubation; cause not specified (hypoxia)	Yes
41	3	Asystole	15	Inadequate reversal of muscle relaxants (hypoxia)	No
85	3	Asystole	5	Respiratory distress; premature tracheal extubation (hypoxia)	Yes
Arrests in recovery room (8.3%)					
81	3	Asystole	35	Oral bleeding, unable to intubate trachea (hypoxia), tracheostomy performed	No
67	3	Asystole	20	Respiratory arrest; unable to reintubate trachea promptly, difficult tracheal intubation (hypoxia)	No

* Patients were hemodynamically stable before receiving respective medication.

ASA PS = American Society of Anesthesiologists physical status; E = emergency status; PEA = pulseless electrical activity; VF = ventricular fibrillation; % = percentage of cardiac arrest occurrences in respect to perioperative time.

arrest during an elective procedure were significantly more likely to survive than those undergoing an emergency procedure. HS was less likely for patients with diabetes mellitus and for patients with end-stage organ failure (table 3). Other characteristics found to be associated with mortality in univariate analysis included the use of vasopressors before arrest; protracted hypotension before arrest; use of an arterial line, central venous pressure monitor, or pulmonary artery catheter for monitoring; duration of surgery; and type of surgery (table 4).

Of the 223 cardiac arrests, 78 (35.0%) were judged to be related to bleeding, 98 (43.9%) were related to cardiac causes, and 47 (21.1%) were attributable to other causes (table 5). Both HS and IS were significantly determined by the cause of the arrest, with hemorrhage associated with the poorest outcome. There were 168 (75.3%) cardiac arrests that occurred during standard working hours and 53 (24.7%) arrests that occurred during nights or weekends. The likelihood of survival was better for patients who experienced cardiac arrest during standard working hours *versus* nonstandard working hours. IS (but not HS) was associated with the phase of anesthesia during which the cardiac arrest occurred, tending to be higher when arrest occurred during induction or emergence than during the course of anesthesia. The likelihood of HS was associated with the primary electrocardiographic rhythm recorded and with the primary provider at the time of arrest (table 5).

In a separate analysis, survival was determined according to whether arrest was judged to be primarily attributable to anesthesia. Anesthesia-attributed cardiac arrests were associated with improved survival. Nineteen of the 24 patients (79.2%) whose cardiac arrests were attributable to anesthesia promptly responded to resuscitation efforts and survived to hospital discharge (table 2), whereas only 58 of 199 (29.1%) who experienced arrest not related to anesthesia survived. The in-hospital mortality attributable to anesthesia-related cardiac arrest was 0.1 (0.096) per 10,000 (or 1 patient per 100,000 anesthetics). Cardiac arrests related to a loss of airway patency had a poor outcome (table 2). Of note, no patient experiencing anesthesia-attributable cardiac arrest and resuscitation duration over 20 min survived; all of these patients had lost airway patency.

Table 3. Preoperative Patient Characteristics Assessed as Potential Predictors of Survival after Cardiac Arrest during Anesthesia

		Immediate Survival		Hospital Survival	
Characteristic	Patients, No.*	%	*P*†	%	*P*†
Age (yr)			0.11		0.06
≤ 50	48	52.1		41.7	
51–60	39	43.6		28.2	
61–70	59	50.8		37.3	
≥ 71	77	41.6		31.2	
Sex			0.86		0.98
Male	130	46.1		34.6	
Female	93	47.3		34.4	
ASA PS class			< 0.001		< 0.001
I–III	126	60.0		46.0	
IV, V	97	29.0		20.0	
Cardiovascular disease			0.54		0.76
No	73	45.2		34.2	
Yes	143	49.6		36.4	
Hypertension			0.06		0.23
No	119	42.0		31.9	
Yes	98	55.1		39.8	
End-stage organ failure‡			0.24		0.02
No	170	48.8		38.8	
Yes	53	39.6		20.7	
Systemic disease			0.15		0.53
No	163	50.9		36.8	
Yes	53	39.6		32.1	
Infectious disease or sepsis			0.41		0.47
No	198	49.0		36.4	
Yes	18	38.9		27.8	
Cerebrovascular disease			0.26		0.44
No	177	46.3		34.5	
Yes	39	56.4		41.0	
Diabetes mellitus			0.12		0.03
No	181	50.3		38.7	
Yes	36	36.1		19.4	

* Because of missing data, the numbers of patients within categories of a given characteristic may not sum to 223. † *P* values from logistic regression assessing the univariate association of the given characteristic with immediate (≥ 1 h) and hospital survival. For this analysis, age was treated as a continuous variable, and all other characteristics were treated as classification variables using the categories indicated. ‡ Renal, hepatic, or respiratory.

