this last component, cooperation between anesthesiologist and surgeon, is crucial, and all participants at the University of Washington are to be congratulated on the evolution of this program.

Future directions for research are also exciting. Though by no means all-inclusive, they include use of new and more specific analgesics—opiate and nonopiate, investigation of additional routes of administration of drugs (as mentioned by Ready *et al.*[1]), and possible extension of these techniques to children. In addition, we need to know why some patients derive only limited pain relief from epidural opiates, how to best manage tachyphylaxis to epidural opiates, and whether patients receiving epidural opiates can safely be cared for in a regular nursing ward, or whether a special care unit is necessary. Finally, and perhaps of greatest importance, extensive long-term studies of outcome addressing risk *versus* benefit are required.

I applaud Ready and his colleagues for their success in organizing this acute pain service. An entirely new and nearly open-ended opportunity awaits our specialty, and we should grasp the chance while it is before us.

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Anesthesia Mortality—A New Mechanism

IN 1979 I POINTED OUT the error bias which pervaded all studies of anesthesia mortality and the commonly held view that, without error, anesthesia mortality should be nil.[1] I wrote "A second implication of the error bias is that it explicitly precludes any new knowledge concerning mechanisms of death attributable to anesthesia. Reviewers of death protocols never entertained the possibility of undescribed and subtle mechanisms by which anesthetics could contribute to mortality." And, later, "Progress requires that reports be accepted as true accounts, that they be collected in a repository or registry, that cause-effect relationships be sought according to rigorous scientific standards and

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that ignorance be admitted when no cause can be found." In this issue of ANESTHESIOLOGY, Caplan *et al.*[2] have done precisely this, and provide the vindication for these statements, as well as vindication for their rigorous approach to the laborious task undertaken by the ASA Professional Liability Committee.

Caplan *et al.* summarize the catastrophic events occurring in 14 patients during spinal anesthesia. The level of anesthesia (T_4) was higher than necessary for the surgical procedure planned, but hardly alarming in healthy patients (ASA Physical Status I & II). In these patients, however, about 30 min after the spinal injection, rapidly progressive hypotension and bradycardia appeared followed by severe brain damage or death, despite prompt institution of cardiopulmonary resuscitation (CPR). What went wrong? What did the expert witnesses diagnose? A spinal anesthetic dose too large? A spinal so high as to cause respiratory insufficiency? Overdose of respiratory depressant drugs? Certainly they incriminated lack of vigilance in diagnosis of hypoxia by whomever monitored the patient. These fit our taxonomy of known complications of spinal anesthesia, and, since this could never happen to the vigilant anesthesiologist, you and me, it was clearly one more human error. Caplan *et al.* disagreed. They describe a phenomenon of which anesthesiologists have been unaware, and which is now apparent only because of their review of a collection of rare events. They were struck by the "overall adequacy of basic anesthesia care." Based on "worse case" estimates, circulation and respiration were adequate a mean of 1.6 min before the first indication of trouble, and only 1.6 min lapsed before starting CPR. They regarded this type of mishap as a "sentinel event," one which should not have occurred under these conditions of anesthesia care. They collected 14 such events, and their in-depth analysis revealed management patterns which may have contributed to the occurrence and the disastrous outcomes. Knowledge of this phenomenon by anesthesiologists can now lead to prevention, adequate treatment if it occurs, and research to discover or verify its mechanisms.

The first clinical management pattern they recognized related to the almost universal practice of providing intraoperative sedation by the intravenous route during spinal anesthesia. When sedation was sufficient to produce apparent sleep, cyanosis preceeded cardiac arrest. The hemodynamic pattern before arrest, however, was the same with or without cyanosis, leading them to suggest unappreciated respiratory insufficiency as the precipitating event. Despite the extraordinarily wide use of hypnotic and analgesic drugs, almost all we know with any precision about their respiratory effects in non-anesthetic doses is derived from studies of the CO_2 response in healthy volunteer subjects.[3] Respiratory effects in pathologic states, including spinal anesthesia, are virtually unknown. Fentanyl and diazepam in small doses and thiopental in sleep-producing doses all decrease responsiveness to CO_2, but ventilation continues at a higher arterial CO_2 tension. Less widely appreciated is the depressant effect of morphine (and probably all morphine-like analgesics) and sleep doses of thiopental on the respiratory response to hypoxia,[4,5] requiring lower oxygen tensions before respiratory stimulation occurs. By contrast, droperidol has no effect on CO_2 responsiveness, and even increases the sensitivity of the hypoxic ventilatory response.[6] Droperidol is, however, a potent sedative, and this aspect of its action is probably more relevant to respiration during spinal anesthesia. All the drugs which supplemented spinal anesthesia in these patients altered awareness or consciousness. More than 20 yr ago, Forrest and Bellville[7] demonstrated that, when healthy subjects who received intramuscular morphine fell asleep, respiratory depression almost doubled. Becker *et al.*[8] noted that patients who received fentanyl intraoperatively and subsequently recovered CO_2 responsiveness suffered recurrent depression of the CO_2 response when left unstimulated in the postoperative period. Surgical stimulation, pain, noise, movement, and wakefulness probably all antagonize the decreased CO_2 responsiveness of narcotics. The role of high spinal anesthesia by its "deafferentation" and loss of facilitatory proprioceptive input into the respiratory center as modifying the respiratory response to these drugs in usual doses is unexplored, and clearly needs description.

