Computerized Protocols Applied to Acute Patient Care

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Introduction

Care of the acutely ill hospitalized patient places demands on the practice of medicine which are demanding of time and intellect. Some of the complexities caused by acute events are:

(1) Patient's attending physician is not always present when decisions are required.
(2) Data required for decisions is complex, voluminous and many times unfamiliar to the physician.
(3) The treatment modalities are more complex than most physicians are prepared for.
(4) Usually there are "teams" of physicians involved in caring for the acutely ill patient complicating data communication. At times data is lost, misplaced or ignored.
(5) Treatment for some acute illnesses can be delayed until the patient is critically ill when evidence of the impending crisis was available hours or days before action is taken.

For these reasons and the belief that systematizing the care of the acutely ill patients can improve his care, computerized patient care protocols are being developed.

The application of protocols to the treatment of patients is not new, having been introduced several years ago in the care of the outpatient (1, 2). In recent years protocols have been applied to the care of the critically ill patient (3-7). The care plans for most intensive care and emergency room settings are well established. These plans (protocols) of procedures and actions that need to be taken form the basis for computerizing the protocols.

Over the past ten years computers have been extensively applied to care of the acutely ill. Computers have been used primarily for data acquisition and reporting schemes. Automated ECG rhythm analysis and hemodynamic data acquisition are two applications which have become common in several large centers in the United States. For example, out of Myocardial Infarction Research Units (MIRU) came knowledge, rules and criteria for the treatment of patients with myocardial infarctions. While the past ten years have been used to develop rhythm monitoring and arrhythmia control techniques, we are now in a position to use the ECG rhythm data, physiological monitoring information, laboratory data, and physical findings to make better patient decisions with computer systems.

Monitoring of physiological data has come into its own in the past 10 years. Techniques usually reserved to the catheterization laboratory or research intensive care units are now developed and in common use in the critical care units of many hospitals (8, 9).

During this same 10-year interval computer technology has advanced so that there are now smaller, less expensive, and more powerful computers available. With this advance in technology it is now possible to commit minicomputers to laboratory and intensive care locations to gather and store patient information. With the integration of data from these computer systems it becomes possible for the computer to integrate and correlate patient data for medical decision making.

With the large amounts of acute patient care data which must be integrated and correlated, the physician, nurse and medical care team have an information overload. At times this information overload may result in some critical pieces of data being ignored or overlooked with the patient's subsequent treatment being suboptimal. The computer is able to carefully evaluate the data day and night and integrate it such that important decisions are not overlooked and therapeutic suggestions can be made effectively. Medical decision-making systems have been developed which take the patient information and make diagnostic, interpretative and therapeutic suggestions (10).

With the important computer elements available (e.g., modular data acquisition, economical hardware, data base, and decision-making system) and the expanding medical knowledge on the treatment of acutely ill patients we are now in a position to implement and test computerized medical protocols.

We are now implementing two classes of protocols, one for triaging the patient for admission to the intensive care unit, the other for treatment of the patient in the acute situation once he arrives in the intensive care unit. The primary goal of this research and developmental effort is to provide assistance to the patient requiring acute care through computerized triage and treatment protocols.

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Materials and Methods

The application of computers to clinical medicine has become a major effort of the Department of Medical Biophysics and Computing, a department of the Medical School of the University of Utah and of the LDS Hospital in Salt Lake City. As a result of this effort, an extensive computerized data base is currently available on every patient in the LDS Hospital. The system developed is shown schematically in Fig. 1. Two computer systems are involved. The clinical laboratory system was developed and installed by the Medlab Company of Salt Lake City and acquires data from a variety of automated laboratory instruments as well as from manual terminal inputs. The laboratory system has its own patient files and generates its own reports. When data is "verified" in the laboratory system it is sent to the decision-making system which has terminals located primarily in patient care locations of the LDS Hospital. Currently there are over 70 terminals and printers connected to this system.

Computer monitoring at LDS Hospital has been in development for 10 years (11, 12). During this time more than 8000 patients have been computer monitored. Monitoring was first developed in a 6-bed postthoracic-surgery intensive care unit. It is now operational in 3 thoracic-surgery operating suites, a 10-bed thoracic-surgery unit, a 12-bed coronary care unit, a 6-bed general surgical unit, and a 3-bed pulmonary intensive care unit (15). The computer system has developed from an intermittently used pressure monitoring system to a complete nurses note and physiological monitoring system where arterial and pulmonary artery hemodynamic data, fluid balance, indicator dilution and thermodilution cardiac output, blood gas, electrolyte and other types of laboratory data are reported and correlated.

