INTEGRATED COMPUTER SYSTEMS FOR MONITORING OF THE CRITICALLY ILL

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Summary

An integrated computer system utilizing distributed minicomputers with a central data base-decision making system is described. Up to 57 critically ill patients can be monitored with the system at one time. Evaluation of elements of the system implemented in the last five years and the new features being implemented are discussed. Major new features include use of distributed minicomputers and computerized diagnostic and treatment protocols.

Introduction

The modalities of care available to critically ill patients have expanded dramatically in the last ten years. The clinical laboratory, physiological and observational data required to manage these patients have also expanded. During this same time interval computers have been applied with varying degrees of success to management of the critically ill.[1,2] Computers have been used primarily for data acquisition and reporting. Monitoring of physiological data has come into its own in these same ten years.[3] ECG rhythm analysis[4] and hemodynamic data acquisition are two of the applications which have become common in several of the large centers in the United States. Techniques usually reserved to the catheterization laboratory or research intensive care units are now in widespread use in most every hospital including the smaller community hospitals.[5]

With the large amounts of data available on the critically ill patient, sometimes the physicians, nurses and the medical care team are faced with a data overload. At times this information overload may result in critical pieces of data being overlooked, misplaced or ignored, resulting in the subsequent suboptimal care to the patient. With the interconnected computer system now operational at the LDS Hospital in Salt Lake City we are able to integrate the patient data base with data from many data sources to provide more than just acquisition and reporting of the data. We are now able to use the data for medical decision making as alerts, alarms and treatment suggestions.

We are in the process of implementing alerting and treatment protocols with distributed minicomputer systems. The minicomputers perform the acquisition and communications functions necessary to implement these protocols. The primary goals of the project are to 1) implement acute care protocols, which will prevent patients in hospital wards from going into crisis conditions as a result of misinformation or having information delayed. These protocols are implemented by a series of patient "alerts" using the HELP system, and 2) development of treatment protocols for management of the critically ill.

Materials and Methods

Clinical application of computers has become a major effort of the Department of Medical Biophysics and Computing at the University of Utah located at the LDS Hospital in Salt Lake City. We have established a large integrated data base system (Figure 1). The clinical laboratory computer system[6] shown in the left panel of Figure 1 operates nearly independently of the central decision making or HELP system shown in the right panel. As soon as laboratory data are verified in the clinical laboratory they are immediately transmitted to the HELP system and are subsequently (within 2 minutes) sent to the ICU minicomputers and printed in the intensive care units, emergency room and other critical care areas. The results are also made available for review on 50 computer terminals located on nursing divisions and other locations throughout the hospital.

There are currently ten critical care units involved in our computerized system. At the LDS Hospital 1) a ten-bed thoracic intensive care unit, 2) a ten-bed shock-trauma intensive care unit, 3) a three-bed respiratory research intensive care unit, 4) a twelve-bed coronary care unit, 5) a six-bed neurological intensive care unit, 6) the emergency room with capability of up to eight beds, 7) a three operating room thoracic surgical monitoring suite. At the University of Utah Medical Center 8) a trauma unit with six beds, 9) a burn unit with five beds, and 10) two operating suites. The total number of computerized beds is 57.

This computer system has developed from an intermittently used pressure monitoring system to a complete monitoring system. Information recorded and reported include nurse notes, physiological monitoring data such as drug and IV therapy, arterial and pulmonary artery hemodynamic parameters, weight and fluid balance, indicator dilution, and thermodilution cardiac outputs, blood gas data, electrolyte and other types of laboratory data procedures performed, and complications noted.

