# Computers in the Intensive Care Unit: The Clinical Challenge

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231. Gardner RM, Clemmer TP. Computer in the ICU: The Clinical Challenge. pages 1917-1924 Chapter 151 In CRITICAL CARE 2nd Edition. Edited by Joseph M. Civetta, Robert W. Taylor, Robert R. Kirby. J.B. Lippincott Inc Publishers. Philadelphia, PA 1992.

Treatment of the critically ill or traumatized patients in an intensive care unit (ICU) places unusual demands on nurses and physicians. These patients are usually admitted into ICUs and connected to sophisticated physiologic monitoring equipment. They have a wide variety of laboratory tests performed, many of which must be repeated and followed for trends over the course of therapy. Therapy for these patients is complex, time critical, and requires careful documentation. Large volumes of data must be stored, processed, and used by nurses and physicians for making clinical decisions.

Computer technology has undergone a period of explosive growth. We think there is nothing unusual about having a cellular telephone or a portable computer that fits into a briefcase. This portable computer exceeds the capability of computers that filled large rooms 2 decades ago.

What has delayed applying this technology more widely to the care of the critically ill? We feel the reason is that the clinical staffs of hospitals have not actively participated in designing patient record systems. Our experience with a computerized hospital information system that grew up around the care of ICU patients provides some insight into the resolution of this problem.

## USES FOR COMPUTERS IN THE INTENSIVE CARE UNIT

Computers in the ICU are used to assist with four functions: acquiring physiologic data, facilitating data communications, keeping electronic medical records, and computerized medical decision-making.

Expert systems that assist physicians and nurses with medical decision-making are becoming common and are used to augment caring for critically ill patients.

## ACQUIRING PHYSIOLOGIC DATA

The use of microcomputers (like those used in personal computers) has revolutionized the way physiologic data are acquired, processed, and displayed. Most bedside monitors, pulse oximeters, ventilators, and intravenous pumps marketed today contain at least one microcomputer.[1–7]

Bedside monitors can store patient waveforms, such as the electrocardiogram (ECG) and arterial pressure curves, and permit sophisticated pattern recognition and feature extraction, which was not available just a decade ago.[7] Because the bedside monitor is computerized, it can transmit data to a central patient database and eliminate the need to chart the data manually or plot the data on a flow sheet. Bedside monitors acquire, process, store, and display data. These same monitors record trend information and sound alarms when life-threatening data are detected. Sophisticated dysrhythmia monitors and sophisticated microcomputer-based noninvasive devices, such as pulse oximetry, have become common.[3,8,9] None of these advanced monitoring capabilities would have been possible without the memory and processing power of microcomputers.

In the modern ICU, it is not unusual for the patient to be connected to several monitoring devices, such as a pulse oximeter, a mixed venous saturation monitor, and a ventilator. The patient is probably connected to several intravenous pumps, a bedside monitor to measure ECG (rate and rhythm), arterial blood pressure, and pulmonary artery pressures (Figs. 151-1 and 151-2).

Each of these devices is currently made by different manufacturers, and each may have a different computer communications interface connector and data sharing protocol. To facilitate automatic data acquisition from these multiple devices, a standardized medical information bus (MIB) has been proposed. The MIB provides a local area network around the patient that can be accessed by all bedside devices and that allows data from each of the devices to be stored in a central database in a standard form.[10–14] The MIB is now being standardized by the Institute of Electrical and Electronic Engineers (IEEE) so that all hospitals and device vendors can use a common data format and easily communicate data from multiple bedside devices.

## FACILITATING DATA COMMUNICATIONS

Computers facilitate timely and accurate data communications from multiple sources (*e.g.*, laboratory, radiology, admitting office, blood bank, surgery) within the hospital, making patient information more readily available. Communications is one of the most important tasks performed by health care professionals. Data underlie every decision, and all data must be recorded and communicated. Often, the data are communicated through several people and by several media (*e.g.*, computer, telephone, written notes, printouts) before reaching the decision maker. Each step in the process can result in delays and errors, especially if handwritten records are involved.

To prevent these problems at LDS Hospital in Salt Lake City and at several other locations, nursing and physician staffs have integrated the patient record into a computerized form. Data from bedside physiologic monitors, intravenous pumps, pulse oximeters, mixed venous oxygen saturation, ventilators, and other devices have been networked using the MIB (see Fig. 151-2). These automated data collection schemes have saved time and improved the accuracy of data collected.

