Computerized Data Management and Decision Making in Critical Care

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Care of the critically ill patient places unusual demands on the practicing physician. The critically ill are usually referred to intensive care units (ICUs) and are connected to sophisticated physiologic monitoring equipment. As a result of their illness or injury, these patients are subjected to a wide variety of laboratory tests. Their therapy is complex, its timing is critical, and careful documentation is essential. The large volume of resulting data must be stored, processed, and used for clinical decision making. The tremendous growth of medical information, the demand for cost-effective care, and the need to document the justification for clinical decisions by patients, utilization review committees, third-party payors, and health care policy makers have placed even more demands on physicians caring for the critically ill.

Concurrently, there has been a rapid development of computer technology. Critical care medicine and medical computing are both less than 25 years old. According to a recent article in Scientific American, if the aircraft industry had evolved as rapidly as the computer industry, a Boeing 767 would cost $500 today, would circle the globe in 20 minutes, and would do it on 5 gallons of fuel. The cost of computer logic is falling at the rate of 25 per cent per year and the cost of computer memory at the rate of 40 per cent per year. Computational speed has increased 200 times in 25 years, and energy consumption and computer size have decreased by 10,000 times.[26] It seems apparent, then, that as the complexity of critical care increases and the cost of computer hardware decreases, soon every critical care unit will have not one but many microcomputers.

The state of the art in critical care computing has advanced rapidly in the past decade. In the early phases of monitoring, computers were used to acquire physiologic data such as blood pressure and cardiac output. After this, programs to communicate data from distant laboratories were implemented. Reports were generated from the more integrated databases. Finally, closed-loop control and decision-making tools were added to assist the physician.[11, 21]

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Whereas at first there was a reluctance on the part of physicians and nursing staff to use computers in the care of their patients, there is now a "cry for help" from these same health care providers. This change in attitude has come as a result of several developments in computing technology, particularly the advent of the personal computer.

STATEMENT OF THE PROBLEM

Barnett's recent review[3] of the application of computers to ambulatory practice quotes Florence Nightingale's 1873 book entitled *Notes on a Hospital:*

> In attempting to arrive at the truth, I have applied everywhere for information, but in scarcely an instance have I been able to obtain hospital records fit for any purpose of comparison. If they could be obtained, they would enable us to decide many other questions besides the one alluded to. They would show the subscribers how their money was being spent, what good was really being done with it, or whether the money was not doing mischief rather than good.

It is ironic that her comments are relevant more than a century later. They are true for records of ambulatory patients[3] as well as for those of the critically ill. The medical record remains the principal instrument for ensuring continuity of patient care. There is a real need to integrate and organize patient's records to optimize medical data review and decision making.[3, 11, 28]

The traditional medical record has several limitations:[3, 28]

1. It is physically inaccesible. Two examples will illustrate. For an emergency admission, the patient's previous record, although very valuable, can seldom be recovered and delivered in time to be of benefit. The complex and usually voluminous records of the critically ill are often "thinned." The process of recovering the "thinned" portion is often too slow to be of much use.
2. Information is available at only one location—where the chart is physically located.
3. The chart is usually poorly organized.
4. Illegible handwriting may make information unavailable or laborious and time consuming to retrieve.
5. There is no recording standardization, so even when charts are retrieved for review, it is difficult to compare them.
6. Retrieval of data for research is cumbersome (manual chart review) because the records must be read by trained personnel.
7. Data recorded from electronic instruments must be handwritten or manually attached to the patient's chart.

HOW THE COMPUTER CAN AID IN RECORD KEEPING, DATA MANAGEMENT, AND DECISION MAKING FOR CRITICALLY ILL PATIENTS

Table 1 shows a six-step sequence indicating how computers can be used to assist in solving record-keeping, data management, and decision-making problems encountered in ICUs.

