49. Vogel RA, Bates ER, O'Neill WW, et al: Coronary flow reserve measured during cardiac catheterization. Arch Intern Med 1984; 144:1773
50. O'Neill WW, Walton JA, Bates ER, et al: Criteria for successful coronary angioplasty as assessed by alterations in coronary vasodilatory reserve. J Am Coll Cardiol 1984; 3:1382
51. Whiting JS, Drury JK, Pfaff JM, et al: Digital angiographic measurement of radiographic contrast material kinetics for estimation of myocardial perfusion. Circulation 1986; 73:789
52. Buonocore E, Pavlicek W, Modic MT, et al: Anatomic and functional imaging of congenital heart disease with digital subtraction angiography. Radiology 1983; 147:647
53. Borgren HG, Bursch JH: Digital angiography in the diagnosis of congenital heart disease. Cardiovasc Interven Radiol 1984; 7:180

Chapter 26

COMPUTERS IN THE INTENSIVE CARE UNIT: MATCH OR MISMATCH?

REED M. GARDNER, PhD
DEAN F. SITTIG, MS
MARGE C. BUDD, RN, MS

INTRODUCTION

Care of the critically ill patient places exceptional demands on physicians and nurses. As a result of their medical problems, patients in ICUs are monitored with complex bedside monitors and are subjected to a wide variety of laboratory tests. Therapy is complex and the timing of their treatment is critical, while careful documentation of the care given is essential. A large volume of 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 and justify why clinical decisions were made has placed a large burden on the medical care team. There is an increased demand for accountability by patients, utilization review committees, third-party payers, and health care policy makers, who insist that complete and accurate records be kept by physicians and nurses caring for the critically ill (1,2).

During the past two decades, there has been a rapid development in computer technology, with a remarkable reduction in cost and size of computers and substantial improvements in speed and power (3). With the decreasing cost of computing, it is very attractive to look at using computers to help solve the problem of data collection, storage, and decision-support needs in the ICU. It seems apparent that as the complexity of critical care increases and the cost of computer hardware decreases, every ICU will soon use not one but several microcomputers.

ICUs have become an integral part of most hospitals. Their concentration on the treatment of the critically ill has made the acquisition and proper use of data even more important. Why aren't computers widely used in critical care? What advantages do they have? How can computers be used in intensive care? Are they justified? These questions are frequently asked by both manufacturers of intensive care monitoring equipment and by physicians and nurses managing ICUs. This chapter will attempt to provide some answers and establish whether computers are a match or mismatch for intensive care.

THE NEED FOR ICU COMPUTER DATA MANAGEMENT

Care of the critically ill patient requires extraordinary skill and necessitates prompt, accurate treatment decisions. Physicians and nurses collect a large amount of data through frequent observations, testing, and data recorded by continuous monitoring equipment. Physicians generally prescribe complicated therapy for such patients. As a result, enormous amounts of clinical data accumulate. Physicians can miss important events and trends unless the accumulated data are presented in a compact, well-organized form. In addition, the problems of managing these patients have been made even more challenging by economic pressures to reduce the cost of diagnostic and therapeutic interventions.

Continuity of care is particularly important for critically ill patients who are generally served by a team of physicians, nurses, and therapists and whose data are often transferred from one individual to another. For example, the laboratory technician calls a ward clerk, who reports the data to a nurse, who in turn passes them on to the physician, who then makes a decision. Each step in this transmission process is subject to delay and error.

Computer Charting

Barnett (4) recently reviewed the application of computers to ambulatory practice and quoted 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 surprising that Florence Nightingale's comments are still applicable more than a century later. They are true for records of ambulatory patients (4) as well as for those of the critically ill.

The medical record remains the principal instrument for ensuring the continuity of patient care. There is a real need to integrate and organize patients' records to optimize medical data review and decision-making (5–9). As the central focus of the care process, the traditional handwritten medical record has several limitations. First, it might be physically unavailable, since it can only be used by one person at one location at a time. Second, it is often poorly organized, available only in the order it was recorded, and many times illegible. Thus, information retrieval may be impossible, slow, and prone to error (2). Third, retrieval of data for research is time-consuming and cumbersome because it must be done manually. Fourth, instruments that present data in electronic form require their data to be taken by a human and written into the chart. Fries (5) has shown that in complicated cases, the conventional record is less helpful than a structured flow chart. Whiting-O'Keefe et al. (7,8) have also shown that structured records are easier and quicker to review and improve information flow.

These criticisms are especially germane to the critical care medical records because of the large amount of data collected and the time pressure for treatment decisions. The importance of having a unified medical record was recently demonstrated by a study conducted at LDS Hospital (9). In this study, detailed records were kept of the data used by physicians to make treatment decisions during teaching rounds in a shock-trauma ICU (Fig. 26–1). It was a surprise to find that laboratory data were the most frequently used (42%, laboratory 33% and blood gas 9%), since physiological bedside monitors have become synonymous with the modern ICU. Clinicians'

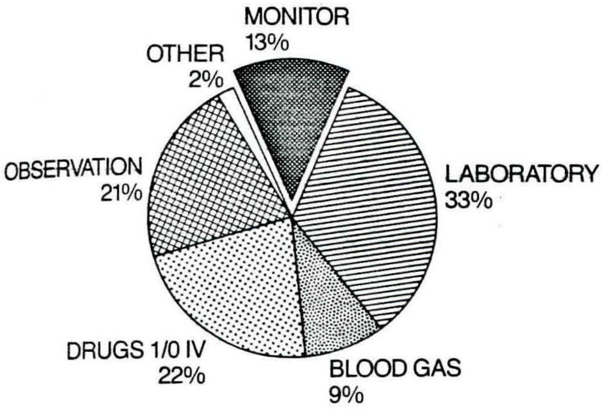


Figure 26–1. Pie chart showing data used for clinical decision-making by physicians during teaching rounds in a shock-trauma ICU. (From Bradshaw et al: Physician decision-making—Evaluation of data used in a computerized ICU. Intl J Clin Monitoring Comp 1984; 1:81.)

observations (21%) and drug and fluid balance data were a close second (22%), while the bedside physiological monitor accounted for only 13% of the data used in making therapeutic decisions. These findings provide evidence that data from several sources, not just from the traditional physiological bedside monitoring devices, must be communicated and integrated into a unified medical record to permit effective decision-making and treatment in the ICU.

Computer charting in the ICU must support multiple types of data collection in order to be effective. As can be seen in Figure 26–1, a large portion of the data needed to make decisions are from manual tasks such as administering a medication or auscultating breath or heart sounds. Thus, for computer charting systems to be successful they must be able to collect a wide variety of data from bedside monitors and ancillary departments such as the clinical laboratory, as well as from nurses and physicians at the bedside. Unfortunately, in the past most of the attempts at computer charting have dealt only with a limited set of the data, usually the data from the bedside monitor.

Figure 26–2 illustrates the complexity of ICU charting. The patient record (chart) must document the action taken by the medical staff, filling both medical and legal requirements (#1 and #2 in Fig. 26–2). In addition, much of the data that are logged on the chart are used for management (#3, Fig. 26–2) and billing (#4, Fig. 26–2) purposes. Many computer systems have ignored these requirements and unwittingly force the clinical staff to double chart. Efficient management in hospitals is a must, especially with the recent implementation of prospective payment strategies used in the United States (10). Hospitals now have strong incentives to know the cost of procedures and to control these costs. As a result, know-

