Chapter 25
The Future of Computerized Decision Support in Critical Care

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Prediction is very difficult, especially about the future.
Neils Bohr (1885–1962)

As we write this final chapter, there is a foot of new snow on the ground in R.G.'s backyard in Salt Lake City, and the snow continues to fall. Last night three local television weather forecasters predicted we would only have two inches of snow, and all they had to do was predict one day into the future! With some trepidation, and without the equivalent of weather satellites and 40 years experience with forecasting, the authors will try to predict the future of computers and decision support systems in critical care. Our projections are based on two decades of experience and a generally optimistic outlook. We believe that seven broad areas will determine the pace of the future of computerized decision support in critical care:

1. Human, cultural, and sociological issues relating to how computers will be used in the intensive care unit (ICU).
2. Standardization in medicine and the ability to share medical knowledge will be essential.
3. Expanded medical knowledge will lead to better patient care.
4. Hardware and software will continue to advance at a rapid rate.
5. Data acquisition methods and instrumentation will provide more accurate, timely, and less expensive measurements.
6. Sharing of computer and clinical knowledge in computer form will become common and encouraged by government and the clinical community.
7. Better methods for prognostic decision-making will enable medical practitioners and society to make better ethical decisions about health care.

Human, Cultural, and Sociological Issues

We believe that people, and not technology, will continue to be the major determinant of how quickly and successfully computers are applied to ICU decision making. To be successful at implementing computers in the ICU, everyone involved in patient care must be a participant in the design and implementation of the computerization process. Designing any human-computer interface is difficult. Designing computer applications for medical use is even more challenging.

Although the authors work with, encourage, and implore the medical products industry to start to work on the issues relating to medical computerization, it is not that easy. There are many human, cultural, and social interaction issues that must be resolved before we can achieve benefits of computerization. A recent book by Greenbaum and Kyng entitled *Design at Work: Cooperative Design of Computer Systems* offers several excellent suggestions that all designers should heed, be they hospital or industry based [1]. One of their contentions is that "We fail more often because we solve the wrong problem than because we get the wrong solution to the right problem. . . . The problems we select for solution and the way we formulate them depends more on our philosophy and world view than on our science and technology."

In addition, these authors provide six excellent guiding principles for designing computers for use by humans. The concepts are clear and filled with common sense, but a careful review by both Gardner and Shabot has humbled us both! We wondered why someone did not tell us this before we started. All of us must take these guidelines under advisement as we progress to future applications.

Guiding Principles of Greenbaum and Kyng

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 one *must* have involvement of laboratory technicians, nursing staff, physicians, clerks, administrators, and medical informatics personnel in a cooperative, teamwork environment to be most successful. With this involvement, the systems developed will better meet the needs of the users and advance the state of the art of computer use in the ICU. With that cooperative spirit, looking at the applications of decision-making in the ICU will be a natural outcome. Patient care will be improved and communications and job satisfaction for all parties will be enhanced.
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 physicians, nurses, therapists, and other clinical staff can be enhanced. By using the computer to better 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." The tools must be developed as a joint venture to best meet the needs of all.

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. Numerous examples of quality improvement have been presented in this book and demonstrated by several other groups. Since the main purpose of a medical record is to improve the quality of patient care, the computerized medical record has the same goal. Enhanced communications, alerting, alarming, advising, critiquing, and finally, consultation are primary areas where ICU computers can and should enhance patient care.

   The ICU is the primary hospital location where "data overload" can occur. Patients in the ICU generate enormous amounts of data—from bedside monitors, lab tests, medications given, procedures performed, and care provided—yet attention to fine detail is crucial. The ICU computer, with its unresting eye and nearly prefect "memory" can help caregivers do the right thing, at the right time, every time.

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 the workers who are going to use it.*

   These statements are particularly true for ICU. Many times physicians and administrators develop plans for computerization without involving nurses, therapists and clerks in the planning process. Institutional politics are never perfect, but involving as many people in the discussion of the future and ICU computer development will ensure that this will be carried out as a "team" activity rather than a dictatorship.

6. *Finally, 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 we call the use situation, as a fundamental starting point for the design process.*

   One of the concepts the Japanese learned during the 1970s and 1980s was to have the entire organization learn to work together. For example, it is stated that the janitor in a Toyota plant in Japan knows why he is sweeping the floor in terms of how his task contributes to the production of better, higher-quality automobiles. On a recent visit to an ICU where computers were beginning to be installed at the bedside, the developers had not given much consideration to how the system would be used. Virtually every item of information about the patient required *manual* entry, including patient name, the vital signs, and all procedures performed by nurses and therapists. To establish patient billing, many of the procedures had to be *simultaneously and manually* entered into two or more systems. The engineers who designed this system had developed something that could be made to work, but they did not optimize the communications and integration capabilities of their system.

