Challenges and Opportunities for Computerizing the Anesthesia Record

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Most observers would agree that the goal of computerizing the anesthesia record is a worthy one. Despite the fact that several academic groups and vendors have attempted to develop and provide computerized anesthesia charting, the practice is not widespread. In this review article, we attempt to outline the reasons for this reluctance to use computers for anesthesia charting. Where there are problems to be solved, there also are opportunities. We discuss the development of strategies to solve these problems and thus present opportunities for medical informatics professionals and anesthesiologists to work toward joint solutions. Solving these problems includes the development of consensus standards and working out technical, social, and educational difficulties. Details of the approaches recommended are outlined.

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Note: Dr. Omar Prakash passed away on April 18, 1993.[1] At the time of his passing, Dr. Prakash was preparing this manuscript for submission. Dr. David J. Cullen, Deputy Editor-in-Chief, and Dr. Paul J. Poppers, one of the guest editors of the Benelux issue, asked that I update and complete the manuscript. I am honored to be invited to assist my dear friend, Dr. Prakash. I hope this work will be of the standard of excellence that he would have prepared. I am certain that the level of energy and enthusiasm that Dr. Prakash would have used to present the material may be a bit lacking. I have made every attempt to make the content current and the future as bright as Dr. Prakash would have.

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Introduction

If you raise the subject of computers in anesthesia with a group of anesthesiologists, you are likely to stir emotions ranging from hope and delight to disbelief, fear, despair, and disgust. Such has been the progress of computerization of the anesthetic record. Despite early projections as far back as the early 1970s that, within a few years, everyone would be using computers to chart the anesthesia record, even today few such systems are clinically operational. Such a statement is made not to downplay or discourage those who have developed and operate excellent systems, but to illustrate the difficulty of the task. This review article addresses several issues that have made the task so difficult and suggests several opportunities and strategies that may make acceptable and worthwhile computerization of the anesthesia record possible.

The need for computerization of the medical record has been recognized as essential by the prestigious Institute of Medicine of the U.S. National Academy of Science.[2] Anesthesia, as one of the more complex and potential areas of medical practice that could benefit most from computerization, should view with favor computerized data acquisition and record keeping. Several studies have shown that the manual anesthesia record has flaws and is often illegible, incomplete, and difficult to use for the multitude of purposes that today's complex medical, legal, quality-assurance, administrative, and management tasks require.[3–19] However, opinions are divided on the importance of computerized medical records.[20–23] Those who are in favor of computerized anesthesia records have started to build a literature database that is becoming convincing. However, as always, we must be wary that those who speak against computerizing anesthesia records may be correct. We must provide the scientific and cost-effectiveness data to prove the value of computerized records.

Most observers would suggest that the goal of computerizing the anesthesia record is a worthy one. What, then, are the issues and problems that have prevented development, installation, and widespread clinical use of computerized anesthesia systems?

In our opinion, there are many reasons for the failure to computerize. This review article outlines what is wrong with our current approaches and suggests future development of anesthesia record computerization. Many of our suggestions dictate the development of consensus standards; some are also social, and they will likely take education and time to solve. We have divided the problems and opportunities for development of computerized anesthesia records into three broad classes: (A) those relating to anesthesiologists and the profession of anesthesiology; (B) those related to use of computer technology, which we have broadly classified as "medical informatics"; (C) those requiring the combined efforts of both professional groups.

A. Anesthesiology Issues (Standards, Medical and Professional Issues)
   1. *Consensus on the content of the anesthesia record.* The detailed substance of the anesthesia record has not yet been clearly specified.
   2. *Coded* versus *free-text record.* To this point, the need to acquire coded as well as "free-text" information has largely been ignored.
   3. *Parameters to be monitored.* Anesthesiologists have not yet determined what parameters should be monitored.
   4. *Frequency of data acquisition.* Frequency at which monitoring parameters should be acquired, how they should be "smoothed," and when they should be charted.
   5. *Legal and responsibility issues.* There is a fear that if you use computerized records, "big brother" will have a better opportunity to look over your shoulder and regulate, castigate, or sue you.
   6. *Training and implementation issues.* The social structure and medical training of anesthesiologists are not yet aligned with the automation process.