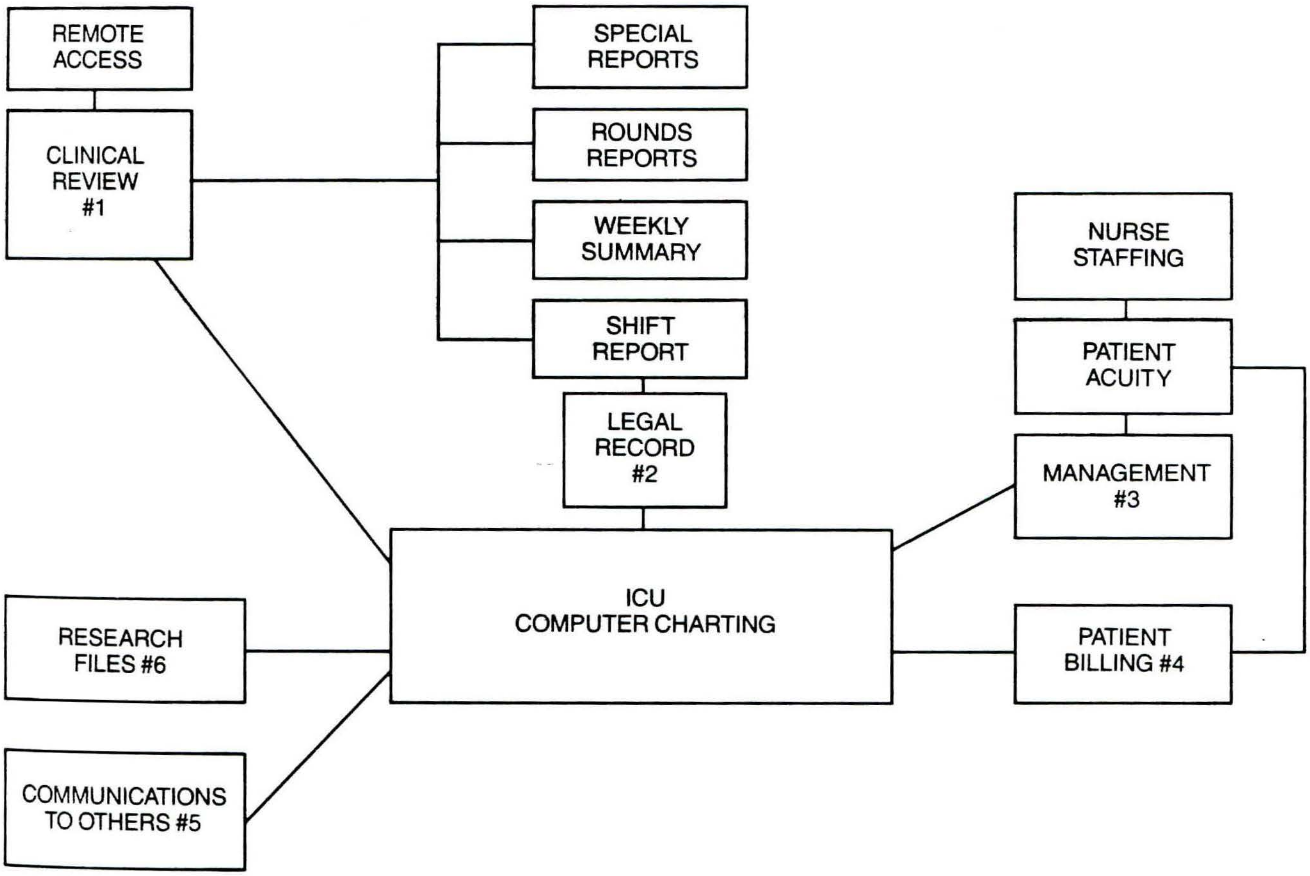


Figure 26–2. Block diagram showing the six major areas where computerized ICU charting interacts with nurses and physicians to make patient care more functional and efficient. See the text for an explanation of each function.

```
      ALVIN                    #   2420    E603

 AGE:  39   WT:  76.20 KG   HT: 163 CM   BSA  1.82 SQM   DR: KNIBBE, W. PATRICK                SEQUENCE #    42
             P HR TEMP
            SD  * O              MAR 22 87 18:01 - MAR 23 87 06:00
                      18  19  20  21  22  23   0   1   2   3   4   5   6
              --------I+---+---+---+---+---+---+---+---+---+---+---+---+
                235 41I
                      I
                220 40I
                      I
                205 39I
                      I   S
                190 38I  S
                      I        OS  S   O  S    O       O               O
                175 37I          SS S  S       S S
                      I    S   S
                160 36I       S      SS  S      S     S
                      I S   SS                         S
                145 35I                           S
                      I                      S                 S       S
                130 34I                    S  S  * S S  SSS
                      I---*---------**.*.***S--**--**----*------S---SSS-
                115   I  * *     ***  *     ***   * S*  * *S*** *SSS* **
                      I * D ** **                     **     S *     *
                100   I       *                             S S
                      I  D
                 85   I    D  DD  DDD  D D
                      I-B---BB--BB---BB---B----BBB----BB----------------
                 70   I                      D                         D
                      I                    DD D   DDDD  DDD    D DDDDDD
                 55   I                                    DDDD D
                      I
                 40   I
                      I
                 25   I
                      I
                 10   I
                      18  19  20  21  22  23   0   1   2   3   4   5   6
              --------I+---+---+---+---+---+---+---+---+---+---+---+---+
WEIGHT (KG)        76.90                               76.20
RESP RATE                     17      14      15      16      14      12
URINE SP G                                                         1.031
URINE GLUCOSE                                                        NEG
BLOOD GLU MG/DL                      124                     115
URINE PH                                                             6.5
URINE BLOOD                                                           3+
STOOL GUAIAC                     POS
UROBILINOGEN                                                           0
URINE PROTEIN                                                         1+
BILIRUBIN                                                             0+
KETONES                                                               0+
TUBE/DRAIN PH                4.0     4.0     7.0     7.0         4.0
OXIMETRY - STO2 (E)           95      97      91      94      91      96
FOLEY CATH URINE               5       0       0       0       0       5
```

```
    YESTERDAY'S WEIGHT:  76.90
    TODAY'S WEIGHT:      76.20
*                                 *
********** 06:00 TO 06:00 *********
*                                 *
   MAXIMUM TEMP: 37.5

  INPUT
     IV:         415
     BLOOD:      750
     COLLOID:
     TOTAL:     2580    NET:   815

  OUTPUT
     URINE:       30
     DRAIN:      702
     TOTAL:     1765
*                                 *
*********** LAB RESULTS ***********
*                                 *
  WBC     15.8     MAR 23 87 05:20
  HCT     34.8     MAR 23 87 05:20
  HGB     12.4     MAR 23 87 05:20

  NA     140       MAR 23 87 05:20
  K        5.0     MAR 23 87 05:20
  CL      97       MAR 23 87 05:20
  CO2     24       MAR 23 87 05:20
  BUN    101       MAR 23 87 05:20
  GLUC   139       MAR 23 87 05:20
  CREAT    4.2     MAR 23 87 05:20
```

```
                                                                               MAR 22 87 18:01 - MAR 23 87 06:00
                                                                          18  19  20  21  22  23   0   1   2   3   4   5   6
                                                             -------------I+---+---+---+---+---+---+---+---+---+---+---+---+
MORPHINE, INJ                                                  4.0 MGM   IV        1 1
CEFAZOLIN (KEFZOL/ANCEF), INJ                                 1000 MGM   IV                        1
CLOTRIMAZOLE 1% (LOTRIMIN), CREAM                                1 APPLICTOPIC             1                           1
METAPROTERENOL (ALUPENT), SOLUTION                            10.0 MGM   INHAL           1                               1
ALTERNAGEL, LIQUID                                              30 ML    NG                1                             1
RANITIDINE HCL (ZANTAC), INJ                                    50 MGM   IV                          1
METHYLPREDNISOLONE (A-METHPRED), INJ                          30.0 MGM   IV                                  1
HYDROCORTISONE 2.5%, CREAM                                       1 APPLICTOPIC             1                           1
NORMAL SALINE, INJ                                               2 ML    INHAL           1                               1
AMIN-AID FULL STRENGTH, LIQUID                                 200 ML    NG D  **************
D5W, INJ                                                       175 ML    IV    *************************************************
AMIN-AID FULL STRENGTH, LIQUID                                 360 ML    NG D               ***************************
MORPHINE, INJ                                                 30.5 MGM   IV                  ***********************************
         INFUSION RATE                                       1.000 MGM/HR                    33223333333344433333333333333333333
  NORMAL SALINE, INJ                                            61 ML
AMIN-AID FULL STRENGTH, LIQUID                                 145 ML    NG D                                         **********
                                                                                                                        #137 - 1
```

