Chapter 18

The Computer for Charting and Monitoring

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INTRODUCTION

Frequent measurement of patient parameters such as heart rate, respiratory rate, blood pressure, and oxygen saturation have become a central feature in the care of acutely ill patients. When timely and accurate decisions are required for providing therapy, patient monitors frequently are used to collect and display physiological data. A patient monitor is usually thought of as a piece of equipment that watches for—and warns against—life-threatening events. Hudson has defined monitoring as: "Repeated or continuous observations or measurements of the patient, his or her physiological function, and the function of life support equipment, for the purpose of guiding therapeutic interventions, and assessment of those interventions."[1] Two decades ago, patient monitoring occurred only in the intensive care unit (ICU), but today it is not uncommon to have ECG telemetry transmitters and pulse oximeters attached to patients throughout the acute care areas of hospitals.

COMPUTERIZED PATIENT RECORDS

The medical record is the principal instrument for ensuring the continuity of patient care. There is a need to integrate and optimize medical data review and decision-making. The traditional handwritten medical record has several limitations:

1. It may be physically unavailable since it can only be used by one person at one location at a time.

2. It is often poorly organized, available only in the order and format in which it was recorded, and many times is illegible. As a result, information retrieval may be impossible, slow, and error prone.
3. Retrieval of data for research is time-consuming and cumbersome because it must be done manually.
4. Medical devices, such as pulse oximeters and ventilators, that present data in electronic form require their data to be captured by a human and written into the chart.

Thus, the medical record is a document that begs to be computerized.[2–4] Improvement in clinical information-management systems is frequently cited as one strategy for coping with the cost and inefficiency of our health care system.[2–4] Often information in a chart is written in illegible handwriting, has missing reports, and pages filed out of chronological order. Many times the data must be transcribed or rerecorded in another format for quality assurance reviews or billing purposes. Recently, the Institute of Medicine (IOM) undertook an 18-month study to examine the status of patient records and of computer-based approaches to their management.[2–4] The IOM called for an unequivocal adoption of computer-based medical records. They pointed out that informed patient-care decisions depend on timely access and management of patient information. The computer record provides an unusual opportunity to meet the objectives pointed out by the IOM.

The IOM made the following recommendations for the computerized medical record[4]:

1. Health care professionals and organizations should adopt the computer-based medical record as the standard for medical and all other records related to patient care.
2. The public and private sector should join in setting up a Computer-based Patient Record Institute (CPRI).
3. Both the public and private sectors should expand support for computerized records through research, development, and demonstration projects.
4. Uniform standards for data and security to facilitate implementation of computerized records and data bases should be developed.
5. Federal and state laws and regulations should be reviewed so that model legislation to facilitate computer records will be developed.
6. The cost of computerized record systems should be shared by public, private, and third-party payers.
7. Health care professional schools and organizations should enhance educational programs for students and practitioners in the use of computers.

In 1985, Andrews et al.[5] pointed out that an ideal computerized respiratory care charting and monitoring system would have the following characteristics:

1. No repetition of work or reporting.
2. Easy access to terminals for data entry and review.
3. Accurate, timely, and descriptive documentation.
4. Automatic performance of many functions from a singe data entry (for example, billing, management statistics, medical record generation, error checking, quality assurance, data interpretation, and computerized patient-care protocol generation).

5. Exact correlation between clinical charting and billing.
6. Integration of respiratory care information with that of other hospital departments (e.g., the blood gas laboratory, clinical laboratory, infectious disease department, and medical records).
7. Availability of information for diagnostic, treatment, and research purposes.
8. Easy implementation.
9. Reliable system operation (i.e., no downtime or loss of data).
10. Cost-effective—inexpensive equipment that pays for itself.
11. Electronic access to data from bedside data collection devices (e.g., pulse oximeters and ventilators).