Table 1. *Uses of the Computer in Intensive Care*

1. Assist in data collection
2. Provide computational capability
3. Assist in data communication and integration of data
4. Record keeping
5. Report generation
   - Variable report format
   - Available at multiple sites
   - Data communications
   - Eliminate redundancy
   - More structured reports
   - More accurate reports
   - Current information
6. Assist in decision making

ASSISTANCE IN DATA COLLECTION

Digital computers are used almost exclusively in the newest bedside physiologic monitors. These microcomputer-based monitors help sort through the approximately 100,000 heartbeats that occur each day and identify those of interest (arrhythmias, asystole, and so on). The measurement of heart rate and arrhythmias and the ever-vigilant logging of these data have become hallmarks of intensive care monitoring. Indeed, the recent Concensus Conference on Critical Care Medicine acknowledged the importance of recognizing life-threatening arrhythmias.[8]

In addition to the bedside monitoring tasks we take somewhat for granted, there are many other medical devices whose operation depends on microcomputers. For example, most of the instruments in the clinical laboratory are automated with microcomputers. Blood gas machines are highly dependent on computers to give prompt and accurate results.

PROVISION OF COMPUTATIONAL CAPABILITY

Just as pocket calculators have become pervasive in our everyday life, so will computers. Programmable computers relieve us from menial tasks. In contrast to humans, computers perform calculations just as well at 3 A.M. as at 9 A.M. Indeed, the computer is the ultimate "slave" because it does exactly what it is told (programmed) to do, does it with great speed, makes virtually no mistakes, works 24 hours per day, and does not complain. Recently, there has been a widespread acceptance of small personal computers in critical care units to assist with the calculation and interpretation of hemodynamic monitoring, drug dosage, and blood gas data.[7, 9, 25] Examples of results of these programs are presented further on.

ASSISTANCE IN DATA COMMUNICATIONS AND INTEGRATION OF DATA

One of the most important tasks of physician and health care providers is to assimilate all data before making treatment decisions. Data on patients can be rapidly and accurately transmitted electronically from one computer system to another. Thus, data from the clinical laboratory can be received promptly by a critical care unit or surgical suite.[12]

The importance of an integrated record was recently emphasized by the results of a study conducted in our department.[5] We examined the data used for the physician's decision making during teaching rounds. We tabulated data used from our computerized shock-trauma unit into six categories: (1) bedside monitor, (2) laboratory, (3) drugs, input/output and intravenous, (4) blood gas laboratory, (5) observations, and (6) other. Figure 1 shows the findings of the study. We were surprised at the small percentage (13 per cent) of the data contributed by the bedside monitor. Equally surprising was the large fraction (42 per cent) that laboratory and blood gas data contributed to the decision-making process. It is clear from the information shown in Figure 1 that data from multiple sources must be combined to allow the physician to make effective treatment decisions. This study clearly showed the need for integrated record keeping. The computer is the ideal medium for such integration, since it can easily communicate with other computers and can archive data for quick review from multiple sites.[2, 6, 19, 20]

RECORD KEEPING

The computer is an ideal record keeper because it can store and quickly recover vast amounts of information. A successful database man-