We have all too frequently observed the situation that Greenbaum and Kyng state: "When organizations don't 'make sense,' the people in them are aware of this, because they themselves work to create a framework of sensemaking." The work of Greenbaum and Kyng, and the example of Hewlett-Packard when the company was trying to develop a simple loading mechanism for a large scale plotter, clearly point out that we have MUCH to learn about the human interface and about solving the correct problem [2]. It is clear to Gardner and Shabot that a spirit of teamwork, a broad interest in sharing data and interface issues will be among the most important activities required to advance the state of the art of computerized medical decision making. We believe that the ICU will be the frontier upon which the practice of computerized medical decision making will occur.

Standardization

Everyone already expects that computers will be used in the grocery store check out line so that an itemized bill with the price and description of each item is provided. To do that, the grocery industry developed a universal product bar coding system and clever methods for scanning the bar codes as the product is swept across the scanner. We think nothing of having our travel agent book a seat for us on a trip three weeks in advance and at the same time giving us seat assignments. Both of these computer applications were developed at great cost and with careful integration of data and knowledge bases. Unfortunately, medicine is just starting the process that these two industries worked out almost two decades ago! In our opinion, standardization is crucial for implementation of computers in critical care, and only standardization will allow medicine to reap the benefits now enjoyed by so many other industries.

As Barnett and Shortliffe state so well in their chapter in the text *Medical Informatics*, lack of standardization of language and communications protocols is a major problem in medicine [3]. The practice of medicine has developed around a "free text" style of description and explanation. However, as medicine prepares to move into the 21st century, there is a need standardize data definitions and languages, data acquisition and communications technologies, and mechanisms to share medical knowledge in computer usable form, using a standard format. Today the effective practice of medicine is dependent on the ability of health professionals to locate relevant pieces of patient information and combine them with medical knowledge to interpret the data correctly [4, 5].

There are a number of forces at work that will increase the use of computerized information systems, enhancing the computer literacy of health professionals, including the development of user-friendly software that allows health professionals to search the medical literature; wider availability of machine-readable information sources; computerized diagnostic and therapeutic assisting systems; and the emergence of local, national, and international research communications networks; efforts to increase health professionals' awareness of currently available information services and the Unified Medical Language System (UMLS), a project of the National Library of Medicine in the United States [4–9].

Efforts are underway to have a common language that will hopefully be used by medical system developers to define the terminology used in the definition and description of diseases. This language can also be used to search the MEDLINE literature referencing system developed and maintained by the National Library of Medicine and used worldwide to allow clinicians and researchers to the medical literature. In addition there are coding systems used for classifying diseases, such as ICD-9-CM, the International Classification of Diseases version 9 with a Clinical Modification. ICD-9-CM codes are typically assigned and stored for each patient admitted to a hospital. The Diagnostic Related Groups (DRG) codes used to establish Medicare reimbursement were derived from the ICD-9-CM codes. A competing terminology is called the *S*ystematized *No*menclature of *Med*icine, or SNOMED. This terminology has its roots in pathology and was developed to help pathologists classify their findings. The physician's Current Procedural Terminology (CPT) is used to define procedures performed by physicians, such as an appendectomy [4–9].

To illustrate the problems associated with categorizing and standardizing medical care, let us take a brief look at medications. By law in the United States, each medication has its own "drug code." Although this level of standardization is worthwhile and somewhat unique in the medical field, it still does not go far enough. For example, a medication containing aspirin will have its own unique drug code. If one wanted to develop a computerized medical knowledge-based system to prevent patients allergic to aspirin from having this medication prescribed, one would need to have knowledge of every drug's contents. As a result, several commercial firms, including First Databank, sell medication databases that detail the contents of each medication.

The UMLS is developing a strategy to enhance and standardize the communication of medical data. However, the UMLS was not designed to encompass the sharing of computer-based medical knowledge. In the past 15 years systems such as INTERNIST-1/QMR, ILIAD, DXplain, CARE, and HELP have been developed that encode medical knowledge [10]. In 1989 a group of medical informaticists assembled at Columbia University's Arden Homestead conference center to discuss sharing of computer-based knowledge. The group determined that there was a need for better ways to map terminology used from one setting or program to another; to catalogue a list of programs available to process medical knowledge; to develop a representational syntax and format for sharing computerized medical knowledge; to look into the possibility of developing standards for interfacing diverse program modules so that they could be shared; to develop methods of evaluating, validating, and testing knowledge-based computer systems; and finally to define the legal and financial aspects of sharing computerized medical knowledge with its implications to patient care [10]. As a result of this initial meeting at Arden Homestead, there has been a growing interest and series of developments that in the future will make sharing of computer-based medical knowledge not only possible, but essential [10–14].