Several of these ideals have been implemented at the LDS Hospital in Salt Lake City, Utah. Challenges and opportunities with this computerized hospital information system will be discussed to illustrate the feasibility of such systems.[5, 6]

LDS HOSPITAL AND THE HELP HOSPITAL INFORMATION SYSTEM

LDS Hospital is a 520-bed, university-affiliated, tertiary care center. The hospital serves as a referral center for trauma victims and maintains active programs in cardiovascular surgery and renal, liver, and cardiac transplantation, as well as other surgical services. The hospital has four adult ICUs with 60 beds and one 12-bed neonatal ICU.

The HELP Hospital Information System uses an integrated clinical patient data base and has decision-making capabilities.[6] Figure 18–1 shows the multitude of data collection sources used in the care of the acutely ill patient. As data flow into the data base, it activates (illustrated by the concentric circles in Fig 18–1) the medical decision-making capabilities of the computer system. The HELP computer runs on a highly reliable computer system that uses redundant processors and has "mirrored" disk volumes to provide the reliability and availability needed for clinical use. There are more than 1000 terminals, including terminals at all ICU bedsides, and more than 200 laser printers for generating reports.

Figures 18–1 and 18–2 illustrate how data flow into the integrated patient data base from multiple sources. The patient data base stores primarily coded data so that it can be used for computerized medical decision-making and report generation. Figure 18–2 shows that for respiratory care, the data entered into the system are used for a host of purposes. The left-hand side shows the more conventional uses of "charting" data and the right-hand side shows how the data are used by the computer for medical decision-making.

Charting

Charting by respiratory therapists and nurses is primarily initiated by entry through bedside terminals (note the computer terminal on the far left-hand side of Fig 18–3). Entries are made by selecting multiple-choice items from a menu, by number entry, or, in some limited situations, by typing in a free-text format. The menu entry format follows a logical sequence that corresponds with the charting requirements. Multiple entries at one time can be done

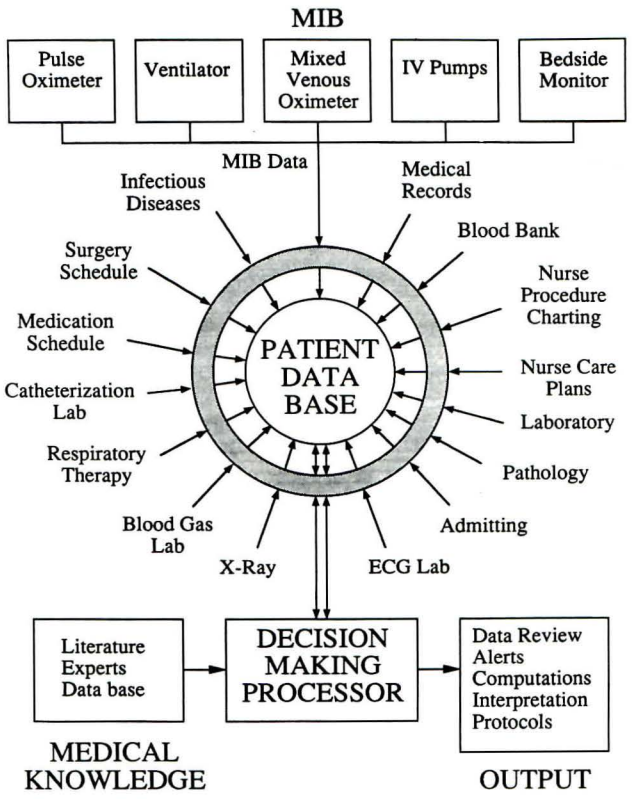

FIG 18–1.
Diagram of the HELP system computerized ICU data collection system. Shown are the large number of data sources required to take care of the ICU patient. The Medical Information Bus is used to collect data from the bedside noted. (*From Gardner RM, Hawley WH, East TD, Oriki T, Young HFW. Real Time Data Acquisition: Recommendations for the Medical Information Bus (MIB).* Intl J Clin Monit and Comput *1992; 8:251–258. Used by permission.)*

together. To speed the process, only questions pertinent to the specific procedure are asked. The only questions to which answers are required are those pertaining to medical, legal or billing issues. Therapists and nurses are responsible for complete and accurate charting. All entries are "tagged" with employee identifications numbers, which serve as an electronic "signature."