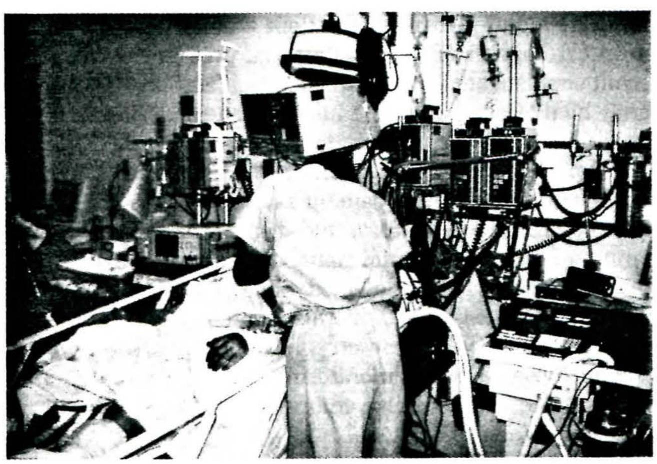

FIG. 151-1. Photograph of a bedside scene with bedside monitor, ventilator, intravenous pumps, pulse oximeters, and mixed venous oxygen saturation monitor. The medical devices at this bedside contain 18 microprocessors.

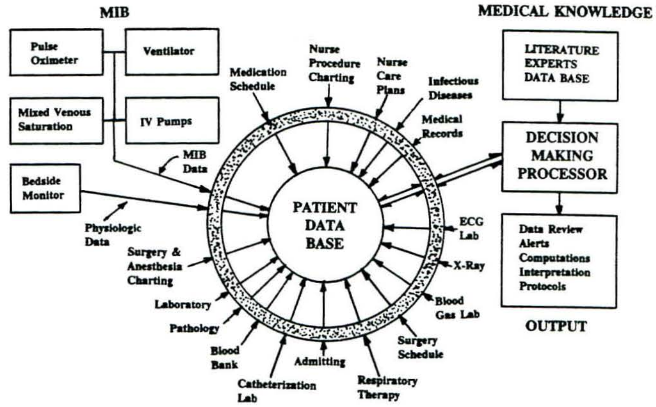


FIG. 151-2. Diagram of a data collection and decision-making system used in a computerized intensive care unit. Notice the wide variety of data sources and how data from three sources are integrated into one patient database. Also illustrated is a medical decision-support system. As data are collected, they are analyzed by the decision-making processor, illustrated by the ring surrounding the patient database. (From Gardner RM, Bradshaw KE, Hollingsworth KE: Computerizing the Intensive care unit: Current status and future directions. *J Cardiovasc Nurse* 1989; 4:68)

Before these schemes become common, technology for collecting "representative and relevant data" must become available. Several issues must be dealt with. What data should be collected? How often should the data be collected?[15] What mechanisms must be in place to collect high-quality data?

The use of the computer to communicate and integrate data is illustrated in Figure 152-2. In this simplified diagram, data flows into the database from 18 different sources. For some of these sources, such as oral medication, data are manually entered into the computer; for others, data are electronically transmitted from remote locations, such as the clinical laboratory.

Data used by physicians to make therapeutic decisions during physician teaching rounds in the shock-trauma ICU at LDS Hospital were assessed.[16] A typical rounds report generated for physicians is shown in Figure 151-3. Figure 151-4 presents a summary of the data used for ICU decision-making in physician teaching rounds. Notice that clinical data from the laboratory makes up the largest single data source (*i.e.*, laboratory and blood gas data = 42%), followed by intravenous, drug, and intake and output data (22%), nursing observations (21%), data from the bedside monitor (13%), and data from other sources (2%). To be effective and complete, the computerized database must integrate data from many sources. Unfortunately, most past attempts to computerize ICUs have dealt only with the very limited (13%) amount of data obtained from the bedside monitor.