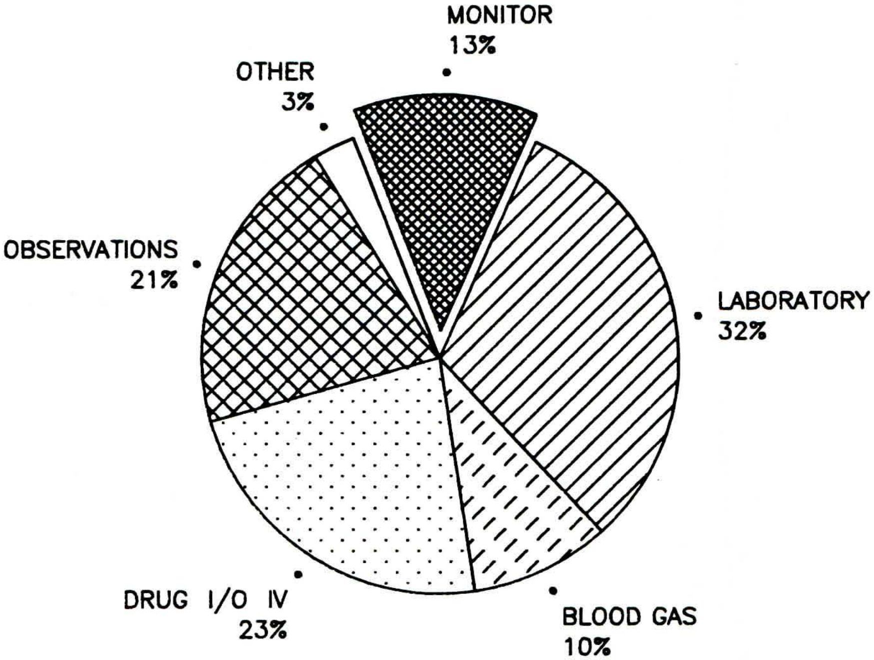

Figure 1. Pie chart shows data used for clinical decision making by physicians during teaching rounds in our shock-trauma intensive care unit.

agement system should be "user-friendly," that is, easy to use after a few minutes of instruction. The recently introduced Apple MacIntosh with its "mouse" and the Hewlett-Packard model 150 with a "touch screen" are examples of computer hardware that is becoming more user-friendly.

In the real-time monitoring environment of a critical care unit, the computer system must also have high availability (no failures or down-time). Fortunately for medical computing, there are several other commercial applications of computers that have a similar need for high availability—telephone switching networks, air traffic control systems, nuclear and conventional power plant monitors, aerospace telemetry, and on-board control systems. As a result, there are a growing number of fault-tolerant computer systems.[20] We use a fault-tolerant system manufactured by Tandem Computer as our central system.[11] The system provides an availability of greater than 99.5 per cent (down-time of less than 0.5 per cent, or about 7 minutes per day), which has proved adequate for our clinical needs.

REPORT GENERATION

The ability of the computer to gain access to the data in its database and generate a variety of reports is a principal advantage of medical computing. The advantages Barnett[3] mentions for the record keeping of ambulatory patients are even more impressive for that of critical care patients. These benefits are as follows.

Generation of Reports of Variable Formats

Flow charts, summary reports, unit reports, and similar reports must be readily available from patient data management systems. Figure 2 shows a specialized summary (rounds) report we are currently using. At any time of the day or night, a physician can get this report in less than 1 minute. To generate this report, the computer searches the patient database and presents the most recent data by organ system. The data are to be reviewed and used for decision making. Note that data from a wide variety of original sources are presented in a clear and legible manner. Cardiovascular data include hemodynamic monitoring information, laboratory data, and electrocardiogram (EKG) data, with computer-assisted interpretations. Respiratory data include blood gas data with computer-generated interpretations and corresponding ventilatory status. A wide variety of data from many different hospital locations are integrated to update the physician on the patient's laboratory, clinical, fluid balance, and medication status.

Data Availability at Multiple Sites

Once the patient's record is in electronic (computer) form, it is simultaneously available at multiple sites. Physicians can review those data from any terminal connected to the system. Thus a critical care staff physician can review the same data on a terminal in his or her office as those simultaneously reviewed by the attending physician, who may be at the patient's bedside or at home using a personal computer. Fully one third of the phy-

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                         L D S   H O S P I T A L   I C U   R O U N D S   R E P O R T
                                           DATA WITHIN LAST 24 HOURS

