International Journal of Clinical Monitoring and Computing **8**: 237–250, 1992.

Medical informatics in the intensive care unit: state of the art 1991

Terry P. Clemmer and Reed M. Gardner
Department of Medicine and Medical Informatics, LDS Hospital/University of Utah, Salt Lake City, Utah, USA

Accepted 25 October 1991

Abstract

Intensive care medicine requires timely, accurate, and integrated patient records to provide the highest quality patient care. Computerized patient records offer the best method to achieve these needs. The expectations of society for medical progress through increased use of computers is growing. For optimal use of computers in the ICU there must be a harmonious collaboration between medical informaticists, physicians, nurses, therapists, and administrators. The future use of computers in ICU care will be evolutionary rather than revolutionary. We are on the frontier of some exciting times in the next decade as computers become commonplace in the clinical care process rather than an unusual event. This paper discusses the progress and challenges of computers in the ICU.

Introduction

Medical Informatics encompasses the broad range of issues in the management and use of biomedical information. It includes medical computing but also incorporates a knowledge of the synthesis, nature, and use of medical information itself. For the science of medical informatics to be successful in achieving the primary goal of improving health care, it requires that the combined skills and knowledge of computer scientists, clinicians, nurses, paramedical professionals and researchers be brought together in a harmonious collaborative effort.

Research efforts to create more sophisticated hardware and software that are developed without bedside testing and integration into the clinical environment will rarely achieve the goal of becoming practical and useful systems that enhance patient care. This is not to say that more basic research oriented program such as physiologic or pharmacologic modeling created outside the clinical environment are not useful but in order to influence care they must eventually be brought to the bedside. This demands that there is a close collaborative relationship between the scientists in medical informatics and the clinician and that they work together routinely on both research and clinical projects with the specific goal of improving patient care.

The intent and purpose of medical informatics is to strengthen and improve medical decision-making and patient care, thus the structure and design of the system should promote this goal above all others. An integrated medical information system brings with it many advantages in meeting the goal of improving health care [1, 2]. It makes possible the retrieval of all the patient's information at a single location for review by the clinician thus saving time and enhancing the utilization of the system rather than making data retrieval repetitious, slow and burdensome. Using standardized menu formatting throughout the hospital simplifies this process by allowing personnel in all areas to access data the same way no matter where they are working. By having the data integrated, reports and

displays can be created that bolsters the transfer of information to the user in such a manner that it focuses attention on specific problems thus strengthening medical decision-making by assuring that the data is complete, appropriately integrated and properly presented [3–6]. The intent and purpose of medical informatics is to strengthen and improve medical decision-making and patient care, thus the structure and design of the system should promote this goal above all others.

In addition an integrated data base allows for more sophisticated data driven alerting [7–11], quality assurance [12–16] and decision-making programs to be developed that reduce errors, improve care, and increase reliance on the system. It also facilitates research, enhances administrative uses and allows some tasks to be accomplished that would be difficult or impossible otherwise [17].

However, an integrated patient data management system also presents many challenges to the developers. Indeed, these challenges are the genesis of the field of medical informatics. Among these challenges are 1) acquisition of data, 2) data quality control, 3) management of large quantity of data in a functional way, 4) standardization and transfer of data, 5) making the data useful to the clinician, 6) making the data useful to the researcher and 7) logistical, cost and confidentiality issues. These challenges will be addressed separately and in some detail in this paper. Many of these problems have not been resolved and present fertile areas for future medical informatics research.

Techniques directed at reducing time and effort for data entry

For a system to be usable the cost and effort of inputing data must be minimized. Several techniques are used to facilitate data entry. Initially, the direct interface of devices capable of generating digital signals is desirable. Many devices are readily adaptable to this concept and direct interface with bedside monitors and other hospital computers such as those in the clinical laboratory is now routine. Bar coding input of patient identification, medications and supplies can simplify or semi-automate data entry. Other devices have outputs that can be directly interfaced but not without some effort [18–21]. These include intravenous infusion devices, pulse oximeters, venous oximeters, ventilators, and gastric pH monitors.

Data derived from direct input is not without its difficulties however. *First,* there must be assurance that the device is identified with the correct patient from whom data is being collected or to whom the therapy is being delivered. Improper patient identification is still a major concern for every hospital. Automated data entry presents its own form of identification errors that must be guarded against. These problems generally revolve around the human error of failing to tell the computer to that patient the devices are connected. When patients are disconnected and reconnected to as many as 15 different devices when moved for special procedures or transferred to other nursing units the potential for error is large. *Second,* although the direct input of data eliminates many data entry errors the quality of automated data is not guaranteed [19, 20]. A blood pressure from a transducer may have erroneous signals for mechanical reasons, because of interferences such as during blood drawing or line flushing or because of sampling non-representative physiologic data while the patient is being stressed, placed in a different position or responding transiently to a medication or procedure. Techniques to control data quality will be addressed in the following section. *Third,* the interface problems can be very challenging at times. The linking of different types of computers is not simple and the same applies to many medical devices. Because of lack of standardization the interface problems of each computer, instrument or device may have to be resolved individually.

The need to develop standards is clear and the Institute of Electrical and Electronic Engineers (IEEE) is pursuing this so that in the future most devices will be compatible with a common medical information bus that will allow the computer to access the information from many different types of instruments and also to communicate back to the device [6, 19–23]. This communication allows the healthcare provider to know what the computer perceives it is monitoring or controlling. For exam-

ple, the computer can flash on the LED display of the infusion pump the drug being infused as perceived by the computer from its database thus allowing the care giver to confirm proper communication with the computer is correct. Such two way communication also helps with patient identification and in the future will be necessary for closed loop control of devices. In addition the standardization of device interface enhances the likelihood of obtaining quality data and reduces the possibility of technical and system errors.

The other problem with direct interface is maintaining data capture while moving patients for procedures and following transfer to other nursing units. While located in one place the patient identification problems are reduced and hardwired interface is possible. But while moving patients and during lengthy procedures in the operating of radiology suites the continuance of monitoring and reliable data capture is compromised. This presents new challenges requiring either portable storage of information for later retrieval, telemetry of data, or at least being able to change the patient's location quickly with proper identification being assured and as little interruption of data storage as possible. The availability of new portable monitors that store data and can later dump into the integrated system is one approach to this dilemma. Another option is providing computer interface in all operating and special procedure areas and software that will allow easy transfer of patient location.

