COMPUTERIZATION OF ANESTHESIA INFORMATION MANAGEMENT

John H. Eichhorn, MD, and David W. Edsall, MD†*

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Anesthesia information management centers on intraoperative data collection but extends to related areas. Computerization of information gathering and processing can greatly enhance information use. Presented here are reasons why automated anesthesia record systems are different from and better than handwritten records, which are without rationale in their customs (such as the five-minute recording interval). Optimal features of graphic information displays are described, as are the great medical-legal values of automated records, even with obvious artifacts. Advances in computers will lead to automated rejection of artifacts and the implementation of smart alarms that analyze monitor data and suggest diagnoses and even treatment. Computerized records will capture many more data and then will be able to feed them directly into a quality assurance analysis program. The future holds the prospect of even easier data entry, still more data capture, and better organization of collected materials, including support for a central anesthesia controller.

INTRODUCTION

Computerization of the anesthesia workstation has surfaced as an issue of interest very recently, and little relevant information has been formally presented. These presentations were the first ever at the annual meeting of the American Society of Anesthesiologists.

The anesthesia workstation can be likened to the cockpit of a commercial airliner. The patient is analogous to the aircraft. There is a take-off, cruising phase, and a landing in both a flight and in the administration of an anesthetic for a surgical procedure. The control center for each has a significant array of knobs, buttons, dials, displays, controls, and alarms. Although computers have been essential tools in the airline cockpit for some time, they are only now being introduced into anesthesia care settings. There are microprocessors now in many, if not most, of the devices used to facilitate anesthesia care. These processors usually function independently, however, and are often almost in competition with each other. Central computerization will center on information management; advances have also been made in central alarm displays and alarm coordination, but the largest impact has come in computerized anesthesia record keeping. These automated systems are evolving very rapidly into practical, valuable tools that are likely to lead the way into the future of anesthesia care.

IMPACT ON PATIENT CARE

David W. Edsall, MD

Computerization of anesthesia information management will be the most important technological development in anesthe-

*Harvard Medical School and Beth Israel Hospital, Boston, and the †Department of Anesthesiology, Burbank Hospital, Fitchburg, MA.

Address correspondence to David W. Edsall, MD, Wachusett Anesthesiology Associates, 33 Electric Avenue, Suite 205A, Fitchburg, MA 01420.

sia care over the next five years. The core of this technology is the gathering and processing of information, which has implications well beyond simple record keeping.

How many of us know, on a monthly basis, the rate of nausea and vomiting among the patients we have anesthetized? How many of us know the average length of stay of our patients in the recovery room? How many of us know the hypertension and tachycardia profiles throughout anesthesia or immediately after intubation on all of our patients, or just on our diabetic patients? Answers to these questions can be obtained once an anesthesia information management system is in place.

Burbank Hospital in Fitchburg, Massachusetts, is the first hospital in the United States to computerize fully all its anesthesia records. In March 1988 we started to use a commercially produced device to create, process, and preserve all of our records. There are five anesthesiologists and eight CRNAs in the hospital. In 18 months, we have done 8,000 cases. In the first 6 months, we lost 12 records with the system. In the most recent 6 months we have lost 1 record. Records are generally lost due to user, not equipment, failure.

A description and the philosophical background of information management can help familiarize people with the technology of automated record keeping. Until recently, the flow of information was solely between the patient and the clinician. We referred to this as the art of anesthesia. However simple—or "pure"—this was, there were some difficulties. Over the years, technology has created the science of anesthesia, so that now we monitor as many as 20 measured variables with more than 40 alarm signals. The direct flow of information between the patient and the clinician is all but obscured by the number of technologically generated data. By default, one's attention is focused on the monitors and on documentation of the information generated.

When the anesthesia information system is computerized, a control panel with an information-processing system monitors the primary monitors and also produces a record, thus giving the clinician much more time to take care of the patient. Information can be entered by direct electronic input from the pimary monitors, by typing characters on a touch screen, and even by the spoken voice of the anesthetist. During or at the end of the case, a printout of the anesthesia record is generated in the operating room. A sample of that record is shown in Figure 1. The time interval in the printout can be retrospectively or prospectively changed. Our system scans all the primary monitors every 2 seconds. No human can possibly do that (Fig 2). With automated record keeping, we spend about 4 to 5 minutes per hour on documentation—far less than with handwritten records—and yet we enter 200% more notes, and thus have a much more complete and accurate record. In addition to automatically documenting 300% more vital signs readings (for example, blood pressure, heart rate, SaO_2), the system allows entries to document events like position changes at the actual time the position is changed. Pretyped notes (the equivalent of computer "macros") about a wide variety of things, including, for instance, X-ray examinations, are ready for quick entry into the record at the touch of one or two keys.

Table 1 lists the attributes of information management systems. One key feature is rapid data entry. We take about 3 to 5 seconds for an average manual entry of information. The system should be capable of monitoring every piece of electronic equipment and its output data automatically. The data must be displayed in a meaningful format so that the clinician can quickly and reliably understand exactly what he or she is seeing, with emphasis on parameter identification, easily read numeric values, and clear trending. The way data are visually presented can have a great impact on the ability to understand and use them, exactly as is the case in evaluating research reports in the literature. The ability of the information management system to generate a printout quickly both during and after the case is very important for user acceptance and ease of communication with other caregivers. Another central consideration is operating room space; often there is no more room on the anesthesia machine to put another piece of equipment. Accordingly, the physical setup is paramount.

Other benefits of a fully developed automated data capture and information management system can be seen in quality assurance, billing, and inventory. When anesthesia records are finished at Burbank Hospital, operating room quality assurance data are already assembled, billing data are already generated, and inventory data are complete and readily available for processing. There is no need to fill out separate inventory check lists for the anesthesia department equipment used or for pharmacy charges.

If an anesthesia information management system has an alarm, then it is a secondary monitor from the point of view of direct patient care. The information management system monitors the primary monitors attached to the patient. If it says in clear English, "Oxygen saturation 82%," you know immediately what the problem is. In the ideal system, all the alarms would be displayed and controlled from one central panel designed for maximal visibility and readability, so the alarms on the primary monitors could be turned off or eliminated. The automated anesthetic record is the ideal venue for this.

Primary monitors need to have the best possible sensing devices so as to provide clear, calibrated output signals that are as free as possible from artifact. As an example, the Emergency Care Research Institute (ECRI) published a report in July 1989 on pulse oximeters which stated that the Datascope and Datex pulse oximeters are almost artifact-free, suggesting that they would be appropriate in this regard. With our system, the average practitioner must deal with about one artifact per hour. It takes an accomplished user about 3 seconds to enter a note that says, "SaO_2 affected by electrocautery," since it is a "prewritten" note. The frequency of this particular note decreased dramatically with the new generation of pulse oximeters.

In primary monitors, the ability to capture a clear, calibrated paper strip of the output signal is critical, regardless of what the signal or wave form is. Five years ago, many people doubted the value of carbon dioxide wave form strips. Gravenstein and colleagues [1], however, have stated that there is a significant amount of valuable information in these tracings. It is also important to have artifact-free output going into the information management computer. One brand of pulse oximeter used to tell the record-keeping computer that the SaO_2 was 150%. With interference, the screen on the SaO_2 monitor would go blank, but the data output from the back of the monitor was an SaO_2 of 150%, and the automated anesthesia record dutifully recorded this value. Clearly, this was unacceptable and, as indicated, newer generations of instruments are much improved.