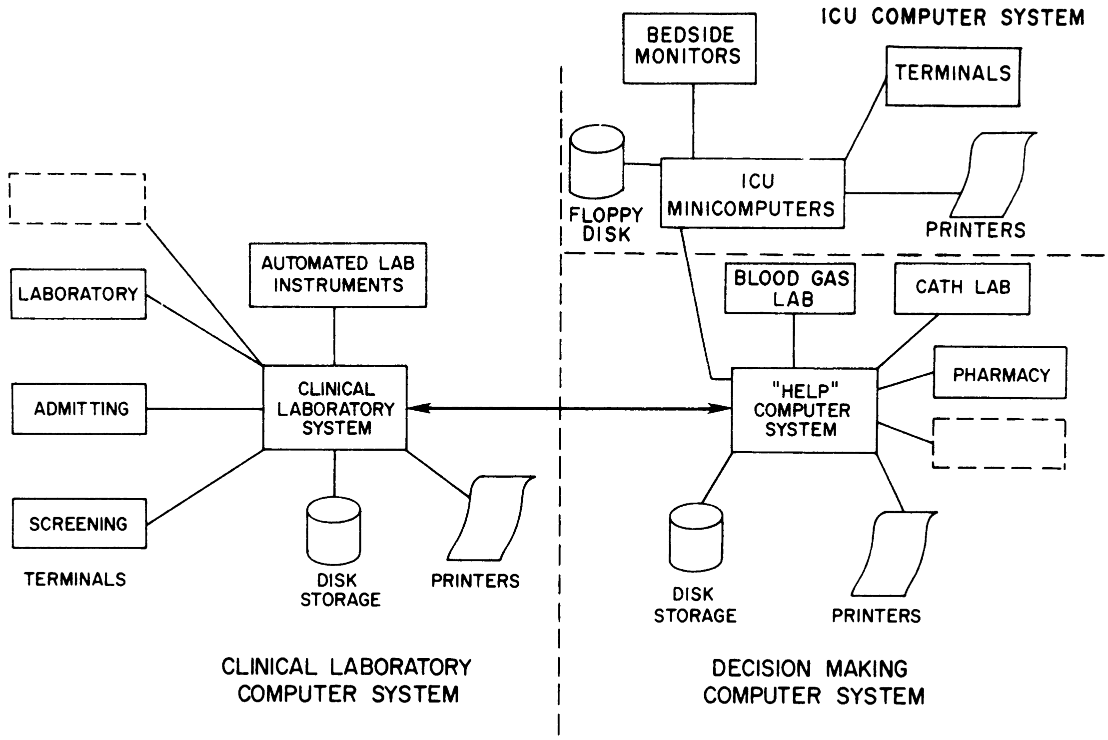

Figure 1. Block Diagram of Integrated Computer Systems Used to Monitor and Treat Critically Ill Patients

Computer technicians have become an integral part of the operating suites and intensive care units. These technicians provide an interface between the computer system and the nursing and medical staff by providing troubleshooting capability, data entry capability, report generation and emergency catheter insertion.

Concurrent with the development of the data acquisition and retrieval sections of the computer system it became apparent that clinical decisions could be made from the data and that these decisions could be useful to the care of the critically ill patient. As a consequence, a medical decision making system called HELP (Health Evaluation through Logical Processing) was developed.[7] The medical decision making language is written in a high level Fortran-like language making it easy to use and simple to use. The HELP decision criteria (sectors) are uniquely capable of handling variable time base data and makes extensive use of Boolean and Bayesean decision making strategies.

Figure 2 is a block diagram of this decision making system. The decision criteria are stored on magnetic disc much as patient data is. Therefore, the decision criteria are easy to change and extremely convenient to use. An example will help illustrate how the system operates. Suppose a "stat" electrolyte were drawn from a patient in one of the intensive care units. The blood is then immediately taken to the clinical laboratory where within minutes it is analyzed with automated instruments and automatically logged into the laboratory computer system (see Figure 1). As soon as the results are checked they are entered into the permanent patient data base in both the clinical laboratory system and the HELP computer system. Once they are stored in the HELP decision making system data base a pointer causes the decision making criteria applicable to that data to be activated and processed. The processing of this data can result in four different types of outcomes 1) an interpretation of the data so that when it is printed in the intensive care unit the data and its interpretation become immediately available,[8] 2) an alarm condition indicating that the data is outside the tolerable limits and may be life-threatening. This causes a special alarm condition to generate in the nurse/clinician area,[9] 3) an alert condition. This is similar to the alarm condition but applies primarily to the pharmacy. Drugs which have already been prescribed may be contraindicated by the new lab data. An alert is flagged and then followed up by a clinical pharmacist,[10] and 4) treatment protocols can be activated as a result of the new data input.

