COMPUTER SUPPORT IN CRITICAL CARE MEDICINE

Clemmer, T. P.; Gardner, R. M.; Orme, J. F., Jr.

LDS Hospital and University of Utah
325 Eighth Avenue
Salt Lake City, Utah 84143

Abstract

Data entered from analog signals, nursing records, various laboratories and medical records is organized, compared, integrated, interpreted, displayed and charted in a ready to use format by a system of mini computers linked to a large central computer with decision making capabilities.

The major advantages of the system include: A) Organization of the data, B) Interpretation of data, C) Focusing personnel attention on problems, D) Manipulation and processing of data, E) Storage of data, F) Guiding clinicians, F) Accelerating the availability of data, and G) Education of physicians and nurses.

The system is highly accepted by physicians, nurses and allied health personnel requiring minimal entry and retrieval time.

Introduction

During the past 20 years advances in critical care medicine have been enormous. The care of the patient based primarily on history and physical exam has been supplemented with more sophisticated scientific data which was not widely known in the 1950's, even in animal physiologic research laboratories.[1]

This has been made possible because of advancements in many areas of science which have now been applied to medicine. As a result we see an increasing number of patients with multiple organ failure who present with extremely complex physiologic conditions which must be promptly recognized and treated with an ever increasing number of pharmacological agents.

This has led to the creation of a new medicine subspecialty called critical care medicine. Physicians trained in this discipline, who care for these very complex patients full time, have developed a systematic approach to their care by integrating the expertise from many areas of medicine. To provide optimum care, frequent evaluations of the function of the various organ systems such as the cardiovascular, respiratory, renal, central nervous system, liver, and their interactions, must be made. Also the status of the fluid and electrolyte balance, metabolic processes, nutrition, coagulation and immunity must be constantly surveyed. Changes produced with various therapeutic manipulations and the interactions between various drugs add to the complexity of the situation. The data generated to evaluate any one of these organ systems is significant in itself, and the timely combination and integration of all of the data may become overwhelming.

Thus, the role of the computer in critical care medicine is easily recognized. It has joined with other scientific advancements being applied to medicine to aid the physicians and help them gather, process, organize, store, integrate, interpret, and communicate data. The computer can display the data in a manner which will focus attention on the areas which need immediate attention and allow easier recognition of complex physiologic interactions.

The computer support of critical care medicine at the LDS Hospital is designed around these concepts.

Methods

The system is designed around a four processor Tandem central computer system with each of the six critical care units interacting with the central system via mini computers (Nova 3) located within the ICU. In addition, the laboratory computer (MEDLAB) is interfaced to the central system. On line data entry is also received from the admitting area, cardiac catheterization laboratory, pulmonary function/blood gas laboratory, ECG laboratory, X-ray, operating suite, pharmacy, screening clinic, and medical records.[2] Entries from all these areas are correlated and integrated into the data base from which clinical decision making processes are implemented on the HELP (Health Evaluation through Logical Processing) Computer System.[3]

In the ICU, the computer automatically collects most of the hemodynamic data directly from the arterial, pulmonary artery, pulmonary wedge, left atrial and right atrial pressures, and cardiac output analog signals. From this data an array of hemodynamic data is automatically derived, including the systemic and pulmonary vascular resistance, cardiac index, stroke volume, stroke index, and left and right ventricular stroke work indexes. Utilizing a Starling curve plot,

0195-4210/80/0000-1557$00.75 © 1980 IEEE

interpretation of ventricular performance is derived and displayed.

Other data obtained from nurses such as fluid intake and output, medications, and neurologic findings are entered by computer technicians reducing the time required for the nursing personnel to interact with the computer.

All laboratory and blood gas data are entered directly by the respective laboratory and admission diagnosis and operative procedure by medical records.

Each patient's data is displayed in several ways. (1) As a graphic record every eight hours. This record includes the vital signs, pulmonary artery catheter pressures, central venous pressure, cardiac outputs, Glasgow Coma Score, all medications by route, dosage, and time of administration, intake, outputs, and net fluid balance. (2) In addition to the eight hour shift report, a daily graphic record displaying a summary of the last five days is generated which also includes a complete nutritional summary of total calories, nonprotein calories, amount of carbohydrate, fat and protein, and nitrogen balance information. (3) All laboratory and blood gas data is printed out in tabular form in the ICU as soon as it is completed in the laboratory and displayed in chronological order. (4) Special alerts are generated when dangerous conditions or trends are recognized by the computer focusing appropriate personnel's attention on specific problems. (5) All of the above data is readily available on CRT terminals located throughout the hospital.