What is the impact of computerizing anesthesia information management on cost? What does it take to convince anesthesi-

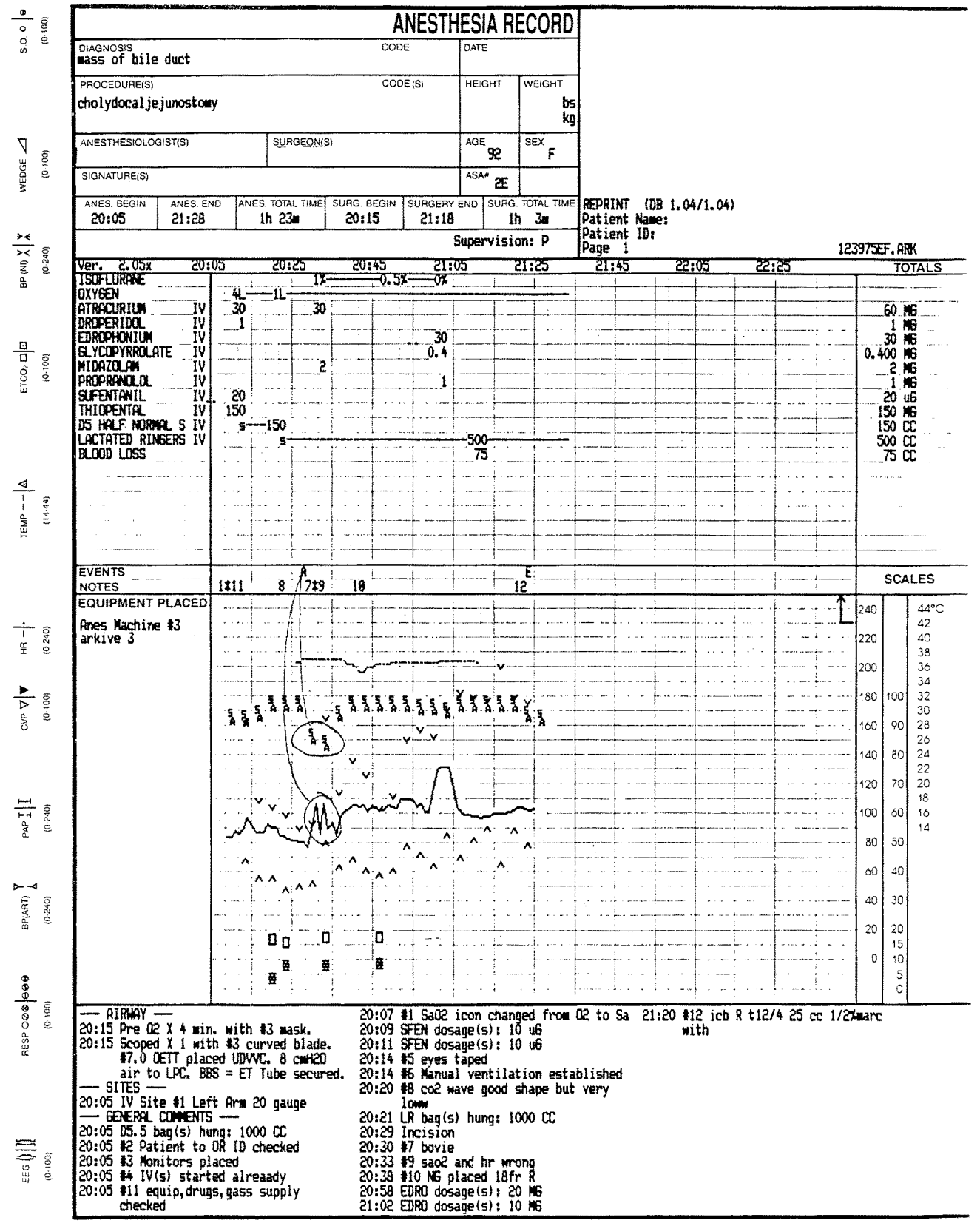

Fig 1. Example of computerized anesthesia record printout generated in the operating room.

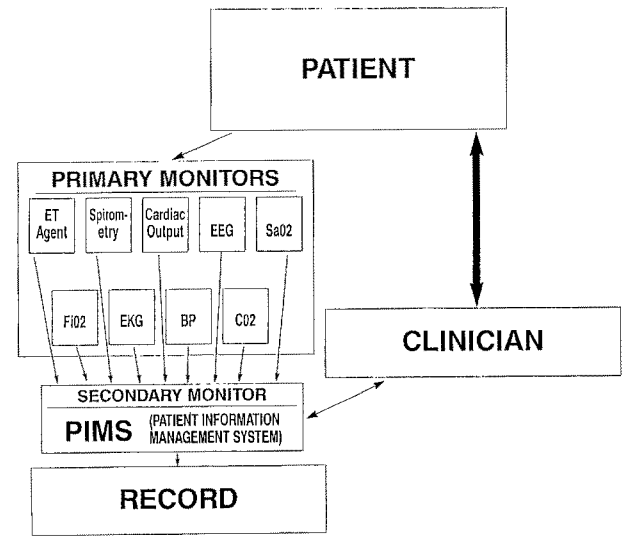

Fig 2. Primary monitor readings scanned every two minutes by secondary monitor (Arkive Patient Information Management System).

ologists and administrators to buy this system? In general, hospital and facility administrators love it. The concept is familiar. They have already experienced computerization of the pharmacy, of medical records, and in other areas, so they intuitively accept the argument that computerization is cost effective and more efficient. Medical records departments will also think highly of it, and billing clerks and secretaries will love it because a billing copy of the record is instantly available, or the requisite information can be taken right from the computer by electronic transfer.

We spent $100,000 to place systems in eight operating rooms. In under 18 months, we saved $70,000 on primary monitor purchases because complete alarm systems are not needed on them. Experience suggests buying the information management system first and then later, as they need replacement, purchasing new (and relatively less expensive) primary monitors without trendy or complex alarms. Otherwise, it may be possible to end up with a primary monitor felt to be great but later found incompatible when connected to the patient information management computer. Burbank Hospital saved money by purchasing Datascope 2001s, which do not have trending, rather than Datascope 2000s, which do trending but cost $1000 more. This sort of logic can be applied to any new monitor or other piece of related equipment that is purchased.

In the same period, we saved $21,000 on pharmacy charges, $8,000 on billing time, and an undetermined amount by preventing the loss of or errors in filling out billing slips. We have saved $1500 on quality assurance costs, just by reducing secretarial time. It is impossible to say how much has been saved (by helping to prevent losses) through having better quality assurance programs. And just recently, two lawsuits were dropped when the plaintiffs' attorneys saw the computer-generated records.

An agreement between the hospital and an insurance carrier appears close in which Burbank anesthesiologists will save 10% on malpractice fees ($2,000 to $4,000 per year for each individual in the deparment). There is at least one insurance company that offers such a discount for an automated anesthesia record system. Finances should not be a big problem when justifying purchase of automated anesthesia record technology. Billing efficiency, inventory processing, and less burdensome quality assurance likewise are strong selling points. The bulk of data gathering is done as soon as the case is done.