Integration of the medical data and data flow are best illustrated in Figure 3. Data for the ICU patient comes from several sources. A. Data acquired automatically includes hemodynamic data such as blood pressures, pulmonary artery pressures, cardiac outputs and ECG rhythm analysis. B. Data which is manually entered includes drugs, IV therapy, patient status, some respiratory parameters, temperatures, weights and other similar data. C. Laboratory data makes up a large part of the patient's data base. These data come from several laboratories, primarily from the clinical laboratory (figure 1). Blood gas data and other specialized data, however, come from other sources. All of this automatically, manually and remotely entered data merges together in the computer system shown in figure 3. Once the

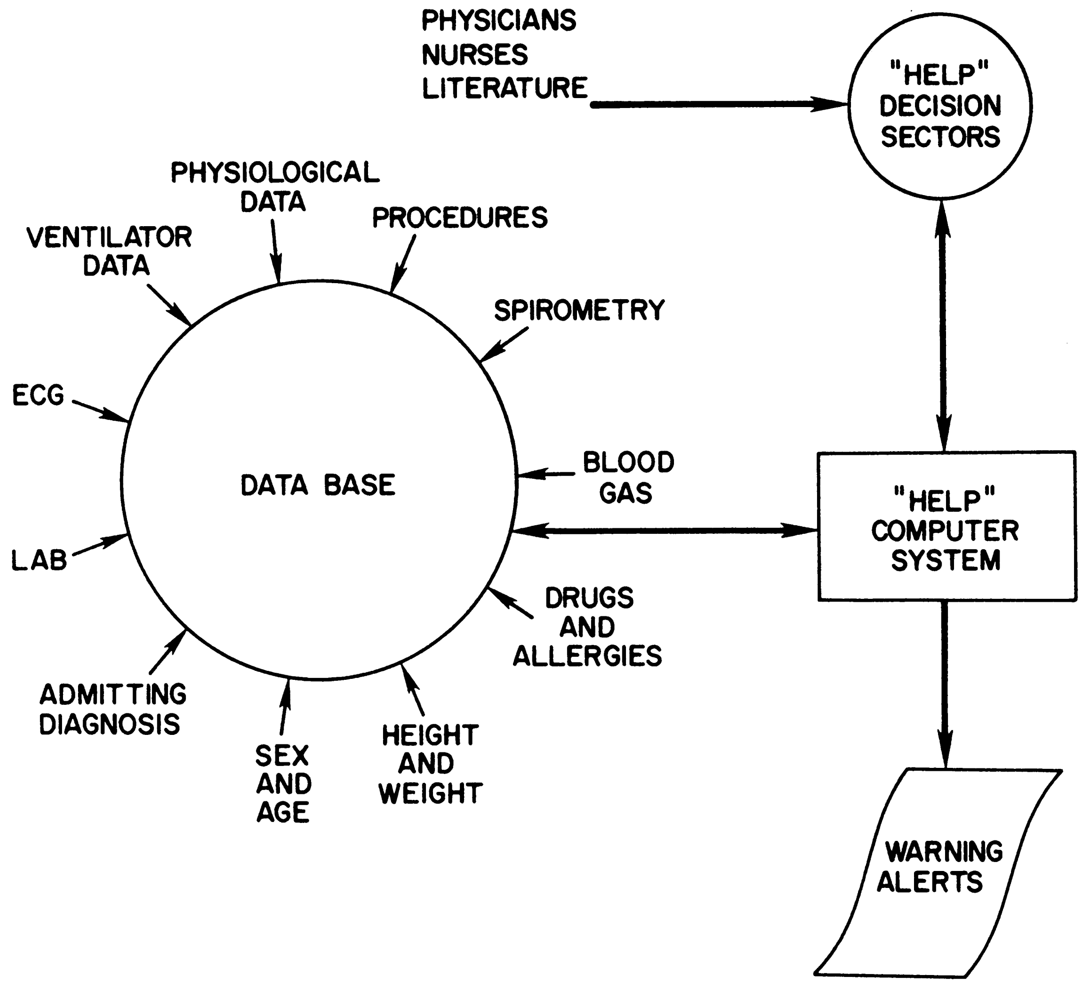

Figure 2. Diagram of the Data Base and HELP decision making System

data is acquired and stored decisions are made resulting in alerts and therapy suggestions which are available to the nurse-clinician and printed in the ICUs. Data and decisions are made available for video terminal review and alarms are indicated by lights in the ICU.