ASA PS = American Society of Anesthesiologists physical status.

Multivariate Analysis of Factors Associated with Survival after Arrest

Multivariate analysis performed by both backward elimination of nonsignificant variables and by a stepwise forward selection procedure identified the same set of final multivariate outcome predictors (table 6). The attribution of arrest to anesthesia (a secondary analysis in our study) was not included as a factor in this analysis. Patients who experienced arrest due to cardiac and other causes were more likely to survive than those who experienced cardiac arrest due to hemorrhage. The likelihood of survival was increased for patients who experienced cardiac arrest during standard working hours compared with nights and weekends and decreased for patients who experienced prolonged hypotension before arrest. Finally, HS, but not IS, was significantly less likely for diabetic patients who experienced cardiac arrest. Other factors significant in univariate analysis were not independent predictors in this multivariate analysis.

Discussion

Incidence of Perioperative Cardiac Arrest

In this study, we examined the frequency and outcome of perioperative and immediate postoperative cardiac arrests in 518,294 patients who underwent noncardiac surgery between 1990 and 2000 at Mayo Clinic Rochester. The overall frequency of cardiac

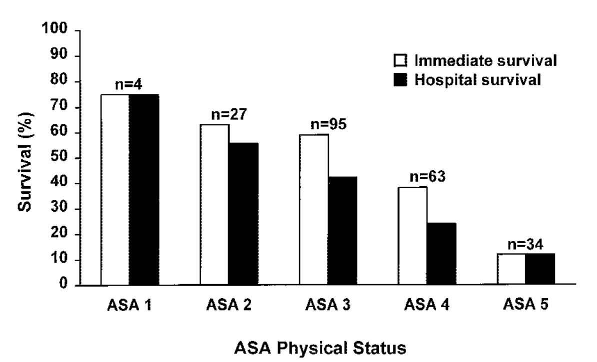

Fig. 2. Immediate and hospital survival as a function of American Society of Anesthesiologists (ASA) physical status score.

Table 4. Procedural Characteristics Assessed as Potential Predictors of Survival after Cardiac Arrest during Anesthesia

		Immediate Survival		Hospital Survival	
Characteristic	Patients, No.*	%	*P*†	%	*P*†
Type of surgery			0.11		0.01
General, orthopedic, neurosurgical, urologic, other	117	54.7		46.2	
Vascular, thoracic, trauma	80	38.8		22.5	
Transplant	26	34.6		19.2	
Urgency			< 0.001		< 0.001
Elective	125	59.2		46.4	
Emergency	98	30.6		19.4	
Type of anesthesia			0.19		0.07
Regional or MAC	16	63.0		56.0	
General	207	45.4		32.8	
Intubated before arrest			0.17		0.08
No	31	58.1		48.4	
Yes	192	44.8		32.3	
Duration of surgery (h)			0.27		0.03
< 1.0	61	62.3		52.5	
1.0–1.9	42	35.7		33.3	
2.0–2.9	26	34.6		26.9	
≥ 3.0	94	44.7		25.5	
Use of vasopressors			< 0.001		< 0.001
No	150	55.3		44.7	
Yes	73	28.8		13.7	
Documented hypotension			< 0.001		< 0.001
No	99	69.7		55.6	
Yes	124	28.2		17.7	
Documented hypertension			0.41		0.93
No	211	46.0		34.6	
Yes	12	58.3		33.3	
Documented tachycardia			0.43		0.12
No	195	45.6		36.4	
Yes	28	53.6		21.4	
Use of arterial line			< 0.001		< 0.001
No	52	73.1		61.5	
Yes	170	38.8		26.5	
Use of CVP monitor			< 0.001		< 0.001
No	113	62.8		51.3	
Yes	109	30.3		17.4	
Use of pulmonary artery catheter			0.002		<0.001
No	157	53.5		42.7	
Yes	65	30.8		15.4	