Table 1. Attributes of Patient Information Management System

1. Speed of entry
2. Monitors vital signs and other patient physiological data as well as anesthesia delivery system function
3. Presents data in meaningful format
4. Printout during and/or after case
5. Convenient spatial configuration in operating room
6. Capability of retrospective analysis
7. Billing and inventory management
8. Interface capability with variety of primary monitors

What is the impact of automation on patient care? We spend 56 to 58 minutes per hour paying attention to and taking care of the patient rather than on record keeping. We are getting back to checking capillary filling, observing what the pupils are doing, checking for patient sweating, and generally doing a number of things most of us have fallen out of the habit of doing in the last 10 years.

Eighty-two percent of our manual entries are made within 2 minutes of an event occurring. Handwritten records are generally charted in a "batch" manner. At the end of a case or for a short case, it is not unusual for 20 or even 30 minutes of data entry to be delayed until the patient reaches the recovery room; only then is the anesthesia record completed—significantly after the event. On the other hand, we chart in real time. We have the added advantage of having many more notes and also very many more vital sign readings that are as accurate as the primary monitors can make them.

A recent paper showed a very poor correlation between automatically recorded noninvasive blood pressure readings and the values for the same time period entered on a handwritten record [2]. This suggests that handwritten anesthesia records can be highly inaccurate. Doubt about the handwritten data can contribute to mistrust of quality assurance analyses based on vital-sign data, which are meaningless unless the data are accurate. At Burbank Hospital, quality assurance reports of this type are easy to obtain and guaranteed reliable. Cases can be reviewed in more detail with one-minute time intervals on the printouts.

In summary, the anesthesia patient information management system is not just a record-keeping mechanism. This device should be the anesthetist's stenographer in the operating room. It should be a secondary monitor that helps improve vigilance in several ways. In addition to synthesizing and displaying information and alarm messages, it should flash reminder messages on the screen, such as to check the patient's pressure points approximately every hour (or at any interval set by the user). It should also serve as a bookkeeper and a calculator. If a dose of 2 micrograms of nitroprusside per kilogram per minute is desired for a patient, the anesthetist puts into the computer, with four key strokes: "Infusion, nitroprusside, 2 micrograms per kilo per minute; Enter." The computer instantly calculates the concentration to be mixed and the infusion rate—in ml/hr—to be set.

THE ANESTHETIC RECORD: BY HAND OR BY COMPUTER, ITS PURPOSE THEN AND NOW

*J. S. Gravenstein, MD**

The first anesthesia record was made about 90 years ago by Codman and Cushing, to determine who was capable of giving the better anesthetic. It thus originated as a tool for post hoc assessment of anesthesia care rather than as an intraoperative record for the anesthesiologist. Post hoc assessment is what we today call quality assurance. For many years, however, anesthesia records were used only intraoperatively, and not for quality assurance. Nowadays, the anesthesia record is used by many individuals within the hospital, as can be seen from Table 2.

A study conducted by Cook and coworkers from Ohio State University [2] has provided an interesting correlation between handwritten and automated blood pressure data. The handwritten recordings were consistently higher than the machine records for minimum diastolic and systolic pressures. Maximum diastolic and systolic pressures, however, were the other way round, indicating a bias on the part of the recorder. The reason for this correction or "smoothing" of data by the clinician appears to be a tendency toward desirable, rather than undesirable, data. Not only are the absolute values of the data affected by "smoothing," but often handwritten records are not made until about 15 minutes later, much too late for immediate clinical use.

The ASA recommends monitoring and recording data every 5 minutes. This value came from a clinical practice pattern rather than from a scientific study, as so many things we do are based on patterns of behavior rather than scientific examinations. Obviously, slow-moving signals do not need to be recorded as often as signals that change rapidly. Table 3 lists the rate of change of monitoring variables.

There are different ways of determining how frequently data should be monitored and recorded. One suggestion is that the clinician determine TT max (e.g., Delta max over Slope max [3]). Delta max is the step change in a signal considered sufficiently noteworthy to record and can be defined for every variable being monitored. Slope max is the maximum rate of change. For example, if a patient has a cardiac arrest, blood pressure decreases rapidly, and the maximum slope for blood pressure is very steep. However, since the frequency of cardiac arrest is very low, we accept a certain rate of change that we find clinically probable and acceptable.

*Department of Anesthesiology, University of Florida, Gainesville, FL.

Table 3. Anticipated Rate of Change of Monitoring Variables During Anesthesia[a]

FAST	Electroencephalogram
	Heart rate
	Blood pressure (arterial and venous)
	Respiratory rate
	Respired gases (physiological and anesthetic)
	Pressure and flow in breathing circuit
	Oxygen saturation
	Response to nerve stimulator
SLOW	Temperature

[a]With sudden cardiac arrest or disconnection, this ranking can change.

For example, the selected maximal rate of change for blood pressure might be 100 mm Hg in 15 seconds, such as can be seen during intubation in a very lightly anesthetized patient. Slope max can also be expressed as units per time. If, for example, the Delta max for blood pressure is 20 mm Hg, and the Slope max is a very conservative 100 mm in 5 minutes, then the ratio (TT max) would be 60 seconds (that is, the data should be recorded once per minute). With more stringent criteria, such as a steeper Slope max for a bigger Delta max, TT max (the monitoring and recording interval) will become shorter.

For an anesthesia record to be valuable, it must be accurate and have the ability to document all the variables at frequent, appropriate intervals. Eventually, this requirement will necessitate a machine that will replace handwritten records.

INFORMATION MANAGEMENT: WHAT IS IT? HOW IS IT DONE?

*Allen K. Ream, MD**

My interest in the anesthesia record began in 1970. I was in the artificial heart program at the National Institutes of Health and was concerned with problems of data acquisition and analysis. We were spending several million dollars a year trying to develop this exotic device, implanting it into animals and testing it, but funding restrictions did not support adequate data collection to evaluate the results. We developed our first automated record system in the animal laboratory in 1975 and have been using versions of it ever since. I have learned many lessons from this experience.

*Department of Anesthesia, Stanford University Medical Center, Stanford, CA.

Table 2. Users and Uses of the Anesthesia Record

Administration: for personnel management, assessment of equipment and supply needs, and for operating room utilization
Business Office: for preparation of bills
Clinicians (physicians, technicians, and nurses): for care in the operating room, postanesthesia care unit, intensive care unit, and postoperative ward; collection of data for research purposes
Clinician and Administration: for statistical analyses of anesthetic techniques
Surgeon: for recording clinical information
Teams (clinicians, administrators, attorneys, insurance and government agencies): for assessing quality of care

In the 1970s, numerous people asked me to work on an anesthesia record, including a psychiatrist, a dermatologist, and several attorneys. None of them was an anesthesiologist, and all were interested in assigning blame after the fact. It was my impression that anesthesiologists did not want automated records because they were afraid of them. More recently, however, we have become very excited about the record for the simple reason that it assists with patient management. While it is important to have quality assurance, there is nothing better than having information early enough to ensure a good outcome for the patient, rather than only learning a lesson that can be applied to the next patient. While we made an initial list of the advantages of an automated record (Table 4), our primary motivation was that we felt we were drowning in data.

