The changing profile of anesthetic practice: an update for internists

THOMAS L. HIGGINS, MD

■ **BACKGROUND** Internists are commonly consulted to "clear" patients for anesthesia and surgery. Newer anesthetic agents and techniques now extend limits and possibilities beyond what many internists were taught.

■ **OBJECTIVE** To update internists on recent changes in anesthetic management and how they affect the preoperative evaluation.

■ **SUMMARY** Recent advances in anesthetic management include new monitoring standards, balanced anesthetic technique, new agents, equipment changes, better understanding of human factors, and expanded pain management techniques.

■ **CONCLUSIONS** Postoperative care will likely assume increasing importance in determining anesthesia-related morbidity and mortality. For this reason, increased interaction and cooperation between surgeons, internists, and anesthesiologists are needed.

■ INDEX TERMS: ANESTHESIA; ANESTHETICS; PREOPERATIVE CARE; INTERNAL MEDICINE ■ CLEVE CLIN J MED 1993; 60:219–232

From the Department of Cardiothoracic Anesthesia, The Cleveland Clinic Foundation.

Address reprint requests to T.L.H., the Department of Cardiothoracic Anesthesia, G30, The Cleveland Clinic Foundation, 9500 Euclid Avenue, Cleveland, OH 44195.

THE PRACTICE OF anesthesia has undergone dramatic changes in recent years. State-of-the-art anesthetic technique now routinely incorporates monitoring that was unavailable or prohibitively expensive a decade ago. Specific drugs now provide the individual components of total anesthesia (pain relief, amnesia, muscle relaxation, and unconsciousness), thus minimizing side effects such as vasodilatation and myocardial depression, which can occur when a single agent is used for all components. This "balanced" technique allows better care of high-risk patients, particularly those with marginal circulatory reserve. Agents such as atracurium, vecuronium, alfentanil, and propofol, which were not available at the onset of the 1980s, allow faster emergence from anesthesia and have contributed to a more pleasant experience for the patient, often with reductions in recovery room stay and, thus, costs. Increased emphasis on physiologic monitoring and on the importance of modulating the

TABLE 1
PERIOPERATIVE MORTALITY

Study	Era	Cases	Deaths	Primary anesthetic deaths		
				Mortality	General	Spinal
Beecher-Todd[3]	1948–1952	599 548	2505	0.42%	1:1560	1:1780
Dripps et al[4]	1947–1957	120 000	1285	1.07%	1:537	1:1560
Memery HN[5]	1955–1964	114 866	1027	0.89%	1:2666	1:4754
Marx et al[6]	1965–1969	34 145	645	1.89%	1:1302	1:732
Turnbull et al[7]	1973–1977	195 232	423	0.22%	Not reported	Not reported

stress response in surgical patients has become widespread. The relationship between perioperative stress and myocardial infarction has been identified and appropriate changes enacted.

The internist asked to "clear" a patient for surgery may be unfamiliar with many of these advances and the latitude they provide in caring for patients previously considered unacceptable for surgery or at very high operative risk. This article addresses current anesthetic practice and its implications for the preoperative evaluation and preparation of patients.

HISTORICAL PERSPECTIVE

Early technical developments

Anesthesia was first publicly demonstrated in 1846, and the first anesthetic death was reported less than 2 years later.[1] As a result of that tragedy, serious debate ensued on the merits of ether vs chloroform, beginning a tradition of evaluation of anesthetic agents and their contribution to operative mortality. (Neither chloroform nor ether is in clinical use today.) The margin of safety with chloroform was extremely small: overdose caused cardiac standstill, and inadequate amounts would allow catecholamine release to precipitate arrhythmias. Diethyl ether gradually became preferred over chloroform; but because of flammability and the availability of newer, better agents, ether also fell out of use. In the mid-19th century, however, ether and chloroform were the only anesthetics available. Sterile technique did not become widespread until 1879,[2] and the first local anesthetic (cocaine) was not introduced until 1884, so regional anesthesia was slow to gain acceptance. Tracheal intubation and supplemental oxygen were introduced in the first two decades of the 20th century. During the 1930s and 1940s, new intravenous agents such as thiopental were introduced, and in the 1940s, blood transfusions became commonplace. Battlefield experiences during World War II introduced surgeons to new techniques and to the advantages of full-time anesthesia coverage. Anesthesia came to be viewed as a medical specialty rather than something to be delegated to the least experienced member of the surgical team, often the medical student.

Mortality and morbidity trends

The "modern" era of anesthesia began in the 1950s, a time of technological advances in anesthesia equipment and the introduction of electrocardiographic monitoring in the operating room. Examination of mortality data prior to this era is probably irrelevant, since relatively fewer people were viewed as good candidates for surgery, and many operative deaths, regardless of cause, were attributed to the "inability to take anesthesia."

In 1954, Beecher and Todd[3] published the results of the first major multicenter study to examine the risk of anesthesia separate from overall operative mortality. The study, which examined nearly 600 000 anesthetic procedures at 10 institutions between 1948 and 1952, concluded that anesthesia was the primary or contributory cause in 384 of 2505 perioperative deaths. The risk of death was comparable with either general or spinal anesthesia. However, an excess risk of mortality could be attributed to the use of the neuromuscular blocking drug curare, which had recently come into widespread use without a full understanding of its risks.

The Beecher and Todd study was widely criticized, yet it led to recognition of the dangers of hypoventilation following the use of muscle relaxants, and it prompted others to examine the problem of anesthesia-related morbidity. Subsequent studies reported varying overall and anesthesia-related mortality (*Table 1*).[3–7] No recent studies have examined anesthetic mortality in a comparable manner, and it is unclear whether anesthesia-related mortality has declined.[8] Recent data suggest that, during the periods 1973 to 1978 and 1979 to 1983, nonfatal complications actually increased from 7.6% to 10.6% of all cases.[9]

The reasons for this apparent increase in complications are debatable, but they likely relate to increasing numbers of elderly and more seriously ill patients rather than to a decline in anesthesiologic or surgical skill. Data from The Cleveland Clinic Foundation cardiac anesthesia registry confirm that, as the patient population ages, perioperative morbidity and mortality rise, with morbidity rising faster than mortality in septuagenarians and octogenarians (*Figure*). The median age of patients undergoing surgery is increasing. For example, nearly 30% of patients undergoing cardiopulmonary bypass surgery are aged 70 and older, and nearly 5% are aged 80 and older. Therefore, despite improvements in anesthetic and surgical care, overall morbidity and mortality have not decreased, because operations are being performed on patients at higher risk than patients in previous years.

In spite of this, the insurance industry feels that anesthesiologists are doing a better job than they were a few years ago, as evidenced by improved "relativity factor" ratings. The relativity factor is used to determine the malpractice premium for a particular specialty. General practitioners have a relativity factor of 1, while neurosurgeons have a relativity factor of 9. In the past 5 years, most insurance companies have downgraded anesthesiologists from their historic relativity factor of 5 to a factor of 3 or, in the case of the Harvard self-insurance group, 2.5.[10] What are some of the possible explanations for this phenomenon?

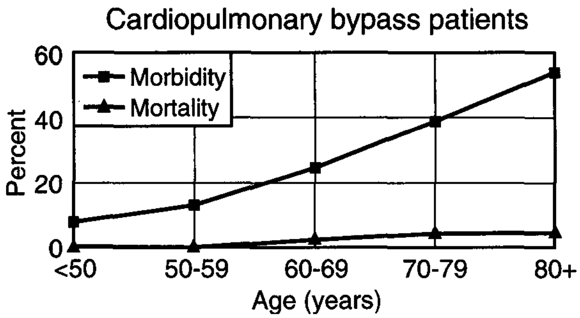

FIGURE. Morbidity and mortality as a function of age in cardiopulmonary bypass patients at the Cleveland Clinic from 1986 to 1988 (N=5049).