NAME:                                  NO.    65209     ROOM: E410                         DATE: SEP 01 06:05
 DR. REES.                    SEX: M    AGE: 42  HEIGHT: 178  WEIGHT: 75.80  BSA: 1.94   BEE: 1709   MOF:   7
=================================================================================================================
CARDIOVASCULAR: 1                                                              EXAM: __________________________
TIME            CO    CI   HR  SV  SI   VP  MSP  MP SVR LWI PW  PA  PVR   RWI      __________________________
SEP 01 05:36  8.20  4.22  82 100  51  7.0M  88  76  8  53  12  18  0.7   7.6
        SEP 01 05:35  DOPAMINE (INTROPIN)  3.00 MCG/KG/MIN
        LV PARAMETERS ARE WITHIN NORMAL LIMITS
                  SP    DP    MP   HR  : LACT          CPK          CPK-MB       LDH-1        LDH-2
  LAST VALUES    101    62    76   78  :
  MAXIMUM        210   110    76  164  : 4.1 (12:30)     (    )       (    )       (    )       (    )
  MINIMUM         72    47    72   40  :
  HEART RATE = 100   QRS =  60   PR = 160   QRS AXIS =   20
        **** PHYSICIAN OVERREAD ****
  NORMAL ECG
     SINUS TACHYCARDIA
  NO SIGNIFICANT ECG CHANGES SINCE 08/15/1984.20:00
=================================================================================================================
RESPIRATORY: 3
SEP 01 84     pH    PCO2    HC03    BE   HB   C0/MT   PO2   S02   O2CT   %O2  AVO2  VO2   C.O.  A-a  Qs/Qt  PK/ PL/PP  MR/SR
01 05:18 V   7.45   37.1    25.6   2.5  10.0   1/ 1    33    71   10.0    40                                /   / 5  16/
01 05:17 A   7.50   31.5    24.5   2.6   9.6   2/ 1    76    95   13.0    40  3.40              128   17    /   / 5  16/
        SAMPLE # 49, TEMP 36.1, BREATHING STATUS : ASSIST/CONTROL
        MILD ACID-BASE DISORDER
        SEVERELY REDUCED O2 CONTENT (13.0) DUE TO ANEMIA (LOW HB)
31 20:46 V   7.43   32.2    21.2  -1.6  12.1   1/ 1    43    80   13.6    40                               48/ 40/ 5  20/
31 20:45 A   7.45   34.2    23.6   0.9  11.9   1/ 1    89    98   16.4    40  3.06              111   12   48/ 40/ 5  20/
=================================================================================================================
NEURO AND PSYCH: 0
   GLASGOW 15 (00:15) VERBAL ________   EYELIDS ________   MOTOR __________   PUPILS ________   SENSORY ______
   DTR ___________   BABIN. ________   ICP ____________   PSYCH __________
=================================================================================================================
COAGULATION: 0
   PT:          (     ) PTT:        (     ) PLATELETS: 419 (05:10)   FIBRINOGEN:    (     ) EXAM: __________________
   FSP-CON:     (     ) FSP-PT:     (     ) 3P:         (     )                                  __________________
=================================================================================================================
RENAL, FLUIDS, LYTES: 0
  IN   8720 CRYST   6360  COLLOID        BLOOD      NG/PO   2310 : NA   142 (05:10) K     3.3 (05:10)  CL  112   (05:10)
  OUT  2945 URINE   1841  NGOUT          DRAINS  265 OTHER   839 : CO2   23 (05:10) BUN  21   (05:10)  CRE   1.0 (05:10)
  NET  5775 WT    76.40   WT-CHG   0.00  S.G.   1.015            : AGAP  10.3       UOSM               UNA      CRCL
=================================================================================================================
METABOLIC --- NUTRITION: 0
  KCAL      2501  GLU  226   (05:10)   ALB    1.5 (05:10)  :  CA    6.5 (05:10)    FE        (     )  TIBC       (     )
  KCAL/N2   158   UUN        (     )   N-BAL               :  PO4   2.7 (05:10)    MG        (     )  CHOL    106 (05:10)
=================================================================================================================
GI, LIVER, AND PANCREAS: 0                                                                         EXAM:
  HCT      31.0 (05:10)  TOTAL BILI   1.6 (05:10)  SGOT   64 (05:10)  ALKPO4  363 (05:10)  GGT      209 (05:10) __________
  GUAIAC      (     )  DIRECT BILI  1.2 (05:10)  SGPT   52 (05:10)  LDH     344 (05:10)  AMYLASE    (     ) __________
=================================================================================================================
INFECTION: 3
  WBC 22.6 (05:10) TEMP  39.3 (08:00) DIFF  34B, 57P,  4L,  5M,   E (05:10) GRAM STAIN: SPUTUM __________ OTHER ________
CULTURES:
  BLOOD ______  SPUTUM _______   URINE ________  CSF _______   CATH _______   WOUND ________   OTHER _____________
=================================================================================================================