* Because of missing data, the numbers of patients within categories of a given characteristic may not sum to 223. † *P* values from logistic regression assessing the univariate association of the given characteristic with immediate ≥ 1 h and hospital survival. For this analysis, duration of surgery was treated as a continuous variable, and all other characteristics were treated as classification variables using the categories indicated.

MAC = monitored anesthesia care; CVP = central venous pressure.

arrest was 4.3 per 10,000 anesthetics. The frequency of cardiac arrest was higher during general anesthesia (5.5 per 10,000) than during regional anesthesia (1.5 per 10,000) or MAC (0.7 per 10,000). Aubas *et al.*[23] suggested that the incidence of cardiac arrest is higher during general anesthesia; however, this may be related to the fact that many high-risk surgeries are performed under general anesthesia. In our study, only 11 arrests occurred in the patients receiving neuraxial anesthesia, and this small number precluded meaningful comparisons with the general anesthesia group. The most comprehensive recent survey of the incidence of cardiac arrest during spinal anesthesia reported 2.7 cardiac arrests per 10,000 spinal anesthetics,[24] which is lower than in the same authors' earlier study[25] (6.4 per 10,000 spinal anesthetics) but still higher compared to the current study.

The reported incidence of perioperative cardiac arrests has varied during the past several decades, ranging between 4.6 and 19.7 per 10,000 anesthetics.[5,7,9,12,17,18] The most recent study[18] reported a relatively high incidence of perioperative cardiac arrests, 19.7 per 10,000 anesthetics. However, this study included cardiac surgery, which contributed a high number of arrests, and examined all arrests occurring within 24 h of surgery. In our study, the incidence of cardiac arrest decreased over the duration of the study period from 7.8 per 10,000 (1990–1992) to 3.2 per 10,000 (1992–2000), with the lowest annual incidence of 2.5 per 10,000 in year 2000

Table 5. Timing and Etiologic Characteristics Assessed as Potential Predictors of Survival after Cardiac Arrest during Anesthesia

Characteristic	Patients, No.*	Immediate Survival %	Immediate Survival *P*†	Hospital Survival %	Hospital Survival *P*†
Probable cause of arrest			< 0.001		< 0.001
Bleeding	78	18.0		10.3	
Cardiac	98	57.1		42.9	
Other	47	72.3		57.5	
Time of arrest			< 0.001		< 0.001
Standard working hours‡	168	54.2		42.3	
Nonstandard working hours	53	24.5		11.3	
Primary provider at time of arrest			0.26		0.04
Resident	55	43.6		34.5	
Certified registered nurse anesthetist	144	45.1		30.6	
Student nurse anesthetist	24	62.5		58.3	
Primary electrocardiographic rhythm recorded			0.06		0.02
Asystole	93	52.7		43.0	
Ventricular fibrillation	79	39.2		24.0	
Pulseless electrical activity	32	31.2		25.0	
Phase of anesthesia at time of arrest			0.03		0.10
Induction	26	65.4		50.0	
Anesthetic course	172	41.9		30.8	
Emergence or transport to recovery room	25	60.0		44.0	

* Because of missing data, the numbers of patients within categories of a given characteristic may not sum to 223. † *P* values from logistic regression assessing the univariate association of the given characteristic with immediate ≥ 1 h and hospital survival. For this analysis, all characteristics were treated as classification variables using the categories indicated. ‡ Standard working hours were 07:00–20:00, Monday through Friday.

(table 1, fig. 1). Such trends should be interpreted with caution due to possible changes in factors such as patient comorbidity and surgical acuity over time, although like many other centers, our practice data suggest that our patients are in fact becoming progressively older and sicker. Subject to this proviso, and considering that our data were obtained using a consistent methodology in a single center, the decrease in the frequency of perioperative cardiac arrest may imply a significant improvement in patient care over this period. Factors responsible for this trend cannot be identified from our data. Olsson and Hallen[12] also reported a declining incidence of cardiac arrest over time (1967–1984) in a single center study.