TABLE 2
MINIMAL MONITORING STANDARDS OF THE DEPARTMENT OF ANESTHESIA, HARVARD MEDICAL SCHOOL (1985)*

- Anesthesiologist or nurse anesthetist present in operating room
- Blood pressure and heart rate every 5 minutes
- Continuous monitoring:
  - Electrocardiogram
  - Ventilation: reservoir bag, auscultation, expired gas flow, end-tidal carbon dioxide
  - Circulation: pulse, auscultation, arterial trace, oximetry
- Breathing system disconnect alarm
- Oxygen analyzer
- Ability to measure temperature

*Adapted from Eichhorn et al, reference 12

RECENT ADVANCES IN ANESTHESIA

Actually, a number of recent developments in anesthesia technique may be responsible for improving safety and effectiveness. These include new monitoring standards, use of the balanced technique, the arrival of new agents, equipment changes, and human factors such as critical-incident analysis and improved residency training programs.

Monitoring standards

Malpractice awareness, partly mandated by federal and state governments, has brought about a change in what is considered acceptable monitoring in the operating room. The Harvard Medical School anesthesia department[11,12] implemented a set of standards in 1985 (*Table 2*) that were subsequently adopted in modified form by the American Society of Anesthesiologists (ASA) in 1986.[13] These standards require that an anesthesiologist or certified registered nurse anesthetist be in the operating room throughout the entire procedure. Blood pressure and heart rate should be checked at least every 5 minutes. Continuous electrocardiographic monitoring is required. Continuous monitoring of ventilation must include observing the anesthesia circuit reservoir bag distending and emptying, monitoring expiratory flow on the anesthesia machine, or monitoring the end-tidal carbon dioxide concentration of exhaled gases. Circulation monitoring should include a hand on the pulse, auscultation of heart sounds, an arterial tracing, or pulse oximetry. A breathing system alarm must be in place to warn the anesthesiologist of accidental disconnection or leakage while the patient is on the ventilator. An oxygen analyzer with alarms ensures that the patient does not receive a

TABLE 3
EFFECTS AND SIDE EFFECTS OF ANESTHETIC AGENTS

	Components of anesthesia				Hemodynamic effects		
	Unconsciousness	Amnesia	Control of stress response	Muscle relaxation	Blood pressure	Heart rate	Cardiac output
Nitrous oxide	+*	+	0	0	0	0 to ↑	0 to ↑
Halogenated hydrocarbons	+++	+	+	+	↓	↓	↓
Barbiturates	+++	+	–	0	↓	↓	↓
Propofol	+++	+	0†	0	↓	↓	↓
Opioids	+	0	+++	0	0 to ↓	0 to ↓‡	0
Benzodiazepines	+	+++	0†	+	0 to ↓	0	0
Neuromuscular blockers	0	0	0	+++	0	0§	0

*+++, primary effect; +, some effect; 0, no effect; –, antagonist effect; ↑, increase; ↓, decrease
†Not fully investigated; may have some effect
‡Bradycardia has been reported when high-dose opioids and muscle relaxants are used for sole induction of anesthesia (reference 17)
§Except pancuronium which has a vagolytic effect

hypoxic mixture. Finally, the ability to measure temperature is mandated so that malignant hypothermia can be diagnosed early and treated appropriately.

Evidence that the monitoring standards have affected outcome is difficult to gather, given that the rate of occurrence of adverse events was already low.[13] However, adherence to a standard of care reduces but does not eliminate the probability of a successful malpractice action.[14] Data from the Massachusetts Joint Underwriting Association reveal 27 closed claims for hypoxic injury from 1975 to 1986 and four claims in 1987 before the standards program had been adopted.[15] In contrast, no hypoxia claims occurred during 1988. Analysis of closed claims supports the contention that most adverse events (72%) are preventable with better monitoring.[16]

Balanced anesthetic technique

Although inhalation technique has progressed from ether delivered via an "open-drop" mask to nonflammable agents delivered through calibrated vaporizers via an endotracheal tube and monitored by agent analyzers, the principle behind inhalation agents remains the same. Anesthetic agents—halogenated hydrocarbons that act upon cellular membranes—affect cellular function in a global manner. The advantage of inhaled agents is that all four components of anesthesia can be provided with a single drug (*Table 3*); the problem is that doses sufficient to provide some of these functions also produce significant cardiovascular effects. This is not a problem in young, healthy patients, but it limits the use of inhaled agents in patients with compromised cardiac function.

In contrast, the balanced anesthetic technique uses drugs that act at specific sites for specific purposes. With this technique, opioids (morphine, fentanyl) provide pain relief and control of the stress response; sedative hypnotics (midazolam, propofol) provide amnesia and hypnosis; and neuromuscular blockers (vecuronium, pancuronium) provide muscle relaxation. Opioids have little effect on myocardial contractility and reduce blood pressure primarily through reduced sympathetic tone.[18] Muscle relaxants can be chosen to provide either no hemodynamic effect or moderate vagolysis, should increased heart rate be appropriate. For example, induction of anesthesia with very large doses of opioids can produce bradycardia,[17] an effect nicely offset by the addition of pancuronium.

Inhaled agents can be added in small amounts as part of a balanced technique to augment the effects of other drugs and to minimize the patient's potential for remembering operating room events. As part of a balanced technique, vasodilation and myocardial depression from inhaled agents are less problematic than when they are used alone. The design of a balanced anesthetic technique thus takes advantage of the primary action of each drug while minimizing effects on other organ systems.

Intravenous anesthesia, initially employing morphine for the opioid component, was rediscovered during the late 1960s when the introduction of coronary artery bypass surgery led to a sudden increase in the number of "cardiac" patients undergoing surgery. The technique spread from the cardiac operating room to other locations as more and more anesthesiologists gained training and experience in this method. However, many internists may be unfamiliar with the advantages of opioid-based anesthesia for cardiac patients, having received their anesthesia training prior to its widespread use.

The availability of opioids with minimal hemodynamic effects has enlarged the pool of patients who can safely tolerate anesthesia. Conventional thiopental-inhaled hydrocarbon anesthesia depresses ventricular function. Patients with pre-existing heart disease are at risk for hypotension and resultant hypoperfusion of the coronary arteries, or for significant reduction in cardiac output resulting in a low-output state during the operation. With the balanced technique, hypotension and low cardiac output are easier to avoid. Until recently, use of opioid-based techniques mandated a period of postoperative ventilatory support, since opioid reversal using naloxone can be associated with hypertension, tachycardia, and the potential for ventricular irritability[19] and pulmonary edema.[20] Shorter-acting opioids (eg, sufentanil and alfentanil), infused anesthetics (eg, propofol[21]), and newer neuromuscular blocking agents (eg, mivacurium, atracurium, vecuronium) make a balanced technique feasible even for outpatient surgery.

