Session 6

COMPUTERIZED ALERT SYSTEM USE IN CLINICAL MEDICINE

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Acute medical care, especially emergency medicine, places heavy demands on the physician's review and interpretation of patient data. We have developed a computerized system for alerting physicians of potential life-threatening conditions. By utilizing a computer in conjunction with paramedical personnel, we have shown that such a computerized system can have a positive effect on physician behavior. Discussed are methods of collecting data and implementing the system to support the above conclusion.

I. Introduction

Acute medical care requires physicians and other health professionals to process a large and diverse amount of data. Optimal treatment of patients must include constant, efficient, and thorough examination of all patient data so that timely and correct decisions can be made. Optimal management of hospitalized patients who are acutely ill must include some methods for early detection of abnormalities. We have developed methods which utilize the computer to efficiently gather and analyze clinical data on hospitalized patients and to alert the medical staff to potential life-threatening problems.

In the process of implementing a medical computer system for the early detection of patient problems and physician notification of these problems, we have identified four process steps that occur when any new patient data is generated. These steps are: (1) communication of the data to the physician, (2) physician review of the data, (3) physician interpretation of the data, and (4) physician action. If any of the first three steps are overlooked or are carried out incorrectly, action taken in treatment of the patient may be inadequate, incorrect, or completely lacking. A delay or loss in communication of diagnostic results to the physician for whatever reason may result in both delayed and inappropriate treatment. Lack of proper review of available data because of time limitation can cause results to be overlooked or misinterpreted. Even if the data is correctly communicated and reviewed, it may not be properly interpreted by the physician because of a failure to correlate all of the patient data, a failure to detect trends in the data or an insufficient knowledge to interpret the data. We believe that potential occurrence of these problems can be greatly reduced using computer techniques.

II. Materials and Methods

The LDS Hospital is a 570 bed private hospital serving the Salt Lake area and the surrounding Intermountain region of the United States. Last year the hospital had over 31,000 admissions and performed nearly 16,000 surgeries, including 600 open-heart surgeries.

The hospital has a large clinically, oriented computer facility which currently consists of two Control Data 3300 computers, one used for research and development and the other providing clinical services. The clinical service computer is interconnected with ten minicomputer systems that service the intensive care units, multiphasic screening and the hospital's laboratories. This distributed minicomputer system enhances reliability, improves throughput capabilities, and provides for local control and storage of data.

In all, the computer facility services 121 clinically-oriented terminals and printers located throughout the hospital on nursing divisions and in intensive care units, laboratories, and special physician review areas. Terminals are used for both data entry and data review. The computer facility provides the capability for convenient and easy acquisition of data from clinical areas of the hospital. Data entry is handled by automated instruments, minicomputers, ward clerks, pharmacists, and other paramedical personnel. This data base, collected on every patient, allows for review of most all clinically-oriented information from each terminal.

Since 1972, a major effort of the Department of Medical Biophysics and Computing of the University of Utah and LDS Hospital has been the development of a computerized decision-making system called HELP (Health Evaluation through Logical Processing). HELP is a computer-based decision-making system designed to provide timely expert interpretations of patient data to physicians and other health professionals. The interpretations are based on criteria developed by medical specialists. New data received by the main computer is processed through the appropriate HELP decision logic to produce sophisticated analysis and interpretations.

A summary of the types of data acquisition and analysis is outlined.

Multiphasic Screening. Upon admission, computerized electrocardiograms and pulmonary functions are performed on selected patients, primarily those admitted for elective surgical procedures.

Clinical and Microbiological Laboratories. Much of this data is entered automatically to a minicomputer from the machine running the test. Data is available for review from any terminal seconds after results are verified by the laboratory technician and sent to the main computer. New laboratory results automatically print out in the intensive care units and the emergency room.

Specialty Laboratories. In the heart catheterization laboratories, hemodynamic data is collected on an in-laboratory minicomputer with the left

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ventriculogram providing additional data. Both the pulmonary function and blood gas laboratories are also served by a minicomputer. Electrocardiograms are performed on patients in their hospital rooms. The data from all these sources is analyzed by the HELP system and the interpretations are reported with the results.

Computer Monitoring. In the intensive care units minicomputers collect and record all vital signs and hemodynamic data. This data is then automatically sent to the main computer and interpreted by the HELP system. Technicians enter other pertinent medication administration and fluid intake and output information. Complete computer charting is available for over fifty intensive care beds.

Pharmacy. A hospital-wide drug surveillance program is operated by clinical pharmacists through the terminals on each nursing division. This surveillance is unique in that not only drug-drug interactions are monitored, but laboratory data is also monitored for drug contraindications and drug adverse reactions.