Table 6. Multivariate Analysis of Characteristics Potentially Associated with Survival following Cardiac Arrest during Noncardiac Surgery*

Characteristics	Immediate Survival OR	Immediate Survival 95% CI	Immediate Survival *P*	Hospital Survival OR	Hospital Survival 95% CI	Hospital Survival *P*
Probable cause of arrest			< 0.001			0.001
Bleeding	1.0	—		1.0	—	
Cardiac	3.6	1.6–8.2		4.8	1.7–13.2	
Other	8.4	3.1–22.9		7.8	2.5–24.2	
Time of arrest			0.006			0.006
Standard working hours†	3.3	1.4–7.7		4.4	1.5–12.8	
Nonstandard working hours	1.0	—		1.0	—	
Documented hypotension			< 0.001			< 0.001
No	1.0	—		1.0	—	
Yes	0.3	0.2–0.6		0.3	0.1–0.6	
Diabetes mellitus			—			0.008
No	—	—		1.0	—	
Yes	—	—		0.2	0.1–0.7	

* Multiple logistic regression with stepwise backward elimination of nonsignificant variables was used to identify a set of independent predictors of survival. Only characteristics found to have some evidence ($P < 0.05$) of a univariate association with either immediate or hospital survival (tables 3–5) were included in the multivariate analysis. After elimination of nonsignificant variables, probable cause of arrest, time of arrest, and documented hypotension before arrest were found to be independently associated with immediate survival. When the analysis was performed with hospital survival as the dependent variable, probable cause of arrest, time of arrest, documented hypotension before arrest, and diabetes mellitus were found to be independently associated with hospital survival. The results of the final multivariate models are presented using odds ratios (OR), which were calculated on the basis of the parameter coefficients from the logistic regression analysis. † Standard working hours were 07:00–20:00, Monday through Friday.

CI = confidence interval.

The attribution of cardiac arrest to primarily anesthesia causes was performed as a secondary analysis, because this was not a primary aim of our study and because it is difficult to objectively determine the cause of arrest in many cases. As rightly pointed out by several authors,[18,19,26] adverse events often are the culmination of a variety of different factors, one of which may include anesthesia interventions (or lack thereof). In defining cardiac arrests as primarily attributable to anesthesia, we did not follow more stringent methods followed by some authors[18,19] involving specific study-related review committees and other measures. However, recognizing this limitation, one interesting feature regarding the etiology of anesthesia-attributed arrest deserves comment. Approximately 21% of cardiac arrests were caused by airway misadventures, whereas 54% were attributed to medication-related events. Specifically, the single largest etiologic category was associated with the use of neuromuscular blocking drugs, either apparently drug-induced asystole associated with by the reversal of neuromuscular blockade or hypoxia caused by inadequate postoperative reversal of block. This contrasts with other studies of anesthesia-related arrest,[12,14,15,18] which found that although medication-related events were relatively common, events related specifically to neuromuscular blocking drugs were not. We cannot explain this difference, but this finding may suggest that practice-specific factors may be important determinants of primarily anesthesia-attributed cardiac arrest. As an interesting historical note, Beecher and Todd[1] also noted an association between the use of neuromuscular blocking drugs and anesthesia-related morbidity.

Over the past several decades, the rate of cardiac arrests due to anesthesia-related factors may be declining, although comparisons among studies are complicated by differing surgical populations, definitions of cardiac arrest, and definitions of what is "anesthesia-related."[19] Keenan and Boyan[8,13] found a significant decrease in the frequency of cardiac arrests associated with anesthesia over time from 2.1 per 10,000 anesthetics (1969–1978) to 1.0 per 10,000 anesthetics (1979–1988). A report from France recorded 1.1 anesthesia-related cardiac arrests per 10,000.[27] In the study of Newland *et al.*,[18] the rate of anesthesia-related cardiac arrests for all surgeries (including cardiac) was 2.06 per 10,000 anesthetics. When analysis was limited to those cases "definitely attributable to anesthesia," the rate was 0.69 per 10,000 anesthetics.[18] In the current study, the incidence of arrest primarily attributed to anesthesia was 0.5 per 10,000 anesthetics. Cardiac arrests primarily attributable to anesthesia represented 10.8% of all cardiac arrests that occurred perioperatively after noncardiac surgery in our study, which is similar to the finding of Newland *et al.*[18] (10.4%).