Caplan *et al.*[2] postulate the hypoxia and hypercarbia associated with even modest respiratory insufficiency caused by these drugs led to vasodilitation, failure of venous return, failure of compensatory tachycardia because of sympathetic block, appearance of bradycardia and hypotension, and, finally, circulatory failure or cardiac arrest. Here is the second clinical management problem they identified. One can hardly fault the early treatment of bradycardia and hypotension with atropine and ephedrine. What is hard to rationalize is the failure to administer epinephrine until almost 8 min after arrest, and almost 3 min after bicarbonate had been administered, despite the essential role of epinephrine in the CPR drill. I speculate that two widely held misconceptions were responsible for the failure to administer epinephrine in this critical situation.

Anesthesiologists, at one time, relied heavily on vasopressors to treat hypotension during anesthesia, whatever the cause. In recent years, they seem to have developed an aversion to them, in the sense that the cause must be treated first and the vasopressor used only as a last resort. Most hypotension is attributed, at least ini-

tially, to hypovolemia, and proper treatment consists of large volumes of crystalloid administered over minutes, rather than a small dose of vasopressor with a response in seconds. Anesthesiologists do not entertain the view that the circulatory bed may have become too large for the volume contained, and prefer the view that intravascular volume must be too small. I believe the antipathy to vasopressors began with concern for uterine artery blood flow during spinal anesthesia for cesarian section when only ephedrine was found acceptable. This was further reinforced by the reciprocal relationship between cardiac output and systemic vascular resistance demonstrated in patients undergoing cardiac and vascular operations as a consequence of the generous use of pulmonary artery catheters. Anesthesiologists do not differentiate between vasoconstriction occurring in the extremities and the viscera, and believe that high systemic vascular resistance is bad whenever it occurs. It is almost as if resorting to the use of epinephrine or norepinephrine represents a personal failure of the anesthesiologist to cope with the cause in a rational fashion. I suggest that the failure to administer epinephrine in the presence of hypotension, bradycardia, spinal anesthesia, and CPR represents the extreme form of this aversion to vasopressors. Certainly, the risk of inducing excessive hypertension or ventricular dysrhythmia by epinephrine could not be greater than the risk of its omission in view of the outcome of these 14 patients.

The second misconception is the widely held view that the institution of CPR within 3 min of circulatory failure ensures sufficient blood flow to the brain for viability. When severe neurologic sequellae follow a catastrophe in which institution of CPR was prompt, it is generally assumed that the period of hypoxia preceding arrest must have been much prolonged, or complete recovery would have followed. The truth is that, under many circumstances, CPR produces little or no cerebral blood flow. Many years ago, we learned in our post-cardiac surgical ICU that, when closed-chest massage fails to demonstrate an intraarterial pulse trace with good pulse pressure, the chest must be opened immediately. Under these circumstances, the heart is almost always empty, either from cardiac tamponade or unreplaced blood loss or excessive vasodilator therapy. The lesson is obvious. CPR is ineffective when there is no blood in the heart. This would apply not only to cardiac arrest in the patient with massive blood loss, but to patients with massive air embolism, anaphylactic shock, and, according to the hypothesis of Caplan *et al.*,[2] to the patient with high spinal anesthesia who vasodilates from the hypercarbia and hypoxia of respiratory insufficiency.

