Anesthesiology
60:34–42, 1984

An Analysis of Major Errors and Equipment Failures in Anesthesia Management: Considerations for Prevention and Detection

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Adaptations of the critical-incident technique were used to gather reports of anesthesia-related human error and equipment failure. A total of 139 anesthesiologists, residents, and nurse–anesthetists from four hospitals participated as subjects in directed or open-ended interviews, and 48 of them functioned as "trained observers." A total of 1,089 descriptions of preventable "critical incidents" were collected. Of these, 70 represented errors or failures that had contributed in some way to a "substantive negative outcome." From these incidents, ten potential strategies were developed for prevention or detection of incidents.

Overall patterns observed in this wider study were similar to those of our earlier report. The incidents most frequently reported included breathing circuit disconnections, drug–syringe swaps, gas-flow control errors and losses of gas supply. Only 4% of the incidents with substantive negative outcomes involved equipment failure, confirming the previous impression that human error is the dominant issue in anesthesia mishaps. Among the broad categories of key strategies for mishap prevention were additional technical training, improved supervision, improved organization, equipment human-factors improvements, and use of additional monitoring instrumentation. The data also suggest that less healthy patients are more likely to be affected adversely by errors. It is suggested that, in future studies of anesthesia mortality and morbidity, untoward events should be classified according to preventive strategy rather than outcome alone as an aid to those who wish to apply the experience of others to lessen the risk in their individual practice. (Key words: Anesthesia: complications. Complications: accidents. Equipment.)

ANESTHESIA RISK has been the subject of numerous investigations, editorials, and journal correspondence since the first anesthetic death was reported in 1848.[1] Yet, even today there is no accurate measure of the magnitude of the mortality and morbidity associated with anesthesia nor is there extensive knowledge about the primary causes of untoward events. There does appear to be some agreement that anesthesia risk is an important public health concern and that it is reducible.[2,3] Further, there is reason to believe that a substantive portion of that risk is related to errors in management or deviations from accepted practice.[4–6]

In 1978 we reported preliminary findings of the relative frequencies and etiology of preventable mishaps and near mishaps.[7] Subsequent reports described our methods[8] and the analysis of one type of frequent incident (disconnections in breathing circuits).[9] A much larger set of errors and equipment failures since has been accumulated. From those events we analyzed the relationship between personnel exchange (intraoperative relief) and the cause and discovery of errors.[10] We now summarize and highlight other characteristics of that larger set of data, including a specific analysis of those preventable mishaps that resulted in substantive negative outcomes. Potential strategies for mitigation are developed and presented.

Methods

Three related adaptations of a method known as critical-incident analysis[11] were used to gather reports of anesthesia-related human errors and equipment failures. Details of the methods used are reported in Cooper *et al.*[7,8] In the first phase of investigation, voluntary reports of anesthesia-related human errors and equipment failures were gathered from 48 anesthesiologists, 30 residents, and 13 nurse anesthetists from four hospitals in the Boston metropolitan area. The two larger hospitals had extensive anesthesia teaching programs. The two smaller hospitals had private practice groups of anesthesiologists supervising nurse anesthetists.

Contact with each of the anesthesia groups began with a lecture presentation of objectives by one of the authors (JBC). Individuals then were asked by letter to participate in the study. Volunteers were interviewed privately, by a trained interviewer who was not an anesthetist. At that time they were given more detailed descriptions of the purpose of the study, the investigators conducting the study, the nature of the groups asked to participate, and the anonymity and confidentiality with which reports would be treated. Each interviewee then was asked to describe, in as much detail as possible, incidents directly observed that involved a preventable human error or equipment failure. The interviewer did not request examples of any specific type of error or equipment failure.

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Received from the Department of Anaesthesia, Harvard Medical School, and the Massachusetts General Hospital and the Department of Biomedical Engineering, Massachusetts General Hospital, Boston, Massachusetts. Accepted for publication July 12, 1983. Supported with funds provided by The St. Paul Companies, The Fannie E. Rippel Foundation, The Aetna Life and Casualty Company and Ohio Medical Products, Inc.