Factors Associated with Survival after Perioperative Cardiac Arrest

In this study, HS after perioperative cardiac arrest was 34.5%, which is higher than the average survival after cardiac arrest for a miscellaneous in-hospital patient population (23%).[28] HS following perioperative cardiac arrest in the current study is similar to that reported by Girardi and Barie[29] (38%) during noncardiothoracic surgery between 1986 and 1994. The overall mortality caused by perioperative cardiac arrest, which depends both on the frequency of arrest and survival, has been reported at between 3.5 and 2.4 per 10,000 anesthetics[7,12]; our value was similar (2.8 per 10,000).

Several factors were associated with survival after cardiac arrest in univariate analysis, but only a few of these were significant independent predictors of survival in multivariate analysis. Here, we concentrate on these independent predictors and selected other factors that have figured prominently in prior reports of perioperative cardiac arrest.

In prior studies, higher ASA PS scores and urgent surgical procedures were predictors of both a higher incidence of arrest and a poor outcome.[3,12,15,18,20,27] Our study was not designed to calculate the frequency of arrest according to ASA PS scores. However, in our study, only 4 ASA PS I patients experienced cardiac arrest, compared to 97 patients with an ASA PS of IV or V, suggesting that increased ASA PS score was associated with an increased frequency of arrest. In the current study, patients with higher ASA PS scores had increased mortality in univariate analysis, but in multivariate analysis, ASA PS score was not a significant independent risk factor for mortality. Thus, it appears that a combination of other factors associated with high ASA PS better predicts mortality (as discussed below).

The current study did not demonstrate an association between survival after cardiac arrest and patient age. In a study of age-related perioperative morbidity and mortality, Morita *et al.*[30] found a high incidence of both cardiac arrest and mortality in children younger than 1 month (incidence, 54.2 per 10,000; mortality, 43.0 per 10,000). In other age groups, the incidence was between 2.6 and 11.0 per 10,000 anesthetics, and mortality was between 1.7 and 6.6 per 10,000 anesthetics. Marx *et al.*[3] also found poor outcome of cardiac arrest in infants and elderly patients. Morray *et al.*[15] reviewed 289 cardiac arrests from the Pediatric Perioperative Cardiac Arrest Registry and determined that age younger than 1 yr was a predictor of poor outcome. Compared with a pediatric hospital, our institution has a relatively low volume of pediatric surgical patients, and only a few of our young patients experienced cardiac arrest. Thus, given the small number of arrests in this age group, it may not be possible to meaningfully evaluate younger age as a risk factor using our data. At the other end of the age spectrum, Olsson and Hallen[12] found that the incidence of cardiac arrest in patients older than 80 yr was 12.4 per 10,000 anesthetics, which was more than four times higher than the incidence in the 30- to 39-yr age group (2.6 per 10,000). We do not have an explanation for why the overall outcome in our elderly population was not different from that of the other age groups.