Computer technicians have become an integral part of the operation of the surgical monitoring and the intensive care units. These technicians provide an interface between the computer and the nurse and physician staff by maintaining bedside instrumentation for measurement of hemodynamic data and are responsible for entry of drug, IV and other types of manually entered patient data. These technicians generate reports and maintain quality control of nursing reports for each nursing shift. They provide troubleshooting capabilities for instrument failures and insert emergency arterial catheters 24 hours a day, 7 days per week. They are available for computer monitoring of emergency surgery, those which go to surgery from either the emergency room or the intensive care unit.

During the development of this medical computing system it became apparent that the computer should do more than gather, store and report data. Therefore, five years ago development of a computer decision-making system to process the incoming data and make interpretations from that data was begun (10, 13, 14). This system called HELP (Health Evaluation through Logical Processing) has currently developed into a powerful tool which can be applied to patient care. Currently HELP is being clinically applied to the interpretation of test results, monitoring drug therapy, making diagnosis from computerized histories and in a variety of other ways. HELP is being used in a research mode to test clinical care protocols in an outpatient setting and being developed for use in several other patient care activities.

Figure 2 is a block diagram of the decision-making system. Decisions are written in a high level language much like FORTRAN using a program called HCOM which develops discrete modules (sectors) for decision making. These discrete sectors are "evaluated" each time data is entered referring to any of the information in the sector. The system data base includes data from several

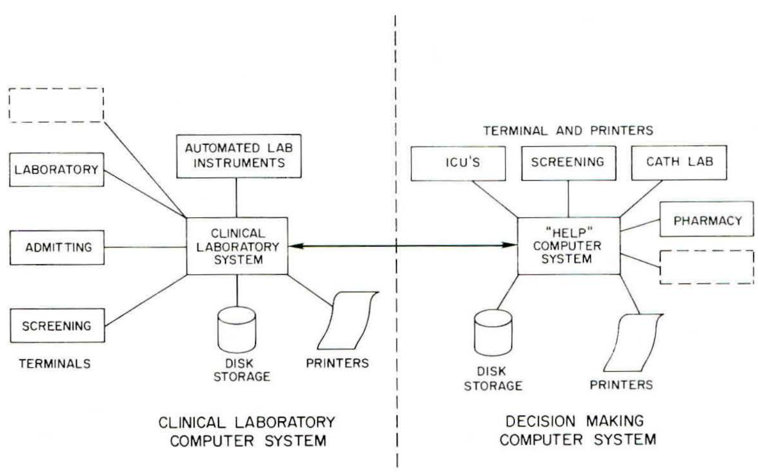

Figure 1

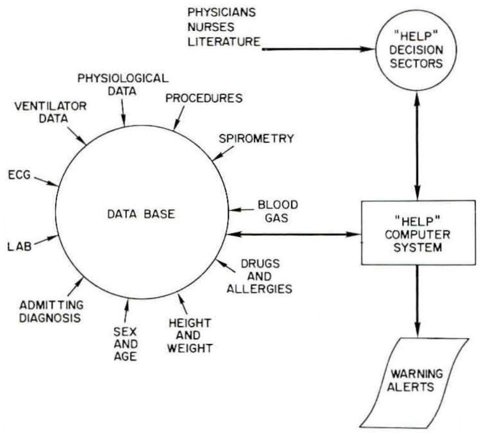

Figure 2

sources (Fig. 2). The patient data are entered either automatically or manually by paramedical personnel. Table I gives information on where, when, and by whom the patient data is entered. As can be seen most of the patient care data is in the computer.

A scenario will help elucidate the system operation. Let us suppose a patient in the intensive care unit has blood withdrawn for arterial blood gases. The blood sample is then taken to a specialized blood gas laboratory where it is analyzed. The computer provides quality control and instructions to the technicians as they perform the test. As soon as the data is acquired and stored it is evaluated by the HELP decision-making system and interpretations of the data are automatically made. The acquired data and interpretations are then printed in the intensive care unit and are available for later computer terminal review. If this data meets certain criteria which would cause an "alert" to be generated a copy of the results is presented at a nurse-clinician station in hard-copy form. The nurse-clinician then has the opportunity of following the data up, making certain that corrective action is taken if the situation warrants.

On-line computerized protocols have been developed for outpatient application at LDS Hospital (18). This experience has given us sufficient expertise to develop protocols for the acute care situations. All of the data acquisition and interpretative elements of the system described are clinically operational. The expansion to protocols and more complex decision processes are just beginning to be tested.

Table I. Computerized Patient Data Entry at LDS Hospital—1975.