The computer is an extraordinary tool for collection and integration of clinical patient data. With the use of computer networks, as soon as data are available from the blood gas or clinical laboratory, they are also available to physicians and nurses in the ICU, other nursing divisions, or by telephone from physicians' offices, clinics, or homes. Delays are avoided,

```
                        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.    117          ROOM: E611                        DATE: JUN 15 23:37
DR. DEAN, NATHAN C.                  SEX: F     AGE:  42   HEIGHT: 167   WEIGHT:  89.70   BSA: 1.99   BEE:  1603   MOF:     0
ADMT DIAGNOSIS: ARDS                                ADMIT DATE: 12 JUN 91
-----------------------------------------------------------------------------------------------------------------------------
CARDIOVASCULAR:   0                                                            EXAM: ______________________________
TIME                CO     CI     HR  SV   SI    VP  MSP  MP SVR LWI PW  PA  PVR    RWI  ______________________________
JUN 15 20:15     8.20  4.13    86  95   48  6.0M 104  89 10  63   8  18  1.2    7.8
          HYPERDYNAMIC LV FUNCTION
                    SP     DP     MP    HR  | LACT          CPK          CPK-MB        LDH-1        LDH-2
  LAST VALUES      104     56     74    78  |
  MAXIMUM          179     87    118   104  |    (     )     (     )     (     )     (     )     (     )
  MINIMUM          102     52     70    73  |
-----------------------------------------------------------------------------------------------------------------------------
 RESPIRATORY:   0
                pH    PCO2     HCO3     BE     HB   CO/MT   PO2   SO2   O2CT   %O2   AVO2  VO2   C.O. A-a  QS/QT  PK/ PL/PP  MR/SR
15 20:16 V   7.39   49.5     29.6     4.4  11.5   1/ 0    41    69   11.2    80                                   60/ 49/19  14/ 0
15 20:15 A   7.41   46.9     29.4     4.7  11.7   1/ 0    67    91   15.0    80   3.58             359   40       60/ 49/19  14/ 0
          SAMPLE # 22, TEMP 38.3, BREATHING STATUS : ASSIST/CONTROL
          MODERATE CHRONIC RESPIRATORY ACIDOSIS
          MILD HYPOXEMIA
          MILDLY REDUCED O2 CONTENT
          HYPOVENTILATION (PREVIOUSLY NORMAL)
15 16:58 A   7.40   39.6     24.2      .2  10.2   1/ 1    58    85   12.3    80                       375            58/  0/17  17/ 0

          ------- 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
15 22:15  7200  CMV   14  700   80    60        24.0  56   50  19         640         14           9.0              20.6
15 20:17  7200  CMV   14  700   79    60        24.9  60   49  19         670         16          10.7              22.3  20
15 22:15  20/23:13   INTERFACE: NASOTRACH TUBE;  POSITION: SEMI-FOWLER;  PATIENT CONDITION: MEDICATED, CALM;  THERAPIST:
         HOLVERSON, JEFF
15 20:17  20/20:21   INTERFACE: NASOTRACH TUBE;  BREATH SOUNDS: COARSE CRACKLES, WHEEZING, END EXPIRATION, BOTH LUNGS;
         POSITION: SEMI-FOWLER;  PATIENT CONDITION: CALM, MEDICATED;  SUCTIONED, 4 CC, LIGHT, TAN, BLOOD STREAKED, THIN;
         THERAPIST: HOLVERSON, JEFF
                                                                                          EXAM: ______________________
  -- NO SPONTANEOUS PARAMETERS WITHIN THE LAST 24 HOURS --                                      ______________________
-----------------------------------------------------------------------------------------------------------------------------
NEURO AND PSYCH:   0
   GLASGOW 11 (20:15) VERBAL ________   EYELIDS ________   MOTOR __________   PUPILS ________   SENSORY ________

   DTR ___________   BABIN. ________   ICP ___________   PSYCH __________
-----------------------------------------------------------------------------------------------------------------------------
COAGULATION:   0
   PT:          (         ) PTT:       (         ) PLATELETS:  161 (20:20    )  FIBRINOGEN:    (     ) EXAM: ____________
   FSP-CON:     (         ) FSP-PT:    (         ) 3P:             (         )                             ____________
-----------------------------------------------------------------------------------------------------------------------------
RENAL, FLUIDS, LYTES:   0
   IN   4085 CRYST    2005  COLLOID          BLOOD   500 NG/PO    1580 | NA   140 (20:20) K   3.7   (20:20)  CL   108  (20:20)
   OUT  2940 URINE    1356  NGOUT        25  DRAINS      OTHER    1399 | CO2 26.0 (20:20) BUN   13  (20:20)  CRE   .8  (20:20)
   NET  1145 WT             WT-CHG           S.G.    1.018             | AGAP    9.7      UOSM                 UNA       CRCL
-----------------------------------------------------------------------------------------------------------------------------
METABOLIC --- NUTRITION:   0
   KCAL     1420  GLU   131(15 20:20)  ALB          (         ) | CA      (         )  FE      (         )  TIBC      (       )
   KCAL/N2  122   UUN      (         )  N-BAL   .0              | PO4     (         )  MG      (         )  CHOL      (       )
-----------------------------------------------------------------------------------------------------------------------------
GI, LIVER, AND PANCREAS:   0                                                                                 EXAM:
   HCT     36.8 (15 20:20)   TOT BILI      (        )  SGOT      (        )  ALKPO4      (        )  GGT      (       ) __________
   GUAIAC NG 0+  (15 04:00)  DIR BILI      (        )  SGPT      (        )  LDH      (        )  AMYL     (       ) __________
-----------------------------------------------------------------------------------------------------------------------------
INFECTION:   0
   WBC 10.4(20:20 ) TEMP  39.3 (14 18:00) DIFF   0 B, 84P, 10L,  5M,  1E (05:51) 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        200   VERAPAMIL, TAB                          MGM   NG          320
ACETAMINOPHEN, ELIXIR                  MGM   NG       1950   FUROSEMIDE, INJ                         MGM   IV           60
MORPHINE, INJ                          MGM   IV         19   SUCRALFATE (CARAFATE), TAB              MGM   NG         4000
MIDAZOLAM (VERSED), INJ                MGM   IV        190   HEPARIN, INJ                            UNITS SUBQ      10000
MIDAZOLAM (VERSED), INJ                MGM   IV         25   LEVOTHYROXINE (SYNTHROID), TAB          MGM   NG         .200

FLUOXETINE (PROZAC), CAP               MGM   NG         40   JEVITY, LIQUID                          ML    NG D       1540
VANCOMYCIN (VANCOCIN), INJ             MGM   IV       2000   TAP WATER, LIQUID                       dL    NG          240

-ROUTINE CULT-  **-PRELIMINARY REPORT-**        15JUN 13:52
    SOURCE:  SPUTUM
    STAIN:   FEW WBCS, NO BACTERIA OBSERVED,

-ROUTINE CULT-  **-PRELIMINARY REPORT-**        14JUN 13:55
    SOURCE:  OF SPECIMEN,  LINE,  ARTERIAL
    RESULT:  NO GROWTH IN 24 HOURS,

-ROUTINE CULT-  **-PRELIMINARY REPORT-**        14JUN 13:55
    COMMENT: SEE PRINTED LAB REPORT FOR COMMENTS
    SOURCE:  OF SPECIMEN,  CATHETER,  TIP
    RESULT:  NO GROWTH IN 24 HOURS,
```