The massive nature of the undertaking of Drs. Cheney and Ward and the ASA Professional Liability Committee in reviewing hospital records, narrative reports, and depositions of 900 closed claims is the newest approach to the study of anesthesia mortality. Even though the design of their study is a model of qualitative research, the authors point out the limitations of this data base—a biased sample of all adverse events, no control group for comparison, and inability to derive an incidence. These limitations are of small moment when objective detailed study of these events reveal patterns of anesthetic management which lead to poor outcomes. In the least, this approach can save brains and lives when a change in management can prevent the pattern. Their efforts have previously rewarded us by creating awareness of the frequency of esophageal intubation and its prevention,[9] and now with a previously undescribed hazard of spinal anesthesia. Their efforts have particularly rewarded me, with undisguised satisfaction, by demonstrating that thoughtfully designed and bias-free study of a collection of rare events can lead to patterns of adverse occurrences not fitting our established taxonomy of errors.

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Unexpected Cardiac Arrest during Spinal Anesthesia: A Closed Claims Analysis of Predisposing Factors

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Fourteen cases of sudden cardiac arrest in healthy patients who received spinal anesthesia were discovered in a preliminary review of 900 closed insurance claims for major anesthetic mishaps. All patients were resuscitated from the intraoperative cardiac arrest, but six suffered such severe neurologic injury that they died in hospital. Of the eight survivors, only one exhibited sufficient neurologic recovery to allow independence in daily self-care. In view of the unexpected nature of the cardiac arrests, as well as the ultimate severity of injury, these cases were analyzed in detail to determine whether there were recurring patterns of management that may have contributed to the occurrence or outcome of these anesthetic mishaps. Two patterns were identified. The first was the intraoperative use of sufficient sedation to produce a comfortable-appearing, sleep-like state in which there was no spontaneous verbalization. Cyanosis frequently heralded the onset of cardiac arrest in patients exhibiting this degree of sedation, suggesting that unappreciated respiratory insufficiency may have played an important role. The second pattern appeared to be an inadequate appreciation of the interaction between sympathetic blockade during high spinal anesthesia and the mechanisms of cardiopulmonary resuscitation. Prompt augmentation of central venous filling through the use of a potent α-agonist and positional change might have improved organ perfusion, shortened the duration of cardiac arrest, and lessened the degree of neurologic damage. (Key words: Anesthetic techniques: spinal. Complications: cardiac arrest; coma.)

FOR THE PAST 2 yr, the Professional Liability Committee of the American Society of Anesthesiologists has been conducting a nationwide study of closed insurance claims for major anesthetic mishaps. At the present time, approximately 900 claims have been reviewed. During a preliminary review of these claims, we encountered an unusual set of cases involving 14 healthy patients who received spinal anesthesia for relatively minor surgical procedures. Each of these patients experienced a sudden cardiac arrest followed by death or severe neurological injury. Although these cases constituted only 1.5% of the existing set of claims, we were perplexed by the apparently unexpected nature of the cardiac arrests and the severity of the outcomes. We were also disturbed that these events were associated with spinal anesthesia, a technique widely recommended for its safety.

When viewed in the context of quality-of-care research, this type of mishap fits the definition of a *sentinel event:* an unusual or unexpected outcome that should not occur under the prevailing conditions of health care.[1] Even if the number of sentinel events is relatively small, a detailed investigation may lead to novel strategies for improving the delivery of health care.[2,3] For this reason, we undertook an in-depth analysis of these 14 cases.

Our hypothesis for this study was that the in-depth analysis of mishaps with a common theme would reveal recurring patterns of clinical management that contributed either to occurrence or outcome. This paper describes two clinical management patterns that are consistent with this hypothesis, as well as our basic technique for investigating sentinel events in closed claims data.

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Materials and Methods

CASE MATERIALS

Two authors (FWC and RJW) reviewed the database of the American Society of Anesthesiologists (ASA) Closed Claims Study§ for all cases involving cardiorespiratory arrest during spinal anesthesia. The Closed Claims Study (a project of the ASA Committee on Professional Liability) is a structured evaluation of closed insurance claims for major anesthetic mishaps in the United States. Fourteen cases, spanning an 8-yr interval between 1978 and 1986, were found in a database of approximately 900 closed claims. Each of these cases satisfied the following four criteria: 1) the patient was relatively healthy—ASA Physical Status I or II; 2) cardiac arrest was sudden and unexpected; 3) outcome was poor despite apparently appropriate care; and 4) extensive written documentation was available for review. Written documentation typically included a complete

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§ The opinions expressed herein are those of the authors, and do not represent the policy of the American Society of Anesthesiologists.

hospital chart and anesthetic record; a detailed retrospective narrative of the cardiac arrest prepared by the anesthesiologist and/or nurse anesthetist; a circulating nurse's intraoperative record of the time course of the cardiac arrest and the specific treatments rendered; consultation notes provided by neurologists, intensive care physicians, and rehabilitation experts; and legal depositions of the involved parties and expert witnesses. Eight cases with poor outcome were not included in the study. The reasons for exclusion were moribund preoperative condition (1 case), well-documented inadequacy of anesthetic care (5 cases), and otherwise qualified cases in which we could not gain access to extensive written documentation (2 cases).