Admit and Discharge. All of the patient's admitting and discharge diagnoses are entered into the computer using Systematized Nomenclature of Pathology (SNOP). In addition, all surgical procedures are coded by modification of this nomenclature. Additional admit information includes patient's name, age, sex, height, and weight. Communications have been set up between the minicomputers and the central computer system for on-line admit, transfer, and discharge of patients.

X-ray. Recently we have added a unique system of x-ray ordering and reporting. Orders are entered by ward clerks and include the type of x-ray and the reason for the order. This information along with laboratory and other data is reviewed by the HELP system to determine the five most probable interpretations. The radiologist can then check one of the five interpretations, and this data is entered into the computer.

Alert Program. This extensive data base provided the basis for development of a program that alerts health professionals to acute or life-threatening situations. By utilizing all the clinical data on the patient the HELP system promptly detects acutely serious events which are then available for display on any terminal. Subsequently, the physician is notified of these events by responsible personnel more quickly than through the usual communication channels. The alert program operates on a twenty-four hour basis with computer reliability and speed. The HELP system is "data-driven" meaning that as soon as new data is available (e.g. laboratory, blood gas, or pharmacy data), each of the appropriate decision criteria relating to that data is evaluated. For example, an elevated serum potassium may generate several alert conditions. It may generate an alert because of the danger of an elevated pH from a recent blood gas. The potassium result may also cause alerts for the pharmacy if the patient is receiving potassium supplements or potassium-sparing diuretics. An alert decision may be made if the potassium level is high enough that a patient might develop cardiac arrhythmias. Therefore, upon receiving an abnormal serum-potassium value, the HELP system reviews recent blood gases and the medication list so that all appropriate decisions can be made.

The alerting system has been used in three major areas of the hospital. A brief description of each area follows.

1) Pharmacy. It is universally recognized that drug therapy, together with its benefits, also poses a significant threat to the delivery of health care due to drug interactions with other drugs, the patient's disease condition, and adverse drug reactions.[1-5] A majority of these adverse effects are defined and predictable. Drug therapy monitoring schemes have been devised to assist the physician reduce the hazards associated with drug therapy. However, drug therapy monitoring is largely a routine activity requiring extensive attention to large amounts of information with relatively rare occurrences of significant events. It is difficult on an ongoing basis to provide sufficient incentive to make a manual system one hundred percent effective. The predictability of the adverse effects, combined with the tedious nature of drug therapy monitoring, make computers well suited to accomplish this task.

The primary objective of a computerized drug monitoring system is to provide a prospective review of all drug therapy to modify physician prescribing behavior prior to the administration of potentially harmful medications. Cohen and his associates at Stanford University have pioneered computerized drug monitoring systems for both hospital and community pharmacy practice settings.[6-9] Others have also worked in this area.[10] The emphasis of these systems is on the detection of drug-drug interactions. A few investigators have developed outpatient monitoring systems which, in addition to drug-drug interactions, monitor for drug contraindications due to diagnosis and drug-laboratory test interactions.[11]

We have developed a computer system which provides the physician with therapeutic suggestions relative to a wide range of medication prescribing problems. Patient specific suggestions are provided for: 1) drug-allergy contraindications, 2) potential drug-drug interactions, 3) adverse drug reactions, 4) drug-disease interactions, 5) laboratory monitoring of potentially toxic drugs, and 6) prevention of excessive drug dosage.

The LDS Hospital has a decentralized medication distribution system where the pharmacists work on the nursing divisions rather than in the central pharmacy. A direct copy of the physician medication order is given the pharmacist on the nursing division. The pharmacist promptly enters the drug information into the computer through a terminal on the nursing division before dispensing the medication. The drug name, dosage, route of

administration, dosing schedule, and time of order are all logged in the patient's computerized medication profile. The HELP system then automatically processes all alert criteria applicable to the drug prescribed, and if any of the alert conditions are true, it presents the pharmacist with the alert conditions. The pharmacist then evaluates the patient for the alert condition and makes personal contact with the physician to discuss the alert. This feedback method is quite different from other computerized alerting systems in which feedback of the alert condition is limited to leaving a computer printout of the alert in the patient's chart.

2) Blood Gases. A study was conducted in 1974 to test physician response to alerts of "severe hypoxemia" on patients. Technicians notified physicians twice a day of any patient whose blood gas indicated a severe hypoxemia. Physician response was enthusiastic and patient care changed as a result.[12] Since this study, rules for computerized blood gas interpretation of acid-base balance have been formalized into a regional standard for interpretation.[13] The recent advance in the ability to measure both arterial and venous blood gases has given the computer more data to use in evaluating oxygenation.