A considerable amount of data cannot be directly interfaced. This includes bolus medications, oral medications, nursing tasks, and most physical findings. To type the data into the computer in 'free text' makes it difficult to use the information for alerting, quality assurance, decision-making support and research purposes and carries with it the problems of typographical and spelling errors. When possible menu driven data entry is desirable because it is faster and uniform. This can be accomplished in several ways. The use of a mouse, track-ball, light-pen, or touch screen is popular using a point and click system. Many systems are now available using these devices [24]. For speed however the ten key pad is hard to beat once the personnel become familiar with the keyboard system and the menus [17]. Using the keyboard allows the user to 'stack' commands and drop quickly to the desired menu and location for charting. With the point and click systems you must wait for the screen to appear before you can point again and this slows the process while still demanding the use the numeric keys to chart much of the numeric data.

Regardless of that charting method is selected, access to the terminal is very important in providing a friendly usable system. In the ICU it is desirable to have a terminal at each bedside along with a stool or chair for comfort so that the personnel can chart directly into the computer eliminating the need to write the information down or chart from memory. This also keeps the personnel at the bedside and reduces the time and effort of walking out to a terminal and guarantees that a terminal will be available when needed. In addition to the bedside terminals it is convenient to have other terminals at the nurse's station for charting when the patient is resting, for review of data and for administrative purposes such as ordering supplies. When data is recorded later the accuracy and timing has been shown to cause frequent errors [19]. The advantages of real time charting are accentuated when trying to drive therapy with computerized protocols that contain time driven decisions. If data is late or unavailable to the computer, then decisions will either not be made or be made incorrectly from data entered earlier. This is an area where direct data acquisition from devices can be very valuable. The same limitation affects clinical decision-making where data may be in the nurses head or pocket and not yet charted and available to the physician at the time of decision-making. With an integrated system, information also can be accessed from other areas of the hospital, medical clinics, physicians offices or even their homes.

Techniques used to control the quality of data entered

One of the most important problems in medical informatics entry of accurate data. Inaccurate data

can result in compromises to patient care and loss of confidence in the system by the care team and even refusal to use the system. In addition poor quality data severely limits the ability to use the power of the information system because alerts, quality assurance programs and clinical decision-making cannot be effective if generated from fallacious data. Therefore it is most important to develop methods to enhance the quality and consistency of the data.

The best control over the quality of the data is to *constantly use it.* The more it is used by the healthcare team the greater the likelihood errors will be found. Those who know the patient best are most likely to recognize errors when they are using the data to make decisions [25]. They are also the most critical of inaccuracies since their actions are determined by decisions made from the data and because they are legally and ethically liable for these actions. Therefore, they are demanding of the data and will insist on accuracy. It is desirable that everyone concerned with the care of the patient uses the data and are not just entering it blindly.

If errors are identified, then it is imperative that a simple mechanism to correct the errors be available otherwise the error will be recognized and ignored for decision-making purposes yet not corrected in the patient record. This incorrect information will interfere with other valuable uses of the data such as the alerting system, quality control, decision-making protocols and research. The key then is to *use the data* and to *correct it* when errors are found.

Another method of improving the quality of data is to create smart filters that will not allow the entry of data that is outside of credible limits. Certainly for physiologic data there are values that are impossible and key stroke errors resulting in such values should be rejected. Other data outside reasonable limits should require verification before being logged to reduce entry mistakes.

When there is redundancy in the monitored data, it can be cross checked for correlation. An example would be the heart rate from the ECG, the pulse rate off the blood pressure monitor and the pulse from the pulse oximeter [19, 20]. Thus ECG artifact resulting in a rate markedly different from the other pulse monitors can be questioned. Other examples could include hemoglobin values on blood gases compared to one from a CBC, the pH verification with the electrolyte panel, weights correlated with intake and output record, respirations on the bedside monitor with data from the ventilator, PaO_2 with the fraction of inspired oxygen, Glasgow Coma Score with sedative and paralytic medications, etc.

Because hand entry of data is associated with many entry errors [19, 20], automatic data entry is desirable but introduces problems of its own. One of the problems is that under normal conditions the healthcare provider unconsciously filters data and records only that they perceive as being representative of the patient's condition. For example, if a patient is turned or is on the bed pan, the transient rise in blood pressure will not be recorded but they will wait until the stress is over and the patient returns to baseline status before inputing vital signs. When a patient is coughing or bucking a ventilator they would not report the peak airway pressure but wait until the patient has passed this episode. With time driven automatic data sampling these episodes may not be avoided and data may enter that would not be useful for decision-making, quality assurance or for research purposes. On the other hand the nurse's perceptions of representative data have been shown to frequently be wrong and can themselves become a source of erroneous data [20]. One of the methods used to circumvent both of these problems is to have the automated data verified or edited by the nurse or therapist. Another is to have the care giver tell the computer when to sample and consider these data different from the routine sampling and of higher value for storage and decision-making purposes. This could be simplified to a few key strokes on the key board to signal the computer to sample the output from all the devices connected to the patient simultaneously at the time the provider determined these data to be representative of the patient's conditions. Other mathematical filtering or averaging of data might be appropriate in some circumstances to eliminate transient fluctuations but caution should be applied not to miss clinically relevant data.

Another technique for controlling quality is to

generate reports that become the legal medical record and have them reviewed by the care giver for verification of their accuracy [26]. Other reports routinely given to personnel responsible for statistical analysis and quality assurance simplifies the recognition of errors and problem areas in data quality. Once again the idea of *using* the computer data frequently is the key to acquiring quality data.