New agents

The classic agents popular during the middle part of the 20th century (nitrous oxide, enflurane, halothane, curare, and methoxyflurane) are being supplanted by newer agents. Isoflurane, an inhaled agent introduced in 1981, has displaced halothane, except for pediatric surgery, primarily because of medicolegal concerns about the association of halothane with liver dysfunction in adults.[22] Isoflurane has been implicated in causing a steal phenomenon (ie, a diversion of blood flow away from marginally perfused coronary beds) in patients with coronary artery disease, although the issue is far from settled.[23–26] Despite the possibility of a steal, coronary blood flow remains adequate with isoflurane, which, compared with enflurane and halothane, has the largest circulatory margin of safety and produces the least myocardial depression for a given degree of anesthetic action.

The shorter-acting opioids fentanyl, sufentanil, and alfentanil, all introduced in the 1970s and 1980s, have almost completely supplanted the older opioids because of their lack of histamine release and their ability to control stress with minimal hemodynamic effect. Pancuronium, introduced in the 1960s, is still in common use, but atracurium and vecuronium, introduced in the 1980s, allow better control of muscle relaxation with shorter duration of action and minimal hemodynamic effects. As a vagolytic, pancuronium has a tendency to produce tachycardia[27]: in a patient with coronary artery disease and a resting heart rate of 80 beats per minute at induction, pancuronium could cause the heart rate to accelerate and allow ischemia to develop. This kind of hemodynamic change is seldom seen with atracurium, vecuronium, or three recently introduced agents (doxacurium, mivacurium, and pipecuronium).

Induction of anesthesia no longer requires the use of a barbiturate such as thiopental or methohexital, now that midazolam, propofol, and etomidate are available. Midazolam, a short-acting benzodiazepine, is familiar to most internists as a sedative for invasive procedures. The hemodynamic effects of midazolam doses required for induction of anesthesia are similar to those seen with thiopental.[28]

Propofol, a recently introduced anesthetic, is used to both induce and maintain anesthesia. It can be thought of as the intravenous equivalent of inhaled agents, although it differs in some respects (*Table 3*). Propofol appears to cause less myocardial depression than thiopental at equianesthetic doses,[29] although vasodilation and hypotension can occur.

Etomidate is another alternative for the induction of anesthesia, particularly when hypotension is to be avoided; however, it cannot be used for prolonged periods because of the risk of adrenal suppression.

Although still in active use, barbiturates have a propensity to accumulate with repeated doses, thus delaying awakening with short procedures. Compared with thiopental, propofol (because of its shorter half-life) is associated with far less residual effect (as measured by amount of body sway) at the conclusion of short procedures, allowing earlier mobilization and discharge from the recovery room.[30]

A number of studies have examined the influence of various anesthetic agents on outcome. Clinically important differences exist with respect to hemodynamics, arrhythmias, and recovery times, yet death rates are so low that it is difficult to draw conclusions regarding mortality outcome.[31] Studies have consistently identified patient factors and the skill of the anesthesiologist—rather than the specific agent utilized—as prime contributors to outcome.[32–34]

Equipment changes

Modern anesthesia machines have temperature-compensated calibrated vaporizers and better monitoring of gas flow; the newest machines interface with computers to chart operating-room events automatically. Operating-room monitors coordinate display of physiologic parameters such as heart rate, central venous and pulmonary pressures, arterial pressures, electrocardiography, oxygen saturation, and end-tidal carbon dioxide concentration.

Safety improvements added to anesthesia equipment over the years include oxygen concentration monitors, supply pressure alarms, and a single oxygen flow control knob that is shaped differently than the other knobs to minimize the risk of inadvertently turning the wrong knob. Plumbing of oxygen flow meters is standardized in the United States, so that in the event of a leak when multiple gases are used, oxygen excess rather than oxygen deficit will be delivered. Central gas supply gauges, color-coded flow meters, pin-indexed tank connections, and diameter-indexed line connections all make it difficult to put the wrong gas cylinder on the anesthesia machine or to hook up the supply to the wall outlets in the wrong manner. Newer anesthesia machines have a linkage mechanism that prevents inadvertent delivery of a hypoxic mixture of nitrous oxide: should the anesthesiologist turn on the nitrous oxide knob without turning up the oxygen, a mechanism automatically raises the oxygen level so that the patient receives at least 21% oxygen.

These improvements were created in response to patient injuries and, although expensive to implement, have paid off by preventing more injuries. All machines sold after 1984 must comply with the American National Standards Institute (ANSI) requirements for safety and performance for anesthesia.[35] As older machines without these safety devices gradually come out of service and are replaced by newer machines, failures due to equipment problems should become even less frequent.

Human factors

Critical-incident analysis, a technique used in human-factors research, has been applied to the study of anesthesia mishaps.[36] The objective of this technique is to retrospectively uncover patterns of incidents that can then be studied prospectively. About 82% of preventable incidents involve human error, such as breathing-circuit disconnections, inadvertent changes in gas flow, and syringe-swap errors resulting in administration of other than the intended drug. Communication problems, haste, and distraction have also been identified as frequent contributors to critical events.[36] This has led in turn to investigation of work patterns and the effect of fatigue on performance.[37] Anesthesia simulators can duplicate some of the situations encountered in the operating room, allowing training and research on performance.[38]

Improved anesthesia residency training programs and additional emphasis on continuing medical education have been credited with increased anesthesia safety.[39] Although difficult to document objectively, there is a perception that more top medical students are choosing anesthesia as a specialty today than 10 or 20 years ago. The continuum for anesthesia is now 4 years following graduation from medical school and includes mandatory critical care exposure. Many anesthesia trainees opt for additional subspecialty training in cardiac anesthesia, pain, pediatrics, and critical care.

Pain management techniques

Anesthesiologists are increasingly involved in aggressive perioperative pain control. Evidence that controlling perioperative stress response improves outcome[40–43] continues to drive clinical practice and research in this area. Options for pain relief include systemic agents such as opioids and nonsteroidal anti-inflammatory drugs, nonpharmacologic management, and site-specific pain control utilizing regional anesthetic techniques. Equipment manufacturers are responding with ever more sophisticated pumps to provide patient-controlled analgesia by intravenous and epidural routes.

A considerable and growing body of knowledge has spawned anesthesia subspecialty fellowships, and subspecialty certification in both critical care and pain management is now available. Pain control need not be the sole province of board-certified individuals; however, interactions between residual operative anesthetic agents and postoperative analgesic drugs require that pain control be well coordinated. For example, maximal respiratory depression after epidurally administered opioids occurs 6 to 10 hours after a single dose.[44] Practitioners unaware of this delay may inadvertently augment this late respiratory depression by administering intravenous opioids prior to the maximal effect.

The methods and the intensity of managing acute pain vary widely, and professional and public demand for high-quality intervention continues to grow. In response to this demand, clinical practice guidelines for acute pain management have recently been released.[45]

WHERE DO THE RISKS PERSIST?

Limitations of neurologic monitoring

Monitoring neurologic function in "real time"—so that rapid interventions can be made in the event of a problem—remains difficult. Since the frequency content of electroencephalography (EEG) correlates highly with cortical blood flow, EEG monitoring has been used to detect severe hypoxia, air embolism, and hypotension with inadequate cerebral blood flow.[46]

Monitoring conventional EEG may be too demanding to allow the anesthesiologist to attend to the patient and the EEG at the same time. Devices that process EEG with Fourier analysis (mathematical simplification of complex periodic data) allow the anesthesiologist to monitor a compressed display of frequency bands from two EEG channels.[47] This technique provides information on the patient's level of consciousness and also provides evidence of ischemia, particularly when it is unilateral and severe. While this EEG technique allows real-time monitoring, it provides less complete information than the standard EEG. It is possible to miss end-organ damage to the brain if ischemia occurs in an area that is not monitored, particularly since this type of EEG only monitors cortical activity.