Advances in monitor design in recent years have enabled use of standard, commercial equipment, eliminating the need to buy special monitors, transducers, and other equipment to support automated measurement. The primary benefit of the anesthesia record is that it has allowed us to focus on what to do with the data after obtaining them.

The time resolution of recording is extremely important. Prior to automation, we recorded data every 5 minutes. With the automated record we could plot every heartbeat, if we wished. At first, anesthesiologists generally disliked the automated record—probably because we realized that we do "smooth" data, or reduce "cognitive dissonance" by recording what we expect to see, rather than what we actually see. Another reason we smooth data is to fit the five-minute recording pattern. We tend to average out transient spikes and troughs from things like respiratory variation.

The basic visual aspects of presentation are generally not addressed by those interested in developing automated anesthesia records. With a little guidance in this area, researchers and manufacturers can learn how to make these records more useful. According to the Weber-Fechner law, the visual perception of an arithmetic progression depends on a physical geometric progression. In other words, our eye tends to make things look linear when they are actually changing at an increasing rate. For example, if the brightness of a light increases in steps of equal size, the size of the step will start to appear smaller as the light becomes brighter. The brain interprets this change as occurring at a constant rate. If the engineer or designer of an instrument presents constant step-wise changes in intensity, for example, higher resolution will be seen at the lower levels, with fine detail being lost at the higher levels. This physiological behavior must be taken into account when designing displays.

In the graphic design of the anesthesia record, if only one line width is used, useful detail is lost. How many times have you looked at an anesthesia record where the line width has been chosen for technological convenience rather than for emphasis appropriate to the data? It would be more helpful to have wider lines for recording more important measurements and thinner lines for less important measurements. These are the kind of visual cues that we respond to automatically. If these clues are not taken into account, the unconscious message, in terms of what is important, can override the conscious, professionally trained, and clinically experienced interpretation of the data, and it is the latter that is more important.

Another example of visual perception can be seen in the work of Bezotal, a rug weaver who experimented with the relationship of colors. He became very interested in what happens when you put colors next to each other. For example, when the same red bricks are placed with black and with white mortar, they appear much darker next to the black mortar [4]. When I photocopied Bezotal's illustration, I found that the xerographic process lightened the bricks next to the dark mortar, altering the contrast substantially. Since anesthesia records may be reproduced, it is important to know that copying can alter visual emphasis in measurable, sometimes dramatic, ways.

To use the anesthesia record to manage patients in real time, one has to be cautious about visual cues that are inconsistent with the rest of our experience. More advanced technology will enable the visual presentations to be substantially improved.

Because of the cost of graphic displays, our 1975 monitoring system scrolled numbers on the screen. Numerical displays can, however, hide significant differences between data sets. For example, sets of numbers that are identical in the basic statistical analysis, having the same statistics, the same number of samples, the same regression slope and intercept, and the same correlation coefficient, can be graphically displayed as two different straight lines, a wave that is concave downward, and a scattergram. The plots are dramatically different, illustrating why digital displays are frequently inappropriate [4]. Digital values may be equally inappropriate on an anesthesia record. One of the most important things that any anesthesiologist can detect when monitoring or reviewing records is a trend which, in many cases, is far more important than the absolute value. Numerical displays do not readily call attention to a trend. The statistics we use are means or regressions. It is easy to get too confident in our methods of reducing numbers to other numbers and to forget that a visual pattern is still extremely important. The visual pathway is a freeway into our minds; if we do not use it, we are missing a marvelous opportunity to improve our clinical performance.

Table 4. Advantages of an Automated Anesthesia Record

1.	Helps defend anesthetists who did not make errors; reduces speculation about what did not occur.
2.	Helps defend anesthetists who did make errors by better defining what occurred, thus limiting accusations about events that did not occur; helps reveal how to avoid same errors in the future.
3.	Promotes improved patient management, because better data will be available in less collection time, leaving more time for interpretation; subtle trends visible earlier.
4.	Reduces anesthetist's workload and promotes faster turnover of cases.
5.	Allows tailoring of recording interval to variable being recorded.
6.	Provides better data resolution, both as to numerical values and time, allowing more precise analysis of unanticipated or untoward events.
7.	Aids those responsible for postoperative care by being more complete and consistent than handwritten record.

The computerized anesthesia record also supports good clinical practice by facilitating the review of data over long time intervals. The primary display of a typical monitor shows only 4 to 10 seconds of data, so it is easy, using our memories and a little cognitive dissonance, to talk ourselves into or out of things that did not happen—although in certain circumstances the averaged 5-minute record may be preferable to a record in which every heartbeat is individually displayed. One of the great advantages of the record is that the entire preceding time in an anesthetic procedure can be examined and used in planning therapeutic responses during the remainder of an operative procedure.

Complex displays or complex records are acceptable as long as they do not introduce information that is inconsistent and irrelevant to our needs. In fact, it is in complexity that we do our jobs; through interrelationships among factors we see the clinical details that we need to see to be superlative at our job. Probably the most complex computer-generated image ever developed has over 65,000 elements. It is a representation of a steel mill. Anyone who knows anything about making steel can look at that picture and in one or two seconds recognize the interior of a steel mill. The fact that there are 65,000 elements does not make it difficult to understand. If the elements are not organized according to our visual experience, then we see mind-boggling complexity with which we cannot deal. We are just learning methods of effective visual presentation in displaying anesthesia records. As we get better at these presentations, we will eventually find that we cannot live without them.

THE AUTOMATED RECORD: LEGAL HELP OR PANDORA'S BOX?

*Donald A. Kroll, MD**

A computerized record can neither immunize against, nor expose one to, a malpractice case.

A loss in a malpractice case can be defined as any time that too much money is paid. If there is minor damage, a settlement should be made. The reportable *threshold* (which varies by state) is that *amount* that necessitates a report to a regulatory body like the Board of Medical Quality Assurance (BMQA). In California, many malpractice suits are settled for $29,999 because the reportable limit in California is $30,000. Reportable limit settlement is generally not considered to be a loss if there is minor damage. If there is major damage there is only a loss if it is not covered within the limits of the insurance policy.

Justifiable payoffs depend on the nature of the patient's injuries and the defendant's role in causing those injuries. Attorneys are going to rely on the facts of the case, which are determined by the anesthesia record. Suits that are filed unnecessarily and cases that are settled for too much money are generally due to bad patient rapport and/or bad charting. Real negligence should never go to trial because for that defendant the verdict will be an automatic loss.

Who determines what the facts are? We like to think about facts as cold, hard numbers. In law, facts are whatever someone says they are. If a case goes to trial, the fact finders could be the judge and jury, since they hear two different sides to the story, and they then decide which side to believe. The believable side becomes the fact. Thus, at trial, the judge and jury have to be convinced about the facts of the case. Attorneys are also fact finders because they carefully go over the case for its possible merits; the result is that the vast majority of malpractice cases never go to trial. Most of these cases are settled reasonably well for the doctors.