Analytic Technique

A standardized survey form was specifically designed for this study. The details of the intraoperative cardiac arrest and surrounding events were usually documented by three or more individuals (typically the anesthesiologist and/or nurse anesthetist, the surgeon, and the circulating nurse). These reports were used to develop a composite picture of the cardiac arrest, using a "worst-case" approach to the determination of time intervals. This technique was intentionally selected to compensate for the assumed tendency of participants to de-emphasize the duration of adverse events. In some instances, circulatory or respiratory insufficiency might have been present but unnoticed for a brief period of time before detection of the cardiac arrest. To construct a "worst-case" estimate of this time interval, all documents were carefully reviewed to determine the last time points prior to the cardiac arrest at which there were well-established observations of adequate circulation and ventilation. Every effort was made to emphasize observations which were made concurrently with events, and to minimize reliance on observations which were recorded retrospectively. For the purpose of this analysis, adequate circulation was defined as a mean arterial blood pressure greater than 60 mmHg (calculated as diastolic blood pressure plus one-third of the pulse pressure) and a heart rate greater than 50 beats/min, or a patient who was able to respond appropriately to verbal stimuli. Adequate ventilation was defined as the presence of normal-appearing or normal-sounding respirations (as determined by the use of a precordial stethoscope), and the absence of abnormal findings, such as stridor, wheezing, obstruction, shallow breathing, and cyanosis. Confidentiality was strictly preserved.

Continuous variables were summarized as mean ± standard deviation and range. One-way analysis of variance was employed for comparison of means, using the sums-of-squares simultaneous test procedure to correct for multiple testing.[4] A significance level of $P < 0.05$ was used throughout.

Results

Basic Features of Anesthetic Preparation and Management

The 14 patients in this series were relatively young (36 ± 15 yr) and healthy (8 ASA Physical Status I; 6 ASA Physical Status II). Conditions leading to the classification of ASA II included hypertension, cigarette smoking, well-controlled diabetes, and obesity. Ten patients were female and four were male. Nine patients were white and five were black.

All patients received an appropriate preoperative anesthetic evaluation which was documented by a written note in the hospital record. Ten patients received an appropriate premedication, usually a narcotic plus an antiemetic or antisialogogue. Four patients received no premedication. All patients were awake and alert upon arrival at the operating room.

Nine procedures were performed electively and five were emergencies. The sites of surgery were pelvic (8 cases), lower abdominal (2 cases), rectal (2 cases), and lower extremity (2 cases). Thirteen patients were in the supine position and one was prone. Monitoring included a blood pressure cuff in 14 cases, an electrocardiogram in 13 cases, and a precordial stethoscope in six cases.

The attending anesthesiologists were generally in mid-career. The average age was 47 ± 9 yr (range 33–62 yr), and the average length of time since completion of anesthesia residency training was 20 ± 9 yr (range 4–33 yr). Ten anesthesiologists were board-certified. All were practicing in accredited community hospitals.

The most common local anesthetic for spinal block was tetracaine (10 patients; average dose 10 ± 2 mg, range 6–14 mg). Two patients received lidocaine, one patient received procaine, and one patient received an injection of mepivacaine through an epidural catheter which had inadvertently entered the subarachnoid space. The highest level of block documented before cardiac arrest averaged $T_4 \pm 1$.

Because of the detailed investigation that occurred during each claims review, an accurate assessment of vigilance was feasible. In 12 cases, we had clear documentation that the anesthesiologist or nurse anesthetist was continuously involved in activities and observations that were directly related to patient care. In two cases, the anesthesiologist or nurse anesthetist was intermittently engaged in reading material not related to patient care, although this individual was still connected to

TABLE 1. Intraoperative Sedatives and Narcotics

	Cases	Amount Administered	
		Average ± SD	Range
Fentanyl	9	108 ± 64 μg	25–200 μg
Diazepam	8	5 ± 3 mg	2–10 mg
Droperidol	5	3 ± 2 mg	1.25–7.5 mg
Thiopental	5	95 ± 62 mg	50–200 mg
Other	2	—	—

a precordial stethoscope and was observing the patient's vital signs and general condition at intervals of 3 min or less.