Somatosensory evoked potentials, which demonstrate neurologic continuity between remote stimulation and the cortex, are increasingly used for monitoring during neurosurgical and orthopedic procedures.[48] The advantage of somatosensory evoked potentials is the ability to monitor subcortical events, at least in sensory pathways. This technique remains investigational rather than routine because of time demands with currently available equipment. Reduced cost of information processing will undoubtedly make these devices more cost-effective in the next decade.

Limitations of respiratory monitoring

Continuous information on oxygenation has contributed to improved outcome by alerting the anesthesiologist to correctable hypoxemia and hypovolemia in time for action to be taken. The pulse oximeter, introduced in the mid-1980s, displays oxygen saturation continuously, but it also has its limitations[49]: oximetry readings can be confounded by intravenous dyes such as methylene blue, indocyanine green, and indigo carmine.[50] Pulse oximetry doesn't work well when the patient is cold and vasoconstricted; this presents a major problem in cardiac surgery, where patients are often cooled during cardiopulmonary bypass. Intra-arterial electrodes and other devices that measure partial pressure of oxygen, pH, and partial pressure of carbon dioxide in real time are just now becoming clinically available, but their cost will initially limit routine use.

Increased emphasis has been placed on identifying risk factors for aspiration of stomach contents (ie, recent intake per os, obesity, pregnancy, and compromised gastroesophageal function). Risk of aspiration can be minimized by pretreating patients with histamine blockers, allowing them nothing by mouth, and using a "rapid-sequence" induction technique.

Adverse physiologic responses

Part of the skill of anesthesiology lies in ablating the response to noxious stimuli—eg, intubation, skin incision, visceral traction, and hemodynamic changes. Blocking the stress response is not only humane but also may reduce the incidence of perioperative ischemia, other morbidity, and mortality.[51–53] The stress response, defined by a rise in cortisol or growth hormone levels, can be blunted with opioids such as morphine[54] or fentanyl,[55] or blocked with regional anesthesia.[56,57]

Generally, blocking the stress response is considered beneficial, although not all of its elements (eg, immune response) have been completely explored. Anesthetic agents modulate the immune response,[58] including lymphocyte function.[59] The endocrine and metabolic responses to the stress of anesthesia and surgery are complex,[60] and consideration of the role of endogenous mediators and how they should be modulated is in its early stages. Cardiovascular morbidity continues to occur, despite recognition of the role of hemodynamic control in affecting this outcome. Research is now focusing on the importance of postoperative control of heart

TABLE 4
EFFECTIVENESS OF MONITORING DEVICES FOR VARIOUS ADVERSE EVENTS*†

	Disconnection	Hypoventilation	Esophageal intubation	Bronchial intubation	Circuit hypoxia	Halocarbon overdose	Hypovolemia	Pneumothorax	Air embolism	Malignant hypothermia	Aspiration	Acid-base imbalance	Arrhythmia	Intravenous drug overdose
Pulse oximeter	++	++	++	++	++	0	++	++	++	+	+	0	+	++
Capnograph	+++	++	+++	0	0	0	+	+	++	+++	+	++	0	++
Spirometer	+++	+++	+	0	0	0	0	+	0	+	0	0	0	+
Autosphygmomanometer	0	0	0	0	0	++	+++	+	++	0	0	0	0	++
Stethoscope	+++	+	++	++	0	+	0	+	+	0	+	0	++	+
Halometer	+	0	0	0	0	+++	0	0	0	0	0	0	0	0
Oxygen analyzer	0	0	0	0	+++	0	0	0	0	0	0	0	0	0
Electrocardiogram	0	0	0	0	0	+	0	0	0	0	0	0	+++	0
Thermometer	0	0	0	0	0	0	0	0	0	++	0	0	0	0

*Reprinted with permission from: Whitcher C, Ream A K, Parsons D, et al. Anesthetic mishaps and the cost of monitoring: a proposed standard for monitoring equipment. *Journal of Clinical Monitoring* 1988; **4:** 5–15.
†+++, high value; ++, moderate value; +, low value; 0, no value

rate to further reduce the incidence of ischemia and infarction.[43]

Equipment failure and human error

Anesthesia-related problems that can still occur in the operating room include breathing circuit disruption, hypoventilation, esophageal intubation, breathing circuit hypoxia, overdose of a drug or inhaled agent, pneumothorax, and air embolism. Currently available monitoring is only valuable for a limited number of potential problems (*Table 4*); no one monitor is sufficient by itself. A capnograph will warn the anesthesiologist of a breathing circuit disconnection or inadvertent esophageal intubation but will not be useful to detect circuit hypoxia, drug overdose, or arrhythmias. With a spectrum of monitors in place, the anesthesiologist can identify most problems early and begin to treat them before they cause injury to the patient; however, there are still gaps in this matrix.[61] Fixation errors (failure to re-evaluate a situation in the face of new information) are still common[38] and account for a substantial fraction of "human" errors.

There is also a very real danger that the anesthesiologist can become more concerned with the monitoring technology than with the patient. Monitors can give false alarms or suddenly cease to work. When a machine displays an abnormal number, it is natural to look for a mechanical malfunction, since this is most often the reason for an alarm status. Valuable time can be wasted when the alarm is real but disbelieved. There is a temptation to concentrate on trying to get a pulse oximeter working instead of first looking at the patient for a possible circuit disconnection or serious hypotension. Too much reliance on technology can be worse than no technology at all. And finally, the ever-present danger of a total power failure makes backup plans and management strategies essential.[62,63]

DOES THE CHOICE OF ANESTHETIC AFFECT OUTCOME?

The spectrum of choices for anesthesia now extends well beyond the simple question of general vs regional anesthesia ("regional" encompasses both spinal epidural and local anesthesia). For general anesthesia, one can administer a pure inhalation anesthetic with an agent such as isoflurane, enflurane, or halothane, with or without intravenous induction with barbiturates, and with or without supplemental nitrous oxide. One could employ a total intravenous technique with an opioid, a neuromuscular blocker, and either propofol or midazolam. A hundred variants could be conceived as long as all four components (*Table 3*) of anesthesia are delivered in some fashion.

Total intravenous anesthesia using short-acting narcotics, sedative-hypnotics, and short-acting muscle relaxants is gaining popularity because the patient can be ready for extubation within minutes of turning off such an infusion. This technique is cost-effective for outpatient surgery, although a major concern with total intravenous anesthesia is that the patient can remain aware of what is going on and be unable to signal distress due to neuromuscular blockade. If general anesthesia is not necessary for a given procedure, options for controlling stress include monitored anesthesia care (patient is awake but sedated with propofol or midazolam), local anesthetics, epidural blocks, and spinal blocks.

General vs regional anesthesia

Controversy continues over general vs regional anesthesia. What are their relative benefits and drawbacks?

Regional techniques offer the advantage of leaving the central nervous system unaffected (the best monitor of cerebral function is an awake, conversing patient). Regional anesthesia also produces less effect on the respiratory, gastrointestinal, and renal systems.[60]

On the other hand, induction of regional anesthesia produces hypotension because of the sudden reduction in afterload as the sympathetic nervous system is blocked. While this can easily be managed with positioning, fluids, or vasopressors, it is an important consideration in patients with coronary insufficiency, in whom a drop in coronary perfusion pressure may cause ischemia. Thus, regional anesthesia is not *necessarily* safer in cardiac patients.