FIG. 151-3. Rounds report used for evaluating patients each day during physician teaching rounds. The report is abstracted from many locations and sources. Data are formatted into a physiologic system structure.

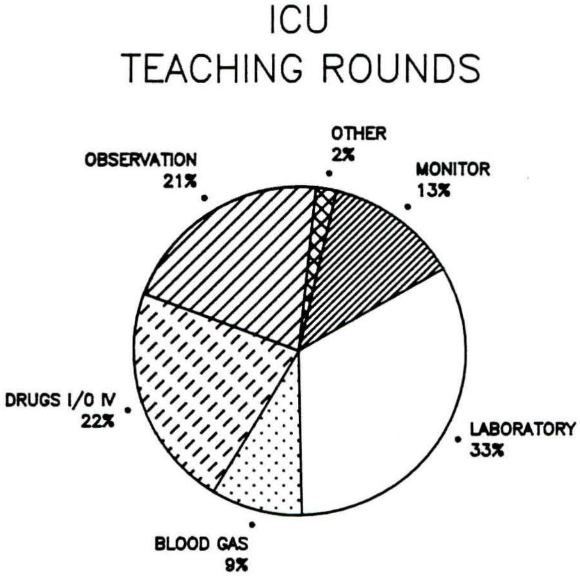


FIG. 151-4. Pie chart shows data used for clinical decision-making by physicians during physician teaching rounds in our shock trauma ICU. (From Gardner RM, Bradshaw KE, Hollingsworth KE: Computerizing the intensive care unit: Current status and future directions. *J Cardiovasc Nurse* 1989; 4:68; data from Bradshaw KE, Gardner RM, Clemmer TP, Orme JF Jr, Thomas F, West BJ: Physician decision-making—evaluation of data used in a computerized ICU. *Int J Clin Monit Comput* 1984; 1:81)

transcription errors are eliminated, and nursing and technician time is saved because telephone calls are unnecessary.[13]

With the increased use of computer technology in the ICU, a growing need exists for nurses and physicians to interact with the computer.[17] Different methods of interaction have been proposed, including conventional keyboards, light pens, and voice recognition. In one study, these three input devices were compared for speed, accuracy, and ease of use by 20 ICU nurses.[18] The study showed that keyboard input was considered the quickest, most accurate, easiest, and most preferred method of interaction.