Managing and storing the data

The quantity of data available on any one patient in the intensive care unit is phenomenal. With the ability to sample automatically it is possible to gather thousands of data points each day for each monitored parameter and each of the support devices. This presents to the medical informatics team an enormous challenge of determining what data is needed, how often it is necessary to sample, and what to store [27]. If data is redundant do we need to store the output from all the devices? If so do we use the same codes for redundant data? What if the redundant data is not identical that takes priority? If we have redundant data, which should be used for decision-making, quality assurance and alerts? These are fertile areas for research activities and crucial to systems development. Currently these decisions are arbitrarily made with little or no scientific validation.

Some modeling can be used to help make such decisions. The rate of change of any given parameter will determine how often the signal must be sampled to detect significant change [27]. For example the serum albumin changes very slowly, over hours or days, so sampling it every few minutes would be inappropriate. The heart rate however, may change in seconds, therefore if all changes are to be detected then continuous monitoring is necessary. We may want to monitor heart rate continuously and alarm if certain limits are exceeded but do we need to store all the data? Most manual and computer systems store on a time driven basis. For example, they are measured and logged every 2 hours. Perhaps it would be better to store when changes are detected. This brings us back to transient changes from activity, medications, etc. Therefore, perhaps it would be best to require that the change be more than transient. Then we have to define what transient means. These are areas where more knowledge and research is needed.

The other area is to discover what data is actually used by the care team in making decisions [28]. We generate ernormous volumes of data but data used in the decision-making process is frequently only a few items [29]. An example is the measurement of respiratory data that can include tidal volume, ventilatory rate, blood gases, thoracic compliance, three different airway pressures, airway resistance, pressure volume curves, vital capacity, forced vital capacity, lung volumes, inspired oxygen concentration and the chest x-ray [19–21, 30, 31]. Is all this data required to make decisions about the ventilator? What is really relevant and needed? How are decisions really made? Recent experience leads us to believe that only a few data items are really being used in most clinical decisions [30, 31].

Even if all this data is needed for immediate decision-making, do we need to store it all long term? Can we eliminate redundant data in long term storage? What kinds of questions are asked of long term data? Our experience is that long term data storage is very useful in answering questions that arise in systems design. An example is the use of long term storage data to develop a consultative blood ordering system to replace our critiquing system [32]. With today's rapid expansion of inexpensive data storage maybe we can afford to keep it all. But when we ask questions of the data, the volumes can become a hinderance. Another question is how should long term data be stored? Is immediate access required? How long is long term (months, decades)? How immediate is immediate (seconds, minutes)? These are all questions that need consideration and answers as informatic systems are planned and implemented.

Standardization and transfer of data

For the computer to be useful it must be searchable and retrievable. Therefore, it is critical that the data be in a standard format and coded in such a way that it can be easily identified, segreted re-

trieved and used by various users and for multiple purposes. Thus the blood oxygen tension that may be entered and used by laboratory technicians, nurses, physicians, respiratory therapists and researchers must be coded and identified in such a way that it can be used by everyone [33, 34]. In institutions where there are many departments, divisions and people, each with their own interests and capability of writing their own programs, the danger of confusion, inappropriate duplication and lack of coordination of data coding and storage is high and can be a major problem. Later, when searching the database for information to generate alerts, quality assurance, medical decision-making or research the task of having data in various places and in different forms creates major difficulties.

These problems are compounded when one tries to transfer data between computers such as downloading them into relational database programs for research purposes [35–37]. Communicating between different types of computers having different operating systems can become very difficult [35–37]. The hospital business computer designed and programmed to process financial data is typically difficult to interface with clinical systems. Such communication however, can be very valuable for automatic billing, administrative needs and for research into the cost of healthcare delivery. The ability to transfer mainframe programs between institutions for collaborative research efforts today is nearly impossible because each system's coding, terms and definitions are different. The need for standardization in this area is great and the speed with that progress is made in medical informatics will depend upon such standardization [2, 38, 39].

Clinical use of the information system

The proof of the success of the medical informatics department is its clinical acceptance and use of the system for patient care. The goal should be more than just facilitating the availability of data in a timely fashion for the clinician. A well designed system should improve patient care above and beyond what would be possible without the system. There are certain tasks computers do better than clinicians and the system should take advantage of this to enrich care.

Friendly, fast and flexible

The time required for the physician and other healthcare personnel to interact with the computer is critical. The system must be fast, reliable, have minimal delays and be user friendly. With little or no training the user should be able to find the information and generate reports. The menus must be logical and easy to follow leading the novice to the right place. When possible the system should be flexible so that users can create their own menus or reports to satisfy special needs. This must be controlled however for the good of the entire system. The importance of the interface and user friendliness was clearly demonstrated by Apple Computer when they challenged IBM.

The organization and display of the terminal screens and printed reports can be crucial to the care of the patient and to the acceptance of the system by the clinical team. With an integrated database many options are available and the data can be organized in different formats for different functions and purposes [40]. This is an area where collaboration with the clinical care provider is critical since they are the primary users. The reports can be used to integrate data and emphasize specific related areas [41, 42]. Certain data can be stress to focus attention on problems [43]. Interpretations can be generated to help those who may be unfamiliar with the meaning of the data [3, 5]. Graphs, tables and charts can be used to show trends or to correlate information. The design of the output screens and reports is a science in itself and can clearly enhance the success and utilization of the system [44, 45]. Because it is so difficult for the clinician to retain all the data in their heads the display of previous data with the current is very useful. In our setting it has become routine to use this type of display for all laboratory data as well as physiologic parameters. It is also valuable to cluster associated data such as the active cardiovascular drugs which are displayed with the hemodynamic data so the clinician can see the level of support being given when interpreting the cardiac performance [43]. Problems arise however with various

types of displays. For example with the use of graphics one may encounter problems with resolution and difficulty interpolating the digital numbers from the display, the handling of multiple scales, overlap of data and time scales, and the use of color versus black and white displays that resolves some problems but significantly increases the cost of a hospital wide system that may have hundreds of terminals and printers. Most users have their own bias. Some like the trend advantages of graphs where others want to see the digital data. Some feel graphs help to correlate data, others find them to slow and a nuisance. Because the use of the data varies, obtaining consensus on the format of reports is impossible. Again, close communications between the computer scientist and users is indispensable in trying to resolve these issues.