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But, if the interviewee required prompting to recall incidents, the interviewer asked a series of general questions from a prepared list.

In addition to incidents collected from these studies at four hospitals, others were gathered by a second type of investigation at one of the teaching hospitals. Again, volunteers were solicited from the department. During an introductory interview, participants were asked questions from a prepared list, about specific types of incidents, such as disconnections in the breathing circuit or drug administration errors. Two of the questions were about relief-related incidents. Then these 48 "trained observers" (18 anesthesiologists, 21 residents, and nine nurse anesthetists) were asked to report future incidents as soon as possible after occurrence. Subsequent reports were made by telephone to the same interviewer.

All interviews and most telephone reports were tape-recorded, summary transcripts of all incidents prepared, and the tapes erased. Information then was coded for computer-aided storage and analysis.[7,8] We classified a reported occurrence as a "critical incident" according to the following definition:

> A critical incident is a human error or equipment failure that could have led (if not discovered or corrected in time) or did lead to an undesirable outcome, ranging from increased length of hospital stay to death.‡

To be included in the study, each report also was required to have the following characteristics: 1) it involved an error by a member of the anesthesia team or a failure of the anesthetist's equipment to function, 2) it occurred at a time when the patient was under the care of an anesthetist, 3) it is described in clear detail by a person who either observed or was involved in the incident, and 4) it was clearly preventable.

A total of 616 critical incidents were collected from the first series of interviews conducted at the four hospitals. An additional 234 incidents were reported during the introductory interviews with the "trained observers." And, 239 incidents subsequently were reported by these observers. Thus, the total set of incidents available for examination is 1,089. There were also 798 other reported occurrences that were transcribed but not coded because one or more of the criteria for qualification as an incident were not met.

The search for causal patterns among incidents was primarily an intuitive process. From the many categories of information collected, important characteristics of incidents were extracted and summarized for the entire data set. Classifications (see Cooper *et al.*[8] for definitions) were created inductively. Incidents were sorted by consensus of at least two members of the study team, which was led by two biomedical engineers and included four anesthesiologists and an information analyst. We found that patterns of errors were better revealed by examining focused subsets of incidents. One such subset consisted of those incidents in which a "substantive negative outcome" (SNO) was reported (mortality, cardiac arrest, canceled operative procedure, or extended stay in the recovery room, in an intensive care unit, or in the hospital). From close examination of these incidents, 10 potential strategies for prevention or detection were developed. One or more of these strategies were assigned to each incident by consensus of the investigators if there was evidence in the description that the incident would have been prevented or detected more promptly had a particular measure been applied beforehand.

‡ Included within this range of undesirable outcomes is increased stay in a recovery room or intensive care unit.

TABLE 1. Distribution of Critical Incidents According to Type of Failure

	Retrospective		Instant Reporting	
	n	%	n	%
Equipment failure	69	11	46	19
Human error	430	70	153	64
Disconnection	80	13	31	13
Other	37	6	9	4
Total coded	616		239	
Nonincidents	541		79	

Results

Incidents are summarized in tables 1 through 3, according to the type of failure and the nature of the activity involved in the human error or the type of equipment involved in the equipment failure. Twenty-five most frequently occurring types of incidents are listed in table 4. The 234 incidents reported in the directed interviews are not in the data shown in tables 1 through 4, since

TABLE 2. Distribution of Human Error and Disconnection Incidents According to the Nature of the Activity or System Involved

	Human Error	Disconnections
Drug administration	138	—
Anesthesia machine use	129	—
Airway management	92	—
Breathing circuit/ventilation	64	79
Fluid and electrolyte management	31	—
iv apparatus	33	22
Monitoring device use	26	10
Other	70	—
Total	583	111

TABLE 3. Distribution of Equipment Failures According to Type of Equipment Involved

	Number of Incidents	Percentage of All Equipment Failures
Breathing circuit	26	23
Monitoring device	22	19
Ventilator	17	15
Anesthesia machine	16	14
Airway device	14	12
Laryngoscope	11	10
Other	9	8
Total	115	

their distribution was biased by the solicitation of reports of specific types of incidents, *e.g.*, disconnections.