Figure 26–3. Shift report for 12-hour ICU nursing shift.

```
                                                                  18  19  20  21  22  23   0   1   2   3   4   5   6
                                                       -------------I+---+---+---+---+---+---+---+---+---+---+---+---+
MAR 22 87 18:01 TO MAR 23 87 06:00   ARMBRUSTER, KAREN J, RN        *************************************************

INTAKE (ML):  NON-BLOOD IV         236   OUTPUT (ML):  INSENSIBLE LOSS    509
              ENTERAL FEEDING      705                 FOLEY CATH URINE    10
              NG DRUG               60                 RESIDUAL             2
              OTHER DRUG             4                 NG TUBE DRG.       500
                TOTAL             1005                   TOTAL           1021     NET BALANCE        -16


MAR 23 87    pH    PCO2    HCO3     BE    HB   CO/MT   PO2   SO2   O2CT  %O2  AVO2  VO2  C.O.  A-a  Qs/Qt  PK/ PL/PP  MR/SR
             --    ----                                ---
NORMAL HI   7.45   40.3    25.8    2.5  17.7   2/ 1                            5.5  300  7.30   21    5
NORMAL LOW  7.35   26.9    15.6   -2.5  13.7   0/ 1     65    91   18.5        3.0  200  2.90         0

23 05:25 A  7.39   39.1    23.4    -.8  11.9   3/ 2     74    92   15.4   35                    88             /   / 5  12/
            SAMPLE # 30, TEMP 37.4, BREATHING STATUS : ASSIST/CONTROL
            NORMAL ARTERIAL ACID-BASE CHEMISTRY
            MODERATELY REDUCED O2 CONTENT


  , ALVIN                        #   2420    E603

If data was not entered by nurse, report must be signed.    COMPUTER TECH ------------------------------------
   TIME OUT: MAR 23 87 16:45                     PROCESS TIME: 00:14                              SEQUENCE #    42

(END)                                                                                               #137  -  2
```

Figure 26–3 *Continued*

ing the patient's acuity (how sick the patient is) is a necessity, not a luxury, and enables one to project nursing staff needs as well as to account for the care of a patient by acuity rather than just a fixed room charge. Communication (#5, Fig. 26–2) to other departments within the hospital is mandatory. Access to clinical and administrative information is a great convenience to physicians from their offices or homes. A computerized record allows this type of communication. Since the computerized ICU record is stored in the system, it is readily available for research purposes (#6, Fig. 26–2). For anyone who has tried to retrieve data from manual patient charts for research purposes, the value of this capability will be apparent.

Examples of Computerized Charting

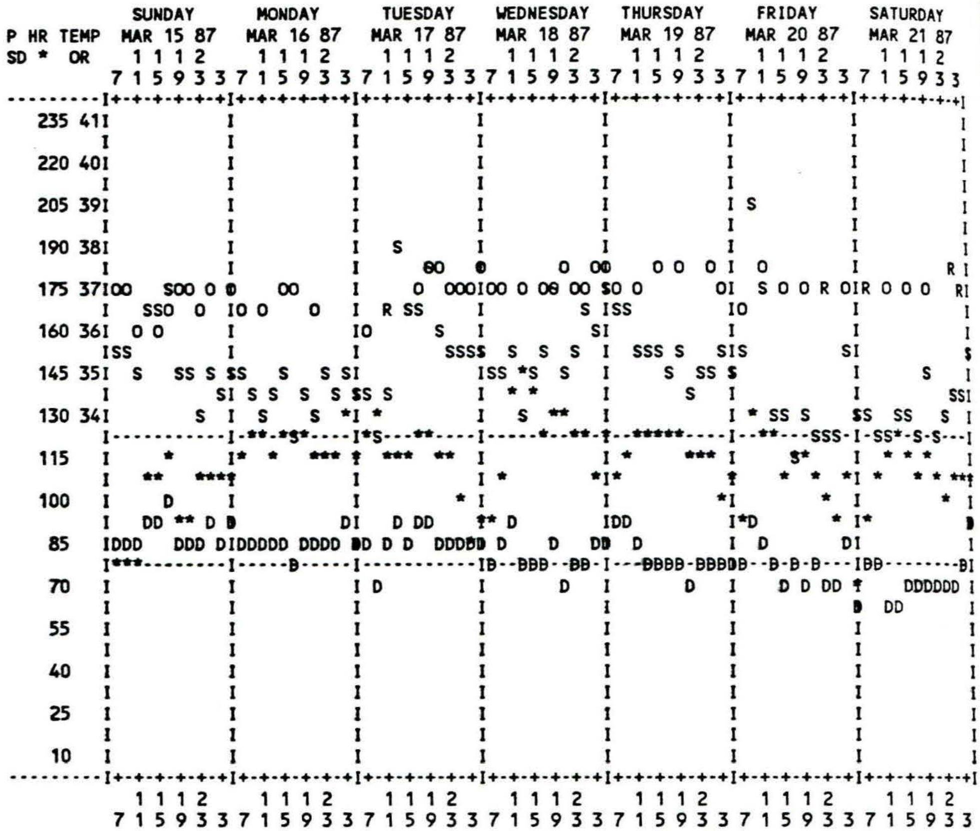
To meet the clinical management needs required by critically ill patients, as well as for providing an adequate legal record, most computerized patient data management systems generate a variety of reports. Figure 26–3 shows a shift report for a patient in our hospital. This 12-hour report documents the physiological data and summarizes the laboratory data in its upper section. Each drug given and the IV fluids administered are presented in the lower section. The nurses who care for the patient are listed, along with an initial indicating that the nurses have verified the data. Fluid balance data are derived from the IV data and fluid output data that are entered by the nurse. A summary of fluid balance information is presented. For the patient who is in the ICU for several days, a broader view of the course of the recovery process is essential. Thus, a 7-day report is generated by the computer, which summarizes the data for each 24-hour period, thus allowing the health care team to better care for and follow the medical course of the patient (Fig. 26–4). Since the data are already stored in the computer, data must only be abstracted and formatted to give the 7-day summary report. Figure 26–5 shows a blood gas report indicating the acid-base status of the blood as well as the oxygen-carrying condition. Note that in addition to the numerical blood gas parameters, the patient's breathing status is indicated. Based on all of the clinical data, the computer generates an interpretation. For life-threatening situations, the computer prompts the staff to take the necessary action. For example, if the PO_2 is too low, the computer promptly notifies the laboratory staff, who are instructed to call the nurse or physician caring for the patient. Figure 26–6 shows an example of a physician's rounds report. This "throw-away report" summarizes data from a wide variety of data sources into physiological system categories so that during teaching rounds, or for patient review purposes, the data can be easily and quickly assessed. This type of reporting helps resolve the problems reported by Whiting-O'Keefe and associates (8), who showed that presenting large amounts of irrelevant data can obfuscate the important or relevant facts.

Development of ICU Patient Data Management Systems

The development of computerized patient data management systems has taken place primarily in universities, medical schools, and their affiliated hospitals. As a result of the interest and excitement of having computer-assisted care in the ICU, several commercial vendors became interested. During the 20-year history of computerized patient monitoring development, there have been few successful transplants of complete computerized patient data management systems (2). Several large, capable, and reputable manufacturers have supplied over 300 computerized patient monitoring systems worldwide. These companies include Hewlett-Packard, which controls almost two-thirds of the market with their Patient Data Management System (PDMS), Mennen Medical, Roche, Kontron, Siemens, Litton Datamedix, General Electric, and Spacelabs. Currently, there are only a handful of successful complete patient monitoring systems (2).

Drazen (11) surveyed hospitals where successful ICU computer systems have been installed and found the following common elements:

ALVIN # 2420 E603



			MAR 15	MAR 16	MAR 17	MAR 18	MAR 19	MAR 20	MAR 21
MORPHINE, INJ	MGM	IV	8.0	18.0	24.0	14.0	32.0	10.0	12.0
OPIUM AND BELLADONNA	SUPP	RECT				1			
LORAZEPAM (ATIVAN), INJ	MGM	IV	1.0	1.0				6.0	6.0
CEFAZOLIN (KEFZOL/ANCEF), INJ	MGM	IV	3000	3000	3000	3000	3000	2000	3000
CLOTRIMAZOLE 1% (LOTRIMIN), CREAM	APPLIC	TOPIC	3	3	4	4	4	4	4
METAPROTERENOL (ALUPENT), SOLUTION	MGM	INHAL			30.0	30.0	40.0	50.0	70.0
DOPAMINE, INJ	MGM	IV	267	258	55				
FUROSEMIDE, INJ	MGM	IV	40	80					
MYLANTA II, LIQUID	ML	NG	30	30	30	30	60	150	90
RANITIDINE HCL (ZANTAC), INJ	MGM	IV	150	150	150	150	150	150	150
FLEET, ENEMA	APPLIC	RECTN			1		2	1	
MAGNESIUM CITRATE, LIQUID	ML	NG						296	
OIL RETENTION ENEMA 4 1/2 OZ	ENEMAS	RECT						1	
BISACODYL (DULCOLAX)	SUPP	RECT			1				
CYCLOPHOSPHAMIDE (CYTOXAN), INJ	MGM	IV				250			
HEPARIN FLUSH, INJ	UNITS	IV	200	100	700	200	300	200	400
METHYLPREDNISOLONE (A-METHPRED), INJ	MGM	IV	80.0	60.0	60.0	60.0	30.0	60.0	60.0
DESMOPRESSIN (STIMATE), INJ	MCG	IV			20				
HYDROCORTISONE 2.5%, CREAM	APPLIC	TOPIC	3	3	4	4	4	4	4
FRESH FROZEN PLASMA	ML	IV	485		730		330		400
PACKED RBC	ML	IV			1500	250	750	1000	
PLATELETS (RANDOM DONOR)	ML	IV			360				
NORMAL SALINE, INJ	ML	INHAL			6	6	8	10	14
NORMAL SALINE, INJ	ML	IV	548	361	572	25	300	375	
D5W, INJ	ML	IV	500	55	280	330	291	332	331
AMINOSYN RF, INJ	ML	IV	564	510	607	591	529	366	58
DEXTROSE 70%, INJ	ML	IV	940	850	819	985	825	583	97
SODIUM	MEQ	IV	150.4	136.0	125.5	157.6	124.2	89.7	15.5
CALCIUM	MEQ	IV	8.5	7.7	7.1	8.9	7.0	5.0	0.9
ZINC	MGM	IV	5.6	5.1	6.2	5.9	5.3	3.7	0.6
COPPER	MGM	IV	1.1	1.0	1.2	1.2	1.1	0.7	0.1
MANGANESE	MGM	IV	0.6	0.5	0.6	0.6	0.5	0.4	0.1
CHROMIUM	MCG	IV	11.3	10.2	12.5	11.8	10.7	7.4	1.2

#139 - 1

Figure 26–4. Weekly (7-day) ICU summary report provides daily weight, fluid balance, drug, and physiological data summary.

ACETATE	MEQ	IV	120.3	108.8	100.2	126.1	106.2	74.9	12.4
PHOSPHATE	MEQ	IV	45.1	40.8	37.9	47.3	27.0	22.2	4.6
GLUCONATE	MEQ	IV	8.5	7.7	7.1	8.9	7.0	5.0	0.9
ELECTROLYTE VOLUME	ML	IV	56.0	50.7	46.5	58.7	45.8	33.2	5.8
AMIN-AID 1/2 STRENGTH, LIQUID	ML	NG D						390	110
AMIN-AID FULL STRENGTH, LIQUID	ML	NG D							970
FAT EMULSION 20% (LIPOSYN), INJ	ML	IV		200	200	200	200	200	
CALCIUM GLUCONATE, INJ	MEQ	IV			4.5				
NACL 0.45, INJ	ML	IV		1750					
POTASSIUM CHLORIDE, INJ	MEQ	IV		40.0					
SODIUM BICARBONATE, INJ	MEQ	IV	280	255	80				
INSULIN REGULAR, INJ	UNITS	IV			25	59	47	34	6
NOVOLIN REGULAR, INJ	UNITS	SUBQ	44	24					
MVI-12, INJ	ML	IV	10.2	9.2	11.0	10.2	9.4	6.4	1.0
PHYTONADIONE (AQUA-MEPHYTON), INJ	MGM	IM		10	10		10		
INTAKE (ML): BLOOD					1860	250	750	1000	
COLLOID			485		730		330		400
NON-BLOOD IV			2619	3785	2537	2201	2200	1896	493
ENTERAL FEEDING								390	1080
NG DRUG			30	30	30	30	60	446	90
OTHER DRUG					6	6	8	10	12
TOTAL			3194	3825	5173	2497	3348	3797	2075
OUTPUT (ML): INSENSIBLE LOSS			823	816	897	946	990	956	954
FOLEY CATH URINE			1315	413	250	110	81	61	41
STOOL								2	3
NG TUBE DRG.			210	350	160	20	200	475	400
RESIDUAL								60	200
WOUND DRG, 1								75	
STOOL					125				
WATERSEAL DRG, 1			90	98					
TOTAL			2438	1677	1432	1076	1271	1629	1598
NET BALANCE (ML):			756	2148	3741	1421	2077	2168	477
WEIGHT (KG)			79.6	80.4	83.5	80.9	80.4	79.2	78.3
NUTRITIONAL: NP ENERGY	KCAL	(IV)	2323	2433	2398	2801	2414	2242	2379
TOTAL ENERGY	KCAL	(IV)	2439	2539	2524	2923	2523	2330	2451
PROTEIN	GM		30	26	31	31	28	22	18
FAT	GM		0	40	40	40	40	53	66
CHO	GM		683	597	588	706	593	493	440
NP ENERGY/N2	KCAL/GM		464	608	479	560	603	560	793
N2 IN	GM		5	4	5	5	4	4	3

ALVIN # 2420 E603

TIME OUT: MAR 23 87 16:47 PROCESS TIME: 00:16

(END) #139 - 2

Figure 26–4 *Continued*

1. The medical staff generally recognized the need for computers and were committed to making them work.
2. A powerful physician advocate of computer system use managed the computer operation.
3. The system not only met needs identified before installation but also accommodated subsequent changes.
4. The hospital staff were properly oriented and trained in the use of the system.
5. System reliability had to be excellent before it was accepted.

Consensus Conference

An outlook of what should be done with computerized patient data management can be gained from a recent consensus conference organized by the National Institutes of Health (NIH) (12). The conference pointed out critical care treatment domains that need improvement. Many of these treatment domains are amenable to computer assistance. Technical difficulties, errors in data interpretation, and increasing interventions caused by continuous monitoring are potential iatrogenic hazards for ICU patients. Listed below are important aspects of a modern ICU and some of the areas where computers can be helpful.