The level of neural blockade with regional anesthesia is not perfectly predictable. "Total" spinal blockade with hemodynamic collapse can occur since the volume of cerebrospinal fluid and the spread of the anesthetic vary by patient even when the same per-kilogram dose is used. Patients often have exaggerated fears of adverse neurologic sequelae following spinal anesthesia. There is a small but real incidence of headache after spinal anesthesia. Some surgeons are uncomfortable having a patient remain awake during surgery. Finally, if the regional technique fails, there is some added risk in converting to general anesthesia if the switch is performed in haste and without the same care that would have been taken if general anesthesia had been planned from the beginning. Spinal anesthesia, while useful, should not be uncritically accepted as the best option in high-risk patients.

The actual risk of neurologic injury from regional anesthesia is small. In a study involving 65 000 patients who received spinal anesthesia, only one case of paraplegia was reported, and this occurred in a patient who had a pre-existing spinal cord tumor.[64] However, this series included seven cases of lower-extremity nerve deficits, three cases of postoperative incontinence, and eight cases of peripheral neuropathy.

Regional techniques suppress the stress response by interrupting sympathetic nerve impulses at the spinal level. Growing opinion holds that side effects of surgery are related to increased catabolic demands triggered by stress; regional techniques modify this response and thus reduce morbidity.

Benefits of epidural anesthesia followed by postoperative epidural analgesia include a lower incidence of overall complications,[40] better cardiovascular stability,[41,65–67] fewer infections,[40] better pulmonary function,[67] and improved nitrogen balance.[42] Blood loss is reduced, particularly in hip replacement surgery[68] (the one operation in which regional anesthesia is clearly preferable to general anesthesia). One intriguing study found that in patients randomly assigned either to epidural anesthesia and postoperative analgesia or to general anesthesia, the former group had a lower overall postoperative complication rate and fewer deaths, cardiovascular failures, and major infections.[40] The trend to fewer renal, hepatic, and respiratory problems was not significant.[40] Hospital costs were also lower in this group. Epidural anesthesia with analgesia has also been shown to reduce postoperative thrombotic events after hip surgery[69] and major vascular procedures.[70]

The choice of anesthetic is less important than the skill and experience of the anesthesiologist, especially for controlling the heart rate in patients with cardiovascular disease.[34,35] Therefore, even though spinal anesthesia is theoretically less invasive from a respiratory standpoint, in the hands of an anesthesiologist expert in performing general anesthesia, even the patient with chronic obstructive pulmonary disease may be at lower risk with

TABLE 5
AMERICAN SOCIETY OF ANESTHESIOLOGISTS' PHYSICAL STATUS SCALE*

Classification†	Patient status
I	No organic, physiologic, biochemical, or psychiatric disturbance; localized operation
II	Mild to moderate systemic disease caused by condition to be treated or other process (hypertension, anemia, smoking, diabetes, obesity, asthma, chronic bronchitis, age <1 or > 70, pregnant)
III	Severe systemic disturbance of whatever cause (angina, poorly controlled hypertension or diabetes, massive obesity, symptomatic chronic obstructive pulmonary disease, or prior myocardial infarction)
IV	Severe systemic disorder already life-threatening and not correctable by operation (unstable angina pectoris, congestive heart failure, debilitating chronic obstructive pulmonary disease, hepatorenal failure)
V	Moribund with little chance of survival (ruptured aneurysm with shock, major cerebral trauma, massive pulmonary embolus)

*Adapted from Owens et al, reference 78
†Add modifier "E" for emergency operation

general anesthesia. Many anesthesiologists are more comfortable with general anesthesia because the depth and duration of anesthesia are easier to control, particularly with the new shorter-acting agents. Maintaining hemodynamic stability is easier, particularly with the use of opioid-based techniques.

The chief argument against general anesthesia is the side effects. General anesthesia decreases renal blood flow and increases antidiuretic hormone. Some inhaled agents that are highly metabolized can produce renal toxicity due to fluoride release. Fluoride toxicity was a major concern with methoxyflurane, which is no longer in use, but it can theoretically occur with enflurane and desflurane when used in high concentrations for extended periods in patients with pre-existing renal dysfunction.[71]

As difficult as it is to determine from retrospective studies whether regional or general anesthesia is safer, it would be even more difficult to conduct a randomized trial to answer this question, since several thousand patients would be needed to demonstrate significance.

EFFECTIVE PREOPERATIVE CONSULTATION

Accurate risk assessment

Physicians often underestimate the risks of anesthesia and surgical operations. In one study,[72] 57% of general surgeons and family practitioners underestimated mortality associated with inguinal herniorrhaphy by 100-fold, whereas only 8% accurately predicted or overestimated the mortality associated with this procedure. Risk must be individualized because it depends on many factors: the skills of the surgeon and the anesthesiologist, the institution's expertise with the particular type of operation, the patient's physical status, and the patient's physiologic reserve. Data from the 1960s and 1970s regarding anesthetic management and technique are not at all comparable to data from the 1990s because of ongoing improvements. A recent study of cardiac surgery patients stratified by preoperative factors showed a lower morbidity in high-risk patients from 1988 to 1990 when compared with 1986 to 1988.[73] Presumably, this was due to an increased awareness of risks and the interventions taken to control them.

Collaborative assessment: when and by whom?

Scheduling logistics, particularly with ambulatory patients, may hinder ideal preoperative assessment. Moreover, for healthy patients, full assessment is not cost-effective, although some procedures require more extensive assessment than others. While the anesthesiologist is the best judge of anesthetic risk, the internist or primary care physician knows the patient best; some collaboration between the anesthesiologist and the patient's physician may provide the optimal preoperative assessment.

Effective preoperative evaluation is best performed by the primary care physician—who has longitudinal knowledge of the patient—and then communicated to subsequent providers. The consultation should identify risk factors and reduce risk as much as possible. Preoperative interventions might include smoking cessation, optimizing antihypertensive therapy, or even a short-term infusion of an inotropic agent, such as dobutamine.[74] Particular attention should be paid to the patient's chronic therapy and how it should be modified perioperatively. Nitroglycerin patches, insulin dose, and conversion of oral to intravenous drugs must be considered.

The consultation should not dictate anesthesiology technique or monitoring, primarily because of medicolegal concerns. (For example, the internist writes "spinal anesthesia indicated," but the anesthesiologist proceeds with an equally appropriate general anesthetic. If complications should occur, a malpractice attorney has an opening to exploit.) In particular, a nonanesthesiologist cannot "clear" a patient for anesthesia surgery but can provide information that is useful to the anesthesia staff in making its decision. The medical evaluation complements but does not replace an independent anesthesiologic evaluation. In the complicated cases, both are essential for perioperative risk management.

Identifying the high-risk patient

A consensus group at Johns Hopkins Medical Institutions recently proposed that ambulatory surgery patients in groups I or II on the ASA Physical Status Scale[75] who are undergoing minimal procedures can be evaluated by the anesthesiologist on the day of surgery.[76] For sicker patients or more invasive procedures, the assessment should be made by the primary care physician before the day of surgery; high-risk patients undergoing high-risk procedures should be seen by the anesthesiologist before the day of surgery to allow plenty of time to intensify the preoperative workup, if necessary.