In addition to spinal anesthesia, 12 patients received at least one intravenous sedative or narcotic (table 1). Nine patients received two or more of these drugs. In seven cases, sufficient medication was administered to produce a comfortable-appearing, sleep-like state in which there was no spontaneous verbalization. The most commonly used sedatives and narcotics were fentanyl, diazepam, droperidol, and thiopental. The average time interval between the *last* dose of sedative or narcotic and the first clue of cardiorespiratory arrest was 12 ± 7 min (range 5–25 min). Six patients received supplemental oxygen in the pre-arrest period (3 by mask and 3 by nasal prongs).

Figure 1 provides an overview of vital signs during the intraoperative period. In the interval preceding cardiac arrest, blood pressure and heart rate declined gradually to approximately 15–20% below admission values. Following resuscitation, systolic blood pressure and heart rate exhibited a 20–40% increase over admission values. Respiratory rate was not analyzed because it was recorded on the chart in only five cases.

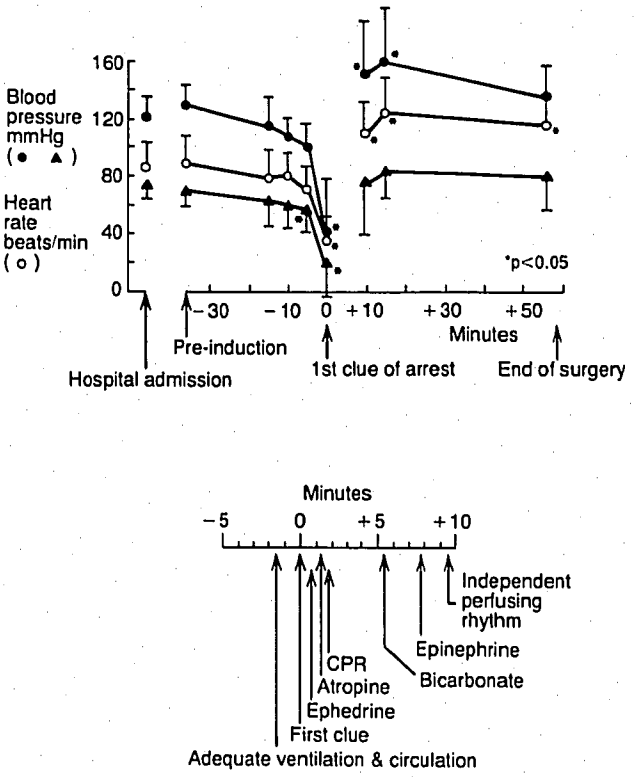

FIG. 1. Composite display of vital signs (upper graph) and key events (lower graph) in 14 cases of cardiac arrest during spinal anesthesia. Events are shown in relation to the first clue of impending cardiac arrest (located at 0 min on the time scale). The values for systolic blood pressure (closed circles), diastolic blood pressure (closed triangles), and heart rate (open circles) are mean ± SD. *$P < 0.05$ *versus* hospital admission values.

TIME-COURSE AND MANAGEMENT OF CARDIORESPIRATORY ARREST

Thirteen of the cardiac arrests occurred while surgery was in progress; only one occurred before the start of surgery. Anesthetic care had been in progress for an average of 36 ± 18 min (range 12–78 min) at the time of cardiac arrest. At the time that cardiac arrest occurred, direct anesthetic care and monitoring was being provided by the primary anesthesiologist in eight cases, and by an assigned nurse anesthetist in five cases. In four of the five cases where a nurse anesthetist was used, the attending anesthesiologist was supervising other rooms at the time of the cardiac arrest.

Each cardiac arrest was initially recognized by the appearance of at least two clinical clues (table 2). Recognition of the first clinical clue seemed to draw immediate attention to a second clue; thus, the time interval between these findings was often just a matter of seconds. In descending order of frequency, the most common clues were bradycardia, hypotension, and cyanosis. Cyanosis was first detected in four cases by the surgeon and in three cases by the anesthesiologist or nurse anesthetist.