There are potentially many ways to define incident types. Almost every single incident is unique in some respect. In creating the subsets in table 4, we chose labels that are easily recognizable and that create subsets of incidents that suggest common remedial strategies. Each label describes the direct cause or primary failure in an incident, even though, in many cases, predisposing causes were indicated clearly. These labels define the specific act of omission or commission that precipitated the actual crisis or that would have precipitated a crisis had prompt recognition not occurred. With few exceptions, the wordings are self-explanatory. The term misplaced endotracheal tube includes endobronchial or esophageal placement. Breathing-circuit control errors most often involved misadjustment of the pressure relief valve, *e.g.*, failure to close during mechanical ventilation. Hypoventilation includes anesthetist judgment errors, regardless of the mode of ventilation.

TABLE 4. Distribution of Frequent Critical Incidents

Incident Description	Number of Incidents
Breathing circuit disconnection during mechanical ventilation	57
Syringe swap	50
Gas flow control technical error	41
Loss of gas supply	32
Intravenous line disconnection	24
Vaporizer off unintentionally	22
Drug ampule swap	21
Drug overdose (syringe, judgmental)	20
Drug overdose (vaporizer, technical)	20
Breathing circuit leak	19
Unintentional extubation	18
Misplaced tracheal tube	18
Breathing circuit misconnection	18
Inadequate fluid replacement	15
Premature extubation	15
Ventilator malfunction	15
Misuse of blood pressure monitor	15
Breathing-circuit control technical error	15
Wrong choice of airway management technique	13
Laryngoscope malfunction	12
Wrong iv line used	12
Hypoventilation (human error only)	11
Drug overdose (vaporizer, judgmental)	9
Drug overdose (syringe, technical)	8
Wrong choice of drug	7
Total	507*

* Represents 59% of all incidents reported, not including those from directed interviews.

TABLE 5. Associated Factors Cited in Critical Incidents

Associated Factors	Number of Incidents
Failure to check	223
First experience with situation	208
Inadequate total experience	201
Inattention or carelessness	166
Haste encouraged by situation	131
Unfamiliarity with equipment or device	126
Visual restriction	83
Inadequate familiarity with anesthesia technique	79
Other distractive simultaneous anesthesia activities	71
Teaching in progress	60
Excessive dependency on other personnel	60
Unfamiliarity with surgical procedure	59
Lack of sleep/fatigue	55
Supervisor not present enough	52
Failure to follow personal routine	41
Inadequate supervision	34
Conflicting equipment designs	34
Unfamiliarity with drug	32
Failure to follow institutional practice	31

In some cases, a report of a physiologic or anesthetic crisis contains no clear primary error. These occurrences have been identified as critical incidents because there was a clearly described failure to recognize a hazardous condition or a failure to act on available information. In these few cases, it is possible that a primary error occurred without being apparent in the report; the incidents are labeled only according to the visible errors.

More than a single primary, related error was identified in each of 50 reports. Typically, the distinction between the two errors was fairly obvious. For example, if an overdose of narcotic was unintentionally administered and the patient was extubated later prematurely, subsequently requiring reintubation, two distinct incidents would be defined. Note that without knowledge of an overdose, only the second error would be coded for such a report.

In most incident descriptions, many circumstances were described that conceivably could have contributed to the occurrence of an error or to a failure to promptly detect an error. We call such circumstances "associated factors." The most frequently mentioned factors are listed in table 5. Again, most of the labels are self-explanatory. The factor inadequate total experience was cited when there was a clear implication that a more experienced, non-