SKIN AND EXTREMITIES:
  PULSES _______   RASH _______   DECUBITI ___________
=================================================================================================================
TUBES:
  VEN _______   ART _______   SG _______   NG _______   FOLEY _______   ET _______   TRACH _______ DRAIN_____

  CHEST ____________ RECTAL _____  JEJUNAL _______   DIALYSIS _______   OTHER _________________________________
=================================================================================================================
MEDICATIONS:

MORPHINE. INJ                       MGM   IV        8.0   DOPAMINE. INJ                           MGM   IV        525
ACETAMINOPHEN, ELIXIR               MGM   NG        650   METAPROTERENOL (ALUPENT), SOLUTION      MGM   INHAL    75.0
METRONIDAZOLE.INJ                   MGM   IV       2000   HEPARIN, INJ                            UNITS IV          0
NAFCILLIN, INJ                      MGM   IV      10000   OSMOLITE, LIQUID                        ML    NG D     2910
CEFOPERAZONE (CEFOBID), INJ         MGM   IV       4000
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Figure 2. A rounds report generated by the computer is divided into sections by organ system or physiology. A multi-organ failure score (MOF: 7) indicates the severity of illness.

sicians on our staff have personal computers. As a result, the level of computer literacy and, consequently, of the physicians' interest in "phone-in" access to patients' records on our computer system is increasing.

Data Communications

Data communication is essential because a patient's care is seldom limited to the primary care physician. Physician specialists, in addition to respiratory therapists, dieticians, nurses, and social workers, have become an integral part of the health care team, especially for trauma patients.

Elimination of Redundant Entry

As Florence Nightingale pointed out, seldom are data on patients used for just a single purpose. For example, administration of a medication must be documented to fulfill the medico-legal requirements of the hospital record, but more importantly it must be charted because it has an effect on the patient's medical recovery. Those concerned with management of costs and efficiency are also interested in what medications were given. To accomplish all of these tasks on paper requires either the redundant entry of data by a nurse or ward secretary or the creation of multiple copies of handwritten records, which are sent through the hospital's "communication system" and eventually archived (usually in a computer). By having the computer capture the record in electronic form and transmit the data to appropriate patient files, redundant and inefficient data entry can be eliminated. Thus, if a nurse charts a medication at the bedside terminal, the data are captured promptly and accurately for all clinical purposes as well as administrative and nonclinical management functions.

The implementation of computerized respiratory therapy charting at our hospital has increased therapist productivity by 18 per cent. This increase came even in the face of having therapists take the time to enter their own procedures into computer terminals. When the therapists chart their clinical procedures by computer, the computer automatically acquires management information, bills the patient, and fulfills medico-legal documentation requirements. By reducing the manual paperwork, a higher percentage of the therapist's time was spent on patient care.