As illustrated in the lower portion of figure 1, detection of the cardiac arrest and initiation of CPR both appeared to be very prompt. Based upon the last available observations of clinical signs, the "worst-case" estimate of inadequate circulation or ventilation before the first clue of arrest was 1.6 ± 1.9 min (range 0–5 min). The subsequent interval between detection of the first clue and the start of external cardiac massage was 1.6

TABLE 2. Initial Clues of Arrest (Number of Cases)

	1st Clue	2nd Clue	Combined Incidence
Bradycardia	7	2	9
Hypotension	2	6	8
Cyanosis	4	3	7
Loss of consciousness	1	1	2
Asystole	0	2	2

TABLE 3. Drug Administration during Cardiopulmonary Resuscitation

	Cases	Amount Administered		Minutes after 1st Clue	
		Average ± SD	Range	Average ± SD	Range
Ephedrine	11	38 ± 15 mg	10–50 mg	0.8 ± 0.9 min	0–3 min
Atropine	10	1 ± 0.3 mg	0.4–1.2 mg	1.4 ± 1.4 min	0–4 min
Sodium Bicarbonate	10	55 ± 19 meq	44–88 meq	5.2 ± 3.4 min	1–13 min
Epinephrine	10	1 ± 1 mg	0.1–2 mg	7.5 ± 6.2 min	1–22 min

± 0.9 min (range 1–4 min). During this second interval, all 14 patients received positive pressure ventilation with 100% oxygen by mask or endotracheal tube. Just prior to the start of external cardiac massage, 11 patients exhibited bradycardia and three patients exhibited asystole.

In 11 cases, the duration of external cardiac massage ranged from 3–16 min (average 7.8 ± 4.4 min). Three slightly unusual cases merit more detailed description. One patient had 38 min of external cardiac massage, with intermittent episodes of atrial and ventricular tachyarrhythmias. When this long period of resuscitation is included, the average duration of external cardiac massage becomes 10.3 ± 9.7 min. Two other patients had cardiac arrest-like episodes lasting 5 and 8 min. During this time, bradycardia and hypotension were treated with vasoactive drugs and respiration was controlled with 100% oxygen by mask. External chest compressions were not administered, and, thus, we have not included these two cases in the calculation of the average duration of cardiac massage. Overall, an average of 5 ± 2 physicians and nurses participated directly in the resuscitation of each patient.

Four drugs were frequently administered during the course of resuscitation (table 3). Ephedrine and atropine were usually given within 2 min of the first clue, whereas sodium bicarbonate and epinephrine were usually given 5 or more min after the first clue. Intraoperative fluid administration averaged 0.9 ± 0.3 liters of crystalloid prior to cardiac arrest and 1.0 ± 0.5 liters between the onset of cardiac arrest and the conclusion of surgery.

In three cases, blood gases were measured during the course of the cardiac arrest and resuscitation. In each of these cases, the anesthesiologist or surgeon believed that the blood was obtained from an artery, but the possibility of a venous sample cannot be completely excluded. The average values during cardiac arrest were P_{O_2} = 41 ± 18 mmHg, P_{CO_2} = 48 ± 7 mmHg, and *p*H = 7.29 ± 0.07. None of the P_{O_2} values was greater than 60 mmHg, and none of these three patients regained consciousness. After resuscitation was completed, arterial blood gases were obtained in seven cases. The average values after cardiac arrest were P_{O_2} = 213 ± 176 mmHg, P_{CO_2} = 40 ± 9 mmHg, *p*H = 7.37 ± 0.06. All P_{O_2} values after arrest were greater than 60 mmHg.

Six patients never regained consciousness and died in hospital within 6 months. Another four patients never regained consciousness, but survived the acute hospital course. Comatose survivors were transferred to various chronic care settings where survival ranged from 4 months to 7 yr.

Four patients regained consciousness. One of these patients has remained in a chronic care setting for over 3 yr. Another patient returned home after 5 months of rehabilitation therapy, but still requires assistance with basic self-care. One patient is able to perform basic self-care, but exhibits a distinct cognitive deficit. The interval between the last observation of stable vital signs and the onset of CPR was 3.5 ± 2.6 min for patients who regained consciousness and 3.0 ± 2.1 min for patients who never regained consciousness. The duration of CPR was 8.7 ± 5.5 min for patients who regained consciousness and 10.9 ± 10.9 min for patients who never regained consciousness. These differences were not statistically significant.

Five post-mortem examinations were performed. These revealed changes in the brain that were consistent with anoxic encephalopathy, but there were no primary organ abnormalities that might have contributed to the occurrence of an intraoperative cardiac arrest.

Discussion

This study has four significant limitations. First, our cases represent a biased sample of the total population of patients who have experienced cardiac arrest during spinal anesthesia. The primary reason for this bias is that all of our cases were obtained because of a highly adverse outcome which resulted in a malpractice suit. Second, we do not know the total number of patients who received spinal anesthesia (with or without complication) during the 8-yr time interval covered by this study. Thus, we cannot provide an estimate of incidence. Third, the closed claims database does not provide us with a set of patients who might serve as a control group. And fourth, the data are derived in part

from the reports of direct participants, rather than impartial observers.