Data driven automatic alerts and alarms

One area where the clinician has difficulty is in handling the overload of data both from the patient and the literature [46]. Thus when a parameter becomes available along with scores of other variables it may be overlooked or fail to be properly integrated with other information from the patient's database or the literature. The result is that a potentially dangerous situation may not be recognized. The computer is very good at processing every new bit of information and comparing it to other available data and to its internal knowledge base. Thus an important role of the information system is to feedback to the healthcare providers alerts about potentially dangerous situations. This can be in the realm of drug-drug interactions or incompatibilities, drug-allergy situations, drug dosing and organ dysfunction or critical changes in laboratory and physiologic parameters. Such alerting is best automated and data driven. The integrated system that has simultaneous access to the patient's laboratory data, allergies, height, weight, age, admitting diagnosis, medications and physiologic parameters allows for much more sophisticated alerting programs to be created [7–14, 47, 48].

A great deal of experience and skill is required to develop a system that is user friendly, acceptable by the care giver, and helpful without being obnoxious. The use of redundant information to avoid false alerts can be helpful [6, 7–14, 49]. The careful evaluation and categorization of alerts into urgency of the alerting situation as not to overburden the clinician with unimportant problems or those that can be handled later makes the system more acceptable. At times the alerts may be channeled through pharmacists, nurses or other paramedical professionals who can screen or respond to the alert without agitating the physician [47, 50]. Where the system allows or demands the physicians personally enter the orders into the computer, immediate feedback at the time of ordering can be useful if done timely and when the information is important.

Stratifying the urgency of the alerts with different mechanisms appropriate to the urgency can be used for feedback. For example, a life threatening alert should be more urgent than an 'information only' alert. An obnoxious sound or light that can only be turned off by recognizing the alert is the most effective way to guarantee attention but is not appropriate for most alerts that do not require such immediate attention. A less obnoxious method of presenting the alerts to the care provider is to bring up an alert screen each time they look at the patient's database file or enters a patient order. This method is not as sure or timely but may be adequate for many messages. At other times a report printed once a day may suffice.

Assuring quality care

The value of a well designed alerting system is clear [48]. It allows the care provider to avoid potential dangers before to the institution of therapy and to avoid incompatible orders. Alerts and prompts can also be used to reduce costs by reminding physicians or more cost effective medications or procedures that would adequately satisfy the situation [14, 15, 32, 51, 52]. Examples of using the alerting system for on line quality control are many. While ordering Total Parenteral Nutrition (TPN) solutions the program can alert the physician of incompatibilities and disallow specific combinations of calcium and phosphates depending on pH [53]. The program can also disallow the addition of medications known to be unstable in the solution.

While ordering antibiotics, the dosage can be questioned as inappropriate for the renal or liver function or for the size of the patient. Intravenous potassium orders can be questioned or denied if dangerous infusion rates are exceeded. When drugs that interact with others are ordered the physician can be reminded of potential problems. Such alerting systems have proven to be very effective with a physician compliance of greater than 90% to computer suggestions [25, 30, 49]. They have also been shown to improve the use of blood products and allow the measurement of improvement in transfusion practice [32, 51, 52].

These same principles can be carried over to cost containment efforts by giving suggestions to physicians to use less costly antibiotics for the given diagnosis and bacteriology results [10, 11]. Reminders to discontinue medications have also proven to be very effective at reducing costs and improving the quality of care especially in the area of prophylactic perioperatively antibiotics [10, 15]. Timely feedback to physicians of potentially dangerous situations such as metabolic acidosis when coupled with suggestions on how to proceed with the patient evaluation and therapy has been demonstrated to reduce the time the patient remains acidemic and to improve outcome [4].

Similar to the alerting system, real time quality assurance reports can be used to improve the quality and cost of care. Most hospitals in the United States do quality assurance by defining criteria for quality and then via a random chart review determine the compliance with this predetermined level of care. Then through educational or procedural mechanisms they attempt to improve the quality following that they restudy the problem by a second random chart review to determine the success of the instituted measures. Using the computerized database, criteria designated for quality care can be explicitly described and when breeches in that 'standard' are found via uninterrupted computer surveillance an immediate report can be generated to the quality assurance personnel and the situation corrected immediately [54]. This allows real time improvement in care along with the institution of educational and procedural steps. This monitor can be continued indefinitely and applied to every patient not just those randomly chosen for review. Thus quality assurance can be vastly improved over manual, retrospective chart review.

Computer monitoring can also dramatically improve the identification of problems. For example, when adverse drug reactions are detected by a continuous computer surveillance program the rate of detecting adverse reactions was 60 fold higher than when reported by hand [12, 55]. These types of audits are only achievable with an integrated clinical decision-making data system.

The best measure of quality care is outcome and cost. Because of the inhomogeneity of patients, disease expression and process of care the ability to define and determine quality of care by using outcome and cost is very difficult. To help circumvent these problems, acuity scoring systems such as the Acute Physiologic and Chronic Health Evaluation (APACHE) [29, 56, 57], the Therapeutic Intervention Scoring System (TISS) [57, 58], the Injury Severity Score (ISS) [59, 60] and others [61] have been created with statistical methods linked to diagnosis that allows one to predict outcome and measure to some degree the quality of care. Scoring every patient by hand is laborious, time consuming and costly. With some effort these scores can be automated and stored as a part of the medical record and statistical methods developed to assess the quality of care continuously.

Another technique used to improve quality of care is to gather data prospectively from a specific group of patients for administrative, quality assurance and research purposes [41, 42]. These patients can be automatically identified by computer screening and be placed into specific data sets such as trauma, respiratory failure or cancer registries. This standardized prospectively gathered database can then be analyzed for various purposes to provide basis for legislation, funding, research and quality control. Once again if properly designed a large portion of the database may be automated from the integrated system significantly reducing the need for hand entry.

The design and use of reports and summaries derived from the database can be very useful in quality control. To have timely data on infectious complications, resource utilization, procedures,

patient demographics, staffing patterns and outcomes can be very valuable in identifying problems, and planning for improved quality care measures at the administrative level [17, 62]. It is very important to maximize the benefit/cost ratio. But when cost reduction measures are implemented the assessment of the impact on care is critical to assure outcome is not compromised. Again real time reports generated from the database can be very valuable in optimizing and managing this process.