Expert witnesses are fact finders because medicine is a complex discipline outside the common body of knowledge of the lay person. The courts rely on medical experts to interpret things like the medical record and standards of care for the fact finders. The primary source of fact is the medical record, with other sources including deposition testimony—which relies upon specific memory of the case—and usual and customary practice testimony.

Juries tend to believe the medical record first, if it is clearly written and documented, considering it the most credible source of fact. The least credible source of fact is a specific memory at the time of deposition, with statements like: "Well, I must have done that because I always do that," or "I specifically remember doing that; the patient is very vivid in my mind from three and a half years ago when I did four cases that day." In that situation the attorney will generally ask the physician whether he or she remembers the cases before and after the case in question. Specific memory is no substitute for what is clearly documented in the medical record. In law, the perception of truth is truth. If it is written, it was done.

It is often said that the record speaks for itself, however, not all records speak the same. Some are difficult to obtain information from because they are inarticulate or illegible. Often the critical piece of information on a record is not a vital sign, but a handwritten note. Sometimes records lie. It is very easy to lie in a medical record. For example, if the patient's blood pressure is 200 over 120, the cuff is recycled. If the next pressure reading is 180, which is preferable, then only the 180 is charted, thus smoothing out the record. When I review a record for an attorney, I know when there is smoothing, and I can even produce journal articles in court which verify that this smoothing occurs.

What about artifacts? They do not represent a major problem because most of them are obvious. However, since juries and fact finders believe first what they see written on paper, it would be nice to have artifacts removed, rather than to have to explain in great detail for an hour of deposition time why it is impossible to have an oxygen saturation of 140%. Most people resist automated records to avoid having to explain embarrassing extremes of vital signs. It is much easier to select the best number when there are 5 minutes in which to make the report. This is a problem in thinking and in processing information; it is not a problem with the record.

It is important to remember that there is more to a patient's medical record than vital signs and artifacts, particularly in terms of anesthesia care. And yet it is this additional information—this patient-specific data—that is so often missing. Having reviewed numerous records for attorneys, insurance companies, and the ASA Closed-Claims study, I have often found it impossible to determine the patient's weight or height, for example, because in many cases, it was never charted.

The physiological data (blood pressure, heart rate, oxygen

*Department of Anesthesiology, University of California, Los Angeles, CA.

saturation, and others) contained on the medical record are usually more or less complete, although they may have been entered with broad, sweeping strokes of the pen indicating, for example, that systolic pressure was recorded every 10 minutes instead of every 5 minutes. From a medical-legal point of view, the number itself is less important than what response that number generated. Was the reaction to a change timely and appropriate? Text data are absolutely vital. Incidentally, it is just as easy to lie to a computer as to lie in writing—one only needs to type instead of write—and the only difference is that lies are more legible on the computer record.

Often information about drugs and doses is inaccurate with regard to timing or is missing from the record completely. "Cardiac arrest" is very difficult to interpret because what led to the arrest is more important than information about the resuscitation. Charting in cardiac arrest is very rarely accurate or timely, making it difficult for the attorney to defend the clinician.

Another potential problem is storage of information. Handwritten records generally go into, and remain in, the patient's chart, causing little concern with regard to confidentiality. Floppy disks, however, contain a vast quantity of patient-specific data, which could include embarrassing information such as drug usage or sexually transmitted diseases. This information could be used for unauthorized purposes or could fall into the hands of unauthorized personnel, thereby leading to a breach of confidentiality.

It is absolutely vital from a medical-legal point of view to ensure that the data base is confidential, not only to protect confidentiality, but to assist with "discoverability." Early on in a lawsuit, during the process called "discovery," further information is requested, which may require producing the record. Although some handwritten information can be excluded from the "discovery" process, by "attorney/client," "peer review," or "quality assurance" privileges, electronically stored mass data may not be protected under current laws. Thus, information that cannot be obtained either by deposition, by specific recall, or by looking at the printed copy of the record may be discoverable. This is an issue that will have to be worked out.

Before getting involved in law and medicine, it is important to determine the advantages and disadvantages of different types of records by asking a few questions. First, is the record accurate and complete? There is little doubt that an automated record has a clear advantage over a handwritten record in this respect. Second, is it contemporaneous? With automation, information is recorded at the time of the event, a particularly important factor in the event of a critical incident. Third, is it believable, is it credible? When a record looks like railroad tracks with absolutely no change in any measured variable and suddenly the next note is "cardiac arrest," it is appropriate to be a little suspicious. Experience in looking at, and generating, numerous records tells us that perfection is almost impossible to achieve. The "perfect" record is not believable, particularly when the result is catastrophic.

A believable, credible record is very important to the credibility of the clinician responsible for the record. We need to determine whether it is better to have every vital sign charted every minute or whether it is acceptable to continue to use smoothing techniques. Is it really important that the blood pressure dropped for 30 seconds, or that the heart rate spiked or had a transient drop? The issue is not one of automation versus hand-generated records, but rather one of educating other people who review the records and of explaining that those transitory changes, for example, are not particularly important. Our method of documenting that a transitory change is unimportant is to point to another 8,000 cases in which it occurred with no adverse consequences. This tool is very powerful and could be useful in a defense.

What else can be determined from the record? If a person giving testimony has coffee stains on his tie and his shirt tail hangs out of his pants but he states that he is neat and precise, he is not going to be believable. The same thing happens with the record. Handwriting leaves a little bit of the writer's personality behind. The very neat, complete, legible record is much more believable than the very sloppy, careless, incomplete record.

Although the automated record has an edge here, it will not provide immunity. If an error is made, the error will be clearly documented, and the clinician will be held accountable for it. However, the major problem in malpractice litigation is not the doctor who errs. It is the doctor who does a good job, but who cannot be defended, because of a bad record, bad documentation, or an incomplete or imprecise story. In this, the majority of cases, the automated record will be an immeasurable help.

ARTIFACTS AND ALARMS: PROBLEMS AND BENEFITS

*Dwayne W. Westenskow, PhD**

Artifacts in the output data from monitors used during anesthesia come from a number of sources, including electrocardiographic (ECG) interference caused by electrosurgery, optical interference in pulse oximetry, and motion artifact in blood pressure cuffs. Artifact can also result from incorrectly set thresholds (such as ECG heart rate trigger), and transducer calibration errors, with the most common probably being the inspired oxygen measurement.

Artifacts theoretically can cause misguided and incorrect clinical decisions because monitor data are not valid. For example, those that cause false alarms can result in unnecessary action being taken on the patient. Artifacts are a particular problem in the automated anesthesia record, since false data are transferred directly from the monitors into the record. With the handwritten record, artifacts are filtered and removed before the data are recorded.

Artifact concerns can be eliminated by using monitoring devices with artifact rejection capability, or by using a record keeper that rejects artifacts before the data are recorded.

Several devices have artifact rejection capability. Many new ECG monitors have a filter that is activated whenever electrocautery is detected. However, while this filter removes interference so heart rate can be detected, it destroys the ability to detect the ST segment depression, because signal quality is reduced. In the newer ECG systems, the heart rate trigger is set automatically.

Calibration artifacts in invasive blood pressure measurements are reduced with new disposable pressure transducers. These precalibrated devices, checked by the manufacturers' quality control procedures, produce much less error than did

*Department of Anesthesiology, University of Utah Health Sciences Medical Center, Salt Lake City, UT.

manual calibration programs in the past, although they do not eliminate artifacts caused by flushing, blood clots, or occluded catheters, for example.