Patient Reports

Review of respiratory care charting is available from any of the more than 1000 terminals in the hospital or from phone-in capabilities from physicians' offices and homes. In addition, laser-printed hardcopy reports are available in the hospital (Fig 18–4). Physicians also have the

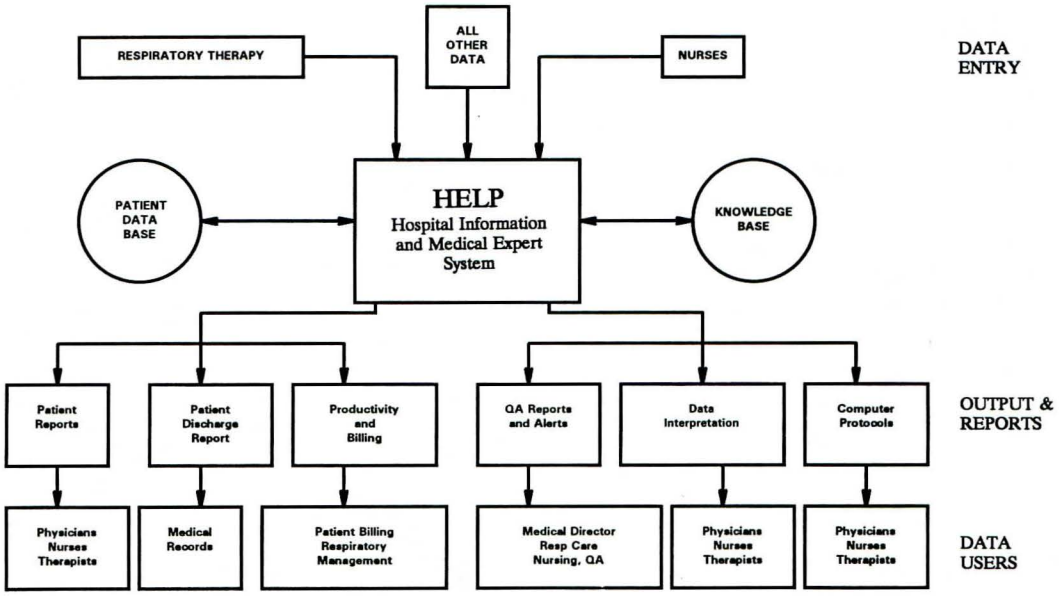

FIG 18–2.
Block diagram of the HELP Hospital Information System and how it integrated the patient data base and knowledge base used for medical decision-making. The system not only provides administrative support, but also uses the medical expert system capabilities of HELP to provide clinical decision support.

option of reviewing a summary of respiratory care data and a large variety of other patient data in a ROUNDS report as illustrated in Figure 18–5.

Administrative and Management Reports

Each night, just past midnight, the computer automatically generates two reports.

1. A patient discharge report for patients discharged the previous day. This report is sent to medical records as the final "official" report.
2. A respiratory therapy and hospital management report on productivity and billing. At the same time this report is generated, an "electronic" bill is automatically transmitted to the hospital's billing system.[5]

MEDICAL INFORMATION BUS: AUTOMATED DATA ACQUISITION

Care of the acutely ill patient requires rapid acquisition, recording, and communication of data. It is not unusual for a hospitalized patient to be connected to several monitoring and recording devices simultaneously (Fig 18–1).[7, 8]