Standardization of care

There are many advantages to standardizing care and the computer lends itself nicely to this task. In hospitals where a large volume of a certain type of patient are cared for, such as coronary artery bypass surgery patients, outcome improves [63]. Much of this improvement is due to the routine or standardization of care that results from repetition. Where care is delivered with standardized care protocols mistakes are reduced. An example used in most intensive care units is in mixing intravenous infusion drugs. If mixed differently each time then administration of incorrect dosages is more common than if the concentration is always the same. In addition the care is more uniform if all the care team members use the same principles and decision logic from shift to shift and day to day [64, 65]. It also enhances communications when everyone uses the same terminology and interprets the data similarly.

Standardization can also reduce cost by reducing the inventory of supplies and drugs required by the institution. Routine also reduces waste and personnel time. With standardization, quality assurance programs are strengthened since it is easier to identify breeches in the standards. Where standardization is commonly accepted in the institution, changes that improve care are simplified and more readily accepted.

One of the major problems today is that we have difficulty defining how we care for patients. For example, the process of care of a ventilator dependent patient is very different depending on what hospital or ICU they are in and who the responsible physician is. Indeed, individual physicians change their style from day to day. For this reason it is very difficult to know if one method of ventilator care is better than another or how to modify the process of care to improved outcome. Standardization of care facilitates identifying areas where improvement can be made and allows evaluation of the effectiveness of changes in the standard [66–73].

One method used to bring standardization into the care environment is to use the computer to guide physicians in their orders. This has been used effectively in ordering more complex items such as TPN [53]. By knowing the patient's sex, age, height and weight and using the Harris-Benedict equations a computer estimated caloric needs can be calculated along with a standard mixture of proteins, lipids and carbohydrates. In addition factors such as the diagnosis, stress and organ function can be factored in as determined by the nutritional experts who designed the program. The physician is given the options of modify the solution but begins at a starting point that is standardized for the patient's needs. This saves the physician time and effort and reduces errors made by physicians inexperienced in ordering TPN. Electrolyte concentrations are then suggested based on the patient's latest serum values. The physician can select the suggested package or modify them. If the physician selects incompatible or dangerous concentrations alerts are presented on the screen. Then standard nursing procedures and monitoring is automatically ordered such as daily intake and output, weights, and every six hour urine glucose checks. Thus using the computer, subtle control of how care is delivered is maintained through indirect expert guidance or critiquing. The number of calories, composition of nutrients, the electrolytes and nursing care related to the TPN are controlled to some degree and the inventory of products reduced [53]. Similar programs for antibiotic ordering [14, 15] and blood banking [51, 52] have also been developed.

Computer assisted orders can also improve quality assurance measures as specific information, such as the indication for transfusion, can be recorded for audit purposes and [51] order overrides reviewed later for appropriateness. Complications can be reviewed to check logic errors and deficiencies in the computer guidance. Thus standardi-

zation facilitates identification of problems and allows potential solution to be proposed and validated.

The computer guided TPN orders are flexible enough to allow the individual physician to maintain control and feel in charge. If designed properly these and similar orders can assist physicians and make their task easier thus enticing compliance. A more severe type of control can be imposed for specific purposes but requires a great deal of coordination and cooperation to introduce. For research purposes detailed protocols have been developed that maintain tight control of the process of care [31, 66–73]. Experience with and acceptance of such control is limited and usually resisted by the medical staffs who have been schooled in making decisions tailored to the needs of the individual patient and clinical situation and feel this would be detrimental to good care. The proof of such logic is lacking and many authors are challenging it by demonstrating the inconsistencies in medical practice and decision-making [64]. They also point out that because of this ideation we are unsure of the benefit of much of the care we now deliver [65]. The use of rigid computerized protocols permits control of the process of care in such a way that will provide answers to many questions involved in the process of medical care that until now have been difficult to establish.

Research uses of the information system

If the initial obstacles of entering quality data into the information system and of proper coding and storage are overcome, the system becomes a powerful research tool providing the data can be accessed by the investigators. The next hurdle for the clinical investigator is to develop mechanisms whereby the data in the integrated system can be put into a format for review and statistical analysis by the researchers. This can be accomplished in several ways but one of the most satisfactory is to have the capability to download the desired information easily into a research database into a research computer database. The original decisions of coding and storage of data become vital to this process at this point. When research use of the information is contemplated establishing a coding system is concret in the system's design.

When designing clinical research projects one objective is to reduce 'noise' as much as possible. One method of accomplishing this task is to develop tight control of the process of care that can enable us to obtain a credible answer with significance not previously attainable [69–73]. For example, we have used this methodology to determine if a new method of caring for a ventilator patient is superior to another. To answer such a question both methods of care must be defined and carried out in a randomized fashion. The control over the process of care conveys with it the advantages of: 1) reducing both random and non-random bias in the experiment, 2) permitting the investigators to describe precisely their methods of care and 3) allowing others to challenge the results by duplicating the methods later [30]. However, the cooperation of all physicians, nurses and therapists involved and a commitment to abandoning stylistic differences thus overriding the protocols only for valid identifiable reasons is required [66, 73].

Our experience with development and use of computerized protocols is that outcome is improved [67, 72]. As the standardization process becomes mature clinical personnel find it easier to care for the patients and want to use the protocols for clinical care outside the research study [66, 71]. Computerized protocols also provide a tool to answer other questions that may arise about ventilator care. We have found that, using the computer database, can be a powerful tool in running complex protocols and also reduces the errors commonly made when following paper flow diagrams protocols [25]. Whether it is the protocols per se or the process of developing the standardization of ventilator care that improved outcome is not clear and will require further research.

Another unique capability of a universal database is that all nursing and therapist tasks along with supplies, laboratory, x-ray and clinical procedures are recorded in the database. From time motion studies of each of these tasks, personnel time is calculated. Thus the true costs of each task and procedure can be determined. It then becomes

possible to calculate from the database true cost of caring for patients [74–77]. This allows research in the area of cost, charges and reimbursement to be carried out easily and with greater accuracy than was previously known, thus adding a valuable dimension to the clinical outcomes research efforts.