The flow chart outlined in figure 4 illustrates how treatment suggestions are made available to assist in the care of the patient. As soon as new patient data is available if conditions warrant a treatment suggestion is made. For example, new blood gas data may prompt a change in ventilator variables. If there is no treatment suggestion , then just interpretations are logged and the data is stored and printed for review in the ICU. If a treatment suggestion results, the suggestion is printed in the ICUs and at the same time printed at the nurse-clinician alerting station. The nurse-clinician will then follow up to see if the suggestion is utilized in patient care and evaluates the use of the suggestion. Life-threatening parameters are evaluated on all hospital patients using a protocol similar to that shown in figure 4. If an alert condition exists the patient is followed up by a nurse-clinician. Half of the hospital patients are "study" and half are "control" patients. An example of the protocol is shown below. The patient will either be a control or a study patient.

HYPERKALEMIA (K+ IS ==.=)

CONSIDER:
1. LAB ERROR
2. STOP KCL SUPPLEMENT
3. STOP K+ SPARING DIURETICS
4. DIURETICS OR KAYEXELATE
5. IF GREATER THAN 6.5, ECG TO CHECK FOR WIDE QRS
6. IF WIDE QRS, EITHER
   A) CALCIUM AND/OR BICARBONATE
   B) GLUCOSE AND INSULIN INFUSION

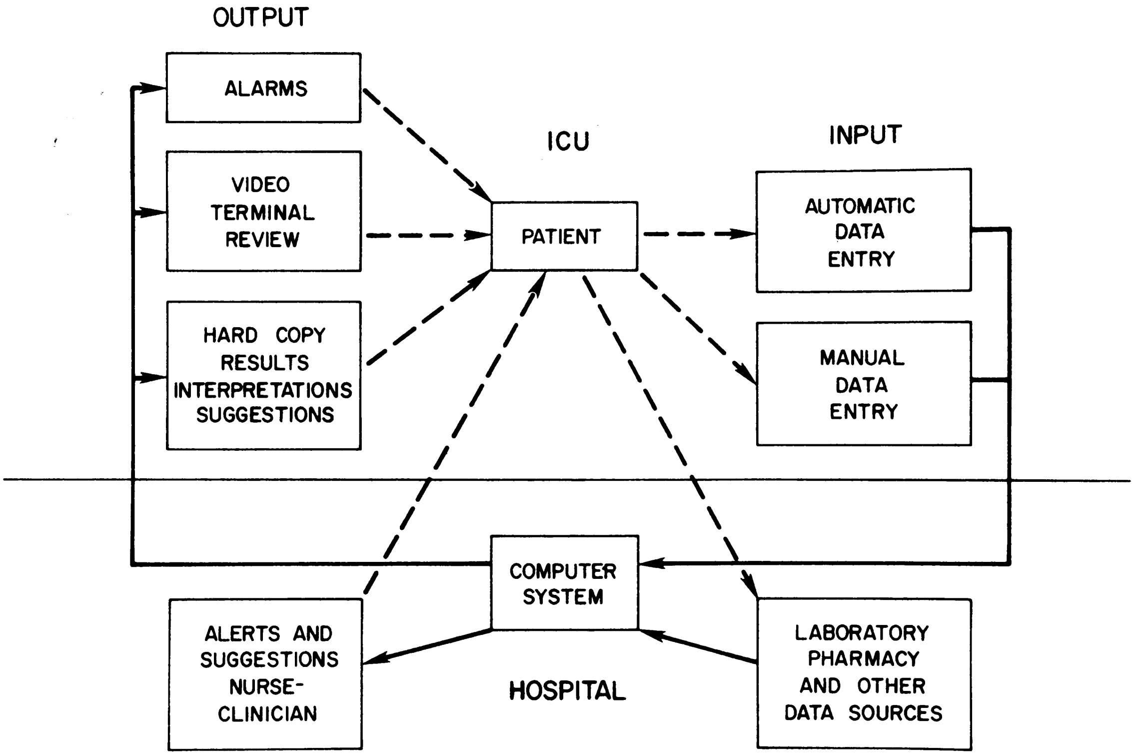

Figure 3. Intercommunications between patient, laboratories, pharmacy and other data sources with feedback and review capability