To improve the potential value of this study, we prospectively adopted several recommendations proposed by Bailar *et al.*[5] for studies which lack "internal controls." First, we devised our analysis instrument before beginning the study. Second, we formulated a general hypothesis: that the analysis of an unexplained set of mishaps with a similar theme would reveal *recurring patterns in management that may have contributed to occurrence or outcome.* By searching for recurring patterns, we hoped to generate more specific hypotheses regarding causation and remedy that might not have been evident to the practitioners who experienced each mishap as an *isolated* event. Third, we asked if the results would be of interest if a recurring pattern could not be identified. And fourth, we asked if the results might have relevance to a larger group of patients. Because spinal anesthesia is a widely used technique, our answer to the last two questions was strongly affirmative.

Analysis of Anesthetic Management

In the aftermath of an anesthetic catastrophe, there is a natural and almost irresistible tendency to assume that overt negligence has played an important contributory role. One of the most striking features of these 14 cases was the overall adequacy of basic anesthetic care. All patients had been appropriately evaluated and selected for spinal anesthesia. Experienced physicians administered and supervised the spinal anesthetics using standard techniques and doses. Vigilance appeared adequate, resuscitation was quickly initiated, and a perfusing rhythm returned within an average of 10 min. During the postoperative period, all patients received meticulous attention.

In the absence of overt and isolated errors, we examined these cases for recurring patterns in routine management that might have contributed to occurrence or outcome. One pattern to emerge was the relationship between verbal nonresponsiveness due to sedation and the detection of cyanosis as one of the initial clues of cardiac arrest. In six of the seven cases where patients exhibited a sleep-like state that was devoid of spontaneous verbalization, cyanosis was observed as one of the first clues of arrest. In five other cases where patients remained verbally responsive up to the time of arrest, cyanosis was detected in only a *single* instance. (In two cases, the closed claims documents did not contain sufficient information to make this analysis.) These observations suggest that respiratory changes produced by sedation may have played an important role in approximately one-half of the arrests. Unfortunately, our data do not provide us with a clear explanation for those arrests which occurred when there were no overt signs of respiratory compromise. Coté *et al.*[6] has recently demonstrated that major hypoxic events ($Sa_{O_2} \leq 85\%$ for ≥ 30 s) can occur without visible cyanosis or obvious changes in the respiratory pattern. Thus, it is possible that respiratory insufficiency may have been present but clinically unrecognized. We also speculate that circulatory changes related to high sympathetic blockade may have played a role in some cases, but we were unable to link this hypothesis to a recurring pattern of management.

It is important to note that we could find no instance in which sedatives or narcotics had been inappropriately or carelessly used. To the contrary, the overall doses (as displayed in table 1) were well within customary ranges, and these drugs had been administered in an incremental and titrated manner. Hilgenberg and Johantgen[7] recently suggested that the combination of sympathetic blockade produced by high spinal anesthesia and the vagotonic effect of fentanyl might account for the sudden appearance of bradycardia. Similarly, Fortuna[8] suggested that the α-blocking effect of droperidol might account for severe hypotension and sudden cardiac arrest during spinal anesthesia. In the group of patients we studied, the time interval between drug injection and the first clue of cardiac arrest was 21 ± 11 min (range 5–41 min) for all doses of fentanyl, 30 ± 27 min (range 5–75 min) for all doses of droperidol, and 25 ± 18 min (range 5–80 min) for any supplemental drug injection. Although we cannot eliminate the possibility of an adverse drug interaction, a strong temporal relationship is not apparent here.

Greene[9] has emphasized that hypoxia and hypercarbia can exert a direct and significant vasodilating effect on the peripheral vasculature when central sympathetic stimulation is blocked. Vasodilation, in turn, can lead to decreased central venous return and atrial filling. Reduced atrial filling and unopposed vagal tone may ultimately produce a sufficient degree of bradycardia and hypotension to result in cardiac arrest. Thus, the potential for an adverse cascade of interactions may be particularly striking if respiratory insufficiency produces hypoxia or hypercarbia in the setting of high spinal anesthesia. Of note in this study, we could not establish any relationship between supplemental oxygen administration and the observation of cyanosis as one of the initial clues of cardiac arrest. Cyanosis was detected with equal frequency in patients who received oxygen prior to cardiac arrest (3 of 6 cases) as those who did not (4 of 8 cases).