In both univariate and multivariate analysis, survival depended on the cause of arrest. Only 10.3% of patients with hemorrhagic cardiac arrest survived to hospital discharge, a rate consistent with prior studies.[17,29] When the cause of cardiac arrest was hemorrhage, patients had much lower rates of successful resuscitation than those who had arrest from any other cause (table 6). The presence of hypotension prior to arrest was also a significant independent predictor of mortality in multivariate analysis, with low survival among patients who were hemodynamically unstable before arrest. In patients who required continuous intraoperative infusion of vasopressors before arrest, the IS and HS were 28.8% and 13.7%, respectively. Furthermore, when protracted hypotension existed before arrest (systolic blood pressure < 80 mmHg for more than 10 min), IS was 28.2%, and HS was 17.7%. Both of these factors may reflect a severity of acute disease or surgical trespass that simply was not repairable. We found that patients who had cardiac arrest during regular working hours had better survival. Only 11.3% of patients (6 of 53) whose arrests occurred during nonregular working hours (including weekends) survived to hospital discharge. This effect remained significant in multivariate analysis, which included consideration of factors such as the urgency of surgery. Newland *et al.*[18] found with univariate analysis that cardiac arrest was more frequent during "evening–night" hours (15:00–07:00). In our earlier study on outcome after in-hospital resuscitation, we found that cardiopulmonary resuscitation during nonregular working hours had lower survival rates, which was, among other factors, attributed to disproportionately higher incidence of nonwitnessed cardiac arrests during the night (00:01–06:00), especially in unmonitored hospital beds.[28] In the current study, all perioperative cardiac arrests during nonregular working hours were witnessed. Therefore, if this criterion is an independent predictor of survival, no difference in outcome would be expected between regular and nonregular working hours for perioperative cardiac arrests; however, this was not the case. We speculate that better survival after cardiac arrest may be attributed to more a more comprehensive response during regular working hours. Specifically, this response during regular working hours is characterized at our institution by involvement of numerous anesthesia personnel, and the response team has immediate access to surgical resources that may not be available during the night and on weekends. This assumption needs to be validated in a future study.

The only patient comorbid condition associated with hospital mortality in multivariate analysis was the presence of diabetes mellitus. The end-organ dysfunction associated with this condition may explain this finding, although it is interesting that the other equally serious comorbid conditions examined were not associated with survival.

In a separate secondary analysis, we found that the outcome in patients whose cardiac arrest was attributable primarily to anesthesia was much better, with an HS of 79.2%. In contrast, Newland *et al.*[18] reported 80% mortality after anesthesia attributable cardiac arrest (4 of 5 died), while the mortality in their anesthesia-contributory group was 30% (3 of 10 died). Interestingly, although in-hospital asystolic cardiac arrests are generally associated with a poor prognosis,[28] asystole was, in current study, the most common rhythm associated with anesthesia-attributed arrests (83% of patients) and was associated with a relatively good prognosis (16 of these 20 patients survived until hospital discharge). This likely reflects that asystole attributable primarily to anesthesia in our series was associated with causes that were readily reversible (table 2), compared with the causes of asystole in a general hospital population.

Anesthesia-related Mortality

To this point, our discussion has concentrated on the frequency of perioperative cardiac arrest from all causes and outcome following this event. Although not a primary aim of our study, it is also of interest to examine overall perioperative mortality related to anesthesia, a related but separate issue (*e.g.*, studies of perioperative mortality alone do not include patients successfully resuscitated from cardiac arrest). In our secondary analysis, in-hospital mortality caused by cardiac arrest attributed to anesthesia was approximately 1 per 100,000 anesthetics, which is similar to prior reports.[11,31,31] The assumption by many in the anesthesia community that anesthesia-related mortality has declined over recent decades has recently been reviewed and challenged by Lagasse.[19] Indeed, the two most recent studies of anesthesia-attributable mortality each found somewhat higher rates (0.55 [within 24 h][18] and 0.75 and 0.79 [within 48 h][19] per 10,000) than ours, but direct comparisons to our study should be made with caution (*e.g.*, cardiac surgery, included in the report of Newland *et al.*,[18] was not included in the current study). Our study was not designed to address the question of trends in anesthesia-related mortality, and the relatively low annual rate makes it impossible to analyze trends over our study period.

Limitations

As with all retrospective studies, there are limitations that need to be considered when interpreting the findings. Although risk factors for the current study were collected using formal definitions and a standardized data collection form, the completeness and accuracy of these data are limited by the amount of documentation available in the medical record. Also, the statistical power for assessing the association of a given risk factor with survival following cardiac arrest is dependent on the prevalence of the given risk factor among patients who experienced arrest. Therefore, nonsignificant findings should be interpreted with caution when the number of patients with or without the given risk factor is relatively small (*e.g.*, regional/MAC *vs.* general anesthesia).