Results

The system has proven to be useful in the care of the critically ill in the following ways:

Organization of the data

Timely review of all the data on ten critically ill patients and then making appropriate decisions for each patient is a demanding task. We have observed that whenever data retrieval is time consuming or inconvenient for the physician, decisions will be made on incomplete information. The computer organizes the data into a legible form with everything in a standard location and displayed so that the complex data is easily reviewed, correlated, and integrated, thereby facilitating the decision making process.

Displaying the data in a chronological format allows for quick review of trends or sudden changes at a glance.

Interpretation of data

Although the data is available to the physician, this does not always mean it is useful for his decision making process. Because of the rapid advancements in critical care medicine and the sophistication of the data being generated, many physicians require some help in understanding the meaning of the unfamiliar numbers and terms. For example, when the stroke work index of 18 gm M/M^2, systemic vascular resistance of 22 resistance units and pulmonary wedge pressure of 18 mmHg is given to many physicians, it is likely they would not recognize this as being cardiogenic shock for which afterload reduction may be useful. Similarly, when a blood gas returns, the nurse may fail to recognize that the normal pH of 7.36 when accompanied by a pCO_2 of 23 mmHg represents a major metabolic acidosis which needs to be investigated.

Therefore, computer interpreted data is more useful to the personnel who do not deal with it on a daily basis, thereby improving the decisions which are made.

Having the computer integrate data from many sources is also of great value to the clinician. When the blood gas report of a metabolic acidosis includes the anion gap, BUN and glucose from time synchronized sample results which come from a different laboratory, the interpretation and differential diagnosis is facilitated.

Focusing attention on problems

Although the clinicians may be very adept at interpreting the clinical data, they often overlook a problem because of the volume of numbers and the complexity of the situation. For example, it is easy to overlook a BUN that is rising from 8 mg% to 28 mg% over 72 hours which if noted might indicate that a gentamycin level should be checked and perhaps the drug dosage altered.

Our computer alert system automatically sends prompting messages to the appropriate personnel to review problems and focuses attention on areas where intervention may be needed. This alert program is frequently used in our pharmacy where current medications can be correlated with the laboratory data and drug interactions can be cross checked by the computer to avoid known incompatibilities[5] and improve patient care.

Another problem physicians have is overlooking information when displayed simultaneously with other data. An example would be the SMA-6 electrolyte results. If the physicians are concerned about a patient's potassium problem when they review the 6 channel, they will probably not remember what the CO_2 content was if you ask them two minutes later, and they certainly will not know what the anion gap was since it requires a calculation. Because they did not focus on the chloride and bicarbonate, they may miss a potential problem. This is not because they are poor physicians; it is simply a limitation of the human mind to process everything at once. The computer, on the other hand, evaluates and compares to the normal standard each result each time new data is available and can alert the personnel if dangerous situations exist.

In a recent study performed at this institution, the computer alerted research nurses about abnormal situations.[6,7] The patients were then randomized. In the control group which were followed by the research nurses, the physicians were not given a special alert. In the study group, the physicians were alerted and suggestions as to a plan of action were generated by the computer

and promptly given to them. During the study all laboratory and other data was available to the physician through the usual mechanisms.

In patients who alerted as having metabolic acidosis, the study group had a significantly shorter time until the problem was recognized, required less time for the first action to be taken, and laboratory values returned more promptly to within non-alert conditions. Patient outcome was improved in the study versus the control population.[7]

Thus, the ability of the computer to analyze and compare each data point and to interpret the results when coupled with feedback loops may modify physician behavior and directly affect patient care.

Manipulation and processing of data

Although data can be processed by hand, it is time-consuming and frequently data entry and computational errors are made, especially when the personnel are unfamiliar with the equations and certain idiosyncrasies of the data. An example is the shunt equation.

$$Qs/Qt = \frac{P(A\text{-}a)O_2 \times 0.0031}{P(A\text{-}a)O_2 \times 0.0031 + (a\text{-}V)O_2 \text{ content difference}}$$

If the user is not aware of the derivation of this equation, he will not recognize that the equation does not apply unless the arterial hemoglobin is 100% saturated and its use otherwise will result in enormous data and treatment errors. With proper programming such errors can be eliminated.