Data	Patients per Year 1975	% of Eligible Patients	Who Enters	How (Terminal or Automatic)	When Entered
Patient identifying data	30 140	(100)	Admitting, lab, other terminals	T	Most within 1 h of admit
Admit diagnosis	30 140	(100)	Medical records	T	Within 24 h of admit
Screening data					
ECG	11 025	(37)	Tech	A	Real time
Pul. function	10 632	(35)	Tech	A	Real time
History	5 752	(19)	Patient	T	Real time
Vital signs	11 025	(37)	Tech	T	Real time
Heart cath lab	993	(100)	Physician	T, A	Real time
ECG (on ward)	2 573	(70)	Tech at bedside	A	Real time
Pulmonary function	710	(100)	Pul. fctn. tech	A	Real time
Blood gas	27 684	(100)	Tech	A, T	Real time
Medications and allergies	20 256	(85)	Pharmacist	T	Real time
Monitoring					
ICU	1 052	(90)	Monitoring tech	T, A	Real time
CCU	725	(100)	Monitoring tech	T, A	Real time
Surgery (open heart)	568	(100)	Monitoring tech	T, A	Real time
Lab data	27 100	(90)	Lab tech	T, A	Real time, when test results verified
Urinary catheter surveillance	4 800	(100)	Tech	T	Within 30 h of special collection
Surgery codes	11 453	(100)	Medical records	T	Within 24 h of surgery
Discharge diagnosis and abstracting	30 140	(100)	Medical records	T	Within 10 days of discharge

Results

Experience in the clinical setting with computerized decision making has all been positive. Physicians and nurses who once were threatened by the thought of a computer "taking over" now are comfortable and appreciate the interpretation of the data made available to them by the computer.

Two examples will illustrate the response and effect of the computerized decision-making systems.

Blood Gas Interpretation

With even the relatively simple interpretations provided for blood-gas data, physician response has been enthusiastic and patient care changed as a result (16). The "rules" for computerized blood-gas interpretation have now been formalized into a regional standard for interpretation (17). With the data readily available indicating "severe hypoxemia" on patients the medical staff of the pulmonary function laboratory started following up by calling physicians. Their calling was done twice each day. During a 3-week study period during which blood samples drawn from cardiac arrest patients were excluded 13% of the samples taken revealed severe hypoxemia. Of the physicians who were alerted 35% were unaware of the results and of the 96 notified 31% took action, which was effected because of the laboratory phone call. In 18.6% of the cases the problem was corrected. Since this activity was carried out only twice a day there were six times when over 5 h had elapsed from the time of measurement until the physician was contacted. Even with these long delays the feedback was helpful and appreciated. One outpatient during this time interval was found dead in the morning after blood-gas results showed severe hypoxemia. The patient's physician was notified the previous afternoon after being alerted that the patient was severely hypoxic but was unable to contact the patient.

Based on these results a faster contacting mechanism was implemented. The blood-gas technicians now contact the nurse or physician any time a severe hypoxemia is detected. Quantitative results evaluating this procedure change are not available, but the feedback obtained by blood-gas technicians from physicians and nurses has been positive.

Pharmacy

Our experience with monitoring of drug alerts has been similar where about 5% of the patients have drug alerts. Of these alerts, the majority were a result of contraindications because of laboratory results. When a drug alert occurs a clinical pharmacist follows up by verifying the alert and contacting the staff physician. Nearly 80% of the contacts result in changed patient treatment (19).

From these experiences we have learned that:

(1) Nurses and physicians appreciate the assistance the computer system can give.
(2) The computer system can have a positive impact on patient care.
(3) The personal contact of a laboratory technician or clinical pharmacist is more effective than just printed reports and is better received than contact from another physician.

Since many of the acute incidents occur in nonintensive care areas within a hospital we are in the process of implementing a hospital-wide monitoring system to minimize the number of crisis situations. Statistics show that most of the patients who go to our medical-surgical intensive care unit come from within the hospital, while most of those who go to the coronary care unit come from the emergency room. Anecdotal information indicates that there are several cases where patients should have been admitted to the intensive care unit sooner than they were. We are in the process of setting up a data gathering scheme so additional patient information can be input to the computer and acute crisis situations on hospital wards minimized. With this hospital surveillance system we hope to alert the appropriate personnel earlier than at present and thus decrease the number of in-hospital emergencies. The flow chart shown in Fig. 3 shows how the system operates. New data activates the HELP system. If the data does not warrant an "alert" it is interpreted and stored for review. If it results in an alert the printer at the nurse clinician station prints the "alert" message. The nurse clinician then personally follows up the alert and determines its validity by evaluation of the patient and the data. If the "alert" is not valid the error is noted. If the "alert" is valid several suggestions are made. These suggestions are followed up to ascertain the utility of the system and to assess its value to the patient.