However, the ASA Physical Status Scale may be increasingly irrelevant. Although it relates preoperative status to the risk of mortality[77] (*Table* 5), it does not predict other more common adverse events that affect outcome, such as myocardial infarction or renal failure. In addition, it fails to account for the type of operation; it has not been modified to reflect advances in medical, surgical, and anesthetic management; and it is subject to observer bias and imprecision.[78]

A scoring system developed by Goldman and colleagues[79] (*Table* 6) quantifies the risk of adverse cardiac events in patients undergoing noncardiac surgery. Subsequent prospective evaluation demonstrates that the Goldman score may underestimate risks in vascular surgery patients.[80] A number of approaches have been applied to preoperative evaluation of this high-risk group: coronary angiography,[81] preoperative electrocardiographic monitoring,[82] stress echocardiography,[83] and dipyridamole-thallium imaging.[84] Clinical data, particularly the presence of Q-waves on the electrocardiogram, a history of ventricular ectopy, diabetes, advanced age, and angina, can be combined with thallium data to optimize preoperative assessment of risk in

TABLE 6
GOLDMAN MULTIFACTIONAL INDEX FOR NONCARDIAC SURGERY*

Patient status	Score
Congestive heart failure (third heart sound gallop or jugular venous distention)	11
Myocardial infarction within past 6 months	10
Electrocardiogram shows other than normal sinus rhythm or occasional premature atrial contraction	7
Premature ventricular contractions ≥ 5/minute	7
Age > 70	5
Emergency operation	4
Aortic stenosis	3
Thoracic, abdominal, or aortic operation	3
Poor general status	3

*Adapted from Goldman et al, reference 79

TABLE 7
SEVERITY SCORE FOR CARDIAC SURGERY*

Patient status	Score
Emergency case	6
Creatinine 1.6–1.8 mg/dL	1
Creatinine ≥ 1.9 mg/dL	4
Severe left ventricular dysfunction (ejection fraction <35%)	3
Reoperation	3
Mitral insufficiency requiring operation	3
Age 65 to 74	1
Age 75+	2
Prior vascular surgery	2
On medication for chronic obstructive pulmonary disease	2
Preoperative hematocrit ≤ 34%	2
Aortic stenosis requiring operation	1
Weight ≤ 65 kg	1
On medication for diabetes	1
Cerebrovascular disease	1

*Adapted with permission from: Higgins TL, Estafanous FG, Loop FD, Beck GJ, Blum JM, Paranandi L. Stratification of morbidity and mortality outcome by preoperative risk factors in coronary artery bypass patients. JAMA 1992; 267:2344–2348. Copyright 1992, American Medical Association.

TABLE 8
TEN COMMANDMENTS OF EFFECTIVE CONSULTATION*

I	Determine the question
II	Establish urgency
III	Look for yourself
IV	Be as brief as is appropriate
V	Be specific
VI	Provide contingency plans
VII	Honor thy turf (or: Thou shalt not covet thy neighbor's patient)
VIII	Teach—with tact
IX	Talk is cheap—and effective
X	Follow-up in the postoperative period

*From Goldman et al, reference 88

the vascular surgery patient.[85] In patients undergoing cardiac surgery, preoperative risk may be quantified by scoring routinely available data (*Table 7*).[83]

Resolving variety of opinion

In a study of 202 consultations requested by the anesthesia-surgical team, Kleinman and colleagues[86] found that a highly specific request was made in only 3%, vs 53% for "evaluation" and 39% for "clearance." Eighty percent of consultations addressed the problem, with a diagnosis and logical recommendations provided in 96%. Monitoring techniques were suggested in 41%, and postoperative follow-up in 41%. Preoperative therapy was changed in 28% of patients, and a new process was identified in 15% of consultations. The complication rate did not differ significantly whether or not preoperative therapy was changed. This study points out the need for internists to participate in the postoperative care of the patient, a recommendation further emphasized by findings in other studies[32,87] that more than a third of perioperative complications occur postoperatively.

Friction may arise as the result of conflicting opinions between the internal medicine consultant and the anesthesiologist, particularly when self-evident statements such as "avoid hypoxia" are included in the preoperative evaluation. Goldman and colleagues[88] have promulgated "Ten commandments for effective consultation" (*Table* 8). Everyone should be allowed to do what they do best. The anesthesiologist should respect the concerns and advice of the internist. Such advice should be presented in the chart so as to allow the anesthesiologist freedom to use his or her skills to advantage. Disagreements and discussions should be limited to a preoperative phone call, which is not a legal document. Some questions, such as whether postoperative ventilation will be needed, cannot always be answered preoperatively and must be allowed to work themselves out without the disadvantage of a chart note which could force a course of action.

THE FUTURE OF ANESTHESIOLOGIC PRACTICE

Looking ahead, from the standpoint of an intensive-care specialist, I expect that postoperative care will assume increasing importance in determining anesthesia-related morbidity and mortality. I base this prediction not only on recent data relating use of analgesia, early postoperative electrocardiographic changes, and outcome,[43] but also on the realization that the problems of increasingly ill patients do not end with successful surgery. Better monitoring and better anesthetic agents will diminish the anesthesia-associated risks of the operating room, but there is the risk that we will "create new mechanisms of mortality at the same rate we solve them."[8]

The period of postoperative recovery still contains many pitfalls and opportunities, and it is here that interventions hold the most promise for improving outcome. Postoperative complications are lower with experienced anesthesiologists,[89] which highlights the importance of continuity of care in the high-risk patient.

Increased interest on the part of government, health-care purchasers, and patients will drive reporting of outcome statistics, indexed by severity of illness.[90] This is already reflected in proposals to study methods of outcome assessment and the impact of postoperative interventions such as stress control and pain relief.

The desire to achieve the best possible outcome for the patient will lead to even greater interaction and cooperation between surgeons, internists, and anesthesiologists. An understanding of each professional's role in the process can only help. As change becomes more rapid, it is increasingly important that the lines of communication remain open so that valuable knowledge will be shared.

REFERENCES

1. **Beecher HK.** The first anesthesia death with some remarks suggested by it on the fields of the laboratory and the clinic in the appraisal of new anesthetic agents. Anesthesiology 1941; **2:**443.
2. **Kitz RJ, Vandam LD.** A history and the scope of anesthetic