TABLE 6. Incidents with Substantive Negative Outcomes

	Number of Incidents
Technical	
iv drug overdose	4
Breathing circuit misconnection	5
Breathing circuit disconnection	4
Inhalation drug overdose	2
Esophageal intubation	3
Gas flow setting error	2
BP monitoring technical error	3
Miscellaneous technical error	5
Judgmental	
Drug overdose	8
Wrong drug	2
Wrong airway management technique	4
Miscellaneous judgmental error	9
Monitoring/vigilance	
Failure to detect	5
Inappropriate ventilation	2
Fluid overload	2
Miscellaneous omission	4
Other	
Equipment failure	3
Other miscellaneous monitoring error or vigilance lapse	3
Total	70

trainee anesthetist would have been unlikely to err as described in the incident. Inadequate total experience was typically but not always coupled with a specific training factor, *e.g.*, unfamiliarity with equipment or device. Failure to follow personal routine was cited if the responsible anesthetist deviated from some specific, individualized routine, *e.g.*, a special arrangement of drug syringes. Inadequate supervision was invoked if, even though present or available, the supervisor provided poor, incomplete, or incorrect guidance according to the reporter's assessment. Seventy-five per cent of all incidents contained at least one such factor, and single incidents contained as many as 15 factors.

Summaries of the specific types of errors and equipment failures in the 70 incidents with substantive negative outcomes are given in table 6. Summaries of the outcomes are given in table 7. Only those incident types occurring more than once are specifically labeled. The three miscellaneous categories include some incident types listed in table 4 that occurred only once in this SNO subset. The physical status of patients prior to the incidents is summarized in table 8 for both the incidents with substantive negative outcomes and for those with no known sequelae. The criteria for designation of strategies for potential prevention or detection are listed in table 9, and the number of SNO incidents classified for each are shown in table 10.

TABLE 7. Substantive Negative Outcomes*

	Number of Patients
Death	25
Cardiac arrest (with subsequent resuscitation)	19
Canceled procedure (and neither of above)	11
Extra stay in recovery room, ICU or hospital greater than 1 day (and none of above)	12
Total	67

* An outcome was associated with an incident if there was sufficient information to clearly establish a cause-and-effect relationship between the error and the outcome. If an outcome was associated with more than one incident, only one case is indicated, *i.e.*, each unit included here represents a different patient.

Discussion

The qualifications and potential bias of critical incident analysis have been examined in general.[12,13] The specific limitations of our application of this technique to anesthesia also have been discussed.[14] In our studies, no attempt has been made to measure the absolute occurrence rate of any one type of incident or to relate one type of error to some ultimate contribution to mortality and morbidity. Rather, the analytic strategy is to examine types of errors and associated factors to elucidate mechanisms of errors. The distribution of the 616 incidents reported during the purely retrospective (nonbiased) interviews, where no specific incident types were solicited, may represent the distribution in actual practice or may simply represent the relative importance with which anesthetists at those four hospitals perceive their mistakes.

TABLE 8. Relationship between Physical Status* and Incident Outcome

	Nonconsequential		Substantive Negative Outcome	
Physical Status	n	%	n	%
Healthy (or ASA 1)	394	59%	14	25%
Moderately ill (or ASA 2)	151	22%	18	32%
Seriously ill (or ASA 3 or greater)	128	19%	24	43%
Total reported	673		56	
Not known or not reported	288		11	

* This pairing of degree of illness and ASA physical status, while not the intended use of the ASA classification scheme, represents the way in which participants generally ranked patient status.

TABLE 9. Criteria for Citation of Strategies for Potential Prevention or Detection

Strategy	Criterion
Additional training	Specific knowledge or technical skills were clearly lacking or the level of total experience of the responsible anesthetist was contributory
Improved supervision/ second opinion	Needed aid or guidance of a supervisor, or the appropriate presence of a second anesthetist was lacking, or supervisory technique or skill was inadequate
Specific protocol development	Lack of a standard protocol for a repetitive task was contributory
Equipment or apparatus inspection	Appropriate inspection of equipment or apparatus was not conducted prior to use and probably would have led to detection of the error or failure earlier
More complete preoperative assessment	Information of substantive importance about the patient's medical history or physiologic status should have been elicited preoperatively
Equipment/human-factors improvements	Inadequacies in the human-engineering of equipment or apparatus were contributory
Additional monitoring instrumentation	The use of commercially available monitoring, alarm, or warning instrumentation would have led to prompter detection of the error or failure
Other specific organizational improvements	A lack of structure, teamwork, or general planning was evident, resulting in contributory haste, disarray, confusion, *etc.*
Improved communication	The transmittal of basic information between two individuals involved in the incident would have provided data or clues relevant to the prevention or detection of the incident
Improved personnel selection procedures	The individual responsible for the incident was clearly deficient in skills or knowledge and, by the strongest suggestion of the reporter, was less than a fully competent anesthetist