In any study of perioperative mortality, it is important to appreciate limitations regarding the applicability of results to other settings. Our institution is a national tertiary referral center that provides comprehensive care to all ages. However, approximately 90% of patients come from within 500 miles, and the majority of these patients receive their primary care at our institution. Although single-center studies such as ours have the advantage of consistent data collection, there may be differences in our practice compared with other institutions that may affect these results. For example, the high frequency of arrests associated with neuromuscular blocking drugs has not been previously reported and may reflect some unknown aspect of our practice. Furthermore, despite the fact that reporting of critical perioperative events is mandatory in our institution, the possibility exists that over the 11-yr study period, some events could have not been reported, which would have resulted in an underestimation of the incidence of cardiac arrests. To minimize this possibility, we used other available institutional databases and were unable to identify any additional cardiac arrests or mortality not included within the Performance Improvement database. Therefore, we believe that our report accurately characterizes perioperative cardiac arrests at our institution.

Summary

In conclusion, the overall frequency of perioperative cardiac arrest in patients undergoing noncardiac surgery at a tertiary referral center was 4.3 per 10,000 anesthetics between 1990 and 2000 (inclusive). The incidence of cardiac arrest decreased over this period, but survival after arrest did not change significantly. The overall incidence of cardiac arrests attributable primarily to anesthesia was estimated to be approximately 0.5 per 10,000 anesthetics; thus, most perioperative cardiac arrests are not directly related to identifiable anesthesia-related causes. Mortality caused by arrests attributable to anesthesia was approximately 1 in 100,000 anesthetics. Although some factors identified as determining survival after perioperative cardiac arrest may not be amenable to modification, the fact that arrests during nonregular working hours had worse outcomes than those during standard working hours may indicate that the availability of human resources in the surgical suite influences survival.

The authors thank members of the Department of Anesthesiology, Mayo Clinic, Rochester, Minnesota, who participated in collecting and maintaining information in the Performance Improvement Database.