Increased Structure in Reports

As can be seen from Figure 2, computer-generated reports are highly structured. Because their format is standardized and predictable, structured reports are efficient for reviewing patients' data. Like a familiar newspaper, they are easy to scan. To illustrate the concept, I like to compare reviewing a patient's chart with scanning a newspaper. As long as I am reading a Salt Lake City paper, I know where to look to find the national, local, and sports news as well as the cartoons. However, when I am in San Francisco and pick up a newspaper, I have to struggle for a few days to find the items I am interested in, but eventually I adapt. The same follows with computerized patient charting. Another newspaper analogy also applies to computerized patients' records. This is particularly useful, since we tend to put far more information on a computer terminal or on a printed report than most people will review. We do this for much the same reason a newspaper does. The information is there if you want it and is acessible in "small print" promptly, at relatively low cost.

Greater Accuracy of Computer-Generated Reports

Computer data are generally entered by means of a conversational, or interactive, mode. The computer terminal prompts the user to enter data in a prescribed format. Thus, as data are entered, a predefined set of rules is applied to validate the data and prevent errors. If errors occur, such as transposed digits (for example, pH 4.7 instead of 7.4), immediate feedback is given to the user, and the data entry error can be quickly corrected. The increased legibility of computer records compared with handwritten records is not questioned.

Finally, there is an attribute of computer reporting that is especially applicable to the critical care situation.

The Computer Record As Source of the Most Current Information

The data flow into the critically ill patient's record takes place almost continuously. The task of updating a single conventional paper record is overwhelming, even with electronic communications and printers. Keeping track of and filing each new piece of paper in the patient's chart become an impossible burden. Thus, in our system, a physician or nurse wanting the latest information about a patient reviews the data from a computer terminal. Until recently, when we installed computer terminals at each patient's bedside, access to terminals was a problem. Now that terminals are located at the bedside, access is no longer a problem. In fact, having the terminals at the bedside allows us to make the data entry and review "patient specific." For example, since the computer "knows" what drugs are prescribed for each patient, pressing a single key on the terminal will cause it to display only those drugs. Then a simple menu selection permits the drug, its dose, and route of administration to be "charted" promptly and easily while eliminating the need to search through a formulary of over 2000 drugs. Bedside terminals with memory capability (similar to personal computers) can store current information about a patient in its local memory. Since patient-specific drug prescriptions and patient care plans are stored in this manner, nurses can quickly and efficiently chart electronically.

ASSISTANCE IN DECISION MAKING

The hallmark of a good physician is the ability to make sound clinical judgments. As Bergman and Pantell[4] point out, this process has traditionally been considered artful and intuitive, rather than scientific. However, in recent years the use of computers to assist in medical decision making has gained wider acceptance.[27] Indeed, the discussion of "artificial intelligence" is commonplace in medicine today.

McDonald[15, 16] has shown that a computer reminder system applied in an ambulatory clinic reduced oversights by physicians. He attributed physicians' errors to "channel noise" or information overload rather than to practitioner ignorance.

The opportunity to use the computer to aid in the complex task of medical decision making in critical care has just begun.[10, 12] Figure 3 is a block diagram of the HELP (Health Evaluation through Logical Processing) computer system operational at LDS Hospital in Salt Lake City, Utah. The system collects and integrates data from a wide variety of data sources. Data are automatically stored and processed by the HELP system to determine if the new information by itself or in combination with other data in the patient's record (such as another laboratory value or a previous computer-generated decision) can be used to make a medical decision. The medical decisions are based on criteria stored on magnetic disk. The decision criteria were established by knowledge gained from physicians, nurses, and literature and from analysis of our own computer database. Decisions made by the HELP system are of the following four types: (1) interpretations—for example, blood gas and hemodynamic interpretations (Fig. 2); (2) diagnoses; (3) alerts, that is, notification of life-threatening events such as critically low PO_2; and (4) treatment suggestions.