TABLE 10. Potential Strategies for Prevention or Detection of 70 Incidents with Substantive Negative Outcomes

	Number of Incidents
Additional training	38
Improved supervision/second opinion	20
Specific protocol development	7
Equipment or apparatus inspection	8
More complete preoperative assessment	8
Equipment/human-factors improvements	18
Additional monitoring instrumentation	18
Other specific organizational improvements	21
Improved communication	8
Improved personnel selection procedures	5
Unknown (none obvious)	1
Total	152

However, the distribution of the 239 incidents reported in "real time" by the trained observers probably approximates the distribution of specific errors at that one hospital. The latter distribution contains more equipment failures than the former, but, in most other respects they are fairly similar.

Study of this broader sample of hospitals and expanded sample population confirms and strengthens the findings we reported previously.[7] In fact, the distribution of incident types (table 1) is almost exactly the same as that from the earlier smaller study, which represented only 359 incidents in one hospital. In comparing them, note that we now group all "disconnection" incidents (including breathing circuit, intravenous lines, and monitoring apparatus) in a separate category. These form a unique set distinct from those of human errors and equipment failures.

In classifying human errors among the SNO incidents (table 6) we distinguished between three categories of human error: technical§ errors, judgmental errors, and monitoring or vigilance failures. Technical errors, in which the action taken is not the action intended, arise from deficiencies of technical skill or from poor human-factors design in the equipment or apparatus involved. Judgmental errors, in which the action represents a bad decision, arise from lapses in training or poorly developed decision making skills. Monitoring and vigilance failures are those in which the essence is a failure to recognize or act upon visible data requiring a response. We did not review the entire data set to reclassify all non-SNO incidents according to this expanded scheme.

We saw only slight differences between the incidents with and without substantive negative outcomes. On average, each SNO incident involved somewhat more associated factors (3.4 factors for SNO incidents and 2.5 factors for non-SNO incidents). However, we saw no substantive difference in the number of patients with multiple incidents in the SNO group. Why some errors lead to injuries, while others are detected and corrected promptly, remains somewhat unclear. Perhaps the former group is a randomly selected subset of the total group of critical incidents. However, table 8 suggests that the smaller margin for error available in sick patients converts more incidents into SNOs. Perhaps, also, the greater number of adverse associated factors slows discovery and reduces the margin for error.

There does appear to be a meaningful difference in the incidence of equipment failures between the SNO

§ In earlier reports, we used the label "inadvertent" for this classification. While that word conveys the character of action in these errors, it also implies carelessness. We have substituted the term "technical" to avoid that misinterpretation.

and non-SNO groups. Only 4.3% (3/70) of SNO incidents involved an equipment failure, compared with 14% (112/785) of the nonbiased non-SNO incidents. The relatively low rate of equipment failure among harmful incidents is almost exactly the same finding as that reported by Lunn and Mushin[15] (equipment failure implicated in 5% of 125 "avoidable" anesthetic deaths in Great Britain and Ireland, 1979–1980). It is possible that equipment failures are detected more readily by anesthetists before irrevocable harm occurs. Perhaps people have more difficulty detecting their own errors than failures of their equipment. Possible bias in reporting must be considered here. Ones own errors may be relatively more memorable when they result in a SNO. One could argue, however, that having one's patient injured by an equipment failure would be relatively unforgettable. The finding suggests more emphasis on technologic aids to vigilance and detection of error than on improving the reliability of equipment.