B. Medical Informatics* Issues (Technology)
   1. *Integration of anesthesiology with other segments of the medical record.* Hospital clinical computing systems developers have not taken advantage of integrating data from multiple sources and distribution of data from the anesthesia charting system to multiple systems.
   2. *Ideal computer interface for the anesthesiologist user.* The development of a convenient and quickly learned "user interface" for the computer has been difficult.
   3. *Artifact elimination.* Determining when monitored signals automatically acquired from the patient are true and when they are artifactual.
   4. *Standards for monitoring device communications, or Medical Information Bus (MIB).* Standards for integrating the communications between monitoring devices have been slow to develop.
   5. *Displays and alarms.* Development of display and alarm technology that will augment rather than detract from the anesthesiologist's performance.

C. Joint Anesthesiology and Medical Informatics Issues
   1. *Decision support.* Development of computerized decision support aids.
   2. *Cost-effectiveness and evaluation.* Evaluation of the effect and cost-effectiveness of computerized systems.

Background

The earliest known anesthesia records were made a century ago in 1894.[24] Since that time, the handwritten anesthesia record has gradually changed and become somewhat standardized.[3] From an engineering point of view, the anesthesiologist is a systems manager; the patient represents a dynamic system whose variables are a function of time. The manager's primary tasks are controlling and decision making. At present, this busy manager (anesthesiologist) acts as a performer of various technical procedures, data gatherer, decision maker, and controller. As surgical and anesthetic techniques grow in complexity, some have suggested that anesthesiologists are reaching the limits of their ability to handle these many tasks simultaneously.[25–27] Since 10% to 20% of an anesthesiologist's time is spent keeping records, some people have suggested that using the computer to assist in the record-keeping task follows naturally.[8,28]

Figure 1 diagrams the data flow in an anesthesia situation. The patient generates most of the important infor-

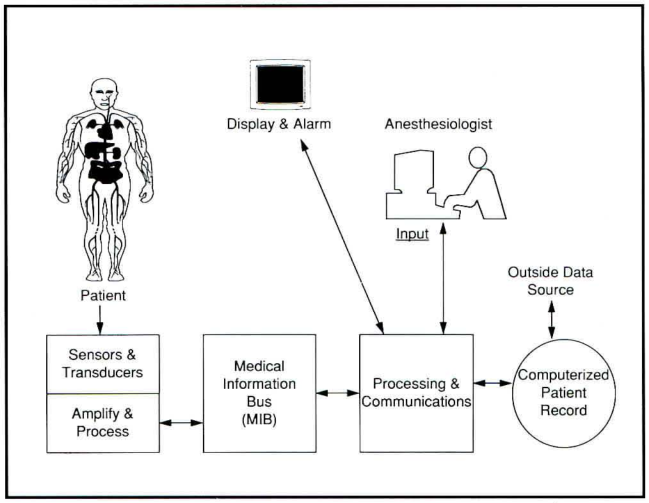

Figure 1. Block diagram of a computerized data acquisition and presentation system for capturing an automated anesthesia record.

*Medical informatics is a field of study concerned with the broad range of issues in the management and use of biomedical information, including medical computing and the study of the nature of medical information itself.

mation. During most surgical procedures, sensors and transducers are used to measure ECG [heart rate (HR) and rhythm], blood pressure (either directly or by use of noninvasive cuff methods) (systolic, diastolic, mean arterial pressure, and HR), arterial oxygen saturation by pulse oximeter (SpO_2 and HR), and temperature. In some cases, pulmonary artery pressure, mixed venous oxygen saturation, electroencephalogram, and anesthesia machine gas concentrations, rates, and volumes also are measured. Each of these signals is typically amplified and processed to display the above-noted parameters. Today virtually every processing and display system contains at least one and sometimes multiple microprocessors. Software written for these microcomputers processes the signals and displays the derived results. Indeed, instruments such as the pulse oximeter would not be possible without such computerization.

Unfortunately, these monitoring devices are not made by the same manufacturer. In fact, most monitoring devices are stand-alone units, with their own processing algorithm, display, and external communication capabilities. Connecting all these devices together is much like trying to speak Russian, German, Spanish, and Japanese simultaneously. As a consequence, few manufacturers and institutions have integrated the patient record electronically. (Elsewhere we discuss the MIB and how it enhances such communications.) In the ideal system, all patient data are communicated to the "processing and communications" block shown in the lower right of *Figure 1.*

In addition to needing the data from the monitoring devices, the anesthesiologist must collect data from the hospital or clinic records. Such data include patient name and address, gender, height, weight, hospital identification number, insurance carrier, and names of nearest relatives, among others. Laboratory data include arterial blood gases, complete blood counts, electrolytes, and coagulation parameters. Data from nurses, such as the latest medications given and special nursing needs, may be needed. Pharmacists may know about the patient's allergies and have recommendations for when and which preoperative antibiotic should be given. Archival medical records of previous visits may be essential to evaluate previous surgeries and complications. Data from radiology, surgical scheduling, "case cart" availability of supplies, blood, and equipment in the room also are essential. By now it should be clear that the anesthesiologist needs an integrated medical record system to care for the patient.