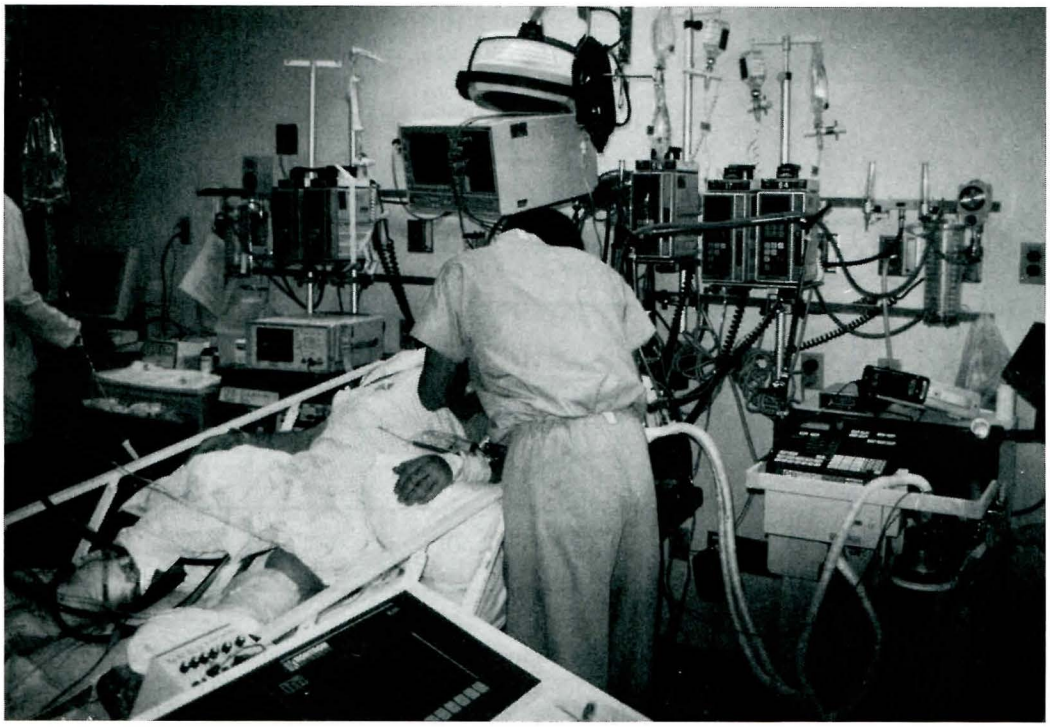

FIG 18–3.
Typical ICU setting. On the far left is a bedside computer terminal. Next is a mixed venous O_2 saturation monitor and four IV pumps. Above the patient's head is a bedside monitor that does ECG, arterial, and pulmonary artery pressure monitoring. To the right of the standing nurse is a Puritan-Bennett 7200 ventilator with a pulse oximeter on top. All of these electronic devices are connected to the HELP computer system through the Medical Information Bus.

Each of these devices is typically made by a different manufacturer who may specialize in one type of measurement (e.g., pulse oximetry). Most of the modern monitoring and recording devices are based on microcomputers and have communications capabilities. Unfortunately, as yet, no standard communications technology is available for all devices.[8] In addition, different clinical staff (physicians, nurses, or respiratory therapists) may be responsible for collection of data from these devices. As a result, the need exists to develop methods, standards, and strategies for automatic gathering of timely, accurate, and representative data from these devices.

To facilitate automatic data acquisition from the multitude of physiological devices located at the bedside, we have integrated data flowing from these devices with the Medical Information Bus (MIB).[7, 8] Experience with the prototype MIB we built gave us insight into the problems of using automated data collection. Problems arise around who owns the data. Should it be the nurses, therapists, blood gas technicians, or physicians who chart the inspired oxygen percentage? There also were problems with the timeliness of data entry as well as deciding

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                                LDS HOSPITAL  RESPIRATORY CARE CHARTING
                                              DEC 26, 1991

[redacted]                      AGE: [redacted]      SEX: M      E60[redacted]                    PATIENT ID#:  12032[redacted]
LIVER CANCER                                 DR. BELNAP, LEGRAND P.                              ADMITTED: DEC 12, 1991