Logistics of running an integrated system

Hardware/software failures and down time

Nowhere in medicine is there a need for timely and accurate data than in the ICU. Patient's physiological parameters are changing beat by beat and breath by breath. Fast systems reponse time and continuous availability are crucial issues that must be achieved before nurses, therapists and physicians will 'trust' and use computer systems. At LDS Hospital in Salt Lake City, the system is available 99.6% of the time. The 0.4% of the time it is not available (on average 5.77 minutes per day) about half the time is for planned downtime for hardware and software maintenance and the other half is for unplanned failures. These unplanned failures might be electrical storms, software glitches, etc. Every effort must be taken to minimize the downtimes. Redundant hardware, battery backed up power supplies, carefully tested and 'debugged' software, systems disk backups, and a host of other steps must be taken to achieve such capabilities [78]. Systems with such reliability are now found several places in our society – banks with automatic tellers, airline reservation and seating scheduling systems. Imagine what it would be like at a busy airport as they loaded a 747 if they did not have computers! The same will be true for the future hospital and ICU system.

Confidentiality of computerized patient records

Confidentiality of patient records is a 'right' expected by patients in intensive care. Fortunately public revelations of 'confidential' data are seldom a problem, but could be in the future. Maintaining confidentiality of hand written paper records is usually maintained by keeping the record 'in the unit.' Unfortunately the same factors that limit the usefulness of the conventional paper record also give some measure of security to it. The computerized record can be made totally secure and confidential to point it may not be useful to anyone caring for the patient. Therefore, a balance must be struck between confidentiality and reasonable access. Current methods used to allow 'reasonable' access to patient records include: 1) All employees and physicians are given 'logon' codes and are required to use them before they can review patient data. These keys expire at frequent intervals (6 months is typical), 2) Hospital employees with only need to access a limited data set (admitting clerks) do not have access to all patient data. Only select management physicians and computer personnel have system wide access, 3) Every access to clinical information is logged, 4) Terminals left unattended log off after 5 minutes, 5) If a Very Important Person (VIP) is admitted, access to any of their data is preceded by a special caution message, 6) Procedures are in place to handle breaches in the security.

How to achieve an integrated medical informatics system?

As the recent Institute of Medicine Report (IOM) tells us, 'The patient record touches, in some way, virtually everyone associated with providing, receiving, or reimbursing health care services' [2]. With computer technology ubiquitous in our society, there is the temptation to 'hook up a PC and do the task'. Unfortunately, such simple approaches of building simple 'stand-alone' systems that do not interface with other systems and do not use a structured and integrated approach are doomed to failure. Data integration and communications are the keys to providing the health care professional with something they cannot now achieve by manual charting methods. There must be minimal changes in the user's environment as computers are introduced. Consistency in how data is acquired, the parameters recorded, the frequency of recording, and who records the data is crucially important.

Many of the issues are not technological but are 'sociological' [79]. A team spirit must exist so that the complex interactions that have been worked out over decades with manual methods can be implemented with computers. Cost of implementation must take into consideration not only the hardware and software costs, but the 'people-ware' costs of training users, educating users as to the system benefits, and evaluating those benefits.

Conclusions

The expectations of society for medical progress and increased use of computers for diagnosis and treatment are fueled by the increased use of computers in everyday life, in science fiction movies, and by the eternal optimism that drives the curiosity about the future. Great strides have been made in the understanding of how to harness computer technology to help the health care professional in the care of the critically ill patient [80].

It seems clear that advances in the use of computers in the hospital and in the ICU will be evolutionary rather than revolutionary. Part of the health care system will require modification before optimally integrated systems will be widespread. The method that health care professionals interact with their patients and colleagues will change. Intensive care medicine is clearly ready and for the new challenges of the future [81].

References

1. Leyerle BJ, LoBue M, Shabot MM. The PDMS as a focal point for distributed patient data. Int J Clin Monit Comput 1988; 5: 155–61.
2. Dick RS, Steen EB. Summary: The computer-based patient record: An essential technology for health care. Summary – Institute of Medicine of the National Academy of Sciences Report, 1991.
3. Gardner RM, Cannon GA, Morris AH, Olsen KR, Price GA. Computerized blood gas interpretation. Med Instrum 1974; 8: 126.
4. Johnson DS, Ranzenberger J, Herbert R, Gardner RM, Clemmer TP. A computerized alert program for acutely ill patients. J Nurs Adm 1980; 10 (6): 26–35.
5. Clemmer TP, Gardner RM, Orme JF Jr. Computer support in critical care medicine. SCAMC 1980; 4: 1557–61.
6. Gardner RM. Computerized management of intensive care patients. MD Comput 1986; 3: 36–51.
7. Bradshaw KE, Gardner RM, Pryor TA. Development of a computerzied laboratory alerting system. Comp Biomed Res 1989; 22: 575–87.
8. Tate KE, Gardner RM, Weaver LK. A computerized laboratory alerting system. MD Comput 1990; 7 (5): 296–301.
9. Kuperman GJ, Gardner RM, Pryor TA. HELP: A dynamic hospital information system. New York: Springer-Verlag Inc., 1991.
10. Pestotnik SL, Evans RS, Burke JP, Gardner RM, Classen DC. Therapeutic antibiotic monitoring: Surveillance using a computerized expert system. Am J Med 1990; 88: 43–8.
11. Evans RS. The HELP System: A review of clinical applications in infections disease and antibiotichse MD Computing 1991; 8: 282–288.
12. Classen DC, Pestotnik SL, Evans RS, Burke JP. Computerized surveillance of adverse drug events in hospital patients. JAMA. 1991; 266: 2847–51.
13. Evans RS, Gardner RM, Bush AR, Burke JP, Jacobson JA, Larsen RA, et al. Development of a computerized infectious disease monitor (CIDM). Comp Biomed Res 1985; 18: 103–13.
14. Larsen RA, Evans RS, Burke JP, Pestotnik SL, Gardner RM, Classen DC. Improved perioperative antibiotic use and reduced surgical wound infections through use of computer decision analysis. Infect Control Hosp Epidemiol 1989; 10: 316–20.
15. Evans RS, Pestotnik SL, Burke JP, Gardner RM, Larsen RA, Classen DC. Reducing the duration of prophylactic antibiotics use through computer monitoring of surgical patients. DICP, Ann Pharmacother 1990; 24: 351–4.
16. Shabot MM, LoBue M, Leyerle BJ, Dubin SB. Decision support alerts for clinical laboratory and blood gas data. Int J Clin Monit Comput 1990; 7: 27–31.
17. Bradshaw KE, Sittig DF, Gardner RM, Pryor TA, Budd M. Computer-based data entry for nurses in the ICU. MD Comput 1989; 6 (5): 274–80.
18. Gardner RM, Tariq H, Hawley WL, East TD. Medical Information Bus: The key to future integrated monitoring [editorial]. Int J Clin Monit Comput 1989; 6: 205–9.
19. Gardner RM, Hawley WH, East TD, Oniki T, Young HFW. Real time data acquisition: Experience with the Medical Information Bus (MIB). SCAMC 1991, 15: 813–17.
20. This issue.
21. East TD, Yang W, Tariq H, Gardner RM. The IEEE Medical Information Bus of respiratory care. Crit Care Med 1989; 17: 580.
22. Shabot MM. Standardized acquisition of bedside data: The IEEE P1073 Medical Information Bus. Int J Clin Monit Comput 1989; 6: 197–204.
23. Gardner RM, Clemmer TP, Morris AH. Computerized medical decision making – An evaluation in acute care.