The specific types of critical incident listed in table 5 are probably familiar to most anesthetists. These are, perhaps, "expected" events to which anesthetists are trained to promptly react, But, the occurrence of substantive negative outcomes supports the view that admonitions of "vigilance" are not always sufficient to prevent injury. Primary errors may occur in conjunction with circumstances that deter prompt discovery. In some cases, examination of the incident types immediately suggests direct potentially effective preventive measures or monitoring strategies. In most cases, however, no clear single remedy can be designated. For instance, each of the five reported incidents in which aspiration resulted in a substantive negative outcome involved a fundamentally different mechanism, *i.e.*, inadequate recovery room monitoring, dislodgement of the tracheal tube, failure to apply cricoid pressure, technical error in use of a double-lumen tube, and insertion of a nasogastric tube immediately following induction, prior to securing the airway, in the presence of an acute intestinal obstruction. This suggests to us that broad strategies are required to prevent injurious outcomes, recognizing that many different types of errors can lead to the same end result. Thus, the generic taxonomy of preventive strategies shown in table 9 has been created. Some observations about these strategies follow.

1. Training and Supervision—Inadequate experience of one form or another was the most frequent associated factor cited among all incidents. This may not be surprising, considering that two of the four hospitals were training centers. We now can reinforce our earlier impression that "most of the errors and associated outcomes related to training could be averted by a more structured approach to preparing residents for the environments into which they often are immersed suddenly. To the extent that certain kinds of errors are frequent, one could sensitize residents more effectively prior to involvement with certain devices or procedures . . ." with the expectation that clinical errors would be far less frequent.[7] This point is illustrated dramatically by the observation that 13 of the 14 SNO incidents involving some form of drug overdose were associated with some directly relevant form of inexperience or inadequate training. In eight SNO incidents, there was a failure to appreciate the implications of rapid administration rates of potent solutions, *e.g.*, nitroprusside or potassium. Other frequently noted training deficiencies in the SNO incidents included 1) lack of appreciation for the fragile cardiovascular state of patients with known myocardial dysfunction, 2) incomplete clinical acumen in assessing volume status and inadequate appreciation of the disastrous potential of such failures, and 3) incomplete or total lack of knowledge about the construction, function, or hazards of anesthesia breathing circuits and ventilators.

More surprisingly, the factor of inadequate training was not confined to anesthetists-in-training. In 16 of the 38 SNO incidents in which the need for additional training was cited, it was a staff anesthesiologist or nurse anesthetist whose skills or knowledge were deficient. Among 69 of the 243 incidents (from the entire data set) in which an attending staff member was responsible, inadequate knowledge of or familiarity with specific equipment, anesthetic technique, pharmacologic action, *etc.*, played some role. Often, the error was associated with use of a relatively new technique or device rather than representing an inadequacy in earlier training. Examples include unfamiliarity with the operation or potential failures of scavenging apparatus, lack of appreciation for the profound effects of errors in nitroprusside administration, or misunderstanding of the proper use of a particular double-lumen endotracheal tube of unfamiliar construction. These observations reinforce the need for continual inservice education concerning new equipment and techniques and the importance of having a real appreciation for the inherent hazards of working with the unfamiliar.

Inadequate training often was compounded by poor supervision (16 of 38 incidents). The most frequent deficiency was absence of the supervisor when a trainee was managing a case or involved in a crisis for which he clearly lacked the experience or skills needed to respond appropriately. On many of these occasions, supervisors provided inaccurate or superficial guidance.