During surgery, anesthesiologists are vigilant observers and recorders. They note important steps in the surgical procedure, such as "going on bypass." They must arrange the anesthetic and monitoring equipment and note that they have carried out these preparatory procedures. They must adjust and calibrate instruments, mix and administer medications, insert catheters, and perform endotracheal intubations. Anesthesiologists must record each medication given, with its dose and route of administration. In addition, they must be ever vigilant to recognize unacceptable signals and alarms from monitors, the patient, and the situation in the operating room (OR). With all of these tasks, it is remarkable that anesthesiologists perform as well as they do and have as few untoward incidents as are reported.

Anesthesiology Issues (Standards, Medical and Professional Issues)

Consensus on the Content of the Anesthesia Record

If we were to interview 25 anesthesiologists from around the world, we would likely obtain at least 25 specifications for what a computerized anesthesia system should be. Most computerized anesthesia charting system manufacturers did not get a consensus on what is needed in a charting system before they built their systems.

Most industries have learned that standardization of processes improves quality and simultaneously decreases costs. There are many advantages to standardizing care in hospitals, and the computer lends itself nicely to this task.[29] When anesthesia is used for large numbers of certain types of procedures, such as coronary artery bypass surgery, outcomes improve,[30] mostly due to the standardized care that results from case frequency and repetition. When standardized care protocols are used, mistakes are reduced. For example, if intravenous infusion drugs are mixed differently each time, administration of incorrect doses is more common than if concentration is set by policy and protocol. In addition, patient care is more consistent if all care team members use the same principles and decision logic.[31,32]

It is important for anesthesiologists to standardize what is expected in the record. Already there have been encouraging attempts to establish monitoring and recording standards.[33,34] McDonald[35] and others[36,37] have shown that using computers to assist in this process provides better quality and can be done in such a manner as to assist the physician in the care process.

Coded versus *Free-Text Record*

Free text is unstructured, uncoded representation of information in text format—*e.g.,* sentences describing the results of a patient's physical examination. Coding schemes are systematized methods for classifying objects and entities (such as diseases, procedures, and symptoms) using a finite set of numeric or alphanumeric identifiers.[38,39] Today virtually all history and physical reports, surgical reports, and discharge summaries are in dictated free-text or narrative form. The computer has allowed at least the capability to review these data properly spell-checked on a screen. Some people feel that the entire record should be recorded in free text.[40] Others, including ourselves, feel the need to code as much patient information as possible.[41–43] An implicit assumption of free text–only systems is that physicians can provide *all* the necessary intellectual analysis of patient data. McDonald,[35] Eddy,[31] and others[32] have clearly shown that humans are not perfect information processors. With free text–oriented computerized systems, there is no mechanism to detect drug interactions, laboratory contraindications, or computer-assisted protocols.[43]

Parameters to Be Monitored

Deciding which physiologic parameters should be monitored and the monitoring frequency is a complex task. However, providing guidelines as to which parameters should be monitored in given conditions would help reduce variability and improve anesthesia care. In addition, guidelines would help the medical informatics specialists to improve the quality of computerized patient records. Computerization of intensive care unit (ICU) records has influenced comparable records in anesthesia. In our view, this has occurred because ICU physicians have had to work in teams, not as the typical single physician/anesthesiologist.[44–47]

As a first step in setting up standardized practices, anesthesiologists may adopt the stance outlined in a position paper of the American Medical Informatics Association on communications and patient identification standards.[48] In the long term, however, studies like those recently published in the anesthesia literature will be required,[49,50] as well as updates on the best standard of care.

Frequency of Data Acquisition

A 5-minute sampling interval is incorporated into standards for monitoring by the American Society of Anesthesiologists.[47] Gravenstein *et al.*[51] have challenged the 5-minute interval and presented data to indicate that many variables are presented more than once each minute. Although some variables such as temperature change very slowly, other variables such as SpO_2 change much more quickly. Gardner *et al.*[52] found that if all 33 parameters from an ICU ventilator were collected, up to 1.5 million bytes of data could be generated per day. The question of how frequently parameters should be collected must be determined. In the modern OR where 10 or more variables are recorded, anesthesiologists could likely keep up with the task if the recording interval were 5 minutes. However, if sampling and plotting intervals of 1 or 2 minutes are required, only automated systems will be able to record the data. The anesthesiology community should investigate and recommend the frequency of data acquisition during surgery. Also, whether to record an average—the so-called smoothed value manually recorded by anesthesiologists—or take a more pragmatic approach must be considered. For example, Oniki and Gardner[53] and Gardner *et al.*[52] have shown that electronically taking multiple samples and then recording a median provides more representative results.