1. All ICUs should be capable of arrhythmia monitoring. Bedside physiological monitors using microcomputers now provide excellent arrhythmia monitoring (13).
2. Invasive monitoring should be safely applied. Computer charting of invasive events such as the insertion of an arterial catheter, in combination with data from the microbiology laboratory, can help avoid infection, a major complication of invasive monitoring.
3. Generated data should be correct. The computer can check data as they are entered to verify that they are reasonable. Also, data communications and calculation errors can be reduced or eliminated by letting the computer do the work.
4. Derived data should be properly interpreted. The computer can assist in the data integration process. In addition, the computer can derive parameters and also provide prompt, accurate, consistent interpretations and

```
                          L D S   H O S P I T A L   B L O O D   G A S   R E P O R T

    ALVIN                      SEX: M  AGE: 39  NO.   2420    DR. KNIBBE, W. PATRICK        RM E603
MAR 12 87    pH    PCO2   HCO3    BE   HB   CO/MT   PO2   SO2   O2CT  %O2  AVO2  VO2  C.O.  A-a  Qs/Qt  PK/ PL/PP  MR/SR
             --    ----                             ---

NORMAL HI   7.45   40.3   25.8   2.5  17.7  2/ 1                             5.5  300  7.30   21    5
NORMAL LOW  7.35   26.9   15.6  -2.5  13.7  0/ 1     65    91   18.5         3.0  200  2.90         0

12 05:26 V  7.56   25.6   23.0   2.9  11.1  1/ 1     30    58    9.0   60                                    /   / 5  24/
12 05:25 A  7.59   21.9   21.1   2.0  11.3  2/ 1     62    92   14.7   60   5.50                  270   23   /   / 5  24/
            SAMPLE # 9, TEMP 37.3, BREATHING STATUS : ASSIST/CONTROL
            MODERATE ACUTE RESPIRATORY ALKALOSIS
            MILD HYPOXEMIA
            MODERATELY REDUCED O2 CONTENT
            HYPERVENTILATION MUCH WORSE

11 20:21 V  7.44   35.2   23.7    .8  13.4  1/ 1     34    47    8.9  100                                  51/ 38/ 5  30/
11 20:20 A  7.48   29.6   21.9    .4  13.5  1/ 1     57    84   15.9  100   6.97                  507   38   51/ 38/ 5  30/
            SAMPLE # 8, TEMP 38.9, BREATHING STATUS : ASSIST/CONTROL
            MILD ACID-BASE DISORDER
            MODERATE HYPOXEMIA
            MODERATELY REDUCED O2 CONTENT
            HYPERVENTILATION (PREVIOUSLY NORMAL)

11 17:36 A  7.36   40.4   22.5  -2.3  13.5  2/ 1     45    82   15.6  100                         507          /   /     30/
            SAMPLE # 7, TEMP 35.4, BREATHING STATUS : ASSIST/CONTROL
            MILD ACID-BASE DISORDER
            SEVERE HYPOXEMIA BREATHING OXYGEN **CONTACT MD OR RN!!!!
            MODERATELY REDUCED O2 CONTENT
            HYPOVENTILATION CORRECTED

11 16:50 A  7.19   68.2   25.2  -4.5  14.5  1/ 1     48    75   15.2   10
            SAMPLE # 6, TEMP 35.4, BREATHING STATUS : VENTURI-FACE MASK
            SEVERE ACUTE RESPIRATORY ACIDOSIS
            SEVERE HYPOXEMIA BREATHING O2 AND CO2 RETENTION **CONTACT MD OR RN!!!!
            MODERATELY REDUCED O2 CONTENT
            HYPOVENTILATION (PREVIOUSLY NORMAL)

11 15:40 A  7.30   36.0   17.3  -7.9  15.6  3/ 1     68    91   19.9    3
            SAMPLE # 5, TEMP 37.0, BREATHING STATUS : NASAL CANNULA
            MODERATE MIXED METABOLIC AND RESPIRATORY ACIDOSIS
            MILD HYPOXEMIA

11 00:00 A  7.43   33.6   22.1   -.7  15.5  2/ 1     70    92   20.0    3
            SAMPLE # 4, TEMP 37.0, BREATHING STATUS : NASAL CANNULA
            NORMAL ARTERIAL ACID-BASE CHEMISTRY

10 22:05 A  7.43   34.4   22.6   -.2  15.8  2/ 1     53    84   18.6   21                          30
            SAMPLE # 3, TEMP 37.0, BREATHING STATUS : ROOM AIR
            NORMAL ARTERIAL ACID-BASE CHEMISTRY
            SEVERE HYPOXEMIA  **CONTACT MD OR RN!!!!

08 12:20 A  7.43   32.1   21.1  -1.4  16.2  2/ 1     58    88   20.0   21                          28
            SAMPLE # 2, TEMP 37.0, BREATHING STATUS : ROOM AIR
            NORMAL ARTERIAL ACID-BASE CHEMISTRY
            MODERATE HYPOXEMIA

03 10:40 A  7.49   31.0   23.5   2.2  17.2  3/ 0     73    92   22.3   21                          15
            SAMPLE # 1, TEMP 37.0, BREATHING STATUS : ROOM AIR
            MILD ACID-BASE DISORDER

PRELIMINARY INTERPRETATION -- BASED ONLY ON BLOOD GAS DATA.  ***(FINAL DIAGNOSIS REQUIRES CLINICAL CORRELATION)***
KEY: CO=CARBOXY HB, MT=MET HB, O2CT=O2 CONTENT, AVO2=ART VENOUS CONTENT DIFFERENCE (CALCULATED WITH AVERAGE OF A &V HB VALUES),
 VO2=OXYGEN CONSUMPTION, C.O.=CARDIAC OUTPUT, A-a=ALVEOLAR arterial O2 DIFFERENCE, Qs/Qt=SHUNT, PK=PEAK, PL=PLATEAU, PP=PEEP
 MR=MACHINE RATE, SR=SPONTANEOUS RATE.        *** SPECIMEN IDENTIFICATION: BLOOD (A=ARTERIAL, V=VENOUS, C=CAPILLARY, W=WEDGE);
                                              FLUIDS (P=PLEURAL, J=JOINT, B=ABDOMINAL, S=ABSCESS); E=EXPIRED AIR


 (END)                                                                                                        #135 - 1
```

Figure 26–5. Blood gas report showing the patient's predicted normal values as well as the measured values. The computer automatically provides the interpretations and will also give alerts for life-threatening conditions.

```
                         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:    , ALVIN                            NO.   2420         ROOM: E603                              DATE: MAR 23 06:00
DR. KNIBBE, W. PATRICK              SEX: M  AGE:  39   HEIGHT: 163   WEIGHT:  76.20   BSA: 1.82   BEE:  1660   MOF:   10
ADMT DIAGNOSIS: POLYMYOSITIS                  ADMIT DATE: 02 MAR 87          APACHE II: 19

SURGERY:
=========================================================================================================================
CARDIOVASCULAR:  0                                                              EXAM: _____________________________________
   -- NO CARDIAC OUTPUT DATA AVAILABLE                                                _____________________________________
                 SP    DP    MP    HR  |  LACT          CPK          CPK-MB        LDH-1        LDH-2
 LAST VALUES    134    69    84   113  |
 MAXIMUM        199   104   133   133  |     (    )     (    )     (    )     (    )     (    )
 MINIMUM         96    52    65    14  |
=========================================================================================================================
RESPIRATORY:  3
               pH    PCO2    HCO3    BE     HB   CO/MT   PO2   SO2   O2CT   %O2  AVO2  VO2   C.O.  A-a  QS/QT  PK/ PL/PP  MR/SR
23 05:25 A   7.39    39.1    23.4   -.8   11.9   3/ 2    74    92    15.4   35                        88          0/  0/ 5  12/ 0
          SAMPLE # 30, TEMP 37.4, BREATHING STATUS : ASSIST/CONTROL
          NORMAL ARTERIAL ACID-BASE CHEMISTRY
          MODERATELY REDUCED O2 CONTENT

          ------- machine settings ------- | -------------------------- patient values ----------------------------
          VENT  MODE  VR   Vt   O2%   PF  IP    MAP   PK   PL   PP  m-Vt  c-Vt  s-Vt  MR  SR  TR  m-VE  s-VE  t-VE  Cth   Pc
23 15:54  B-II  A/C   12  900   35    50              40   30    5  1192  1007        18            18.1              40.3
23 05:25  B-II  A/C   12  900   35    50              38   27    5  1075   900        12            10.8              40.9
23 15:54 75442/  5/15:54   INTERFACE: NASOTRACH;  ALARMS CHECKED; POSITION: FOWLER;
23 05:25 42213/ 10/05:33   INTERFACE: NASOTRACH;  BREATH SOUNDS: RHONCHI, THROUGHOUT INSPIRATION AND EXPIRATION, BOTH LUNGS;
         ALARMS CHECKED; POSITION: FOWLER;  PATIENT CONDITION: CALM;  SUCTIONED;

 DATE     TIME   THPST#  HR   VR    VT    VC    VE   MIP  MEP  MVV  PK FLOW    EXAM: _____________________________________
03/23/87 06:52    222   104   29   220   580   6.4   -22                              _____________________________________
=========================================================================================================================
NEURO AND PSYCH:  0
   GLASCOW   (      ) VERBAL ________   EYELIDS ________   MOTOR _________   PUPILS ________   SENSORY ________

   DTR __________   BABIN. ________   ICP ___________   PSYCH _________
=========================================================================================================================
COAGULATION:  2
   PT:   10.1   (05:20) PTT:     32 (05:20) PLATELETS:   63 (05:20)   FIBRINOGEN:   0 (00:00) EXAM:_____________________
   FSP-CON:   0 (00:00) FSP-PT:   0 (00:00) 3P:          (00:00)                                 ___________________
=========================================================================================================================
RENAL, FLUIDS, LYTES:  2
   IN   2580 CRYST     415  COLLOID          BLOOD   750 NG/PO    1405 | NA    140 (05:20) K    5.0   (05:20)  CL    97   (05:20)
   OUT  1765 URINE      30  NGOUT        700  DRAINS       OTHER  1033 | CO2 24.0 (05:20) BUN   101 (05:20)  CRE   4.3 (05:20)
   NET   815 WT    76.20    WT-CHG      -.70  S.G.     1.031           | AGAP   24.0       UOSM                UNA        CRCL
=========================================================================================================================
METABOLIC --- NUTRITION:  0
   KCAL     2696   GLU  136   (05:20)   ALB    2.8 (05:20)  |  CA    7.4 (05:20)   FE     .0 (00:00)   TIBC     0 (00:00)
   KCAL/N2   889   UUN   .0 (00:00)     N-BAL   .0          |  PO4   5.9 (05:20)   MG     .0 (00:00)   CHOL   129 (05:20)
=========================================================================================================================
GI, LIVER, AND PANCREAS:  0                                                                                    EXAM:
   HCT      34.9 (05:20)   TOTAL BILI    5.0 (05:20)  SGOT  590 (05:20)  ALKPO4  780 (05:20)  GGT     440 (05:20) __________
   GUAIAC 1+     (20:45)   DIRECT BILI   3.0 (05:20)  SGPT   10 (05:20)  LDH    3000 (05:20)  AMYLASE   0 (00:00) __________
=========================================================================================================================
INFECTION:  3
   WBC 15.8 (05:20) TEMP  37.5 (02:00) DIFF  15B, 83P,   L,  2M,   E (20:15) GRAM STAIN: SPUTUM __________ 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     30.500   RANITIDINE HCL (ZANTAC), INJ             MGM   IV        150
MORPHINE, INJ                               MGM   IV         20   MYLANTA II, LIQUID                       ML    NG         30
CEFAZOLIN (KEFZOL/ANCEF), INJ               MGM   IV       3000   HEPARIN FLUSH, INJ                       UNITS IV        600
CLOTRIMAZOLE 1% (LOTRIMIN), CREAM           APPLICATIONT      4   METHYLPREDNISOLONE (A-METHPRED), INJ     MGM   IV         60
METAPROTERENOL (ALUPENT), SOLUTION          MGM   INHAL      50   AMIN-AID FULL STRENGTH, LIQUID           ML    NG D     1255
ALTERNAGEL, LIQUID                          ML    NG        150
```