Finally, standardization of methods and transport mechanisms to move medical data from one instrument or system to another are very important. As covered elsewhere in this book, the adoption and widespread use of specifications and standards such as Health Level 7 (HL7), the IEEE P1073 Medical Information Bus (MIB), and the IEEE P1157 Medical Data Interchange (MEDIX) standards are crucial to the implementation of ICU decision support systems.

Medical Knowledge

The acquisition of medical knowledge in a form that will be functional for computer-directed patient care will require a change in our operating paradigm. Medical scientists in general are not now prepared to put the required specificity and detail into the description and definition of the patient care process. For example, the statement "increase the FiO_2 if the pO_2 is low" seems clear when used in ordinary speech, but in terms of a computer algorithm what does "increase" mean, e.g., exactly how much of an increase? What does a "low" pO_2 mean? In addition there was no specification of time in these instructions nor was there an implied or stated indication of when or how often the pO_2 should be measured after the FiO_2 is increased. Thus, every physician and nurse "thinks" the other caregiver knows what to do, but in fact there is a large amount of variability in the patient care process. This variability is not the beneficial kind which may be related to thoughtful, personalized patient care.

Rather it involves a type of random variability which in other industries has been found to be at cross purposes to quality.

Recently at the LDS Hospital clinicians were developing protocols for the care of patients with Acute Respiratory Distress Syndrome (ARDS) a syndrome that when severe is fatal for about 90% of patients. As protocols were being developed, a computer scientist presented specific patient data to five physicians on a consensus panel. He then asked what treatment strategy each would use. To everyone's surprise, there were five different plans from a group of physicians who work together each day and thought they used the same treatment strategies!

Clearly if we are going to optimize patient care we must acquire and apply optimal treatment strategies. However, with each physician using his or her own "best" strategy, we do not have a scientific platform from which we can determine the most effective treatment plan. We are much like the electrical engineer who is trying to tease a "signal" from an overwhelming amount of "noise." With such "noisy" or variable medical treatment strategies, we will be a long time in determining optimal care. Therefore, we must develop strategies that will maximize the "signal" and minimize the "noise" in our care processes. Guidelines and critical pathways have recently been suggested as methodologies to help optimize patient care. However, many guidelines are outlined in very broad terms, much like our "increase the FiO_2" example above. Care processes must be standardized to a finer level of detail to allow improvement and eventual computerization.

Hardware and Software

Hardware

Hardware costs for computers have dropped dramatically in just the last decade, and it appears that in the next decade we will see further rapid hardware development. As stated in Chapter 14, if one compared computer systems' development with that of airplanes, a Boeing 767 in 1993 would be able to circle the globe in five minutes on one gallon of fuel! This represents a significant improvement from the 1985 projection in which the jet would circle the globe in twenty minutes and consume five gallons of fuel. Perhaps the largest change in hardware development has been the downsizing of mainframe and minicomputer systems to PCs and workstations.

Whereas ten years ago we might have projected that supercomputers would be ubiquitous, the market for large computers has been disrupted by technological progress and a paradigm shift in how work is done on computers. These changes, coupled with the move toward so-called "open systems" based on industry standard operating systems, allow smaller systems to be integrated into massive computing networks. The net result has been downsizing, with mainframes giving way to networks of personal computers anchored by mid-range "server" computers, while workstation clusters are substituting for supercomputers [15, 16]. Thus, we have computers on our desk or at the bedside that have the power of systems that in former times filled large computer rooms.

Mainframe vendors like IBM and DEC have finally realized that the era of mainframe dominance is over and that the market has shifted to networks and workstations. Personal computers and workstations which operate at 100 million instructions per second (MIPS) are readily available. A new interesting measure of processor capability will be in MIPS per milliwatt. Power consumption has always mattered in battery-powered laptops and palmtops, but it has become more important in general, as lower-voltage, lower-power, and longer-battery-life computers continue to be developed. These computers may push us to the point that we have very thin, very low power, very light portable computers that will allow nurses, physicians, and others to enter and review data from any place in a patient's room. At the same time we will be able to communicate quickly, efficiently, and accurately through optical or radio links to communication sites within the room. These computer and communications devices will not be as small and portable as a piece of paper, but they will be much more interactive and much more mobile than the terminals and workstations now used at the bedside.