2. Specific Protocol Development, More Complete Preoperative Assessment, and Equipment and Apparatus Inspection—One or more of these three strategies applied to about one-third (23) of the SNO incidents. And, in 22% (223/1089) of all incidents, some form of failure to check or

inspect was cited as an associated factor. Craig and Wilson, using methods similar to those described here, found that a "failure to inspect" was associated with 33% of 81 incidents reported by anesthetists.[16] Further confirmation of the seriousness of inadequate preparation or inspection is found in the New South Wales (Australia) study of anesthesia mortality.[17] A special committee investigating deaths under anesthesia, in analyzing 286 deaths directly or indirectly due to anesthesia, noted inadequate preparation in 150 of the cases. Their examples include failures to adequately prepare patients for surgery or to assess the initial degree of fluid imbalance. Thus, while their definition of terms was somewhat different from ours, the issue appears to be the same. There are strong indications of a need to develop and use appropriate protocols for preoperative assessment of patients and for preoperative inspection of equipment and apparatus.¶ The need to follow a protocol at an exchange of anesthesia personnel has been recommended,[10] and a suggested guideline is available. Some examples of incidents from our data that probably would have been prevented by such strategies are 1) failure to detect an internal anesthesia machine leak, 2) failure to review patient record leading to complication from a contraindicated drug, 3) failure to have needed drugs on an anesthesia tray before a crisis, and 4) failure to review medical status when one anesthetist replaced another in a case of developing hypovolemia.

3. Additional Monitoring Instrumentation, and Equipment and Human Factors Improvements—Examples of human-factors improvements that probably would have avoided some SNO incidents are improved standardization or arrangement of drugs on the anesthesia workspace and improvements in design of gas-flow control knobs and breathing circuit scavenging connections (both of which now are mandated by national standards for new apparatus). No fewer than 14 of the SNO incidents probably would have been detected much more promptly had some combination of monitoring based on oxygen sensing and surveillance of ventilation been in use. It is difficult to generalize about monitoring tactics, since hazards vary with equipment configurations. The simplest but not the only approach would include oxygen concentration monitoring with a low limit alarm and airway pressure monitoring capable of alarming in the event of a disconnect or large leak in the breathing system. Fortunately, these "vigilance aids" are becoming standard in anesthesia. Lack of ECG or blood pressure monitoring was *not* an issue in any SNO incident, perhaps because all of the hospitals studied had adopted these long ago as a minimal standard practice in anesthesia. In only one case, use of an esophageal stethoscope could have provided earlier warning of the accidental extubation. However, in two other SNO incidents disconnects went unnoticed, despite such monitoring (see Newbower *et al.*[9] for further discussion).

4. Organizational Improvements—Most of the strategies imply a need for improvement of the overall planning and managing of anesthesia delivery services. In a third of SNOs, we identified some specific organizational deficiency not described by the other labels. For instance, there were numerous instances in which trainees were assigned to cases for which they clearly had inadequate experience or preparation. Although inadequate supervision or training also may have been cited as preventive strategies for these incidents, the initial failure was in the deployment of personnel.

How can these incidents be related to the earlier literature describing anesthesia mortality and morbidity? Anesthetic risk studies have been reviewed by Goldstein and Keats[4] and by Phillips and Capezzi.[2] More recent studies from outside the United States have been reported by Wylie[5] (United Kingdom), Harrison[6] (South Africa), Utting *et al.*[18] (United Kingdom), Holland[17] (Australia), and Lunn and Mushin (United Kingdom).[15] Estimates of the annual mortality attributable to anesthesia in the United States range between 2,000 and 10,000.[2,3,19] Roughly 75% of the deaths involve moderately ill to very ill patients (ASA III or greater). Estimates of the contribution of errors to anesthesia-related mortality also vary widely. Yet, there does appear to be concensus that at least half of the deaths are preventable, given existing medical knowledge and accepted anesthesia practice. The report by Lunn and Mushin provides the most recent and thorough analysis of anesthesia-related deaths, suggesting that at least 55% are "avoidable."

There are no firm statistical data on the extent of anesthetic injuries in the United States. However, even the lowest estimates suggest cause for concern. Although anesthesia mortality is low when compared with most causes of death in the United States, it is relatively high when compared with the mortality of commercial aviation (approximately 125 deaths/yr). This comparison is particularly relevant because the exposure in aviation is similar to that of anesthesia (20×10^7 passenger boardings *vs.* 20×10^6 anesthetics). In both cases injured parties have no direct responsibility for or practical defense against injury. Thus, in both cases, extraordinary measures may be warranted to minimize the risk. In aviation, such measures have been taken, perhaps because of the dramatic nature of airline crashes. In anesthesia, prevention is left primarily to the vigilance of individual

¶ Suggested guidelines for preoperative apparatus inspection and relief exchange protocols are given in Cooper, JB: Prevention of Anesthetic Mishaps. 1983 American Society of Anesthesiologists Refresher Course Lecture.

anesthetists, although there recently have been extensive efforts to improve the safety of anesthetic equipment and apparatus by developing standards at the national level.