12/26/91                                                VENTILATOR MONITORING

        VENT MODE  VR  Vt   O2  PF  IP TEMP IE RATIO PK  PL  MAP PP m-Vt c-Vt s-Vt  MR  SR  TR m-VE s-VE t-VE  Cth  aOX vOX Pc  CF
26 07:29 B-II A/C  23  750  49  65     35.0  1: 2.0  40  29       5  910  781       26          20.3            32.5  88  73 19 3.7
26 05:47 B-II A/C  22  750  50  65     35.0  1: 2.1  42  30       5  930  793       27          21.4            31.7  88  73    3.7
26 04:36 B-II A/C  23  750  50  65     35.0  1: 2.2  40  30       5  940  811       26          21.1            32.4  88  75    3.7
26 04:36 B-II A/C              50

12/26/91 DUR/ENTRY                                      OBSERVATIONS
26 07:29  20/07:35 - INTERFACE: ORALTRACH TUBE;  ALARMS CHECKED;  TEMP SETTING:  5.0;  POSITION: SEMI-FOWLER;  PATIENT CONDITION:
                     CALM;  SUCTIONED, 2 CC, AMBER, THICK;  COMMENT: CASCADE FILLED,TUBING DRAINED. HR=116, BP=93/49  THERAPIST:
                     GORDON, LAYNE  RRT
26 05:47  15/05:48 - INTERFACE: ORALTRACH TUBE;  PEEP SETTING: 5 CM;  TEMP SETTING:  5.0;  POSITION: SEMI-FOWLER;  THERAPIST:
                     COOMBS, JOE  RRT
26 04:36  15/04:38 - INTERFACE: ORALTRACH TUBE;  BREATH SOUNDS: COARSE CRACKLES, BOTH LUNGS;  ALARMS CHECKED;  TEMP SETTING:  5.0;
                     POSITION: SEMI-FOWLER;  THERAPIST: COOMBS, JOE  RRT
26 04:36   0/04:36 - DISCUSSED THERAPY CHANGE WITH: JAY/PROTOCOLS  THERAPIST: COOMBS, JOE  RRT


12/26/91                                                VENTILATOR MONITORING

        VENT MODE  VR  Vt   O2  PF  IP TEMP IE RATIO PK  PL  MAP PP m-Vt c-Vt s-Vt  MR  SR  TR m-VE s-VE t-VE  Cth  aOX vOX Pc  CF
26 01:47 B-II A/C  23  750  40  65     35.0  1: 2.1  40  30       5  940  811       26          21.1            32.4  88        3.7

12/26/91 DUR/ENTRY                                      OBSERVATIONS
26 01:47  15/01:48 - INTERFACE: ORALTRACH TUBE;  PEEP SETTING: 5 CM;  PLACED TRACH CARE CATHETER IN CIRCUIT;  TEMP SETTING:  5.0;
                     POSITION: SEMI-FOWLER;  THERAPIST: COOMBS, JOE  RRT


12/26/91                                                VENTILATOR MONITORING

        VENT MODE  VR  Vt   O2  PF  IP TEMP IE RATIO PK  PL  MAP PP m-Vt c-Vt s-Vt  MR  SR  TR m-VE s-VE t-VE  Cth  aOX vOX Pc  CF
25 23 49 B-II A/C  23  750  40  65     35.0  1: 2.4  40  30       5  950  821       24          19.7            32.8  88  72    3.7
25 21 43 B-II A/C  23  750  40  65     35.0  1: 1.8  40  30       5 1030  901       24          21.6            36.0  88  75    3.7

12/26/91 DUR/ENTRY                                      OBSERVATIONS
25 23:49  15/23:50 - INTERFACE: ORALTRACH TUBE;  PEEP SETTING: 5 CM;  BREATH SOUNDS: COARSE CRACKLES, THROUGHOUT INSPIRATION, BOTH
                     LUNGS;  TEMP SETTING:  5.0;  POSITION: SEMI-FOWLER;  PATIENT CONDITION: QUIET;  SUCTIONED, 3 CC;  THERAPIST:
                     COOMBS, JOE  RRT
25 21:43  15/21:44 - INTERFACE: ORALTRACH TUBE;  TEMP SETTING:  5.0;  POSITION: SEMI-FOWLER;  THERAPIST: COOMBS, JOE  RRT