Distributed databases and distributed access mechanisms are becoming widely available. During the past year, Hewlett-Packard announced a matchbox-sized magnetic disk drive with a diameter of 1.3 inches and a storage capability of 42 MB, which is projected to increase to 120 MB!

Although many have predicted that keyboards would disappear, this does not seem as clear to the industry as it did five years ago. Touch screens were not successful for data-intensive applications. Although pen-based systems and other types of devices are making progress, keyboards are still effective, and in our projections, will continue to be an effective method for data entry and retrieval. For pen-based systems to be widely accepted, they must be reasonably priced and have the ability rapidly to recognize any person's normal writing and translate it into computerized characters. It is a real challenge for computer systems to recognize hand scribbles and translate them into words when presently humans have great difficulty reading the handwriting of other humans. Indeed, this is one of the major problems of current-day medicine. Pointing devices such as mice and trackballs will remain crucial to graphically oriented systems.

Video displays will make dramatic improvements over the next decade. Currently 14–15-inch color displays are common and 21-inch color displays are available. Very high resolution color displays costing $4,000–$5,000 must be used to project x-ray images. In a "rounds room" which currently has 8 to 12 x-ray viewboxes, an investment of $50,000 would be required! Clearly this display technology must be made more cost-effective.

There are exciting prospects for the future with flat panel displays. These flat panel displays can be either in monochrome or color and have the advantage of being small, lightweight, low-power devices. Flat panels will typically be 0.5–1 inch thick and can be posted on the wall much like a framed picture, or they can be carried around as portable devices. Because these devices consume so little energy, there is no need for cooling. Space around the patient is usually quite limited, so we expect flat panel displays to have a major positive impact on adoption of bedside computer systems.

Software

Software development, debugging, and integration continues to be a major problem for the entire computer industry, not just in medicine or the ICU. Although software is becoming more standardized, the ability to exchange software is still a major problem. Clearly, the development of standards for data retrieval, display, and decision support will have to be universal. Medicine requires that local customization be available, but hopefully on a backbone of standardized data elements and display capabilities. Hospitals and ICUs in particular must place themselves in a position to take advantage of these developments [17].

Data Acquisition

The area of automated patient data acquisition is one that needs much more development and one where little progress has been made. Data acquisition of the physiological signals from patients is common for blood pressure, electrocardiogram (ECG), electroencephalograph (EEG), and a few other parameters such as oxygen saturation. There will be a dramatic improvement in our ability to acquire data from ventilators and other instruments. Exciting prospects are in the offing for promptly acquiring data that previously had to be sent out to distant locations such as clinical laboratories. The scenario in 1993 is to bring the clinical chemistry laboratory physically into the ICU in the form of a bedside "stat" lab. The scenario in the year 2000 will be that a major part of clinical laboratory services will be performed with implantable devices, typically catheter-tipped sensors. A number of companies have introduced instruments for measuring blood gases, pH, the PO_2, and the PCO_2 with catheter-tipped fiber optic sensors. Since flowing blood is a very difficult medium to work in, progress in this field has been long and difficult, but is steadily progressing. We project that over the next decade we will be able continuously to monitor serum electrolytes, glucose, and other chemistries, in addition to blood gases. Thus, rather than having to order laboratory results, which may take 10–15 min; then have a phlebotomist travel to the unit and draw the blood; transport the blood to another location; do the analysis; and transfer the results back, results will be "on-line" and continuous. The former delays caused instability in the care process because information was not immediately available [18, 19].

Having "real-time" data will require us to develop a new set of decision support strategies based on "decision–driven data collection." These strategies will allow us to use the computer to predict when certain data should be gathered. For example, if a physician decides to increase the inspired oxygen fraction from 40 to 50% and wants to see what the patient's response is, the computer will advise the caregiver to make additional measurements once the patient has stabilized from the step change in therapy. Once the measurements are made, the computer can then direct patient care through protocols.

The acquisition of timely and representative data, which seems like a trivial task but is really rather complex, will continue to develop. We clearly need to develop methodologies for acquiring timely and representative data from instruments such as ventilators, bedside monitors, pulse oximeters, IV pumps, and other instruments. However, some acquisition strategies have already been devised and are incorporated into commercially available instruments and ICU computer systems.