IVAC's closed-loop controller, which automatically infuses sodium nitroprusside based on mean arterial blood pressure measurements, can identify and remove artifacts by comparing the pressure waveform with predetermined criteria. This artifact rejection capability should be included in all our blood pressure monitors.

New noninvasive blood pressure monitoring devices remove motion artifact by comparing the shape of each pressure sensing with expected waveforms. These devices reject artifact without prolonging the measurement time.

Numerous other opportunities for improved artifact rejection capability include amplitude limits, pulse pressure limits, and frequency analysis.

Pulse oximetry is sensitive to ambient light, motion, and electrosurgical interference. Artifacts appear in more than 5% of all patients unless extreme care is taken in probe placement.

Artifacts are becoming less frequent in gas monitoring as faster responding paramagnetic and Raman scattering spectrometer devices replace slower fuel cell and polarographic sensors. Again, automatic calibration results in fewer artifacts than manual calibration, and agent specificity eliminates a potential 600% error in the gas concentration reading from incorrect agent selection [5]. End-tidal carbon dioxide and agent measurements are more accurate when new monitors with good response times are used. Older, slow-responding multiplexed mass spectrometers and some agent analyzers with time constants of 300 msec will have 30% errors in end-tidal measurements when the respiratory rate is 50 or more breaths per minute (Fig 3) [6].

Gas monitoring artifacts are much less common, particularly in infants and children, when rapidly responding monitors are used. Artifact rejection capability is further enhanced as monitors are integrated into a single monitoring system. For example, heart rate is measured by the pulse oximeter, the blood pressure monitor, and the ECG monitor. In an integrated monitoring system, a computer would supervise and compare these three measurements of heart rate and choose the one that is the most reliable. In the intensive care unit, the pulse oximeter is generally the most reliable and would probably be used when the ECG or blood pressure measurements are suspect.

In addition to enabling better artifact detection, the current trend toward device integration allows for better alarm detection. With discrete monitors, heart rate alarms are set on the ECG monitor, on the pulse oximeter, and on the blood pressure monitor. This redundancy is inconvenient and results in three sources for possible false heart rate alarms. With a truly integrated system, the threshold limit for heart rate is set once, and an alarm sounds only when the measurement from the most reliable heart rate monitor crosses the threshold. Further, an integrated system can generate very specific and descriptive alarm messages such as "rebreathing: valve leak," "occluded inspiratory hose," or "leak in the expiratory hose." Ninety-five percent accuracy has been achieved by prototype systems [7].

Integrated artificial intelligence monitoring systems will eventually provide extremely smart alarms and allow detection of many patient-related problems. In addition, the number of artifacts in patient monitoring systems can be reduced significantly if the system is assembled using individual monitors which have "state of the art" filtering and smart artifact rejection capability. The current trend toward integration will help to further reduce artifacts, as artificial intelligence combines multiple variables (on multiple monitors) to detect single events. The benefits will be a trust in the data that are displayed, a confidence in alarms, and an improved decision-making support system.

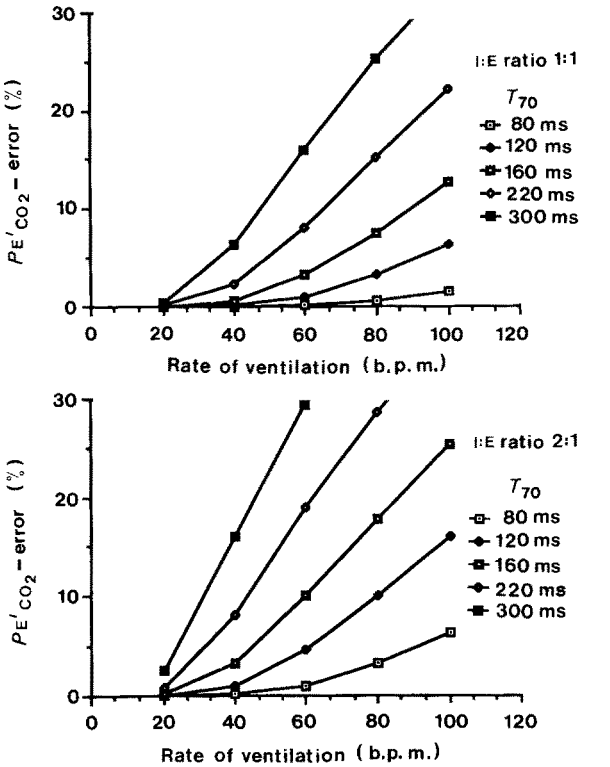

Fig 3. End-tidal carbon dioxide measurement error (percent of reading) as a function of rate of ventilation. With a CO_2 analyzer T_{70} (10 to 70% rise time) one can calculate the predicted "worst case" error in end-tidal measurements. (Reproduced with permission from [6].)

QUALITY ASSURANCE: NO LONGER A SEPARATE PROCESS

John H. Eichhorn, MD

What is quality assurance, and how is it related to a computerized anesthesia patient information management system?

Quality assurance (QA) is often perceived negatively, as an intrusion or a burden. But it doesn't have to be that way. Once established, a properly managed QA system can be run with relatively little effort and can yield fascinating and extremely valuable information.

Quality assurance in general involves a four-step process: problem identification, evaluation, resolution, and follow-up. Objective assessment is critical, and usually means quantitative measurements. Then the good (outcome or process) is reinforced and the bad is corrected. Process is what you do; outcome is what happens. Process is how things are done and

examples are easy, but the documentation is not easy. This is, as Dr. Kroll very correctly pointed out, a problem in the vast majority of medical-legal cases. The spirit of the ASA monitoring standards is almost universally followed. The question is, will the anesthesia charts reveal that fact when closely scrutinized—not necessarily by an attorney or by an expert witness for the plaintiff, but by you, by the peer review committee, or by anybody.

Outcome is the result of care. There are two kinds, objective and subjective. Identifiable complications have always been the focus, but patient satisfaction and impressions are equally valid outcomes and should be stressed more in the future. Patient impressions, or subject outcome, can be entered into the patient information management system that includes the automated anesthesia record. The information management system will extend beyond anesthesia care; it will include preoperative data and postoperative follow-up, as well as notes on patient satisfaction, possibly one day even generated by the patients themselves.

Indicators are the events we look for in the QA process. There are many possible examples—canceled cases, chipped teeth, recognized esophageal intubations, myocardial ischemia, and unplanned admissions to a unit or to the hospital for outpatients. These are classic anesthesia QA indicators.

Criteria are the numerical values attached to indicators where appropriate, and it may be difficult to ascertain what is appropriate. It is necessary to calculate what is an acceptable or common rate (incidence) of appearance of an indicator. Obviously, for deaths on the table, the criterion should be zero. Ideally, there would no deaths on the table from anesthesia care. If more than 4 to 5% of same-day-surgery patients are admitted to the hospital for reasons attributable to anesthesia, that number is probably too high, and it is an appropriate criterion to set for that indicator. This kind of manipulation can be made infinitely easier with a patient information management system, which can instantly reveal statistics of this type once the system is programmed to record them.