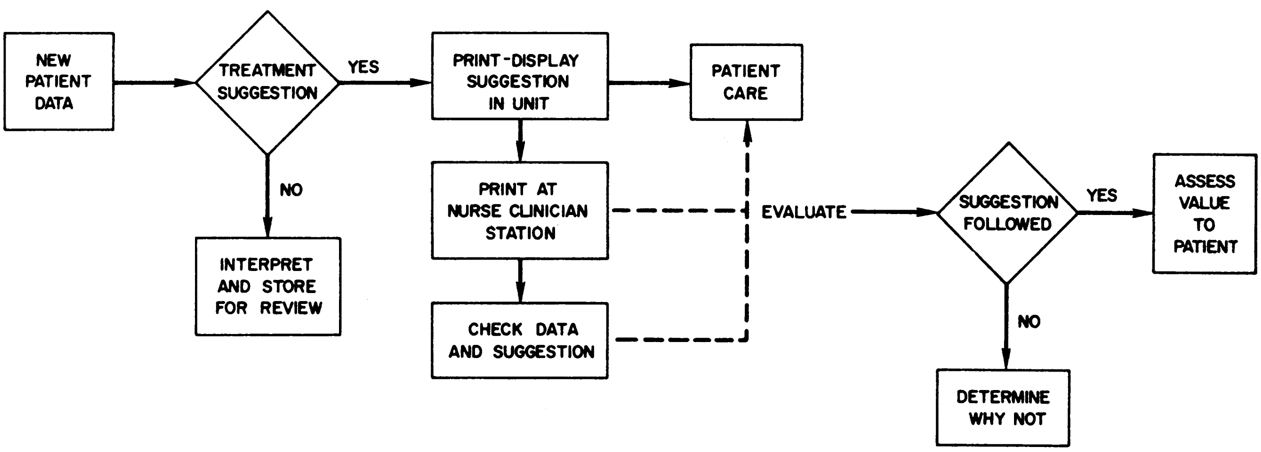

Figure 4. Flow chart of computerized treatment decision followup and evaluation

If a study patient alerts the information will be made available to the physician by a phone call and follow up with the appropriate protocol being placed on the chart and the nurse-clinician following up to see if appropriate action was taken. If the patient is a control patient no verbal or written followup is given to the physician or nursing staff but the patient is followed up by the nurse-clinician to assess the differences which the computerized alarming and alerting system can make.

Minicomputers

Because of the overload on the central processor and the need to have soft failures when the central processor goes down, minicomputer systems are now being installed in several intensive care areas. These minicomputers will carry out the analog pre-processing, permit limited data review, data entry, and data storage, so that during times when the central system is down the peripheral minicomputer will be able to handle time critical data (see figure 1). Re-entrant Fortran programs are resident in the memory of the minicomputers. Using this strategy it is possible to use high level language minimum coding and obtain optimum packing in the data package. Figure 5 is a block diagram of the computer system used. Note that each system uses a dual floppy disc. The floppy disc is used for two purposes 1) for program storage of programs such as the thermodilution program which are seldom used and need not be resident in the computer's MOS memory, 2) for temporary data storage and review in case the central system is down. The central computer system is used for data integration, correlation and decision making, as well as for report generation.