References

1. Beecher HS, Todd DP: A study of the deaths associated with anesthesia and surgery. Ann Surg 1954; 140:2–34
2. Harrison GG: Anaesthetic contributory death: Its incidence and causes: II. Causes. S Afr Med J 1968; 42:544–9
3. Marx GF, Mateo CV, Orkin LR: Computer analysis of postanesthetic deaths. Anesthesiology 1973; 39:54–8
4. Harrison GG: Anaesthetic-associated mortality. S Afr Med J 1974; 48:550–4
5. Minuck M: Cardiac arrest in the operating room: I (1965-1974). Can Anaesth Soc J 1976; 23:357–65
6. Harrison GG: Death attributable to anaesthesia: A 10-year survey (1967–1976). Br J Anaesth 1978; 50:1041–6
7. Pottecher T, Tiret L, Desmonts JM, Hatton F, Bilaine J, Otteni JC: Cardiac arrest related to anaesthesia: A prospective survey in France (1978-1982). Eur J Anaesthesiol 1984; 1:305–18
8. Keenan RL, Boyan CP: Cardiac arrest due to anesthesia: A study of incidence and causes. JAMA 1985; 253:2373–7
9. Cohen MM, Duncan PG, Pope WD, Wolkenstein C: A survey of 112,000 anaesthetics at one teaching hospital (1975–83). Can Anaesth Soc J 1986; 33:22–31
10. Tiret L, Desmonts JM, Hatton F, Vourc'h G: Complications associated with anaesthesia: A prospective survey in France. Can Anaesth Soc J 1986; 33:336–44
11. Lunn JN, Devlin HB: Lessons from the confidential enquiry into perioperative deaths in three NHS regions. Lancet 1987; 2:1384–6
12. Olsson GL, Hallen B: Cardiac arrest during anaesthesia: A computer-aided study in 250,543 anaesthetics. Acta Anaesthesiol Scand 1988; 32:653–64
13. Keenan RL, Boyan CP: Decreasing frequency of anesthetic cardiac arrests. J Clin Anesth 1991; 3:354–7
14. Morgan CA, Webb RK, Cockings J, Williamson JA: The Australian Incident Monitoring Study. Cardiac arrest: An analysis of 2000 incident reports. Anaesth Intensive Care 1993; 21:626–37
15. Morray JP, Geiduschek JM, Ramamoorthy C, Haberkern CM, Hackel A, Caplan RA, Domino KB, Posner K, Cheney FW: Anesthesia-related cardiac arrest in children: Initial findings of the Pediatric Perioperative Cardiac Arrest (POCA) Registry. Anesthesiology 2000; 93:6–14
16. Pollard JB: Cardiac arrest during spinal anesthesia: Common mechanisms and strategies for prevention. Anesth Analg 2001; 92:252–6
17. Wu KH, Rau RH, Lin CF, Chan YL: Cardiac arrest during anesthesia in a teaching hospital: A 4 years survey. Int Surg 1997; 82:254–6
18. Newland MC, Ellis SJ, Lydiatt CA, Peters RK, Tinker JH, Romberger DJ, Ullich FA, Anderson JR: Anesthetic-related cardiac arrest and its mortality: A report covering 72,959 anesthetics over 10 years from a US teaching hospital. Anesthesiology 2002; 97:108–15
19. Lagasse RS: Anesthesia safety: Model or myth? A review of the published literature and analysis of current original data. Anesthesiology 2002; 97:1609–17
20. Vacanti CJ, VanHouten RJ, Hill RC: A statistical analysis of the relationship of physical status to postoperative mortality in 68,388 cases. Anesth Analg 1970; 49:564–6
21. Hosking MP, Warner MA, Lobdell CM, Offord KP, Melton LJ: Outcomes of surgery in patients 90 years of age and older. JAMA 1989; 261:1909–15
22. Warner MA, Shields SE, Chute CG: Major morbidity and mortality within 1 month of ambulatory surgery and anesthesia. JAMA 1993; 270:1437–41
23. Aubas S, Biboulet P, Daures JP, du Cailar J: [Incidence and etiology of cardiac arrest occurring during the peroperative period and in the recovery room: Apropos of 102,468 anesthesia cases]. Ann Fr Anesth Reanim 1991; 10:436–42
24. Auroy Y, Benhamou D, Bargues L, Ecoffey C, Falissard B, Mercier F, Bouaziz H, Samii K: Major complications of regional anesthesia in France: The SOS Regional Anesthesia Hotline Service. Anesthesiology 2002; 97:1274–80
25. Auroy Y, Narchi P, Messiah A, Litt L, Rouvier B, Samii K: Serious complications related to regional anesthesia: Results of a prospective survey in France. Anesthesiology 1997; 87:479–86
26. Cooper JB, Gaba D: No myth: Anesthesia is a model for addressing patient safety. Anesthesiology 2002; 97:1335–7
27. Biboulet P, Aubas P, Dubourdieu J, Rubenovitch J, Capdevila X, d'Athis F: Fatal and non fatal cardiac arrests related to anesthesia. Can J Anaesth 2001; 48:326–32
28. Dumot JA, Burval DJ, Sprung J, Waters JH, Mraovic B, Karafa MT, Mascha EJ, Bourke DL: Outcome of adult cardiopulmonary resuscitations at a tertiary referral center including results of "limited" resuscitations. Arch Intern Med 2001; 161:1751–8
29. Girardi LN, Barie PS: Improved survival after intraoperative cardiac arrest in noncardiac surgical patients. Arch Surg 1995; 130:15–8
30. Morita K, Kawashima Y, Irita K, Kobayayashi T, Goto Y, Iwao Y, Seo N, Tsuzaki K, Dohi S: Perioperative mortality and morbidity in 1999 with a special reference to age in 466 certified training hospitals of Japanese Society of Anesthesiologists: Report of Committee on Operating Room Safety of Japanese Society of Anesthesiologists. Masui 2001; 50:909–21
31. Arbous MS, Grobbee DE, van Kleef JW, de Lange JJ, Spoormans HH, Touw P, Werner FM, Meursing AE: Mortality associated with anaesthesia: A qualitative analysis to identify risk factors. Anaesthesia 2001; 56:1141–53