The application of protocols to treatment of patients was introduced several years ago in the ambulatory setting.[15] In recent years protocols have been applied to the care of hospitalized patients.[23] These protocols have been used to prevent adverse drug reactions[12] and to suggest fluid management,[22] cardiac management of surgical patients,[18] and therapy according to hemodynamic monitoring information.[14]

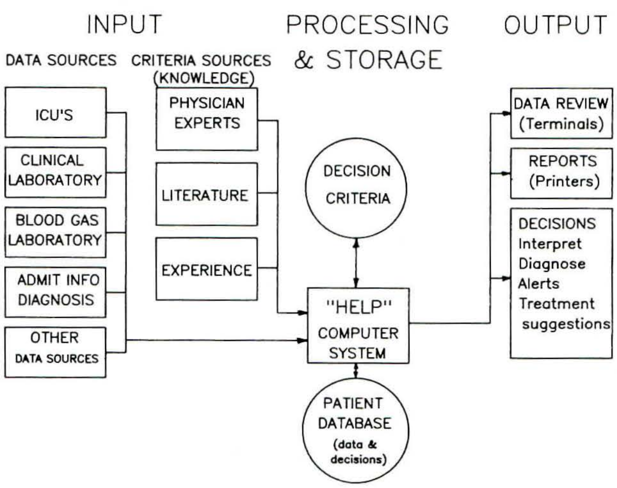

Figure 3. Patient data flows into the "HELP" decision-making computer system from a variety of sources. The decision-making criteria (knowledge base) are then automatically applied to the data, giving an output of computer-aided decisions. A variety of output is generated, including information for review on computer terminals, printed reports, and medical decisions.

IMPLEMENTATION ISSUES

A growing body of computer software tools and strategies is being developed for use with decision-making or "intelligent" systems.[13] Shortliffe[24] lists some excellent criteria for ascertaining which problems are appropriate for computerized medical decision making. These include (1) demonstrated need for computer assistance (2) recognized need for assistance by physicians, (3) core of formalized, readily available knowledge, (4) straightforward mechanism for introducing the computer-based tool into daily routine, (5) maintenance of the physician's role as ultimate decision maker, (6) identification of highly motivated collaborators, and (7) avoidance of major theoretic barriers for the initial prototype system.

These criteria are idealized and cannot all be achieved. On the basis of Shortliffe's experience at Stanford University and our experience at LDS Hospital, however, these criteria are excellent guidelines.

EVALUATION OF THE COMPUTER SYSTEM

As with computerized record systems for ambulatory patients, evaluation of cost and benefit of critical care computing is crucial. Unfortunately, there is no well-formulated technique for studying either manual or computerized medical records systems, especially those with medical decision-making capabilities. Shortliffe[24] mentions six guidelines for assessing the effectiveness of such systems. A system must (1) demonstrate that it is needed, (2) demonstrate that it performs at the level of the medical expert, (3) show that it is usable, (4) demonstrate its impact on management of patients, (5) show its impact on the well-being of patients, and (6) demonstrate its cost-effectiveness.

The computer will not solve all the problems of a modern ICU.[17] However, we need to harness its power to help us cope with the mass of detail required to manage the care of critically ill patients.[1] We must use the computer as a tool to assist us in integrating, evaluating, and simplifying data management, while at the same time using our human skills to make patient care more personal.

SUMMARY

Computers are being increasingly employed in all levels of society. Computer applications in clinical medicine have lagged behind administrative and billing functions. However, computers are now finding an increasingly useful place in critical care medicine. The complexity of the patients' conditions and the large amount of data generated by critically ill patients provide an ideal area of application for computers. The computer can assist in collecting data, calculating derived parameters, speeding data communications, record keeping, report generation, and decision making. This article has discussed and illustrated how the computer can aid in the care of the critically ill.