Discussion

The rationale for this computerized approach to acute care is that:

(1) Prompt transport and transfer of critically ill or injured emergency patients to well staffed intensive care units can save lives and decrease morbidity.
(2) Early identification and treatment of life-threatening problems are more likely to end in an acceptable outcome than a last-minute "heroic" attempt.
(3) That algorithms or protocols can be developed for triaging and treating most emergency life-threatening problems.
(4) That computerization of protocols and applying the protocols to the hospital data base can detect problem patients earlier than they are now being detected, thereby

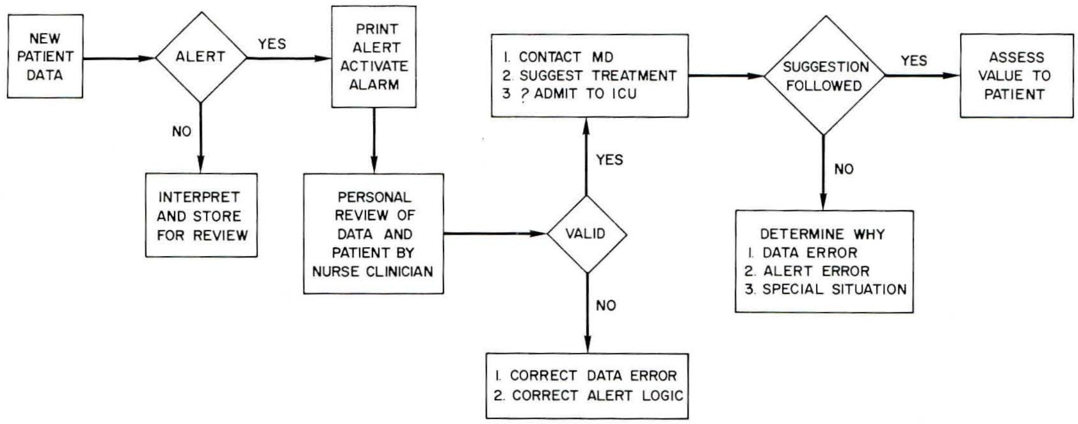

Figure 3

facilitating rapid treatment and optimal care of the patient.

(5) That early identification of the problems and more prompt stabilization of patients' physiological condition can result from applying computer protocols.

Based on our experience with blood gas, pharmacy and urinary catheter alerting schemes we are implementing a system to apply protocols to acute care for the following reasons:

(1) Extensive computer data base already available for hospital-wide monitoring. A primary strength of the system described is that most of the data is collected automatically by the clinical laboratory, the blood gas laboratory, the pharmacy and by other paramedical personnel. Most other systems require physicians or nurses to enter the patient data via a teletype or terminal before interpretations and suggestions are available.

(2) Several years' experience with computerized intensive care units. This real world clinical experience has given us the skills to interact an interface with the complex medical structure of the intensive care unit.

(3) Experience in developing treatment protocols for the ambulatory care setting.

(4) The HELP system for medical decision making is well developed and clinically operational. This powerful decision-making system will form the foundation under which the triage and treatment protocols can be easily and quickly implemented.

(5) Experience with computer alerts has already shown that prompt feedback from paramedical personnel such as clinical pharmacists, blood gas technicians and nurse clinicians can have a positive effect on patient care.

(6) Hospital medical and nursing staff support and cooperation. Both of these groups have been supportive during the developmental years and in the last two years have encouraged the planning of even greater patient care computer usage.

Conclusion

Perhaps the most intriguing part of this entire project is establishing the criteria for the decision making. Development in this area is still in its infancy. However, our experience has already shown that a clear definition of the problem and its treatment implications results in more prompt and rational patient treatment. By establishing rules by which interpretations and treatment decisions are made, the data needed to make the decision is apparent. The question of how promptly data is needed can then be clearly outlined. Therefore, the protocols can become a driving force used to determine what should be done about putting laboratory data or equipment in the ICU or having it in the remote centralized laboratory. Primary elements to consider when evaluating requirements of laboratory tests: (1) how promptly the data is needed; (2) the cost of doing the tests; (3) what therapy can be effected by getting the test result; (4) what are the costs if an error is made or the laboratory data is delayed; (5) are the people available and is the medical situation such that treatments can be carried out as soon as the patient data are available.

Computerized medical decision making—especially its application to the acutely ill patient—is a technique whose "time has arrived." As modules are developed they can be implemented. It is not necessary that the entire knowledge of medicine be in the computer before it is useful. On the contrary as new knowledge and techniques are developed they can be quickly and easily integrated. For example, a new computerized blood-gas machine will be installed in our hospital soon which will speed up the acquisition of this type data. This unit will allow our nurses and technicians in the intensive care unit to acquire blood gas data much more rapidly. They will not have to worry about going through complex calibration and equipment maintenance procedures, since this is already built into the machine.

As the state of the art of pocket calculators is injected into the medical computing field one has difficulty in projecting the exciting advances the next 10 years offer. The primary challenge in applying this new technology will be development of "medical ware." The computer technology will likely be available before medical experts can develop sufficient protocols, before all the patient data acquisition systems are developed, before methods for preventing erroneous data from cluttering the patient files are developed. The next 10 years in computerized medical decision making are going to be stimulating and exciting ones.

Acknowledgments

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