From the various studies of anesthetic risk, it is almost impossible to infer an overall pattern of causes of anesthetic deaths. The lack of crucial information as well as differences in the populations studied probably accounts for some of the discrepancies among published distributions of causes of anesthetic mortality. Typically, only broad categories are examined and only factors associated with the patient, (*e.g.*, physical status, age, anesthetic technique, and surgical procedure) are examined. The causes of injury are grouped according to the most obvious and superficial features. More importantly, there are inconsistencies in the ways incidents are classified. For instance, the inadvertent missetting of an anesthetic vaporizer variously could be called a technical error (see Utting *et al.*[18]), improper anesthetic management (see Phillips *et al.*[20]), or a drug overdose (see Boba[21]) depending upon the investigator's perspective. The death of a particularly ill patient during intravenous induction with pentothal could be reported as caused by the patient's disease, by misdiagnosis of volume status, or by drug overdose. In the final analysis, these classifications are not very meaningful to the individual anesthetist who wishes to apply the general experience of others to improving his or her specific practice. Neither is it particularly meaningful to report data merely on the ultimate physiologic cause of death from anesthesia, *e.g.*, cardiac arrest, hypoxia, aspiration. For these reasons we offer classification techniques related to potential preventive strategy.

Although human error was the failure in the vast majority of both injurious and noninjurious incidents, in only four of the SNO incidents was there an indication of staffing by less than a basically competent anesthetist or anesthesia trainee. Certainly, this is a subjective observation, yet, we believe it to be both valid and of significance. Our impression coincides with that of Davis, formed in an unpublished study of 50 anesthesia malpractice claims.** He concluded ". . . that many of these claims were generated because of temporary and atypical lapses in the vigilance of otherwise competent anesthetists. . . ."

Perhaps the most insidious hazard of anesthesia is its relative safety. The individual anesthetist rarely, on average, will be responsible for a serious iatrogenic complication. It is our impression from the process of collecting incidents, that most seemingly minor errors are not taken seriously and that risk management depends almost solely on the anesthetist's ability to react instinctively and flawlessly every time a problem arises. Yet reducing the number of such challenges to vigilance would seem prudent. One could infer from indications of a steady improvement in overall levels of anesthesia risk that no special additional efforts are warranted. Yet, most of the specific errors listed here, in fact, are related to complex advances in anesthesia that have reduced inherent physiologic dangers, *e.g.*, the increased armamentarium of drugs and anesthetic agents (with resultant serious drug errors), artificial ventilation (with resultant devastating disconnections and misconnections), and tracheal intubation (with resultant errors in airway management technique and occasional esophageal intubations). Anesthetists also are faced with a patient population at higher risk undergoing increasingly severe surgical interventions. Other studies confirm the expected—that higher risk patients have a higher anesthesia-related mortality. The data in Table 9 suggest that higher risk patients are also more likely to be affected by errors than are healthy patients, *i.e.*, only 41% of all reported errors involved moderately or severely ill patients, while 74% of SNOs involved this class of patients. We may have reached a point of diminishing returns. Concomitant with the increasing complexity of care and increasing demands on the human operator may be an expected increase in the incidence and effects of errors. Yet, such problems should be solvable by additional attention to human factors. Awareness of the problems is a necessary first step.

The authors are indebted to the anesthesiologists and nurse anesthetists whose participation made this study possible. They gratefully acknowledge the contributions of their colleagues Ms. Charlene Long, Dr. James Philip, Dr. Edwin Trautman, Dr. Miachel D'Ambra, and Dr. Michael Long.

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