Conference on Computers in Critical Care and Pulmonary Medicine; 1980 Jun; Lund (Sweden).
24. Toong HD, Gupta A. Personal computers. Sci Am 1982; 247 (12): 87–105.
25. Henderson S, Crapo RO, East TD, Morris AH, Gardner RM. Computerized clinical protocols in an intensive care unit: How well are they followed? SCAMC 1990; 14: 284–8.
26. Brahams D, Wyatt J. Medicine and the law. Lancet 1989 Sept 9: 632–4.
27. Gravenstein JS, DeVries A Jr, Beneken JFW. Sampling intervals of clinical monitoring variables during anesthesia. J Clin Monit 1989; 5: 17–21.
28. Bradshaw KE, Gardner RM, Clemmer TP, Orme JF Jr, Thomas F, West BJ. Physician decision-making – Evaluation of data used in a computerized ICU. Int J Clin Monit Comput 1984; 1: 81–91.
29. Knaus WA, Wagner DP, Lynn J. Short-Term Mortality Predictions for Critically Ill Hospitalized Adults: Science and Ethics. SCIENCE 1991; 254: 389–94.
30. Sittig DF, Gardner RM, Morris AH, Wallace CJ. Clinical evaluation of computer-based respiratory care algorithms. Int J Clin Monit Comput 1990; 7: 177–85.
31. Sittig DF, Gardner RM, Pace NL, Morris AH, Beck E. Computerized management of patient care in a complex, controlled clinical trial in the intensive care unit. Comp Met Pro Biomed 1989; 30: 77–84.
32. Gardner RM, Laub RM, Golubjatnikov OK, Evans RS, Jacobson JT. Computer Critiqued Blood Ordering Using the HELP System. Comp Biomed Res 1990; 23: 514–28.
33. Pryor TA, Gardner RM, Clayton PD, Warner HR. The HELP system. J Med Syst 1983; 7: 87–102.
34. Pryor TA. The HELP medical record system. MD Comput 1988; 5: 22–33.
35. McDonald CJ. The search for national standards for medical data exchange. MD Comput 1984; 1: 3–4.
36. McDonald CJ. Interchange standards revisited. MD Comput 1990; 7: 72–4.
37. McDonald CJ, Hammond WE. Standard formats for electronic transfer of clinical data [editorial]. Ann Intern Med 1989; 110: 333–5.
38. Report to congress: The feasibility of linking research-related data bases to Federal and Non-Federal Medical Administrative data bases. Agency for Health Care Policy and Research; 1991 Apr. AHCPR Pub. No. 91-003.
39. Report to congress: Progress of research on outcomes of health care services and procedures. Agency for Health Care Policy and Research; 1991 May. AHCPR Pub. No. 91-004.
40. Gardner RM, Scoville DP, West BJ, Cundick RM Jr, Clemmer TP. Integrated computer systems for monitoring of the critically ill. SCAMC 1977; 1: 301–7.
41. Sittig DF, Gardner RM, Elliott CG. Screening for adult respiratory distress syndrome patients: Use of the HELP hospital information system. J Clin Eng 1989; 14: 237–43.
42. Evans RS, Burke JP, Classen DC, Gardner RM, Menlove RL, Goodrich KM, et al. Computerized identification of patients at high risk for hospiral-acquired infections. Am J Infect Control 1991. In press.
43. Gardner RM, Clemmer TP. Computerized protocols applied to emergency and acute care. J Emerg Med Serv 1978; 7 (6): 90–3.
44. Helander M, editor. 2nd ed. Handbook of human-computer interaction. New York: North-Holland, 1991.
45. Cole WG. Quick and Accurate Monitoring via Metaphor Graphics. SCAMC 1990; 425–9.
46. McDonald CJ. Protocol-based computer reminders, the quality of care and the non-perfectibility of man. N J Med 1976; 295: 1351–5.
47. Hulse RK, Clark SJ, Jackson JC, Warner HR, Gardner RM. Computerized medication monitoring system. Am J Hosp Pharm 1976; 33: 1061–4.
48. Gardner RM, Clemmer TP, Larsen KG, Johnson DS. Computerized alert system use in clinical medicine. Proceedings of the 32nd Annual Conference of Engineering in Medicine and Biology; 1979; Denver (Colorado): 1–5.
49. Gardner RM, Hulse RK, Larsen KG. Assessing the effectiveness of a computerized pharmacy system. SCAMC 1990; 14: 668–72.
50. Miller PL. Goal-directed critiquing by computer: Ventilator management. Comp Biomed Res 1985; 18: 422–38.
51. Gardner RM, Laub RM, Golubjatnikov OK, Evans RS, Jacobson JT. Computer critiqued blood ordering using the HELP system. Comp Biomed Res 1990; 23: 514–28.
52. Lepage EF, Gardner RM, Laub RM, Golubjatnikov OK. Improving blood transfusion practice: Role of a computerized hospital information system. Transfusion 1992; 32.
53. Larsen KG, Clemmer TP, Nicholson L, Conti MT, Peterson H. Computer support in monitoring of nutritional therapy. Nutr Supp Serv 1983; 3 (6): 7–16.
54. Elliott CG. Computer-assisted quality assurance: Development and performance of a respiratory care program. QRB 1991; 17: 85–9.
55. Evans RS, Pestotnik SL, Classen DC, Bass SB, Menlove RL, Gardner RM, et al. Development of a computerized adverse drug event monitor. SCAMC 1991; 15. Accepted Jun 24.
56. Knaus WA, Draper EA, Wagner DP, Zimmerman JE, Branbaum ML, Cullen DJ, et al. Evaluating outcome from intensive care in major medical centers. Ann Intern Med 1986; 104: 408–10.
57. Shabot MM, Leyerle BJ, LoBue M. Automatic extraction of intensity-intervention scores from a computerized surgical intensive care unit flowsheet. Am J Surg 1987; 154: 72–8.
58. Cullen DJ, Civetta JM, Briggs BA, Ferra LC. Therapeutic intervention scoring system: A method for quantitative comparison of patient care. Crit Care Med 1974; 2: 57.
59. MacKenzie EJ, Steinwachs DM, Shankar BS. An ICD-9-CM to AIS conversion table: Development and application. Thirteenth Annual Proceedings; 1986 Oct. Montreal (Quebec): American Association for Automotive Medicine.