Generic screening is a process in which all cases, without exception, are examined for the appearance of certain indicators. Such a process is obviously going to be much easier with a computerized patient information management system than by trying to gather data from a written record, with respect to both the completeness of the record and the physical task of reviewing all the data. Regarding completeness, anesthesiologists are no different from anyone else, and when it comes down to prioritizing, if they have to decide whether to take care of the patient or write out a chart, obviously they will take care of the patient. It is unusual or even unheard of for a practitioner or group of practitioners to have such scrupulously complete handwritten records as to allow the same level of evaluation possible with the automated systems. Follow-up data—what happens after the patient leaves the operating room and the anesthesia chart is turned in—is very difficult to obtain with the handwritten record system. Further, on a generic screen, looking at every single chart is remarkably labor intensive, both in time if it's done by us and in money if we hire somebody to do it. In contrast, we have access to far more data with patient information management systems than with handwritten charts, primarily because of accuracy, timeliness, but especially completeness.

Eventually, there may be sensors that automatically record, for example, which monitors or which syringe pump is in use. Perhaps when you set it on the sensor, the information management system would sense the make, model, and serial number of the piece of equipment and record that permanently. That's not here today, but it is coming very soon. It may not be commercially available for a while, but the concept exists. This device will not only simplify all sorts of inventory utilization and cost issues, but it will enhance quality assurance. In the 2 to 5% of the cases where there is a machine or equipment malfunction leading to an adverse outcome, it would be very useful to have the serial number of the piece of equipment in use at the time. There may be no connection whatsoever, but if there were, that could be a critical datum for the subsequent events, particularly medical-legal events.

Postoperative outcome data represent another applicable area. Currently, postoperative notes (if they are done at all) are not easily trackable. If, however, this information went into the information management system, the outcome analysis could be extracted from the system literally with the touch of a button. The postoperative input could be done by the anesthetist or even by the people who do the discharge coding for the facility. These people could be trained to add an extra code that would trigger the anesthesia QA system to call for more information, which they would then enter.

An information management system that includes pre- and postoperative data is the genesis of an outstanding generic screening system, because every single case has all that completeness. Getting the information put into the system is a human issue and can be done eventually. It takes training, it takes education. But once that goal is achieved, it becomes very quickly the only possible way to do it. In addition to improving patient care and efficiency, all the information can be used to track trends in complications, among many other things.

Massachusetts, New York, and New Jersey have very elaborate reporting systems, with the latter two just starting this year. Practitioners not from those states may be amazed to find what the state government demands health care providers report to the state bureaucracy. Other states are sure to follow. These reports are very burdensome to do by hand. However, all this could be done easily (even printed onto the appropriate forms) with an automated system. The Joint Commission on Accreditation of Healthcare Organizations has a list of 13 basic indicators for anesthesia, and it is expected that all hospitals will be required to develop criteria for these indicators. The list of indicators, which includes such things as death, major and minor complications, and changes in protocol, has been around for a while. These could be tracked in the patient information management system in the JCAHO-specified format, guaranteeing compliance with the regulations.

What about improving practice? All practitioners are trying to take the best possible care of their patients and then comes the "Big Brother" issue. Is the patient information management system looking over your shoulder, waiting to nail you the minute you take a false step? This is simply not true, although it is easy to feel that way at first, until it becomes clear what this technology can and cannot do. Complete and accurate recording of patient data need not be threatening to anybody. For example, in the near future some papers will be published that show that some swings in vital signs are a common occurrence.

Generic screening is easy and will enable identification of problems that previously did not attract enough attention. This will be the QA process genuinely in action. It will allow the calling up of study data that could not have been tracked before. Examples are postoperative nausea and vomiting,

which can be recorded very easily with the follow-up. Then we can ask questions like: "Does intraoperative droperidol reduce nausea and vomiting? But, even if it does, does it extend the Post-Anesthesia Care Unit time? What is the trade-off, what is the risk-benefit analysis?" This is the spirit of trying to improve and modify and fine-tune patient care through genuine QA activities, without the burdensome forms that the government wants you to fill out. When something good develops, we will be able to monitor it easily, to verify that it is still continuing.

FUTURE POSSIBILITIES

*N. Ty Smith, MD**

Many aspects of future advanced technology in automated record-keeping systems have already been discussed, including alarms, artifacts, data bases, quality assurance, and graphic presentations. This section will focus briefly on three other areas: connections, teaching high technology, and implementing control systems.

In looking at the future, we must look at the past, as always. The Black Box has been in routine use by the airline industry for about 20 years. Although it was initially perceived as threatening by pilots and was fought by the unions, it is now well accepted. That will also be the case with the automated anesthetic record in the operating room; we predict that the automated record will become routine, just as it now is in our operating rooms in San Diego.

One of the many complaints about the current *manual* anesthetic record is that information, including information about preoperative patient status, is sometimes missing. It is also sometimes difficult to obtain information. A partial solution involves connections, or networking, among the intensive care unit, operating room, wards, and the various clinical laboratories. On preanesthetic rounds, the clinician could be handed an anesthetic record with most of the information about the patient already entered—including demographic information, medical information (medications, allergies, vital signs, etc.), as well as information from the medical subspecialties (cardiology, neurology, pathology, radiology, and laboratory services), and from the hospital administration. Not only would this eliminate some of the drudgery of manually entering the information while conducting preoperative rounds, but the information would be more accurate and the preanesthetic assessment more thorough.

A tremendous number of data should be transcribed onto the anesthetic record, but it is becoming impossible for us to enter this information ourselves. Some time ago, Whitcher and associates [8] published a proposed list of operating room monitors in the *Journal of Clinical Monitoring*. Most of these have become standards now. In that same issue, Block [9] proposed an even longer list, and it is possible that many of these will be required in the future. And there are now anesthesia systems having as many as 100 controls, 50 displays, and 70 alarm messages. An automated system could provide access to many areas of information in the operating room that currently have to be retrieved manually.

Part of the problem is that data must be entered into the computer before they can be used by the computer. To do this, it is preferable to have automated inputs. There are several types of information that need to be entered, including physiological data, information about drugs, recordings from machines and ventilators, and annotations [10].

The physiological data are relatively easy to automate, since they are derived from monitors. As a matter of fact, one current automated record can derive information from just about any monitor on the market. With regard to the administration of drugs, once the information is entered, the automated record can calculate such things as cumulative totals, but the information is difficult to enter automatically, particularly with injectable drugs. Many modes of entry have been proposed for drugs injected as a bolus, including bar code readers. Ultimately, we shall see specially designed syringes that will enter the drug and amount into the computer on injection. Information about infused drugs is easier to enter, because there are infusion devices that provide continuous information about the infusion rate. Again, drug concentration, rate of drug per kilogram per minute, and cumulative drug totals can be calculated by the record keeper.

Microprocessor-controlled anesthesia machines will soon be commercially possible and could provide important information for the automated record, such as gas flow, vapor concentrations, gas remaining in sources, and disconnects. In this area, monitors are taking up some of the slack until connections are made with electronic machines. For example, the Arkive (Diatek, Inc, San Diego, CA) system can record inspired or expired concentrations of oxygen, nitrous oxide, and inhaled agent, as measured by a mass spectrometer.