## ELECTRONIC MEDICAL RECORDS

The medical record for every patient is a document that begs to be computerized.[19] For ICU patients and those undergoing anesthesia and surgery, this need is especially urgent. Information in the medical record should be easily retrievable and reviewable. Records having these characteristics simplify the routine processing of data required for medical decisions. As a result, many investigators have attempted to computerize the medical record and make it "paperless."

The patient record remains the principal instrument for ensuring the continuity of care. There is a need to integrate and organize patient records to optimize data review and decision-making. The traditional handwritten record has many limitations. For example, it can only be used by one person at a time at one location. Also, it is often poorly organized and is available only in the format in which it was recorded. In many ICUs, nurses must process and organize data from the written chart and then re-record the data on large flow sheets. Data retrieval for quality assurance and research must be done by hand. Unfortunately, output from instruments that produce digital results must be logged by hand, leading to inefficiency and entry errors.

Although the limitations of accessibility, format, and availability are germane to all patient records, they are especially problematic in the ICU. Computer charting in the ICU must support the collection of multiple types of data to be effective. Results of a recent study conducted in the shock-trauma ICU at LDS Hospital showed that much of the data needed for making treatment decisions was obtained from observations and manual tasks, and many results came from outside the ICU. Figures 151-1 and 151-2 illustrate the wide variety of data needed to care for a critically ill patient.

To meet the clinical management needs of the ICU patient and provide an adequate legal record of care given, several computerized data management reports have been developed. Figure 151-5 shows a computer-generated 12-hour nursing shift report for a patient who has undergone open heart surgery. The upper section of the report documents physiologic data and summarizes laboratory data. In the lower section, drugs, intravenous fluids given, and intravenous infusion rates are presented. Other reports can be generated by using different formats from the same data set. Physician rounds reports are used to summarize data by organ system. Reports such as these replace the large handwritten flow sheets commonly seen in the ICUs and can be generated as needed so they remain current (see Fig. 151-3).

Because an increasing number of computer programs are being used in medicine, there is some concern about legal and ethical issues.[20,21] Guidelines for deciding when it is appropriate to use a medical program have not yet been developed. A computerized record can neither immunize against nor expose one to a malpractice case.[22] The legible and complete record that computers can provide should assist in the defense. As Kroll said, "It is the doctor who does a good job, but who cannot defend because of a bad record, bad documentation, or an incomplete or imprecise story who may be helped by computer charting."

The legal problems associated with computer programs that provide medical advice have yet to be addressed by the courts.[20,21] In all likelihood, adverse outcomes resulting from the use of computerized decision-support systems will be governed by the legal principle of negligence liability.[21]

## COMPUTERIZED MEDICAL DECISION-MAKING

The hallmark of a good physician or nurse is his or her ability to make a sound clinical judgment. In the past, clinical judgments and the decision-making process were thought to be artful and intuitive rather than scientific. Nevertheless, computers have been used to aid medical practitioners in the care process.