60. Baker SP, O'Neill B, Hadden W Jr. The Injury Severity Score: A method for describing patients with multiple injuries and evaluating emergency care. J Trauma 1974; 14: 187–96.
61. Horn SD, Sharkey PD, Buckle JM, Backofen JE, Averill RF, Horn RA. Med Care 1991: 305–17.
62. Kuperman GJ, Maack BB, Bauer K, Gardner RM. Impact of the HELP system on the LDS hospital medical record. Top Health Rec Manage 1991; 12 (1): 1–9.
63. Berwick DM. The double edge of knowledge. JAMA 1991; 266: 841–2.
64. Eddy DM. Clinical decision making from theory to practice: The challenge. JAMA 1990; 263: 287–90.
65. Eddy DM. Clinical decision making from theory to practice: Anatomy of a decision. JAMA 1990; 263: 441–3.
66. East TD, Morris AH, Clemmer TP, Orme JF Jr, Wallace CJ, Henderson S, et al. Development of computerized critical care patients – A strategy that really works! SCAMC 1990; 14: 564–8.
67. Morris AH, Wallace CJ, Clemmer TP, Orme JF Jr, Weaver LK, Dean NC, et al. Extracorporeal CO_2 removal therapy for adult respiratory distress syndrome patients: A computerized protocol controlled trial. Reanimation Soins Intensifs Medecine d'Urgence 1990; 6: 485–90.
68. East TD, Bohm SH, Peng L, Wallace CJ, Clemmer TP, Weaver LK, et al. A successful computerized protocol for clinical management of PC-IRV in ARDS patients. Chest 1991 Apr. accepted.
69. East TD, Morris AH, Clemmer TP, Orme JF Jr, Wallace CJ, Henderson S, et al. Development of computerized critical care protocols – A strategy that really works! SCAMC 1990; 14: 564–8.
70. East TD, Henderson S, Morris AH, Gardner RM. Implementation issues and challenges for computerized clinical protocols for management of mechanical ventilation in ARDS patients. SCAMC 1989; 13: 583–7.
71. Henderson S, East TD, Morris AH, Gardner RM. Performance evaluation of computerized clinical protocols for management of arterial hypoxemia in ARDS patients. SCAMC 1989; 13: 588–92.
72. Suchyta MR, Clemmer TP, Orme JF Jr, Morris AH, Elliott CG. Increased survival of ARDS patients with severe hypoxemia (ECMO criteria). Chest 1991; 99: 951–5.
73. Henderson S, Crapo RO, Wallace CJ, East TD, Morris AH, Gardner RM. Performance of Computerized Protocols for Management of Arterial Oxygenation in an Intensive Care Unit. Intl J Clin Monit & Comput (In press November 1991).
74. Thomas F, Larsen K, Clemmer TP, Burke JP, Orme JF Jr, Napoli M, et al. Impact of prospective payment on a tertiary care center receiving large numbers of critically ill patients by aeromedical transport. Crit Care Med 1986; 14: 227–30.
75. Thomas F, Fox J, Clemmer TP, Orme JF Jr, Vincent GM, Menlove RL. The financial impact of medicare diagnosis-related groups. Effect upon hospitals receiving cardiac patients referred for tertiary care. Chest 1987; 91 (3): 418–23.
76. Thomas F, Clemmer TP, Larsen KG, Menlove RL, Orme JF Jr, Christison EA. The severity, outcome, cost of care, and economic impact under DRG payment policies of trauma patients referred to a major trauma center. J Trauma 1988; 28: 446–52.
77. Clemmer TP, Orme JF Jr, Thomas FO, Peterson M, Merrow L, Peterson H. The impact of medicare prospective reimbursement system on nutritional support service patients. The importance of pass throughs. JPEN 1989; 13: 71–6.
78. Gray J, Siewiorek DP. High-availability computer systems. Computer 1991; 24 (9): 39–48.
79. Lundsgaarde HP, Gardner RM, Menlove RL. Using attitudinal questionnaires to achieve benefits optimization. SCAMC 1989; 13: 703–8.
80. Gardner RM, Shabot MM. Computerized ICU data management: Pitfalls and promises. Int J Clin Monit Comput 1990; 7: 99–105.
81. Rand T. Automated records aren't such a stretch. Healthweek 1991 Sep 9; 5 (17): 4–8.