Legal and Responsibility Issues

The anesthesia record is often crucial to a successful defense in nonmeritorious legal claims. The anesthesia record also may be pivotal in determining whether quality care was rendered. Despite the fears of anesthesiologists, having the computer acquire and automatically document physiologic data has not been problematic.[9–12,54] The analogy between flight recorders used on commercial aircraft and anesthesia records is frequently made. Flight recorders are the principal source of evidence for the causes of airline accidents.[11] It would be interesting to know the history of the flight recorder and the battles that pilots and engineers fought *not* to have these data recorded. The liability danger of automated record keeping is apparent. If computer-generated records are not reliable, they are worthless. Anesthesiology must deal with multiple aspects of computerized record keeping, including privacy of the record, correction of errors in the record, and the need for and storage of records in long-term databases.[11,12,55–58]

Training and Implementation Issues

If we lived in an ideal world where all of the factors mentioned in this article could be dealt with, there would still be major problems in implementing computerized anesthesia records. Funding for the computer system hardware and software is not a trivial issue. In addition, capital for interfacing existing monitoring devices or replacing them with MIB-compatible equipment will be problematic. Probably the largest problem to be dealt with is the training of practicing anesthesiologists *and* medical students in the use of the technology. Given the experience LDS Hospital in Salt Lake City in developing an integrated computerized patient record, it has become evident that the problem is about 20% technological and 80% sociological.[59]

Medical Informatics Issues (Technology)

Integration of Anesthesiology with Other Segments of the Medical Record

The ultimate purpose of a medical record, whether in handwritten or computerized form, is to provide data so that physicians and other caregivers can make timely and accurate medical decisions. Integrating data from a wide variety of sources into a computerized record is worth more than the sum of the parts. For example, with most current computerized anesthesia charting systems, the anesthesiologist or an associate must enter the patient's name and identification number into the record, even though the information is probably read from another computer screen from the hospital's billing system. Similarly, most of the time, data from the handwritten or printed anesthesia record are read by pharmacy and surgical clerks to extract billing and coding information.[4,5] Extracting data from paper records is expensive, and even when it is done, the results have large error rates.[60]

Our experience at LDS Hospital has shown the value of integrating data from a wide variety of sources to minimize data reentry. More important, the integrated computerized data can be used for computerized decision support.[45,61–63] In fact, because of this integrated system, we find nurses and physicians complaining whenever they have to read data from one computer screen and either manually record it or enter it into another computer. They now understand that data from the multiple computers in the hospital can and should be integrated.[48,62]

Dr. John J. Osborn, one of the pioneers in the field of ICU computerization, wrote an excellent overview[64] of the field a dozen years ago and made the following statement: "The great mass of useful numbers we generate by computer has got to be tamed and controlled. We have learned how to make the measurements. Now we must learn how to handle the resulting data and present them in understandable terms. Used right, automation can integrate these data, simplify them, scan and evaluate them. Automation is not a cold-blooded monster-machine between us and the patient. It is a tool to expand our medical power, to let us get closer to the patient, and take better care of him."

Ideal Computer Interface for the Anesthesiologist User

If the anesthesia record can be standardized and reliable automated methods developed that acquire data from monitoring devices, computer systems can become more integrated. If such an event happens, we will have made major progress in computerizing the anesthesia record. However, the anesthesiologist is the principal observer during the surgical procedure, and the observational data must be entered into the computerized record to make the record complete and comprehensible. Thus, methods must be developed that allow the anesthesiologist to enter observational data, medications data, and the like. It seems that each new innovation in computer data entry technology is examined and touted as *the* data input device answer. For example, we have seen keyboards, touch screens, light pens, a mouse, or a track ball extolled as *the* input device.[65–68] More recently, voice input devices have been tried, with limited success.[69] The search for the optimal device or method is still in progress. In 1994, handwriting tablets are available at a low cost. Unit doses of medications are being packaged in bar-coded packets, which can then be read with a wand just before being administered. Computer schemes that are customized to the anesthesiologist and list the most common medications given and their doses have been tried with some success.[70,71] Up to this point, the ideal input device for the anesthesiologist has not been developed. In fact, there may not be one device, but a number of different devices appropriate for different tasks. The devices used may be selected by particular anesthesiologists depending on personal preference. The main objective is to acquire the needed data in the minimum time and with the highest accuracy. There is still much research to be done in this area.