Figure 26–6. Rounds report used for the evaluation of patients each day during teaching and decision-making rounds. The report abstracts data from a diversity of locations and sources, and formats them into a physiological system orientation. Listed at the top of each report is patient identification and characterization information. The next information is about the cardiovascular system, and so on.

alerts. For example, see the blood gas report with computer interpretations shown in Figure 26–5.

5. Therapy should be safely employed. The computer can assist in suggesting therapy and help avoid drug errors. Computerized closed-loop control of some intravenous drugs and fluids may help improve therapy.

6. There should be rapid and comprehensive access to laboratory data. Computer networking provides both rapid and comprehensive access to laboratory data and can even provide interpretation and alerts.

7. Enteral and parenteral nutritional (tube feeding) support services should be available. Interactive computer prescribing can help physicians with this complex task.

8. Titrated therapeutic interventions with infusion pumps should be available. Computer-assisted drug administration using computer-controlled infusion pumps will assist in the care of the patient and provide an accurate log of the therapy.

Calculation of Derived Variables

The increased sophistication of hemodynamic, renal, and pulmonary monitoring has resulted in the necessity of calculating derived parameters. ICU staffs have had to learn to crunch numbers. At first, pocket calculators were used, with each step performed carefully by a nurse. Then, programmable calculators took over this task, making the computation simpler, faster, and more accurate (14,15). Soon these devices were replaced by personal and portable computers (16,17). Some of these systems have even been enhanced to provide graphs and interpretations.

Establishing Standard Communication Networks

Communication is one of the most important tasks of the health care professional. Data underlie every medical decision. Except for personal observations made by and acted upon by physicians and nurses at the bedside, all patient data must be communicated. Often, the data are communicated through several people and by several media before getting to the appropriate medical decision-maker. Each step in the process, especially if it involves a handwritten record, can also result in delays and errors. Computers can solve these problems and are being used in more and more centers to enhance communications (18).

Most bedside patient support devices such as IV pumps, ventilators, pulse oximeters, and physiological monitors contain microcomputers. However, each device has its own display; since they come from different manufacturers, each device is designed to stand alone. As a result, it is common for a nurse or therapist to read a computer display from one of these devices and enter the data through a terminal to get the data into the main computer. The need to develop an integrated patient "information bus" is apparent. Recently, an Institute of Electrical and Electronic Engineers (IEEE) committee was organized to develop the standards for a Medical Information Bus (MIB) (2,18). The MIB communications system will permit the connection of up to 255 devices to a network, allowing communication with each of these devices within seconds. The communication technology being developed will allow the connection of a variety of bedside devices to the computer and will automatically record their data. The potential for more accurate and timely data acquisition as well as labor savings is enticing.

Simpler, More Efficient Data Entry Methods

To computerize patient monitoring, with all the patient data available, requires further development of computer entry methods. Presently, a ball point pen and blank piece of paper provide a fast, easy, familiar, and convenient method for nurses and physicians to chart patient information. Unfortunately, the conventional handwritten chart has many deficiencies, as noted earlier. However, the ease and flexibility of charting with the usual manual method is still the standard against which ICU computer charting is compared. Therefore, data entry methods must be developed that are efficient and effective for data recording and review. It is highly likely that such methods will include some of the newer screen and graphic functions that have become available on personal computers (3). These devices include a mouse and cursor, light pens, and touch screens. Although each of these devices may help, the largest payoff is likely to be in a system that is smart. That is, the terminal or work station at the bedside will know a great deal about the patient, his/her condition, what drugs are prescribed with the dose, route of administration and schedule, and the personal preferences of the physician caring for the patient. Thus, by being smart the computer will be able to quickly present the personalized data entry and review menus helping the nurse or physician to customize the care process.

Nursing Time Utilization

Figure 26–7 shows how nurses in a thoracic ICU (post open-heart surgery patients) spend their working day. As one would expect, nurses spend the majority of their time in direct patient care (48%). Another 19% of their time is spent documenting (charting), which amounts to over 2 hours and 15 minutes per 12-hour shift. The next most frequent activity is the communication (7%) of patient status information about their patients to other members of the health care team. Through the use of a good hospital computer system, the quality, accuracy, and ease of data communication within the ICU can be improved (19). There is also an opportunity to reduce the data handling time of the nursing staff.

Decision-Making—Access to a Medical Knowledge Base

The mark of a good physician is the ability to make sound clinical judgments (20). Medical decision-making has tra-

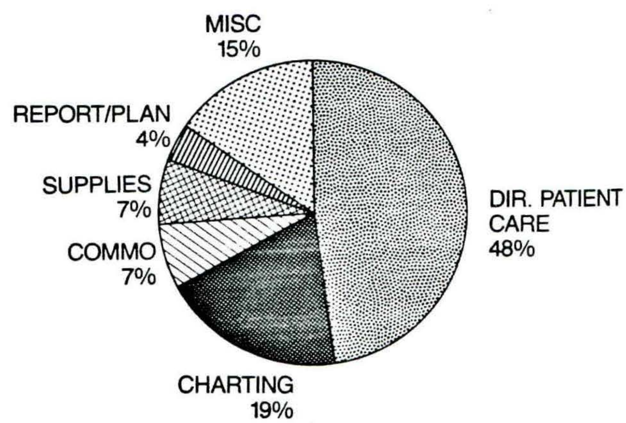


Figure 26–7. Pie chart indicating how nurses spend their time in a thoracic surgery ICU.

ditionally been considered an artful and intuitive process rather than a scientific process. In recent years, however, computerized medical decision-making has gained wider acceptance (21–27). Indeed, the discussion of artificial intelligence is commonplace in medicine today (27,28). The opportunity to use the computer to assist in the complex task of medical decision-making in the ICU has just begun (1,2,27,28). Figure 26–8 is a block diagram of the Health Evaluation through Logical Processing (HELP) computer system that is operational at LDS Hopsital in Salt Lake City, Utah (2,21,29). For several years, the HELP computer system at the LDS Hospital has been used effectively to assist in ICU decision-making. For the ICU patient, the system collects and integrates data from a wide variety of sources. The data are automatically processed by the HELP decision-making system to determine if the new information by itself, or in combination with other data in the patient record (such as laboratory results or a previously generated decision), leads to a new medical decision. These computer-generated medical decisions are based on criteria (knowledge base) stored on the magnetic disk.

The HELP decision-making system has been used in the following areas: (a) interpretations, e.g., blood gas and hemodynamic parameter interpretations; (b) diagnoses; (c) alerts, i.e., the notification of life-threatening events; and (d) treatment suggestions.

The application of protocols to the treatment of critically ill patients is not new (30). Protocols have been used to prevent adverse drug reactions, suggest fluid management, improve cardiac management of surgical patients, and suggest therapy based on hemodynamic information.