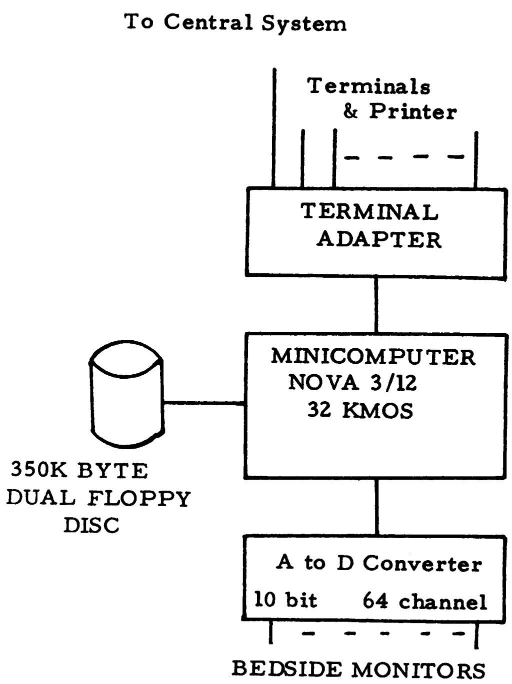

Figure 5. ICU Minicomputer System Block Diagram

Four similar minicomputer systems such as this are being implemented. Three at the LDS Hospital and one at the University of Utah Hospital, which will communicate with the central data base system located at LDS Hospital. In addition to these intensive care modules other modules are in place or are planned for 1) multiphasic screening, on-floor ECG, 2) pulmonary function and blood gas laboratories, and 3) cardiac catheterization laboratories.

Results

The system implemented in the intensive care units using the large central system has been operational for several years. The minicomputers are a new addition to this system and should improve the overall reliability and the response time of the system. To this point we don't have enough operational data to document these improvements and any additional problems which may come up as a result of this distributed computer network system. However, we are very confident, based on our experience with the rhythm monitoring in the coronary care unit, that its hardware reliability will improve from our current operating point of 98-1/2% up time to 99.8% up time capability.

During the past twelve-month period we have monitored 805 open heart surgeries and monitored over 6,000 patient days in these various intensive care units. The system has become an integral part of the operation of these units and now any time patient data isn't immediately available and results aren't accurate we get a call within minutes of the time they expect the data, indicating to us that the people are strongly dependent on the system.

Vital signs, operative procedures data and drug information from patients in the thoracic operating suites is available to the intensive care units, thus enabling the nurses to see how the surgery is progressing. With this data they can see what complications might have occurred, such as having to return the patient to the bypass pump, and make estimates of patient status and estimate when he will arrive in the intensive care unit. All this can be easily accomplished without telephone and without interrupting the surgical team. These "small" but very significant convenience factors have made the acceptability by the nurses and physicians greater in the past three years than ever before.

Battelle Evaluation[11]

Between December of 1976 and February of 1977 Battelle Columbus Laboratories conducted studies of the hospital medical staff to evaluate the computer system as a support to physicians. The study was to measure the awareness and acceptance of the HELP system by the medical staff and to determine their attitudes and expectations of the system. This was accomplished by a two-stage approach utilizing personal interviews of a sample number of the medical staff in addition to in-depth questionnaire sent to all the medical staff. This evaluation covered the entire HELP medical system and only a summary of that part which is applicable to the care of the critically ill will be presented here. A major finding was that "as opposed to the usual negative attitudes and opposition encountered in adoption of innovation, particularly in a hospital environment; a positive attitude toward the system is prevalent among the physicians on the staff of LDS Hospital. Those negative attitudes toward the system and particular expectations of the system encountered by Battelle appear to be based on biases toward the hospital or toward computers in general rather than toward the system." In addition to this general finding there were findings from the 30 physicians who responded to the intensive care module questionnaire. Most of the respondents indicated that their expectations could be met by a computer system. That is to say, they expected the ICU module would be able to provide much of the information in the patient's chart, that it would provide a more complete and easy to interpret intake-output report, that printout formats could be made completely acceptable, and that the monitoring system would be reliable and have satisfactory response time, resulting in greater capability to respond to patients' needs and to reduce patient morbidity rates. The evaluation of experience to date is very positive with the respondents very often indicating that the attributes listed above are in fact present. The only major negative evaluation (if it can be so classified) was that 15 of 23 respondents did not feel that the ICU monitoring system reduced length of time in the ICU for the patient. Most indicated that the system provides more information than can be assimilated. Overall, the system has received positive evaluations, both in terms of expectation and experiences to date.