The HELP system not only provides sophisticated interpretations but it also reviews clinical laboratory data for abnormalities. If a metabolic acidosis is interpreted on a blood gas, the HELP system reviews the most recent SMA-6 and lactic acid level to determine possible reasons for the acidosis. The computer also calculates the anion gap from the electrolytes and indicates in the interpretation whether it is high, low, or normal. Recently, use of minicomputers to automatically measure and record hemodynamic data in the intensive care units has enabled the HELP system to use cardiac outputs in more sophisticated interpretations of oxygenation. An example of an interpretation that might appear with a blood gas of a critically ill patient is:

SEVERE MIXED RESPIRATORY AND METABOLIC ACIDOSIS
ANION GAP GREATER THAN NORMAL (25.0 MEQ/L)
CONSIDER LACTIC ACIDOSIS
HYPOVENTILATION WORSE
SEVERE HYPOXEMIA BREATHING 02 AND CO2 RETENTION
(A-A GRADIENT 191 MMHG A/A 21%)
TECHNICIAN CONTACT MD OR RN
02 CONSUMPTION 250 ML/MIN: 02 EXTRACTION RATIO (35%)
ESTIMATED R-L SHUNT 23%

With all of this information available for use by the HELP system, blood gas interpretations can alert the physician or nurse to a variety of problems. Interpretations are available for review on any terminal and with each printout of results.

3) Nurse Alerts. Based on the positive experience we have had with both the pharmacy and blood gas systems, we then chose to expand our alerting system to include alerts on patient condition based on clinical laboratory data. We have established over sixty alert criteria applied to data coming from the clinical laboratory data that indicate potentially life-threatening problems for the patient. A two-year study has been conducted to test this new program. Nurse clinicians assisted in data collection and evaluation. They frequently reviewed the alert list on a terminal, made certain each alert was valid, and then randomized the patients into control and study groups. For the study patient, the physician or nurse was immediately notified and a simple computer-generated, action-oriented alert protocol was placed in the chart. For both study and control groups, the nurse clinician reviewed each patient's chart daily for a 48 hour period documenting notes and orders pertinent to the abnormal laboratory value. With this data, we have been able to measure the effects of the alerting program on physician's behavior in treating patients.

A scenario will illustrate utilization of the HELP computerized system. A 62 year old female was admitted to the emergency department of the LDS Hospital, confused, vomiting and unsteady on her feet. A "stat" electrolyte series was ordered on the patient. The patient was admitted through a computer terminal in the emergency department, which also admitted the patient to the clinical laboratory system. A laboratory sample was drawn at 18:35 hours. At 19:20 hours the data from the Technicon SMA-6 was acquired by the laboratory computer, verified and sent to the HELP decision-making system. The HELP decision-making system then processed the patient's electrolyte data through its drug, laboratory and other appropriate decision-making criteria. On performing this decision-making task, the computer generated a "hyponatremia alert" indicating the sodium level of 110 m/eq per liter. The nurse clinician observed the alert on the computer terminal at 19:30 hours and obtained a printout of the alert and treatment protocol. Since the patient was in the study group, the nurse clinician then went to the emergency department to assess the physician's awareness of the problem. The admitting diagnosis chart stated "left temporal cerebral accident" and no laboratory work was charted. It was felt by the nurse clinician that the physician was unaware of the hyponatremia and that he had probably mistaken the patient's symptoms for signs of a stroke. The physician was notified at 19:45 hours and expressed surprise at the low sodium. The physician's assessment was changed from "cerebral vascular accident" to "hyponatremia-seizure." Because of the severity of the symptoms which developed, including the seizure, the patient was transferred to the Medical/Surgical intensive care unit. Appropriate treatment with intravascular saline was begun three-quarters of an hour after the alert was posted (available for viewing on a terminal). The laboratory values went out of the alert limits in 10.25 hours and were within normal hospital limits in 33.25 hours. The patient stayed in the intensive care unit for four days and was discharged a few days later with a normal serum sodium. The above scenario illustrates some of the important features of the HELP system and the alert program: 1) patient data on admission was transferred between two computer systems, 2) laboratory data was quickly reported through a computer system, 3) medical decision-making and alert criteria were automatically applied, 4) prompt feedback to the nurse clinician and physician

led to prompt treatment, thus minimizing the time the patient was in a life-threatening condition, and 5) automated decision criteria were applied without having the physicians ask for the data. It illustrates the importance of automated decision-making and the impact it can have on patient care.

III. Results

1. Pharmacy. Results from the pharmacy system are contained in a preliminary publication by Hulse, et al., and in an upcoming publication by Clark, et al.[14,15] Utilizing the methods described we have achieved a very high (about 74%) rate of physician compliance to the alert-suggested therapeutic actions. This excellent compliance rate is probably attributable to two factors: (1) few false positive alerts due to an extensive computerized patient data base, and (2) personal contact with the physician by a knowledgeable clinical pharmacist.