A computerized medical decision-support system is any computer program designed to help health care professionals

```
TEMPORARY REPORT FROM: JUN 15 91 06:01   TO: JUN 15 91 18:00

        NORM                    # 1172     E611

 AGE:  42   WT:  89.70 KG   HT: 167 CM   BSA  1.99 SQM   DR: DEAN, NATHAN C.
             P HR TEMP
            SD *  C   P      JUN 15 91 06:01 - JUN 15 91 18:00
                       6   7   8   9  10  11  12  13  14  15  16  17  18
            --------I+---+---+---+---+---+---+---+---+---+---+---+---+
              235 41I                                                          YESTERDAY'S WEIGHT:
                    I                                                          TODAY'S WEIGHT:
              220 40I                                                    *                              *
                    I                                                    ********** 18:00 TO 18:00 *********
              205 39I                          CC                        *                              *
                    I     P     P            CCCCCCCC                     MAXIMUM TEMP: 39.0
              190 38I                                CCCCCCCCCCCC
                    I       S                                              INPUT
              175 37I                                                        IV:         2005
                    I                                                        BLOOD:       500
              160 36I                                                        COLLOID.
                    I                                                        TOTAL:      4085   NET:  1145
              145 35I                SS S
                    I       S  S  SSS   S                                  OUTPUT
              130 34I   SS     S S     S   S                                 URINE:      1356
                    I-S--S--SS-----S---S------SSSSS------------------        DRAIN:       185
              115   I  SS                         SS S     SS  SSSSS         TOTAL:      2940
                    I               *              S SSSSS  SS     S     *                              *
              100   I                ****                                *********** LAB RESULTS ***********
                    I      **       *     *****  *                       *                              *
               85   I  * ** *  *******          **  *** ****  * ***
                    I.**.*..*.............D...............*.....**.*...*    WBC      8.2     JUN 15 91 05:51
               70   I         D  D  DD  D DDD           *                HCT     31.2     JUN 15 91 05:51
                    I DDDDDDDD  D DD  DD       DD DDDDD D DDDDDDD DDDDD  HGB     10.3     JUN 15 91 05:51
               55   I        D                  D     D D       D    D
                    I                                                    NA      139      JUN 15 91 05:51
               40   I                                                    K         3.8    JUN 15 91 05:51
                    I                                                    CL      111      JUN 15 91 05:51
               25   I                                                    CO2      22      JUN 15 91 05:51
                    I                                                    BUN      12      JUN 15 91 05:51
               10   I                                                    GLUC    142      JUN 15 91 05:51
                       6   7   8   9  10  11  12  13  14  15  16  17  18  CREAT     0.7    JUN 15 91 05:51
            --------I+---+---+---+---+---+---+---+---+---+---+---+---+
RAP (MMHG)                                     14  14      14      15
PA SP (MMHG)                                   50  50      48      54
PA DP (MMHG)                                   24  30      32      26
PA MEAN (MMHG)                                 32  36      37      35
PA WEDGE (MMHG)                                14  14      18      18
CO (L/MIN)                                   8.40
RESP RATE                    21      20        20  18      19      21
URINE SP G                1.018
URINE GLUCOSE               NEG
URINE PH                    6.0
URINE BLOOD                  1+
UROBILINOGEN                  4
URINE PROTEIN                1+
BILIRUBIN                    4+
KETONES                      0+
TUBE/DRAIN PH               6.0
OXIMETRY - SVO2                                60  67      59      59
OXIMETRY - STO2 (F)          92      87        87  89      89      85
MEAN BP (MMHG)               86      91        80          79      76
FOLEY CATH URINE             80      80       120  60      60     400

TIME           CO    CI   HR  SV  SI  VP  MSP  MP SVR LWI  PW  PA  PVR  RWI
NORMAL HI    7.30  3.50   89 101  48   5  123 105  18  85  12  19  1.0  11.0
NORMAL LOW   2.90  2.80   49  47  38   1   80  70  12  48   4   9  0.5   8.0

JUN 15 13:00  8.40  4.23  89  94  48 14.0M 102  81   8  57  14  32  2.1  11.8
        LV PARAMETERS ARE WITHIN NORMAL LIMITS


                                                                  JUN 15 91 06:01 - JUN 15 91 18:00
                                                               6   7   8   9  10  11  12  13  14  15  16  17  18
                                                   -------------I+---+---+---+---+---+---+---+---+---+---+---+---+
ACETAMINOPHEN, ELIXIR                      650 MGM   NG                              1
MORPHINE, INJ                              1.0 MGM   IV          5     4
MIDAZOLAM (VERSED), INJ                    2.5 MGM   IV          1     1             1 21
FLUOXETINE (PROZAC), CAP                    40 MGM   NG                1
VANCOMYCIN (VANCOCIN), INJ                1000 MGM   IV                1
                                                                                                    #128 - pg1
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FIG. 151-5. Example of a 12-hour shift (6:00 AM to 6:00 PM, June 15, 1991) generated by the computer. The top line shows the patient's identification, weight, and height. Moving down the sheet, physiologic data (systolic and diastolic pressures, heart rate and temperature) are plotted. To the right are shown the weight comparison, daily maximum temperature, and a 24-hour intake and output summary, along with the most current laboratory results.