Alerting System Results

We are in the process of alerting on more than 60 alert sectors using the HELP system to flag life-threatening situations--blood gases 25 sectors, clinical laboratory 27 sectors, pulmonary functions 5 sectors and other special sectors 4. We are currently following an average of 54 alerts per day in this 550 bed hospital. Of these 54 alerts, 24 (44%) occur on patients in the intensive care units. The other 30 alerts are for patients located in general hospital wards. On the average if a patient gets one alert he will get another within a 24 hour period. Ten percent of the alerts are for patients we are already following, while another 16% of the alerts are for patients requiring new visits. Each of these patients is evaluated by a personal visit from a nurse-clinician. After a careful data evaluation to eliminate data errors and computer or technical errors, we are finding that approximately 2% of the hospital patients have alerts and that approximately half of these (1%) are followed optimally.

Treatment Protocol Experience

Initial experience with treatment protocols has shown that in order to make adequate decisions a tighter data acquisition procedure must be maintained than is usual in the hospital. For example, the computer must have data on ventilators parameters at the time when blood gases are drawn. The computer must have physiological data taken in reasonable time sequence because the "extrapolation" techniques currently used by physicians saying, "Well, this is in the same time as the other data and we can use it for decision making" does not fare well in the computer application. Strict time constraints and rules need to be followed. Data acquisition and timing of that data acquisition are most critical and tend to make data acquisition more difficult and at times convenient. The primary problems in this area are 1) the acquisition of sufficient amounts of data to make reasonable decisions, and 2) establishment of the "medicalware" in order to make wise and prudent decisions.

Conclusion

Friedman and Gustafson in a recent review article[12] have listed six reasons why computers have not been more universally applied to medicine. Their points are summarized as

1) Unsuccessful user-computer interface.
2) Computers haven't exceeded the physician's own capability.
3) Inability to prove significant positive impact.
4) Difficulties of transferrability.
5) Inability to change and adapt.
6) We haven't learned from previous mistakes.

The system we now have operational responds favorably to many of these points.

1) The user-computer interface has been made simple with a minimum number of keystrokes and rapid response time (less than one second). The future application of computers in critical care will depend on further improved input devices which allow simple, prompt and accurate data to be entered into the patient record at a reasonable cost from multiple sites to eliminate queuing.

2) The medical decision making computer system described exceeds the physician's own ability in at least three ways A) Prompt data reporting as soon as the data is available, B) Integration of data from multiple sources for review and evaluation, C) Prompt, continuous (24 hours per day), reliable, sophisticated data interpretation alert and treatment decisions are made. Our computer system eliminates some of the complexities encountered in caring for the critically ill[9] a) Physician not always present when decisions required, b) data is complex and many times unfamiliar, c) Complex treatment modalities in ICU, d) lost, misplaced or ignored data resulting from "team" care or other causes, e) earlier detection of problems. The challenge here is as much medical as it is technological. The criterion on which physicians make decisions is not well-defined nor reproducible. The development of "medicalware" is in about the same position that computer software was 15 years ago.

3) Proving positive impact is a difficult but most important requirement. We have recently been reviewing the cost/benefit of the pharmacy module of our system.[10] Preliminary results show even in our teaching hospital setting that the benefit to cost ratio is 5.2 to 3.1 depending on the underlying assumptions. The acceptance of the system by

physicians[11] and hospital administration is probably our best indication of positive impact. Most all programs are self supporting. After initial development using grant funding the clinical projects such as the one described here have become self supporting from patient revenues.

4) Difficulties of transferrability are addressed by our transfer to minicomputer hardware with Fortran as a language. We still have a long way to go in overcoming this impediment. The problems are not all computer related since many of them are medical system related.

5) We have made a giant stride in our transfer to minicomputers. It is difficult to change and adapt, but it is also very necessary as they show. Our transfer to a distributed minicomputer system is illustration of our adaptability.

6) We have learned from our mistakes. Many times the lesson learned has cost us lots of time and money. Like others we have not chosen to publish our failures. We feel that publication of effective evaluations of physician attitudes, cost/benefit analysis and other similar measures will be most effective in promoting successful applications of computers in the care of the critically ill.

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