                          ******  REPORT ONLY SHOWS CHARTING OF LAST 12 HOURS  ******
                           TO OBTAIN LONGER REPORTS, PLEASE USE OPTION #2 ON RT MENU
(END)                                                                                    #886 - pg1
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FIG 18–4.
A typical 12-hour respiratory therapist's chart.

what was "representative" for a time frame. Figure 18–6 shows examples of these errors. The issues illustrated by Figure 18–6 are just the "tip of the iceberg." We must establish methods and strategies to decide how often and what data should be recorded. Once these issues are dealt with, automated data collection will be more accurate and efficient.

Figure 18–7 shows a closeup view of IV pump number 77. This pump is infusing lidocaine (see upper display window) at 3 mL/hour (see lower display window). Any time the physician or nurse changes the drip rate, the MIB and computer system automatically log the data. With the MIB connected to the IV pumps, we are able to record infusions in a much more timely and accurate manner than the manual charting methodology. Note in the ROUNDS report of Figure 18–5 that the patient was receiving dopamine at 2.00 mcg/kg/min and that the information was presented in the "Cardiovascular" section near the cardiac output determination since it will have a major effect on cardiac output production.

Figure 18–8 shows the MIB interface box and a pulse oximeter on top of a Puritan-Bennett 7200 ventilator. We store 20 different parameters from the ventilator into the patient's

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

NAME: [redacted]                          NO.  12032[redacted]     ROOM: E60[redacted]                    DATE: DEC 26 08:15
DR. BELNAP, LEGRAND P.          SEX: M    AGE: [redacted]  HEIGHT: 187  WEIGHT:  98.70   BSA: 2.24  BEE:  2054  MOF:    0
ADMT DIAGNOSIS: LIVER CANCER                ADMIT DATE: 12 DEC 91
SURGERY: PANCREATIC-LIVER RESECTION

CARDIOVASCULAR:  0                                                                                    EXAM: _____
TIME              CO    CI   HR  SV  SI   VP  MSP  MP SVR LWI PW  PA  PVR   RWI                      _____
DEC 26 04:00   21.60 10.82  116 186  93 16.0M  80   65  2  78  18  26   .4  12.6
         DEC 26 02:42  DOPAMINE (INTROPIN)  2.00 MCG/KG/MIN
         LV PARAMETERS ARE WITHIN NORMAL LIMITS
                  SP    DP    MP   HR  |  LACT        CPK          CPK-MB       LDH-1        LDH-2
  LAST VALUES     94    50    65  116  |
  MAXIMUM        118    67    78  206  |     (   )      (   )        (   )        (   )        (   )
  MINIMUM         67    28    44  104  |

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
26 04:01 V  7.35   47.6    25.8    .5   9.7   3/ 1    44    71    9.8    40                                  0/  0/ 5  25/ 0
26 04:00 A  7.36   44.7    24.9   -.2  10.3   2/ 1    58    85   12.3    40                                  0/  0/ 5  25/ 0
         SAMPLE # 53, TEMP 37.9, BREATHING STATUS : ASSIST/CONTROL
         HB ERROR SUSPECTED, AV-O2, SHUNT, O2 EXTRACT RATIO NOT CALCULATED
         MODERATE ACUTE RESPIRATORY ACIDOSIS
         MODERATE HYPOXEMIA
         SEVERELY REDUCED O2 CONTENT (12.3) DUE TO ANEMIA (LOW HB)
         HYPOVENTILATION NOT IMPROVED
25 22:09 A  7.34   46.3    24.5   -.9  10.3   3/ 1    64    87   12.7    40                  120             0/  0/ 5  25/ 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
26 07:29    B-II  A/C   23  750   49    65              40   29   5   910   781        P6          20.3                32.5  19
25 21:43    B-II  A/C   23  750   40    65              40   30   5  1030   901        P4          21.6                36.0
26 07:29   20/07:35   INTERFACE: ORALTRACH TUBE;  ALARMS CHECKED;  POSITION: SEMI-FOWLER;  PATIENT CONDITION: CALM;  SUCTIONED,
       2 CC, AMBER, THICK;  COMMENT: CASCADE FILLED, TUBING DRAINED. HR=116, BP=93/49  THERAPIST: GORDON, LAYNE,  RRT
25 21:43   15/21:44   INTERFACE: ORALTRACH TUBE;  POSITION: SEMI-FOWLER;  THERAPIST: COOMBS, JOE,  RRT
                                                                                                    EXAM: _____
  -- NO SPONTANEOUS PARAMETERS WITHIN THE LAST 24 HOURS --                                                _____