Artifact Elimination

It is expected that human observers such as anesthesiologists consider all the important factors when they record data from monitors. Unfortunately, numerous studies have shown a "smoothing" of the data.[72–76] Also, some of our observations of nurses and respiratory therapists have shown more data-logging errors than expected.[52] To implement effective computerized anesthesia records, data must be entered promptly and correctly. It is no longer adequate to have the anesthesia record correct only at the conclusion of surgery.

Monitoring manufacturers have not taken care to eliminate artifact in the data "sent" from their instruments. Therefore, a major effort must be undertaken to do so—perhaps something as simple as giving a "quality of signal" status so that the human observer or computer "monitor" can understand that the output might be in error. Many patients under anesthesia have multiple indicators of the same parameter. For example, HR may be simultaneously derived from ECG, pulse oximeter, and arterial pressure signals. Integration of data from multiple signals to acquire the "best" parameters is a research area worth pursuing,

Deciding what data need to be recorded and at what frequency was discussed earlier in this review. Data selection using "smoothing" methods will likely be needed. Although our group has used a moving median[52,53] successfully, we encourage others to investigate even better methods.

Standards for Monitoring Device Communications (MIB)

Communication is one of the most important tasks performed by anesthesiologists. As outlined in the background section, data from a wide variety of sources underlie every decision. With all the monitoring instruments available in anesthesia, the developer of a computerized anesthesia charting system must create customized interfaces with each device. Imagine what it would be like today if we were required to have 10 or 12 different facsimile (fax) machines depending on what device our recipient had. Fortunately for us, fax machines operate on very detailed and standardized communications protocols. As a result, we can send a fax anywhere in the world.

Progress is being made to develop a similar standard for the MIB.[77,78] With an MIB standard in place, medical monitoring devices will be able to interconnect and communicate in much the same way that fax machines do. When the standard is finalized and devices become available, the monitoring device will identify itself to the "processing and communications" module shown in *Figure 1.* The device type, serial number, software modification number, quality of the monitoring signal, and derived values will be transmitted.[79] Using this technology, it will be possible to acquire and integrate signals from a wide variety of devices.[52,53,80]

Displays and Alarms

Presenting the data from an anesthesia record is a major technical challenge. The amount of data to be displayed is enormous: more than that required during the flight of a commercial airplane. The anesthesiologist has become accustomed to a single sheet of paper that has information

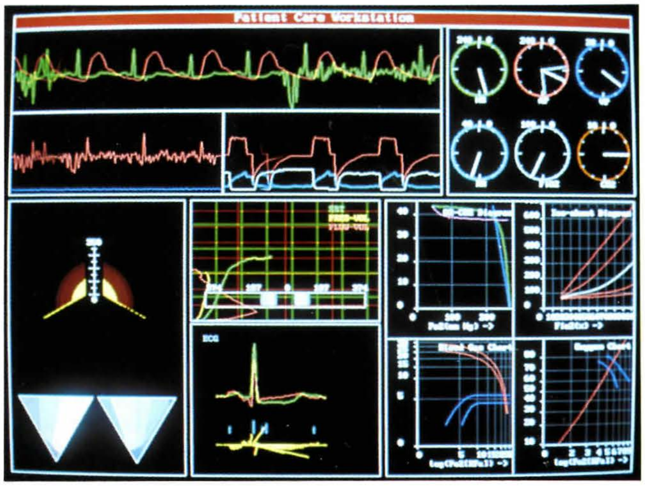

Figure 2. Computer screen showing a sophisticated display of physiologic data. The screen was shown as a pilot by Dr. Prakash in March 1993.

organized and displayed with a variety of techniques—notes, codes, and graphs.[81–83] Simulating this single-sheet display is difficult with today's cathode ray tube displays, and especially with the smaller flat-screen liquid crystal displays. With laser printers, ink-jet printers, or color plotters, one can "print" more than three times as much information on a letter-size sheet of paper than can be displayed on an electronic display device. Given this limitation, plus the fact that anesthesiologists cannot agree on what should be on the display, the designer of an anesthesiology display system faces unusual challenges. A likely solution to these problems is carefully designed and tested display systems similar to those used in commercial airlines. The selection of parameters to be displayed and their color, location, and time scale presentation are major human factor design considerations. This is one area in which the medical informatics and anesthesiology communities can join together and design a better system.[84,85] *Figure 2* is an example of a display developed by Dr. Prakash and his colleagues in Rotterdam, The Netherlands. Dr. Gardner had the opportunity to see and review these prototype displays while visiting Dr. Prakash. The displays were presented on IBM PC/2 personal computers.