```
VERAPAMIL, TAB                                                80 MGM   NG               3                                   1
FUROSEMIDE, INJ                                               20 MGM   IV                                             1   2
SUCRALFATE (CARAFATE), TAB                                  1000 MGM   NG                           1                       1
HEPARIN, INJ                                                5000 UNITS SUBQ                         1
LEVOTHYROXINE (SYNTHROID), TAB                             0.200 MGM   NG               1
TAP WATER, LIQUID                                             30 ML    NG               1   1       1                       2
LACTATED RINGERS, INJ                                        250 ML    IV   *******
        INFUSION RATE                                      10.00 CC/HOUR    5555 5
        INFUSION RATE                                      750.  CC/HOUR        11
JEVITY, LIQUID                                               100 ML    NG D *********************
LACTATED RINGERS, INJ                                        797 ML    IV         *******************************************
        INFUSION RATE                                      10.00 CC/HOUR          55555555 555555555  55555555555555551111111
        INFUSION RATE                                      50.00 CC/HOUR                5        99
JEVITY, LIQUID                                               520 ML    NG D                     *****************************
NORMAL SALINE, INJ                                            19 ML    IV                               *********************
        INFUSION RATE                                      1.000 CC/HOUR                                    44444444445555555
MORPHINE, INJ                                               44.0 MGM   IV                                   *****************
        INFUSION RATE                                      5.000 MGM/HR                                     12222222222222222
  NORMAL SALINE, INJ                                          44 ML
MIDAZOLAM (VERSED), INJ                                     45.0 MGM   IV                                   *****************
        INFUSION RATE                                      5.000 MGM/HR                                     12222222222222222
  NORMAL SALINE, INJ                                          45 ML
PACKED RBC                                                   250 ML    IV                                               ***
  O NEGATIVE
  NO.                                                    2076545
NORMAL SALINE, INJ                                           100 ML    IV                                               *****
        INFUSION RATE                                      1.000 CC/HOUR                                                55555
PACKED RBC                                                   250 ML    IV                                                 ***
  O NEGATIVE
  NO.                                                    2076548
                                                                            6   7   8   9  10  11  12  13  14  15  16  17  18
                                                            --------------|+---+---+---+---+---+---+---+---+---+---+---+---+

INTAKE (ML):  BLOOD                500  OUTPUT (ML):  INSENSIBLE LOSS    710
              NON-BLOOD IV        1255                DRAINAGE
              ENTERAL FEEDING      770                Foley cath out     800
                                                      NG tube drg.        25
                TOTAL             2525                  TOTAL           1545    NET BALANCE        980

                                  # 1172    E611


TIME OUT JUN 15 91 23:42
(END)                                                                                              #128 - pg2
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FIG. 151-5. *(Continued)*

make clinical decisions.[23–25] Shortliffe,[25] one of the pioneers in applying artificial intelligence to medicine, outlined three types of decision-support tools:

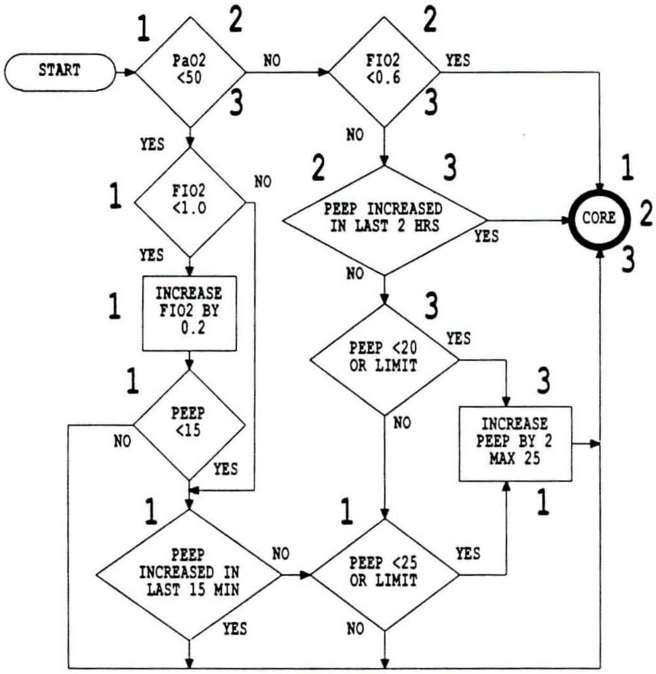
1. *Information management*, such as those available through Grateful Med or other mechanisms to search the National Library of Medicine MEDLINE library resources
2. *Focusing attention*, such as flagging an abnormal laboratory value
3. *Patient treatment suggestions*, offering patient-specific protocols for directing care

The opportunity to use computers to help in the complex task of decision-making in critical care has just begun. To make effective decisions, health care professionals and computers must have access to relevant data in an accurate, timely, and machine-usable form. Typically, physicians collect information from several sources, extract the appropriate information, and try to remember what data are relevant so they can make optimal patient-care decisions.[26] Eddy[27] challenged the validity of this process: "It is simply unrealistic to think that individuals can synthesize in their heads scores of pieces of evidence, accurately estimate the outcomes of different options, and precisely judge the desirability of those outcomes for patients. The complexity of modern medicine exceeds the inherent limitations of the unaided human mind." McDonald and his associates[26,28] have shown that humans are not perfect data processors and that they do not always make consistent decisions. The issue of data overload is a major problem of critical care today.