Development of Open-Loop Treatment Protocols

The development of algorithms for the care of the critically ill is a new and developing field. Use of the computer to provide open-loop control is intriguing. A computerized open-loop control system can be implemented in a variety of ways. Making treatment recommendations using computer methods is currently the most feasible. The art of medicine must be combined with the science of medicine to develop the best set of treatment strategies so that the best medical care can be made available to all. Figure 26–9 is a flow chart of a ventilatory care protocol. This protocol has been implemented on the HELP computer system to provide prompt and reminder messages for nurses and physicians caring for patients with the acute respiratory distress syndrome (ARDS).

Closed-Loop Control Systems

Closed-loop therapeutic devices, which use a computer to sense and control a physiological variable by altering therapy, have been applied clinically (31–33). The work of Sheppard and associates (32) at the University of Alabama has been innovative and effective. They have used a computer-controlled infusion pump to control the infusion of sodium nitroprusside to regulate blood pressure. These investigators have shown that the controller performs better than the nurse in regulating a constant blood pressure. The system works well under a wide range of clinical situations and is designed with several fail-safe features. Subsequently, other investigators have effectively applied the closed-loop technology, and others have shown a clear clinical need for the technology (33). The application of this type of technology is exciting because the computer may be able to give the patient better care while reducing nursing time. Future applications of closed-loop systems will require much the same care and research as do the development of other medical decision-making algorithms.

The Future

With more ICU patient data becoming available in computer form, we have a great opportunity to capitalize on

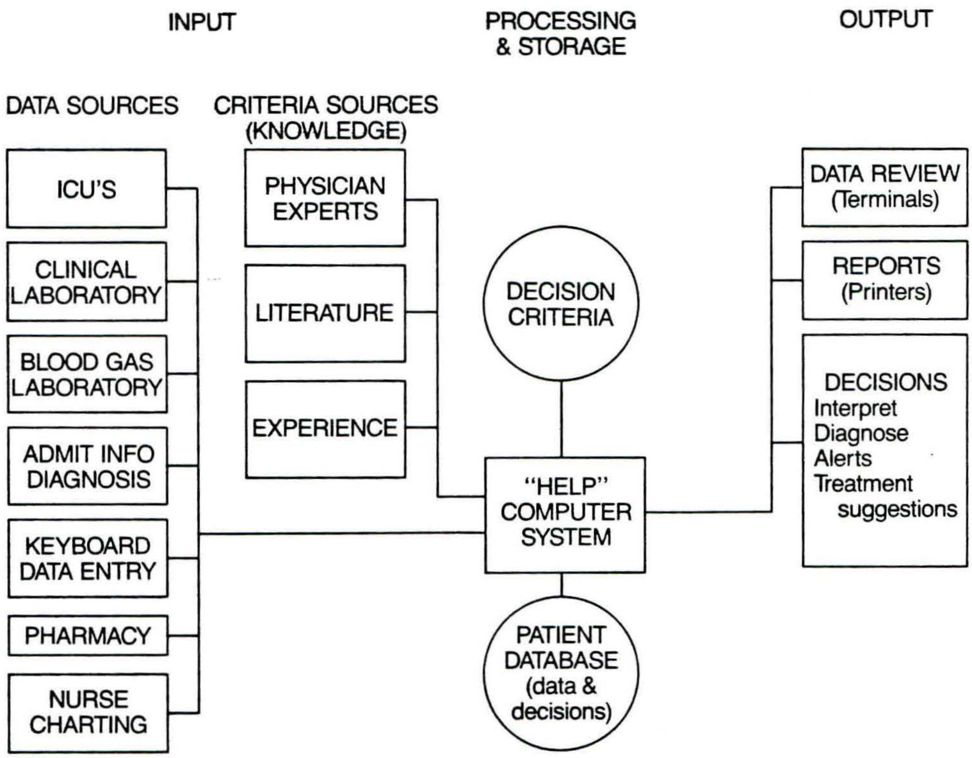


Figure 26–8. Patient data flows into the HELP decision-making computer system from a variety of sources. The decision-making criteria (knowledge base) are then automatically applied to the data, giving an output of computer-aided decisions. A variety of output is generated, including information for review on computer terminals, printed reports, and medical decisions.

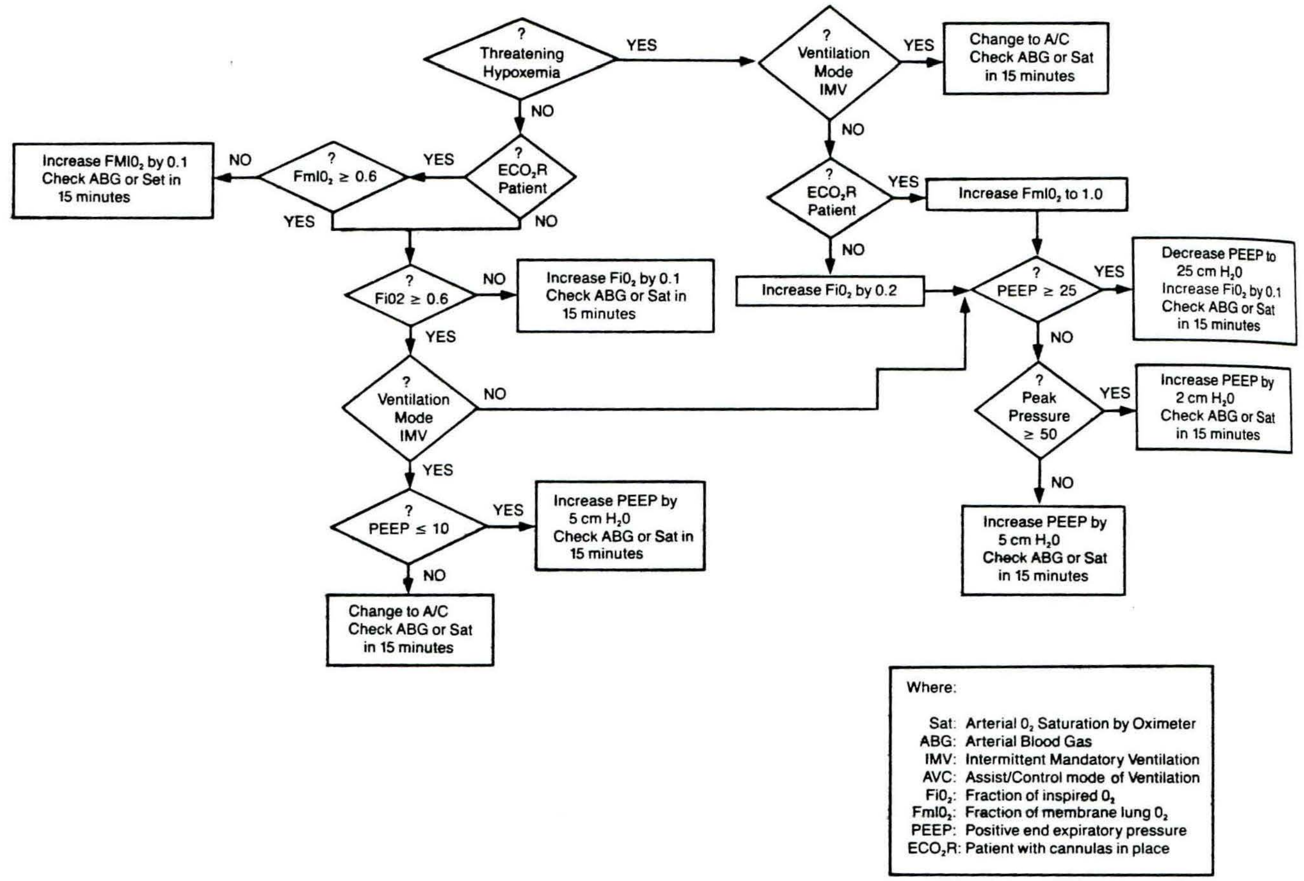


Figure 26–9. Simplified flow chart for treatment of hypoxemia.

expanded patient care capabilities by computers. These capabilities will likely include the following.

Remote Access to the Patient Data Base

Prompt and efficient physician access to an ICU patient data base from the office or home is possible. The technology is already in place for physicians with personal computers and modems to have ICU data base access. This communication enhancement will not only assist the physician and his staff in better caring for a patient but will make the important communication task more efficient.