Also, the time required to manipulate the data discourages many clinicians from using the data in the decision making process. Thus, many physicians continue to look only at the cardiac output and pulmonary wedge pressure and make decisions that might be markedly altered if they would calculate and review the systemic vascular resistance and stroke work index.

This can be demonstrated by comparing the ventricular function of two patients both of whom have cardiac outputs of 5 liters/minute and pulmonary artery wedge pressure of 15 mmHg. However, one has a heart rate of 120 with a mean blood pressure of 60 mmHg and the other has a heart rate of 60 with a mean blood pressure of 90 mmHg. The stroke work index of the left ventricle in the first patient is 18.2 gm M/M^2, whereas in the second patient, it is 56.7 gm M/M^2.

Thus, automatic delivery of derived parameters, along with interpretation of data and alerts, helps the physician in caring for his patient.

Acceleration of the availability of the data

In caring for the critically ill, it is not uncommon that immediate decisions must be made. Minutes may make the difference between life and death. Therefore, immediate availability of the data aids the physician in making the correct decisions. It is no longer acceptable to wait until noon for the result of the morning blood draw or for even one hour for critical electrolytes.

Certainly, some data such as cardiac output, which is now available in minutes, would take many hours or be completely unavailable if it were not for computers. This is also true of CT scans and other procedures that are only available because of computers.

Prompt computer aided communications have enabled the physician to work in real time, measuring the results of therapeutic interventions so as to tailor therapy to the individual needs of the patient. Computers have made possible the minute by minute titration of care in the shock syndrome and severe respiratory failure patients.

Thus, the history and clinical exam have been augmented with the availability of sound scientific data presented in a time frame, whereby it is useful in making critical judgments.

Storage of data

The storage of data for review is useful, not only for research, but also has impact on the daily care of patients. Review of the procedures and complications in an intensive care unit on a monthly basis helps us focus on problem areas and aids in development of policies and procedures for the unit. Recently, the review of our arterial catheter complications has led to the development of a more rigid arterial catheter protocol to reduce complications.

Another example involved an epidemic of a gram negative bacillus which was discovered in the unit. It was easy to review exactly what tubes and catheters the patients had in place as the possible source of the infectious problem.

The hyperalimentation team maintains a running computer log of breaks in the protocol on all parenteral hyperalimentation patients in the hospital. This is recorded by nursing units. Thus, when a catheter is improperly dressed, or the line is inappropriately violated, when the weights are not measured or recorded, or the intake and output is not accurate, this is put into the computer along with the metabolic and infectious problems.

Monthly, a report is generated and the data organized by nursing units and fed back to all the units. The head nurse of each unit can then compare their care of this group of patients to the care on other nursing units. Because of this feedback, there has been a remarkable improvement in the care of these patients. The computer has been an important tool in accomplishing this task and a significant decrease in breaks in procedure and complications have been observed.[9]

Retrospective research projects can also be quickly accomplished because of the large volume of data which is stored in the computer. Utilizing this data, a study to show the effects of a program of education of protocol adherence to reduce hyperalimentation catheter infection was recently completed at this institution and the data reported.[9]

Guiding clinicians

Because of the complexity of medicine today, it is impossible for the physician to keep abreast of the developments in all areas. Therefore, to be reminded of a more complete differential diagnosis or a possible course of action can be helpful.[8] This was demonstrated in the alert study utilizing research nurses who gave to the physicians of the study patients, not only the alert, but a computer generated differential diagnosis and/or treatment plan. When suggestions were given the physicians approach to the problem was more appropriate and complete.[7] Though this feedback is not as helpful to physicians who deal with such problems frequently, such a system can have a significant impact on those who deal with a given problem only occasionally.

Education

Another spinoff of the alert system was the improvement in patient care that resulted over a period of months of giving treatment protocols to physicians. This resulted in improved care in the control group over a period of time because of physician education and the approach to the study group and control group deviated less and less over time.[7]

In the critical care units, because of the prompt recovery and organization of patient data, more time is available for discussion of the data and focusing on concepts of patho-physiology, differential diagnosis, and therapy. The medical students, interns, residents and staff physicians constantly being exposed to such data now utilize it to help make decisions and manipulate therapy.

This allows for a high level of medical education by providing insight and understanding of physiologic changes which were previously only vague concepts extrapolated from the physiologic laboratory to patient care. The physician being trained today in a program where critical care medicine is a discipline have first-hand knowledge of these changes because of the opportunity to experience such changes on a minute by minute basis. The observation of these changes have been made possible by computers.