Figure 151-2 shows the flow of data into the Health Evaluation through Logical Processing (HELP) computer system used at LDS Hospital. The HELP system is unique among hospital information systems because it collects data and performs decision-making on the clinical data that are acquired. Notice the stippled ring surrounding the patient database. As data are gathered and entered into the system, they are used to "data drive" computerized decision-making "frames."

The decision-making processor uses medical knowledge derived from the medical literature, interrogation, and interaction with medical experts and from data stored in computerized data bases. The HELP system has a data drive capability that processes incoming information to provide a variety of data reviews (see Fig. 151-5). Alerts that warn of life-threatening situations are also generated.[29,30] Calculated parameters like stroke volume are derived from heart rate and cardiac output, and interpretations for blood gas and cardiac output measurements are made (see Figs. 151-3 and 151-5).

Computerized alerts and quality assurance have become important activities of medical computing, especially in the ICU.[29–38] Alerts are generated as a result of the automatic




PATIENT DATA:

| | 0 MINUTES | 15 MINUTES | 120 MINUTES |
|---|---|---|---|
| PaO2 | 49 | 58 | 59 |
| FIO2 | 0.4 | 0.6 | 0.6 |
| PEEP | 10 | 12 | 12 |

PROTOCOL INSTRUCTIONS:

| | | |
|---|---|---|
| INCREASE FIO2 BY 0.2 AND PEEP BY 2 CM H2O, OBTAIN ABG IN 15 MINUTES | WAIT 1 HOUR 45 MINUTES, OBTAIN ABG IN 1 HOUR 45 MINUTES | INCREASE PEEP BY 2 CM H2O, OBTAIN ABG IN 15 MINUTES |
| 1 | 2 | 3 |

FIG. 151-6. This protocol flow chart illustrates a simplified and selected portion of one of approximately 30 pages of protocols used for control of arterial oxygenation in ARDS patients. (Morris AH: Use of monitoring information in decision making. In *Contemporary Management in Critical Care 4: Respiratory Monitoring,* pp 213–253. New York, Churchill Livingstone, 1991)

interpretation of laboratory data, from respiratory care, and from the pharmacy.[29,30,32,33,39]

A more comprehensive application of computers in medical decision-making involves computerized protocols that are used to aid and guide physicians in the conduct of a patient's therapy.[40] Computer-driven protocols using the HELP system have been successfully used to manage patients with severe arterial hypoxemia.[41–46] Although these protocols are limited to application in only one hospital, they have proven the feasibility and utility of using computer-directed patient care. Physicians have followed the protocols more than 90% of the time during more than 20,000 hours of use. Survival rates for adult respiratory distress syndrome (ARDS) have been improved approximately fourfold using the protocols.[45,46] Figure 151-6 illustrates in simplified form a small segment of more than 30 pages of detailed ARDS protocols. Results from using a computerized ICU patient advice system has shown that we can standardize patient treatment and enable investigators to compare scientifically the effects of different treatment regimes.

## FUTURE DIRECTIONS

Society has an expectation of "star wars" technology from the military, entertainment, and medical fields. Many consider the progress we have made as the stuff of science fiction. Real progress has been made, and the beliefs and hopes for the future inspire further development of computerized medical decision-making. We must learn to harness the power of computers to assist health care professionals.

The advances of computers in the ICU will be evolutionary rather than revolutionary. The infrastructure of the health care system needs to be changed to maximize the benefits of computerized ICU care.

Critical care is not just practiced in an ICU. It is not unusual to have a patient on an ordinary hospital floor bed connected to pulse oximeters, ECG telemetry, intravenous pumps, and other sophisticated instruments. Care given in an ICU today will be applied to floor patients within a few years. The medical computer systems of the future will take an active, yet subordinate, role in providing quality patient care. Computers, however, will never have the capability of the human being to deal with unexpected and complex situations.

This chapter is based in part on Gardner RM, Bradshaw KE, Hollingsworth KW: Computerizing the intensive care unit: Current status and future directions. *J Cardiovasc Nurs* 1989; 4:68.

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