practice. In: Miller RD, editor. Anesthesia. 2nd ed. New York: Churchill Livingstone, 1986:3–25.
3. **Beecher HK, Todd DP.** A study of the deaths associated with anesthesia and surgery. Ann Surg 1954; **140:**2.
4. **Dripps RD, Lamont A, Eckenhoff JE.** The role of anesthesia in surgical mortality. JAMA 1961; **178:**261–265.
5. **Memery HN.** Anesthesia mortality in private practice. JAMA 1965; **194:**127–130.
6. **Marx GF, Mateo CV, Orkin LR.** Computer analysis of postanesthetic deaths. Anesthesiology 1973; **39:**54–58.
7. **Turnbull KW, Fancourt-Smith PF, Banting GC.** Death within 48 hours of anesthesia at the Vancouver General Hospital. Can Anaesth Soc J 1980; **27:**159–163.
8. **Keats AS.** Anesthesia mortality in perspective. Anesth Analg 1990; **71:**113–119.
9. **Cohen MM, Duncan PG, Pope WDB, Wolkenstein C.** A survey of 112 000 anaesthetics at one teaching hospital (1975-83). Can Anaesth Soc J 1986; **33:**22–31.
10. **Pierce EC Jr.** Anesthesia Patient Safety Movement—1991. American Society of Anesthesiologists Newsletter 1991; **55:**4–8.
11. **Eichhorn JH, Cooper JB, Cullen DJ, et al.** Anesthesia practice standards at Harvard: a review. J Clin Anesth 1988; **1:**55–65.
12. **Eichhorn JH, Cooper JB, Cullen DJ, Maier WR, Philip JH, Seeman RG.** Standards for patient monitoring during anesthesia at Harvard Medical School. JAMA 1986; **256:**1017–1042.
13. **Orkin FK.** Practice standards: The Midas Touch or The Emperor's New Clothes? Anesthesiology 1989; **70:**567–571.
14. **Cheney FW, Posner K, Caplan RA, Ward RJ.** Standard of care and anesthesia liability. JAMA 1989; **261:**1599–1604.
15. **Pierce EC Jr.** Introduction: Anesthesia safety. Int Anesthesiol Clin 1989; **27:**133–136.
16. **Caplan RA, Posner KL, Ward RJ, Cheney FW.** Adverse respiratory events in anesthesia: a closed claims analysis. Anesthesiology 1990; **72:**828–833.
17. **Starr NJ, Sethna DH, Estafanous FG.** Bradycardia and asystole following the rapid administration of sufentanil with vecuronium. Anesthesiology 1986; **64:**521–523.
18. **Estafanous FG, Higgins T.** Opioids and the cardiac patient. In: Estafanous FG, editor. Opioids in Anesthesia II. Boston: Butterworth-Heinemann, 1991:93–109.
19. **Michaelis LL, Hickey PR, Clark TA, Dixon WM.** Ventricular irritability associated with the use of naloxone hydrochloride. Ann Thorac Surg 1974; **18:**608–614.
20. **Flacke JW, Flacke WE, Williams GD.** Acute pulmonary edema following naloxone reversal of high-dose morphine anesthesia. Anesthesiology 1977; **47:**376–378.
21. **White PF.** Propofol: pharmacokinetics and pharmacodynamics. Seminars in Anesthesia 1988; **7:**4–20.
22. **Farrell G, Prendergast D, Murray M.** Halothane hepatitis. N Engl J Med 1985; **313:**1310–1314.
23. **Becker LC.** Is isoflurane dangerous for the patient with coronary artery disease? Anesthesiology 1987; **66:**259–261.
24. **Reiz S, Balfors E, Sorensen MB, Ariola S, Friedman A, Truedsson H.** Isoflurane—a powerful coronary vasodilator in patients with coronary artery disease. Anesthesiology 1983; **59:**91–97.
25. **Hartman JC, Kampine JP, Schmeling WT, Warltier DC.** Altercations in collateral blood flow produced by isoflurane in a chronically instrumented canine model of multivessel coronary artery disease. Anesthesiology 1991; **74:**120–133.
26. **Inoue K, Reichelt W, El-Banayosy A, et al.** Does isoflurane lead to a higher incidence of myocardial infarction and perioperative death than enflurane in coronary artery surgery? A clinical study of 1178 patients. Anesth Analg 1990; **71:**469–474.
27. **O'Connor JP, Ramsay JG, Wynands JE, et al.** The incidence of myocardial ischemia during anesthesia for coronary artery bypass surgery in patients receiving pancuronium or vecuronium. Anesthesiology 1989; **70:**230–236.
28. **Reves JG, Fragen RJ, Vinik R, Greenblatt DJ.** Midazolam: pharmacology and uses. Anesthesiology 1985; **62:**310–324.
29. **Park WK, Lynch C III.** Propofol and thiopental depression of myocardial contractility. A comparative study of mechanical and electrophysiologic effects in isolated guinea pig ventricular muscle. Anesth Analg 1992; **74:**395–405.
30. **Marais ML, Maher MW, Wetchler BV, Korttila K, Apfelbaum JL.** Reduced demands on recovery room resources with propofol (Diprivan) compared to thiopental-isoflurane. Anesthesiology Review 1989; **1:**29–40.
31. **Forrest JB, Cahalan MK, Rehder K, et al.** Multicenter study of general anesthesia II. Results. Anesthesiology 1990; **72:**262–268.
32. **Cohen MM, Duncan PG, Tate RB.** Does anesthesia contribute to operative mortality? JAMA 1988; **260:**2859–2864.
33. **Slogoff S, Keats AS.** Randomized trial of primary anesthetic agents on outcome of coronary artery bypass operations. Anesthesiology 1989; **70:**179–188.
34. **Tuman KJ, McCarthy RJ, Spiess BD, DaValle M, Dabir R, Ivankovich AD.** Does choice of anesthetic agent significantly affect outcome after coronary artery surgery? Anesthesiology 1989; **70:**189–198.
35. **Dorsch JA, Dorsch SE.** The anesthesia machine in understanding anesthesia equipment: construction, care and complications. 2nd ed. Baltimore: Williams & Wilkins, 1984:38–76.
36. **Cooper JB, Newbower RS, Long CD, McPeek B.** Preventable anesthesia mishaps: a study of human factors. Anesthesiology 1978; **49:**399–406.
37. **Gravenstein JS, Cooper JB, Orkin FK.** Work and rest cycles in anesthesia practice. Anesthesiology 1990; **72:**737–742.
38. **Schwid HA, ODonnell D.** Anesthesiologists' management of simulated critical incidents. Anesthesiology 1992; **76:**495–501.
39. **Goldsmith MF.** As better training and machines improve safety, speed becomes focus of newest anesthetic drugs. JAMA 1992; **267:**1576–1578.
40. **Yeager MP, Glass DD, Neff RK, Brinck-Johnsen, T.** Epidural anesthesia and analgesia in high-risk surgical patients. Anesthesiology 1987; **66:**729–736.
41. **Breslow MJ, Jordan DA, Christopherson R, et al.** Epidural morphine decreases postoperative hypertension by attenuating sympathetic nervous system hyperactivity. JAMA 1989; **261:**3577–3582.
42. **Brandt MF, Fernandes A, Mordhorst R, Kehlet H.** Epidural analgesia improves postoperative nitrogen balance. Br Med J 1978; **1:**1106–1108.
43. **Mangano DT, Siliciano D, Hollenberg M, et al.** Postoperative myocardial ischemia. Therapeutic trials using analgesia following surgery. Anesthesiology 1992; **76:**342–353.
44. **Cousins MJ, Mather LE.** Intrathecal and epidural administration of opioids. Anesthesiology 1984; **61:**276–310.
45. Agency for Health Care Policy and Research. Clinical practice guideline. Acute pain management: operative or medical procedures and trauma. Rockville, MD: U.S Department of Health and Human Services, 1992.
46. **Salerno TA, Lince DP, White DN, Lynn RB, Charrette EJP.** Monitoring of electroencephalogram during open-heart surgery. A prospective analysis of 118 cases. J Thorac Cardiovasc Surg 1978; **76:**97–100.
47. **Myers RR, Stockard JJ, Saidman LJ.** Monitoring of cerebral perfusion during anesthesia by time-compressed fourier analysis of the electroencephalogram. Stroke 1977; **8:**331–337.
48. **Veilleux M, Daube JR, Cucchiara RF.** Monitoring of cortical evoked potentials during surgical procedures on the cervical spine. Mayo Clin Proc 1987; **62:**256–264.
49. **Severinghaus JW, Naifeh KH.** Accuracy of response of six pulse oximeters to profound hypoxia. Anesthesiology 1987; **67:**551–558.
50. **Scheller MS, Unger RJ, Kelner MJ.** Effects of intravenously administered dyes on pulse oximetry readings. Anesthesiology 1986; **65:**550–552.
51. **Lowenstein E.** Perianesthetic ischemic episodes cause myocardial infarction in humans—a hypothesis confirmed. Anesthesiology 1985; **62:**103–106.