The sharing and the correlation of data measured by a variety of devices will become essential. To give an example, a patient may be connected to an electrocardiogram, a direct arterial blood pressure measurement, and a pulse oximeter. All three of these devices are capable of continuously measuring the heart rate. The heart rate determined from each of the devices for a normal patient should be identical. However, if a device is affected by noise or artifact, it may not be able to make the heart rate measurement. For example, if a patient moves the finger used for pulse oximetry measurement, artifacts are produced. At that time the heart rate from the pulse oximeter may be different from the heart rate derived from the ECG and direct arterial pressure sensor. Cross-correlating these signals and deciding which is "correct" is not a trivial problem, and thus this capability is not yet available in any patient monitoring system. However, from the example just given, one should be able to measure the heart rate from the other two signals and come up with a reasonable and rational estimate of what the heart rate is. However, if the patient has an arrhythmia and does not generate a reasonable stroke volume, the heart rate determined from the pulse oximeter and the direct arterial blood pressure may be quite different from that determined from the ECG. Thus, it is important to share and correlate data from multiple devices to gather real knowledge about the patient, rather than reporting different heart rates from each device. The same will be true for catheter-tipped sensors and other devices attached to patients. Integrating all of the data and making proper patient care decisions will be a crucial goal for the future.

Sharing of Knowledge

The development of practice guidelines and protocols for care is gaining importance in the medical field. David Eddy and others such as James Galligher [20–24] have shown that in the future, medicine will be practiced according to standards and guidelines. It is clear from the theory of continuous quality improvement that standardization of care is important to eliminate random variations and to enable us to determine what is appropriate care [25]. Physicians, nurses, and therapists are constantly subjected to an overload of data and need to use a standardized strategy to maximize the quality of care given to each patient.

If caregivers follow no guidelines and use different care strategies in the morning, at noon, and then in the evening, optimal practice can never be determined. The strategy that must be adhered to is to provide the *same* care each time. Even though the care may not be exactly the "optimal care," until we have standardized the care process, we will not be able to determine what optimal care is. Once care has been standardized, we can then by using scientific methods, perform experiments to determine what "optimal care" is. Measuring the effect of standardized changes will be the equivalent of clinical trials. Computerized ICU decision support will allow us to perform these tasks easily and rationally [26–29].

Most of us are faced with a huge information overload when we go to our office each day and sort through our mail. The problem is dealing with the incoming data contained in the envelopes. The equivalent happens to caregivers for critically ill patients. Information filtering has become a promising technology in the information age. Just as we must sort through what is important and unimportant in our "paper" mail and electronic mail, we must develop information filtering and retrieval methods that will allow us to care for critically in patients optimally [30–34]. Development of guidelines and specifically protocols for the care of the patients will allow us to use computer technology to maximize the information content from the flood of data emanating from the multiple devices and observers at the bedside.

Predictive Methods and Societal Decisions

A major focal point in United States today is putting a cap on the continued increase in the cost of health care. There are three major factors driving up the cost of health care today: quality waste, productivity waste, and provision of care with a limited cost-benefit ratio. The first two factors are well understood, but cost-benefit analysis is more difficult.

Quality waste could be considered having to reinsert a catheter because it became clotted, or having to repeat a laboratory test because a sample was inappropriately drawn. Inefficiencies can result from inefficient processes at all stages of the health care delivery system. The health care industry has within its capability the responsibility and need to eliminate quality waste and operating inefficiencies in the system.

However, cost-benefit is not a measurement that can be quickly and easily changed by the health care system by itself, rather it must involve the will of society. How does one decide whether or not to perform coronary artery bypass surgery on a 100-year-old male? And not only whether the surgery should be done, but at what cost and who should pay? These are questions that must be answered by *society*. However, the society is not anxious to make these decisions. Although it is relatively easy to theorize about society in general, for any given patient the family and physician are tempted to say, "Let's go for it." These issues are not easily resolved and will continue to grow as the "baby boomers" reach middle age and diseases such as AIDS continue to plague our society. The ethics of these issues are very complex and this represents another area that must clearly be defined so that caregivers can provide the best care for society and for the individual. Computers will not play a role in this kind of decision-making, beyond their ability to measure severity of illness and predict outcome, under certain circumstances.

Summary

Computer-assisted decision support for the care of critically ill patients is inevitable, but much more challenging than the use of computers in other industries. The need to deliver cost-effective and medically effective critical care will bring computers to the ICU bedside. In the end, this will become a simple business decision, one in which higher quality and lower cost are achieved through automation. The demands for these kinds of improvements in medical practice are converging on a computer industry that is beginning to deliver inexpensive, high-powered computer systems and networks to hospitals. Our patients will be the beneficiaries of this progress, which, though slow, remains inevitable.

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