Design of alarm systems for anesthesiology is likewise challenging.[86,87] At first it might appear that since the anesthesiologist is at the patient's side and ever vigilant, sophisticated alarms are not necessary. However, the recent work of Westenskow *et al.*[87] showing that "intelligent alarms" have the potential to reduce time to correct critical faults is provocative.

Joint Anesthesiology and Medical Informatics Issues

Decision Support

Decision support systems represent a specific type of medical informatics. Such systems receive medical *data* as input and apply *medical knowledge* to help caregivers interpret the data and make better decisions.[88] For example, it has been shown that giving a prophylactic antibiotic within a 2-hour window before certain types of surgeries reduces postoperative wound infection.[37] By advising nurses, surgeons, and anesthesiologists by way of a simple "flag" on the surgery schedule, the number of patients receiving the prophylactic antibiotic on time increased and the prophylactic wound infection rate decreased.[89] Computerized decision support strategies have come into more common use in medicine and have resulted in important improvements in quality of care and cost reduction.[35,90,91]

Cost-effectiveness and Evaluation

Anesthesiologists and medical informatics scientists must evaluate computerized record-keeping systems and prove their clinical value as well as cost-effectiveness.[8,19,91–94] Several investigators have presented interesting and encouraging material. However, to make computerized anesthesia records the standard of practice, additional studies are needed. Stead *et al.*[95] have provided a framework for such evaluations.

The Future: Where from Here?

We now have an opportunity to design and build computerized anesthesia record systems that will help solve the problems enumerated above and help improve the quality of anesthesia care. In the process of doing the research and development work that must be undertaken, we feel that the six guiding principles on computer system design presented by Greenbaum and Kyng[96] will be helpful.

1. Computer systems that are created for the workplace need to be designed with *full participation* from the users. Full participation, of course, requires training and active cooperation, not just token representation in meetings or on committees.

This statement means that anesthesiologists, surgeons, nurses, administrators, and medical informatics personnel must be involved in a cooperative, teamwork-oriented environment to be most successful.

2. When computer systems are brought into a workplace, they should *enhance* workplace skills rather than degrade or rationalize them.

If teamwork and a collaborative spirit are developed, the work environment for anesthesiologists and other clinical staff can be enhanced. By using the computer to communicate and share data and patient concerns, the quality of patient care can be improved.

3. Computer systems are *tools* and need to be designed to be under the control of the people using them.

Clearly, computers should be used as tools and not as a mechanism to force a round peg into a square hole. They should be used to solve real problems and to meet the needs of all parties.

4. Although computer systems are generally acquired to increase productivity, they also need to be looked at as a means to increase the *quality* of results.

Quality of health care can be improved with the use of computers. The primary purpose of a medical record is to improve the quality of patient care; the computerized medical record has the same purpose. Enhanced communications, alerting, alarming, advising, critiquing, and, finally, consulting, are primary factors that computers can and should address.

5. The design process is a political one and includes *conflicts* almost every step of the way. Managers who order the system may be at odds with workers who are going to use it.

This statement is particularly true for anesthesiology and surgery. Many of the computerized systems in anesthesia have been developed without the involvement of anesthesiologists or surgeons in the planning process. Medical politics is difficult, especially in these days of major changes occurring in the health care system. However, involving as many people as possible in the discussion of new developments is key, and the work will best be carried out as a team effort rather than a dictatorship.

6. The design process highlights the issues of how computers are used in the context of work organization. We see this question of focusing on how computers are used, which Greenbaum and Kyng call the *use situation,* as a fundamental starting point for the design process.

One of the faults of medical and hospital organizations is that departments become strong by being independent and self-sufficient. Many times, there is little communication with other departments, and integration with other departments is seldom a goal. However, with the changes now occurring in medical care, there is a greater need to share and integrate. Anesthesiology is no different from any other department.

Finally, we should ever be aware, as Greenbaum and Kyng[96] state, that "when organizations don't 'make sense,' the people in them are aware of this, because they themselves work to create a framework of sensemaking!" We should take advantage of computers as tools to acquire and communicate data.

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