52. **Rao RLK, Jacobs KH, El-Etr AA.** Reinfarction following anesthesia in patients with myocardial infarction. Anesthesiology 1983; **59**:499–505.
53. **Rosenbaum SH, Barash PG.** Is anesthesia therapeutic? Anesth Analg 1989; **69**:555–557.
54. **George JM, Reier CE, Lanese RR, Rower JM.** Morphine anesthesia blocks cortisol and growth hormone response to surgical stress in humans. J Clin Endocrinol Metab 1974; **38**:736–741.
55. **Haxholdt OS, Kehlet H, Dyrberg V.** Effect of fentanyl on the cortisol and hyperglycemic response to abdominal surgery. Acta Anaesthesiol Scand 1981; **25**:434–436.
56. **Pflug AE, Halter JB.** Effect of spinal anesthesia on adrenergic tone and the neuroendocrine responses to surgical stress in humans. Anesthesiology 1981; **55**:120–126.
57. **Madsen SN, Brandt MR, Engquist A, Badawi I, Kehlet H.** Inhibition of plasma cyclic AMP, glucose and cortisol response to surgery by epidural analgesia. Br J Surg 1977; **64**:669–671.
58. **Stevenson GW, Hall SC, Rudnick S, Seleny FL, Stevenson HC.** The effect of anesthetic agents on the human immune response. Anesthesiology 1990; **75**:542–552.
59. **Hole A, Unsgaard G.** The effect of epidural and general anaesthesia on lymphocyte functions during and after major orthopaedic surgery. Acta Anesthesiol Scand 1983; **27**:135–141.
60. **Chernow B, Higgins TL.** The endocrine and metabolic responses to the stresses of anesthesia and surgery. In: Scurr C, Felman S, Soni N, editors. Scientific Foundations of Anesthesia, The Basics of Critical Care. 4th ed. Oxford: Heinemann Medical Books, 1990:354–359.
61. **Whitcher C, Ream AK, Parsons D, et al.** Anesthetic mishaps and the cost of monitoring: a proposed standard for monitoring equipment. J Clin Monit 1988; **4**:5–15.
62. **Welch RH, Feldman JM.** Anesthesia during total electrical failure, or what would you do if the lights went out? J Clin Anesth 1989; **1**:358–362.
63. **O'Hara JF, Higgins TL.** Total electrical power failure in a cardiothoracic intensive care unit. Crit Care Med 1992; **20**:840–845.
64. **Kane RE.** Neurologic deficits following regional or spinal anesthesia. Anesth Analg 1981; **60**:150.
65. **Mason RA, Newton GB, Cassel W, Maneksha F, Giron F.** Combined epidural and general anesthesia in aortic surgery. J Cardiovasc Surg 1990; **31**:442–447.
66. **Diebel LN, Lange MP, Schneider F, et al.** Cardiopulmonary complications after major surgery: a role for epidural analgesia? Surgery 1987; **102**:660–666.
67. **Shulman M, Sandler AN, Bradley JW, Young PS, Brebner J.** Postthoracotomy pain and pulmonary function following epidural and systemic morphine. Anesthesiology 1984; **61**:569–575.
68. **Chin SP, Abou-Madi MN, Eurin B, Witvoet J, Montagne J.** Blood loss in total hip replacement: extradural v. Phenoperidine analgesia. Br J Anaesth 1982; **54**:491–494.
69. **Modig J, Borg T, Karlstrom G, Maripuu E, Sahlstedt B.** Thromboembolism after total hip replacement: role of epidural and general anesthesia. Anesth Alag 1983; **62**:174–180.
70. **Tuman KJ, McCarthy RJ, March RJ, DeLaria GA, Patel R, Ivankovich A.** Effects of epidural anesthesia and analgesia on coagulation and outcome after major vascular surgery. Anesth Analg 1991; **73**:696–704.
71. **Higgins TL.** Specific consideration with renal disease. In: Firestone LL, Lebowitz PW, Cook CE, editors. Clinical anesthesia procedures of the Massachusetts General Hospital. 3rd ed. Boston: Little Brown & Co, 1988:45–61.
72. **Kronlund SF, Philips WR.** Physician knowledge of risks of surgical and invasive diagnostic procedures. West J Med 1985; **142**:565–569.
73. **Higgins TL, Estafanous FG, Loop FD, Beck GJ, Blum JM, Paranandi L.** Stratification of morbidity and mortality outcome by preoperative risk factors in coronary artery bypass patients. JAMA 1992; **267**:2344–2348.
74. **Unverferth LV, Magorien RD, Altschuld R, Kolibash AJ, Lewis RP.** The hemodynamic and metabolic advantages gained by a three-day infusion of dobutamine in patients with congestive cardiomyopathy. Am Heart J 1983; **106**:29–34.
75. **Dripps RD, Lamont A, Eckenhoff JE.** The role of anesthesia in surgical mortality. JAMA 1961; **178**:261–266.
76. **Pasternak LR.** Preoperative assessment of the ambulatory and same-day admission patient. Wellcome Trends in Anesthesiology 1991; **9**:11.
77. **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**:564–566.
78. **Owens WD, Felts JA, Spitznagel EL.** ASA physical status classifications: a study of consistency of ratings. Anesthesiology 1978; **49**:239–245.
79. **Goldman L, Caldera DL, Nussbaum SR, et al.** Multifactorial index of cardiac risk in noncardiac surgical procedures. N Engl J Med 1977; **297**:845–850.
80. **Jeffrey CC, Kunsman J, Cullen DJ, et al.** A prospective evaluation of cardiac risk index. Anesthesiology 1983; **58**:462–464.
81. **Hertzer NR, Beven EG, Young JR, et al.** Coronary artery disease in peripheral vascular patients. A classification of 1000 coronary angiograms and results of surgical management. Ann Surg 1984; **199**:223–233.
82. **Raby KE, Goldman L, Creager MA, et al.** Correlation between preoperative ischemia and major cardiac events after peripheral vascular surgery. N Engl J Med 1989; **321**:1296–1300.
83. **Popp RK.** Echocardiography. Second of two parts. N Engl J Med 1990; **323**:165–171.
84. **Boucher CA, Brewster DC, Darling R, Okada RD, Strauss HW, Pohost GM.** Determination of cardiac risk by dipyridamole-thallium imaging before peripheral vascular surgery. N Engl J Med 1985; **313**:389–394.
85. **Eagle KA, Coley CM, Newell JB, et al.** Combining clinical and thallium data optimizes preoperative assessment of cardiac risk before major surgery. Ann Intern Med 1989; **110**:859–866.
86. **Kleniman B, Czinn E, Shah K, Sobotka PA, Rao TK.** The value to the anesthesia-surgical care team of the preoperative cardiac consultation. Journal of Cardiothoracic Anesthesia 1989; **3**:682–687.
87. **Tiret L, Desmonts JM, Hatton F, Vourc'h G.** Complications associated with anaesthesia—a prospective survey in France. Can Anaesth Soc J 1986; **33**:336–344.
88. **Goldman L, Thomas L, Rudd P.** Ten commandments for effective consultations. Arch Intern Med 1983; **143**:1753–1755.
89. **Duncan PG, Cohen MM.** Postoperative complications: factors of significance to anaesthetic practice. Can J Anaesth 1987; **34**:2–8.
90. **Green J, Wintfeld N, Sharkey P, Passman LJ.** The importance of severity of illness in assessing hospital mortality. JAMA 1990; **263**:241–246.