Since the implementation of this system in 1975 there have been 586,512 prescription orders for 100,317 patients that have been monitored by the system. Medication monitoring by the HELP system has yielded alert therapeutic suggestions on 3,138 patients. Therefore, therapeutic suggestions occurred on 3.1% of the patients and 0.59% of prescriptions ordered. Significantly, the physicians modified drug therapy in response to the alert suggestions on 2,316 or 73.8% of the patients. It is interesting to note that drug-drug interactions accounted for less than 30% of the computer alerts generated, while drug-laboratory contraindications accounted for 45% of the alerts. Drug allergy interactions were the third highest alert causing criterion and resulted in approximately 15% of the alerts. Drug excessive dosage alerts accounted for 7%.

2. Nurse Alerts. For the past eighteen months we have reviewed more than 3,000 alerts. About half of these alerts occurred on study patients and half on control patients. Documentation by the nurse clinicians included time intervals from posting time of the alert to first physician-ordered action towards treatment and time the laboratory value was out of alert range. Also measured was compliance of physicians in treating patients according to appropriate actions listed on the alert protocol.

The metabolic acidosis alert will serve as a good example for the differences one could expect between control and study group in this particular alerting system. We found that in the study group (208 patients) it took an average of 3.6 hours for the first action to be taken while in the control group (181 patients) it took 6.7 hours. The time difference is statistically significant. We also found that no action was taken by the physician in 13 of 140 cases (9.3%) in the study group and in 28 of 91 cases (30.8%) in the control group, also very statistically significant. Therefore, the conclusion was that there was very significant difference in how promptly and how often action was taken in the treatment of particular serious problems. We evaluated how long patients stayed in the alerting condition, that is, how long the patient was in metabolic acidosis. We found that the mean time for patients in the study group was 23.7 hours, while it was 34.3 hours for the control group. This is a statistically significant difference. Similar to our findings when evaluating the first action taken, we found that there were significantly more patients in the control group than in the study group who never came out of the alert range. Another interesting observation was that prompt protocol-suggested care of the patient with metabolic acidosis either in the study or control group, had a marked effect on how quickly the patient recovered. This gave us confidence that the simple therapy protocols used in the alert system were valid.

During the time the study was conducted physicians were seeing patients in both study and control groups. Therefore, there was a training effect in operation. What a physician learned on a study patient could be applied to the next control patient who had the same condition. Even with the contamination of the training effect, there was significant statistical differences between the two patient groups. Therefore, we are confident that the computer alert system does have a positive effect on the quality of patient care.

3. Physician Attitudes. During the past three years we have conducted several of our own evaluation studies of program user attitudes. We also have had Battelle Columbus help us conduct a study entitled "Physicians Evaluations and Expectations of the HELP System."[16] The evaluation studies show our medical staff to be supportive of the computerized developments. A questionnaire polling physicians on the nurse alert program revealed that 75% "always" use the terminals to obtain laboratory results and that all felt the nurse alert program to be a beneficial, justified service. Quoting one of the conclusions from the Battelle study; "... as opposed to the usual negative attitude and opposition encountered in adoption of innovation, particularly in the hospital environment; a positive attitude towards the system is prevalent among the physicians on the staff at 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 towards computers in general rather than towards the HELP system." Questionnaire responses from Battelle's report showed that for many of the individualized computer services there was great enthusiasm along with expectations of the computer system. In the case of the intensive care units, physicians thought the computer should provide more complete and easy-to-read fluid intake and output records. This problem was remedied several months after the report came out. Also, many of the respondents to the questionnaire indicated that the attributes they expected from the system were in fact present. Overall the computer system has received positive evaluations both in terms of expectation and experiences to date.

IV. Conclusion

We have shown that the computer system at LDS Hospital has been beneficial in changing physician behavior to reduce therapy errors and improve physician decision-making. Three process steps

are completed by the physician before action is taken whenever new patient data is generated: (1) communication, (2) review, and (3) interpretation of the data. Each of these process steps is improved by the computerized system. The communication and review of the patient data is improved by organizing the data and presenting it on demand at the computer terminals at the nursing divisions.

The review and interpretation processes are improved by automatic computer review and analysis of the patient data by the HELP system. This continuous analysis generates alerts on abnormal data that poses potential problems for the patient. We have shown that feedback to the physician of these alerts through pharmacists and nurse clinicians has resulted in physician compliance to the alert suggestions. We have also shown that the alerts caused a more prompt treatment of the patient and a more rapid return to normal of his laboratory parameters.

Our future investigations will more carefully evaluate the key elements of physician compliance and will determine the cost-benefit ratio of the computerized alert and feedback mechanisms.

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