Ventilators are now becoming microprocessor controlled, and they can transfer to the automated record such information as rate, volume, flows, pressures, inspiratory/expiratory ratio, resistance, compliance, or any other information that the ventilator's computer can develop.

Annotative information is much more difficult to enter than potentially automated information, not only with regard to preanesthetic information, but also with regard to events, such as the onset or end of anesthesia, anesthetic technique, patient position, or the size of the endotracheal tube. The information can be entered into the computer by means of standard or special purpose keyboards, touch screens, bar codes, or voice recognition. There is a touch screen on one anesthesia record-keeping system. Voice recognition allows the anesthetist to enter information while he is busy with his hands. We started working on speech recognition back in 1980, and soon found that computers are just like people: they talk much more easily than they listen. Speech recognition is a fairly complicated process, but the end result is that the computer is trained by the person's voice. The computer will store each word as a template of 1s and 0s. When a word is spoken for recognition, the computer quickly compares the spoken word with the stored templates and matches the correct templates, thereby "recognizing" that word.

As part of our work on voice recognition, we developed a system called EARS (Entry into the Anesthesia Record by Speech), which uses a language called LARK (Language for Anesthetic Record Keeping). A language is made up of a vocabulary plus a syntax. A vocabulary is the set of all words allowed by a language, and a syntax is the set of formal rules for combining those words. A typical sentence in LARK might be, for example: "Event—auscultation—breath sounds equal, clear bilaterally." For the computer to hear a sentence, it first listens for one of a set of key words. When the key

*Department of Anesthesiology, University of California, San Diego, Veterans Administration Medical Center, San Diego, CA.

word, "event," is entered, the computer will call up another set of words and be ready to listen to those; the word entered—for example, "anesthesia"—will cause it to call up another set of words and phrases. The final word in this simple sentence might be "begin." The language has obviously been made as simple as possible, both for computer and user. Even this simple language necessarily involves some complexity, however. When a drug is entered, for example, "diazepam five," the computer can automatically enter the time, units, and route, as well as calculate the cumulative amounts. Since entering words into a computer by any method, including by voice, is not always accurate, the computer has to be able to tell the anesthetist what it heard. This it can do through a set of earphones.

Some people have difficulty learning to use the technology of automated record keepers, but this learning could be simplified by the use of stimulation training, which would allow one to learn to use Arkive, for example, outside the operating room, in a much more relaxed, less threatening, environment. We have developed a simulator based on a multiple model of the body, with a heart and lungs, and a separate area for uptake and distribution of various agents. Each agent is a separate model, and to add an agent, for example, halothane or carbon dioxide, one adds a model [11].

There are three types of simulators used by the airlines and the military. The best-known one is the "Full Flight Trainer" used in the final training of pilots. A "Full Anesthesia Trainer" could involve a simulated operating room environment with machine, ventilator, monitors, and agents. Some simulators are relatively small and are called Computer-Based Trainers, for example, the anesthetic trainer called "Sleeper." In between these two extremes are the Part-Task Trainers, which would use certain parts of the Full Trainer, and could function in such areas as cardiopulmonary resuscitation, advanced cardiac life support, or instruction for respiratory therapists. Teaching the use of the automated anesthesia record would be in that category of a Part-Task Trainer.

Control systems (automatic pilots) could be significantly improved by automated anesthetic record keepers. These control systems can make the anesthetist's job easier and the patient's "flight" safer. In general, they can perform better than a human controller [12], but they also can have disadvantages as well as advantages. These systems are potentially dangerous if they use incorrect data or if they interpret correct data incorrectly. In fact, the epitome of requiring accurate nonartifactual monitoring data is the control system, and this is where the automated record can be very useful. Many of the disadvantages can be taken care of by an automated record keeping system. By bringing together data from several sources, the automated anesthetic record could serve as a valuable resource for the controller.

Many of the problems of control systems can be bypassed by making a robust controller, developing different types of controllers, or by incorporating some sort of intelligence. A robust controller will ignore the wrong drug concentration mixed in the bottle, or take into account changes in the drug–blood pressure gain of a patient, such as when an anesthetic is given, when the patient is put into Trendelenburg, or when the infusion line is disconnected and then reconnected. A robust controller can be constructed from a series of simple models that are graded by the patient's sensitivity to, say, nitroprusside. The computer is constantly updating which model it thinks most closely matches the patient. This is called a Multiple Model Adaptive Controller [13]. However, even with the best and most robust controller, things can go wrong, and so it needs some sort of intelligent shell that can, for example, distinguish artifact from real changes in blood pressure. Even with artifact-free data it needs to be able to tell a significant from an insignificant change in blood pressure. The automated record will be invaluable for control systems because it will collect the information needed to put together an intelligent shell. For example, redundant heart rates from several sources will allow the control system to detect artifact in that variable. We tested one control system and shell for 61 hours and found that one intervention was required approximately every 30 hours.

The main key to the future is learning to use new technology. This is not easy, and it is our job to make it easier both technologically and psychologically. Therein lies the real future.

REFERENCES

1. Gravenstein JS, Paulus DA, Hayes TJ. Capnography in clinical practice. Boston: Butterworth, 1989
2. Cook R, McDonald JS, Nunciata E. Differences between handwritten and automatic blood pressure records. Anesthesiology 1989;71:385–390
3. Gravenstein JS, de Vries A, Bencken JEW. Sampling intervals for clinical monitoring of variables during anesthesia. J Clin Monit 1989;5:17–21
4. Ream AK. Automating the recording and improving the presentation of the anesthesia record. J Clin Monit 1989;5(4):270–283
5. Guyton D, Gravenstein N. Alcohol interference with infrared anesthetic gas analysis. Anesthesiology 1989;71: A465 (Abstr)
6. Brunner JX, Westenskow DR. How the rise of carbon dioxide analysers influences the accuracy of carbon dioxide measurements. Br J Anaesth 1988;61:628–638
7. Loeb RG, Brunner JX, Westenskow DR, et al. The Utah anesthesia work station. Anesthesiology 1989;70:999–1007
8. Whitcher C, Ream AK, Parsons D, et al. Anesthetic mishaps and the cost of monitoring: a proposed standard for monitoring equipment. J Clin Monit 1990;4:5–15
9. Block FE. A proposed standard for monitoring equipment: what equipment should be included? J Clin Monit 1990;4:1–4
10. Smith NT, Quinn ML, Sarnat AJ. Speech recognition for the automated anesthesia record. In: Gravenstein JS, Newbower RS, Ream AK, et al, eds. Automated record keeping and alarms. Boston: Butterworth, 1987:115–134
11. Smith NT. Mathematical model of uptake and distribution of inhalation anesthetic agents. In: Balagny E, Conseiller C, Cousin MT, eds. Anesthesia by inhalation. Paris: Arnette, 1987:87–118
12. Smith NT, Quinn ML, Flick J, et al. Automatic control in anesthesia: a comparison in performance between the anesthetist and the machine. Anesth Analg 1984;663: 386–393.
13. Martin JF, Schneider AM, Smith NT. Multiple-model adaptive control of blood pressure using sodium nitroprusside. IEEE Trans on Biomed Eng 1987;34:603–611