REFERENCES

1. Arnell, W. J., and Schultz, D. G.: Computers in anesthesiology—a look ahead. Med. Instrum., *17*:393, 1983.
2. Asbury, A. J., Lush, K., and Franks, C. I.: Computers in high dependency units—ABC of computing. Br. Med. J., *287*:472, 1983.
3. Barnett, G. O.: The application of computer-based medical-record systems in ambulatory practice. N. Engl. J. Med., *310*:1643, 1984.
4. Bergman, D. A., and Pantell, R. H.: The art and science of medical decision making. J. Pediatr., *104*:649, 1984.
5. Bradshaw, K. E., Gardner, R. M., Clemmer, T. P., et al.: Physician decision-making—evaluation of data used in a computerized ICU. Int. J. Clin. Monitor, *1*:81, 1984.
6. Brimm, J. E., and Peters, R. M.: Applications of computers and other new techniques. *In* Berk, J. L., and Sampliner, J. E. (eds.): Handbook of Critical Care. Edition 2. Boston, Little, Brown, 1982, pp. 545–555.
7. Cottrell, J. J., Pennock, B. E., and Grenvik, A.: Critical care computing. J.A.M.A., *248*:2289, 1982.
8. Critical Care—Consensus Conference. J.A.M.A., *250*:798, 1983.
9. Gardner, R. M.: Information management—hemodynamic monitoring. Semin. Anesth., *2*:287, 1983.
10. Gardner, R. M., and Clemmer, T. P.: Computerized protocols applied to acute care. Emerg. Med. Serv., *7*:90, 1978.
11. Gardner, R. M., West, B. J., Pryor, T.A., et al.: Computer-based ICU data acquisition as an aid to clinical decision-making. Crit. Care Med., *10*:823, 1982.
12. Hulse, R. K., Clark, S. J., Jackson, J. C., et al.: Computerized medication monitoring system. Am. J. Hosp. Pharm., *33*:1061, 1976.
13. Lenat, D. B.: Computer software for intelligent systems. Sci. Am., *251*:204, 1984.
14. Marino, P. L., and Krasner, J.: An interpretive computer program for analyzing hemodynamic problems in the ICU. Crit. Care Med., *12*:601, 1984.
15. McDonald, C. J.: Protocol-based computer reminders, the quality of care and the non-perfectability of man. N. Engl. J. Med., *295*:1351, 1976.
16. McDonald, C. J., Hui, S. L., Smith, D. M., et al.: Reminders to physicians from an introspective computer record—a two-year randomized trial. Ann. Intern. Med., *100*:130, 1984.
17. Osborn, J. J.: Computers in critical care medicine: Promises and pitfalls. Crit. Care Med., *10*:807, 1982.
18. Rao, T. L. K.: Cardiac monitoring for the noncardiac surgical patient. Semin. Anesth., *2*:241, 1983.
19. Saunders, R. J., and Jewett, W. R.: System integration—the need in future anesthesia delivery systems. Med. Instrum., *17*:389, 1983.
20. Serlin, O.: Fault-tolerant systems in commercial applications. I.E.E.E. Computer, *17*:19, 1984.
21. Sheppard, L. C.: Computer control of the infusion of vasoactive drugs. Ann. Biomed. Eng., *8*:431, 1980.
22. Shoemaker, W. C.: Fluid management. Semin. Anesth., *2*:251, 1983.
23. Shoemaker, W. C.: Protocol medicine (editorial). Crit. Care Med., *2*:279, 1974.
24. Shortliffe, E. H.: Computer-based clinical decision aids: Some practical considerations. First American Medical Informatics Association Conference Proceedings, San Francisco, May 2–5, 1982, pp. 295–298.
25. Silage, D. A., and Maxwell, C.: An acid-base map/arterial blood-gas interpretation program for hand-held computers. Resp. Care, *29*:833, 1984.
26. Toong, H. D., and Gupta, A.: Personal computers. Sci. Am., *247*:87, 1982.
27. Warner, H. R.: Computer-Assisted Medical Decision-Making. New York, Academic Press, 1979.
28. Whiting-O'Keffe, Q. E., Simborg, D. W., and Epstein, W. V.: A controlled experiment to evaluate the use of time-oriented summary medical record. Med. Care, *8*:842, 1980.

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