Analysis of Intraoperative Resuscitation

Although we did not have a similarly detailed series of intraoperative cardiac arrests for comparison with our cases, we did find comparable features in the re-

ported experience for *out-of-hospital* resuscitation in Seattle.[10,11] The Seattle experience bears considerable resemblance to our series in that the majority of cardiac arrests were witnessed and definitive resuscitation measures were initiated in approximately 3 min. However, a major difference between these groups is that the patients in our series were all relatively healthy, while the majority of patients who had cardiac arrest out-of-hospital had cardiac disease. In addition, the cardiac arrests in our series occurred in a well-equipped hospital environment, whereas the out-of-hospital cardiac arrests initially took place under "field" conditions.

Fifty-five percent of patients resuscitated from out-of-hospital cardiac arrest in Seattle survived the initial hospital course. This is essentially equivalent to our series of intraoperative cardiac arrests in which eight of 14 patients (57%) were discharged alive. In contrast, 41% of patients resuscitated from out-of-hospital cardiac arrest recovered without gross cognitive or motor deficits, while only one of 14 patients (7%) who arrested during spinal anesthesia ultimately attained this high level of neurologic recovery.

The comparatively poorer neurologic outcome in our series of intraoperative arrests may be attributable to the degree of sympathetic blockade produced by high spinal anesthesia. The presence of nearly complete sympathetic blockade may have increased peripheral blood flow during CPR, thereby decreasing perfusion of the brain. In contrast, patients who had cardiac arrest outside of the hospital presumably had more sympathetic tone and less diversion of blood flow to the periphery. Although blood flow to the brain during CPR may be reduced to approximately 10–20% of normal,[12,13] it is believed that even these low levels of flow can offer some measure of protection until a perfusing cardiac rhythm is re-established.[14,15]

Directly related to the issue of blood flow is the role of α-adrenergic stimulation during CPR. The importance of α-adrenergic agents during resuscitation has been repeatedly suggested.[16–19] By promoting peripheral vasoconstriction, α-agonists may increase venous return to the heart and thereby improve cardiac output during external compression. Additionally, peripheral vasoconstriction may increase diastolic blood pressure and coronary perfusion, thereby speeding the recovery of cardiac function.

If these hypotheses regarding sympathetic blockade are correct, it is possible to propose a recurring pattern in routine management that may have contributed to outcome. Ephedrine was given almost immediately after the first clue of impending arrest, but we speculate that conventional doses of this relatively weak α-agonist were ineffective in the setting of nearly complete sympathetic blockade. Epinephrine, a much more potent α-agonist,[20] was not given until an average of 8 min of asystole had elapsed. Following administration of epinephrine, spontaneous rhythm and independent perfusion returned within an average of 3 min. Although we cannot offer clear-cut evidence of causality, this temporal relationship suggests that epinephrine may have played an instrumental role in the termination of arrest. Earlier administration of epinephrine might have shortened the duration of cerebral ischemia and reduced the degree of neurologic damage. It is also possible that the chronotropic effect of epinephrine might have been more effective than ephedrine in *preventing* bradycardia from progressing to cardiac arrest. Although these hypotheses may be difficult to test in the clinical setting, indirect confirmation may be feasible in animal models of spinal anesthesia and cardiac resuscitation.

In addition to the use of a potent α-adrenergic agonist, such as epinephrine, a prompt increase in central venous filling can be produced by elevating the legs or by placing the patient in Trendelenberg position.[21] Neither approach was used in this series. However, a potential hazard of Trendelenberg position during cardiac arrest is that elevation of cerebral venous pressure may impede cerebral blood flow.

Previous case reports and surveys have described cardiac arrest as a rare complication of spinal anesthesia.[22–26] Because of the varied nature of these reports, a precise picture of predisposing factors and preventive measures has been difficult to obtain. Our current series differs from previous reports in that detailed and consistent information was collected by a structured analysis of closed claims data.

On the basis of the present study, we would offer three specific recommendations regarding the management of routine spinal anesthesia. First, a pulse oximeter should be employed whenever sedative agents are administered or when the ability to communicate with the patient is impaired. Second, epinephrine should be considered *early* in the treatment of sudden bradycardia, especially if conventional doses of atropine or ephedrine are not effective. Third, and perhaps most important, a full resuscitation dose of epinephrine should be given *immediately* upon the recognition of cardiac arrest.

All of these cardiac arrests seemed to evolve with unexpected speed against a background of apparently stable hemodynamics. Our data do not provide us with an explanation for this finding. For this reason, we wish to emphasize that spinal anesthesia—conducted under routine conditions and in a standard manner—carries a poorly understood potential for sudden cardiac arrest and severe brain injury in healthy patients.

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