Conclusion

The computer is a valuable tool in critical care medicine today. It facilitates the gathering, processing and understanding of complicated physiologic data and the interaction of multiple organ patho-physiology while improving the efficacy of therapeutic interventions.

Because of computers and microprocessors, tasks which were previously too laborious to be practical are now routine bedside procedures. Although dedicated task oriented computers that perform cardiac outputs or dysrhythmia detection are ubiquitous in intensive care units, the use of the computer for interpretation and decision making are uncommon. This situation has occurred because of the complexity of the various problems and their interactions in the critically ill which requires a large data base before practical and logical decisions can be made.

Much of the data upon which the physician makes judgments is observational obtained from the history and physical examination. At the present time it is difficult to give the computer such data. Therefore, the decision making process must include the physician and nurse's judgments. Still, with proper programming, the computer can enhance the physician's ability to collect, assimilate and display complex data in a meaningful manner and direct their attention to problem areas.

It should always be remembered, however, that the computer is at the mercy of the data it receives. Improper analog signals or data entry must be closely guarded against and places new demands upon the personnel in the Intensive Care Unit. They must maintain clean analog signals and collect accurate data. This requires strict protocols for data collection and entry and a strong commitment to educational efforts so that the equipment and physical problems which arise in the gathering of good data are clearly understood, recognized, and corrected.

In some instances, the computer itself can be utilized to recognize poor wave forms, artifact and other problems which may cause errors. Built-in quality checks in the computer software prevent many data collection errors. Timely feedback of data by the computer and on line review of the data adds to the accuracy and quality of the data because past results are available and expected results are fresh in the physician's mind. Mechanical devices like the "Intraflo" which continuously flushes the arterial line can avoid the frequency of certain mechanical problems. Still the computers reliability is very dependent upon receiving accurate input of data and this is the most difficult problem to solve and requires obsessive adherence to correct protocols.

Physicians and nurses, because of their busy schedules, are usually unwilling to spend much time interfacing with the computer. Therefore, the acceptance by the health personnel will be poor unless this problem can be solved. Automating the input of data whenever possible, and organizing the input and output interface so that minimal time is required by the physician and nurse, will improve the acceptance and utilization of the computer. We have successfully utilized technicians for inputting data to help alleviate this problem.

Once the above problems have been solved, the computer becomes extremely valuable in critical care medicine and actually generates the majority of the patient's permanent chart.

The data stored in the computer can be utilized for research and audit purposes, thus, influencing the care, not only of the patients who are presently in the unit, but for future critically ill patients.

References

1. Hilberman, M.: The Evolution of Intensive Care Units. Critical Care Medicine. Vol. 3, No. 4, p. 159-164. 1975.

2. Gardner, R.M.; Scoville, D.P.; West, B.J.; et al: Integrated Computer Systems for Monitoring of the Critically Ill. Proc. First Annual Symposium on Computer Application in Medical Care. p. 301-307, Oct. 1977.

3. Pryor, T.A.; Morgan, J.D.; Clark, S.T.; et al: HELP - A Computer System for Medical Decision Making. IEEE Computer. 8:34-38, 1975.

4. Gardner, R.M.; Cannon, G.H.; Morris, A.H.; Olsen, K.R.; Price, W.G.: Computerized Blood Gas Interpretation and Reporting System. IEEE Computer. 8:19-25, 1975.

5. Hulse, R.K.; Clark, S.J.; Jackson, J.C.; et al: Computerized Medication Monitoring System. Am J. Pharm. 33:1061-1064, 1976.

6. Johnson, D.S.; Ranzenberger, J; Herbert, R.; et al: A Computerized Alert Program for Acutely Ill Patients. J. of Nursing Adm. Vol. 10, No. 6, p. 26, 1980.

7. Gardner, R.M.; Clemmer, T.P.; Larsen, K.G.; Johnson, D.S.: Computerized Alert System Used in Clinical Medicine. Proceedings of the 32nd Annual Conference of Engineering in Medicine and Biology. Oct. 1979.

8. Gardner, R.M.; Clemmer, T.P.: Computerized Protocols Applied to Emergency and Acute Care. Emergency Medical Services. Vol. 7, No. 6, p. 90, 1978.

9. Larsen, K.G.; Clemmer, T.P.; Nicholson, L.; et al: Computer Support in the Management of Parenteral Nutrition. (Abstract) JPEN 3:516, 1979.

Work supported in part by Grant HS02463 from the National Center for Health Service Research and Grant GM23095 from the Institute of General Medicine.