Closed-Loop Control

Although only a few closed-loop control protocols have been implemented in ICUs, their future looks bright. Currently, the regulation of blood pressure by a computerized closed-loop infusion of medication provides better and more efficient patient care. In the future, the control of other drug infusions as well as ventilator control will be accomplished by computerized systems.

Telemedicine with Remote Consultation

An expansion of remote access capabilities will allow a much broader sharing of medical expertise. Since ICU data will be easily communicated, it will be possible to seek consultation outside the local medical community. For example, if a special problem occurs in Salt Lake City, experts from San Francisco or New York could be called in; by sharing the data, a much broader range of expertise could be brought to bear on the patient.

Cost Effectiveness

The cost of hospital care is rising at an unprecedented rate. As a result, prospective payment schemes that encourage hospitals to be more efficient have recently been implemented. Computerized methods of data collection will enhance the ability to assess the costs of various procedures and assist in making them more efficient.

Protocol Medicine

Applying patient care protocols to the critically ill is a growing field. The timely and accurate treatment of the critically ill is the most demanding aspect of hospital care. Clearly computer-assisted treatment protocols will soon become a major focus in the ICU.

The use of computers in the ICU is still in its infancy. Several exciting and challenging areas of research still await the interested and innovative physiologist–computer scientist.

SUMMARY

Match versus Mismatch

The computer is certainly a MATCH for the needs of the modern ICU. Several advantages of computer systems in the ICU have been demonstrated. These systems can (a) assist in data collection; (b) provide computational capability; (c) assist in data communications and integration of data; (d) improve record-keeping; (e) enhance report generation; and (f) assist in medical decision-making.

Computers can assist in data collection by taking information already in digital form and storing it in the patient record. Examples are the bedside monitor and IV pumps. Industry/hospital standards for a MIB are being developed. Once these are complete, it will be possible to acquire data in a common computer format from bedside devices such as IV pumps, urine output measuring devices, and a variety of other instruments. Computers can assist in providing computational capability. For example, the calculation of peripheral vascular resistance from the hemodynamic parameters is possible. Computers can assist in data communication and function as a data integrator. One of the most important tasks physicians and health care providers do is assimilate data to make treatment decisions. Data can be rapidly and accurately transmitted electronically from one instrument system to another, e.g., from the clinical laboratory or a blood gas laboratory to the ICU. The computer is an ideal record-keeper because it can store and quickly recover vast amounts of information. The computer has an unusual capability of generating a variety of reports because it has access to all the patient data. Reports can be generated in variable formats, data are available at multiple sites, and redundant data entry can be minimized. Increased structuring of data in reports can also assist in medical decision-making. Finally, computer-generated reports are more accurate and timely. The hallmark of a good physician is the ability to make sound clinical judgments. The computer is able to make medical decisions and is a tool that can provide assistance to physicians in the ICU.

How then does one implement such a system in the real world? A growing body of computer tools is being developed for ICU applications. Whether computers can successfully match the needs of ICUs revolves around two issues: first, is there a critical mass of patient information in the computer data base, and second, has the ICU developed an adequate computer society with the maturity to live through the change in style of patient care required by computer implementation? Both issues must be resolved for ICU computer systems to be properly implemented.

The user friendliness of personal computers will have a great impact on the use of computers in ICUs. Personal computers have attracted the attention of all segments of our society and can increase productivity. Because personal computers have been used so widely and because of their ease of use, it is no longer necessary to convince medical staffs about the value of computers.

References

1. Gardner RM: Computerized data management and decision-making in critical care. Surg Clin North Am 1985; 65:1041
2. Gardner RM: Computerized management of intensive care patients. MD Computing 1986; 3:36
3. Tong HD, Gupta A: Personal computers. Sci Am 1982; 247:87
4. Barnett GO: The application of computer based medical records systems in ambulatory care. N Engl J Med 1984; 310:1643
5. Fries JF: Time-oriented patient records and a computer databank. JAMA 1972; 222:1536
6. Stead WW, Hammond WE, Straube MJ: A chartless record—Is it adequate? J Med Syst 1983; 7:103
7. Whiting-O'Keefe QE, Simborg DW, Epstein WV: A controlled experiment to evaluate the use of time-oriented summary medical records. Med Care 1980; 8:842
8. Whiting-O'Keefe QE, Simborg DW, Epstein WV, et al: A computerized summary medical record system can provide more information than the standard medical record. JAMA 1985; 254:1185
9. Bradshaw KE, Gardner RM, Clemmer TP, et al: Physician decision-making—Evaluation of data used in a computerized ICU. Intl J Clin Monitoring Comp 1984; 1:81
10. Berenson RA: Health Technology Case Study 28: Intensive Care Units (ICUs)—Clinical Outcomes, Costs and Decisionmaking. Washington, DC, Congress of the United States. Office of Technology Assessment, 1984
11. Drazen EL: Use of computerized monitoring systems in intensive care. Comput Card 1981; 8:323
12. Ayers SM, Achoff SC, Armstrong CJ, et al: NIH consensus conference —Critical care medicine. JAMA 1983; 250:798
13. Jenkins JM: Automated electrocardiography and arrhythmia monitoring. Prog Cardiovasc Dis 1983; 15:367
14. Shabot MM, Carlton PD, Sadoff S, et al: Graphical reports and displays for complex ICU data: A new, flexible and configurable method. Comput Methods Programs Biomed 1986; 22:111
15. Finlayson DC, Yin A: Calculator assisted cardiorespiratory monitoring. Crit Care Med 1981; 9:604
16. Gardner RM: Information management—Hemodynamic monitoring. Semin Anesth 1983; 2:287
17. Cottrell JJ, Pennock BE, Grenvik A, et al: Critical care computing. JAMA 1982; 248:2289
18. Gardner RM, Hawley WL: Standardizing communications & networks in the ICU. Patient Monitoring and Data Management Conference. AAMI Technology Analysis and Review TAR No. 11–85, 1985, pp 59–63
19. Blaufuss J: Promoting the nursing process through computerization. MEDINFO 86 585-586, Washington, DC, 1986
20. Bergman DA, Pantell RH: The art and science of medical decision making. J Pediatr 1984; 104:649
21. Gardner RM, West BJ, Pryor TA, et al: Computer-based ICU data acquisition as an aid to clinical decision-making. Crit Care Med 1982; 10:823
22. Shortliffe EH, Buchanan BG, Feigenbaum EA: Knowledge engineering in medical decision making. A review of computer based clinical decision aids. Proc IEEE 1979; 67:1207
23. Szolovits P, Pauker SG: Computers and clinical decision making: Whether, how, and for whom? Proc IEEE 1979; 67:1224
24. Warner HR: Computer-assisted Medical Decision-making. New York, Academic Press, 1979
25. Fagan LM, Shortliffe EH, Buchanan BG: Computer-based medical decision making: From MYCIN to VM. Automedica 1980; 3:97
26. Miller PL: Extending computer-based critiquing to a new domain: ATTENDING, ESSENTIAL-ATTENDING, and VQ-ATTENDING. Intl J Clin Monit Comput 1986; 2:135
27. Gardner RM: Artificial intelligence in medicine—is it ready? Editorial. Intl J Clin Monit Comput 1986; 2:133
28. Schwartz WB, Patil RS, Szolovits P: Artificial intelligence in medicine: Where do we stand? N Engl J Med 1987; 316:685
29. Pryor TA, Gardner RM, Clayton PD, et al: The HELP system. J Med Syst 1983; 7:87
30. Shoemaker WC: Protocol medicine (Editorial). Crit Care Med 1974; 2:279
31. Sheppard LC, Sayers BM: Dynamic analysis of blood pressure response to hypotensive agents studied in post-operative cardiac surgery patients. Comput Biomed Res 1977; 10:237
32. Sheppard LC: Computer control of infusion of vasoactive drugs. Ann Biomed Eng 1980; 8:431
33. Mitchell RR: The need for closed-loop therapy. Crit Care Med 1982; 10:831

Chapter 27

COMPUTERIZATION: PROBLEMS IN THE INPUT, MANIPULATION, AND STORAGE OF INTENSIVE CARE UNIT DATA

JEFFREY S. AUGENSTEIN, MD, PhD
ERNEST A. PETERSON, PhD

OVERVIEW

During the past two decades, advances in computerized ICU data management have paralleled clinical advances and the growing sophistication of computer hardware and software. Both intensive care technology and com-