NEURO AND PSYCH:  0
    GLASGOW  3 (08:00) VERBAL _____   EYELIDS _____   MOTOR _____   PUPILS _____   SENSORY _____

    DTR _____   BABIN. _____   ICP _____   PSYCH _____

COAGULATION:  0
    PT:   14.7   (05:30   ) PTT:     39 (05:30   ) PLATELETS:   90 (05:30   ) FIBRINOGEN:     (     ) EXAM: _____
    FSP-CON:     (     .  ) FSP-PT:     (       ) 3P: Neg          (24 20:17 )                            _____

RENAL, FLUIDS, LYTES:  0
    IN  13472 CRYST   2732  COLLOID    425  BLOOD       NG/PO     20 | NA   147 (05:30) K   4.3  (05:30)  CL   107  (05:30)
    OUT  6945 URINE    923  NGOUT           DRAINS 5705 OTHER   1317 | CO2 26.0 (05:30) BUN   83  (05:30)  CRE  3.3 (05:30)
    NET  6527 WT     98.70  WT-CHG    2.20  S.G.    1.017            | AGAP  18.3       UOSM               UNA      CRCL

METABOLIC --- NUTRITION:  0
    KCAL    2942  GLU   154(26 05:30)  ALB     1.7 (26 05:30) | CA   6.8 (26 05:30)  FE       (       )  TIBC      (       )
    KCAL/N2  446  UUN       (       )  N-BAL   .0             | PO4  6.6 (26 05:30)  MG       (       )  CHOL    80 (26 05:30)

GI, LIVER, AND PANCREAS:  0                                                                          EXAM:
    HCT    30.7 (26 05:30)  TOT BILI 35.0 (26 05:30)  SGOT  741 (26 05:30)  ALKPO4  970 (26 05:30) GGT  227 (26 05:30) _____
    GUAIAC       (     )    DIR BILI 28.0 (26 05:30)  SGPT   87 (26 05:30)  LDH 1330 (26 05:30)  AMYL 311 (26 05:30) _____

INFECTION:  0
    WBC 25.5(05:30 ) TEMP  38.0 (08:15)    DIFF   7 B, 73P, 14L,  6M,   E (05:30) 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

ACETAMINOPHEN, SUPP                MGM  RECT    650   MAGNESIUM                MEQ  IV    10.000
METRONIDAZOLE (FLAGYL), INJ        MGM  IV     2000   ZINC                     MGM  IV     6.000
NYSTATIN, SUSPENSION               ML   ORAL     20   COPPER                   MGM  IV     1.200
CEFTAZIDIME (FORTAZ), INJ          MGM  IV     3000   MANGANESE                MGM  IV      .600
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FIG 18–5.
An ICU ROUNDS report used by medical staff during morning rounds in the Shock Trauma ICU. Note the respiratory care data summarized in the middle of the report.

AMPHOTERICIN B, INJ	MGM	IV	45	CHROMIUM	MCG	IV	12.000
DOPAMINE, INJ	MGM	IV	315	CHLORIDE	MEQ	IV	0
NOREPINEPHRINE (LEVOPHED), INJ	MGM	IV	27	SULFATE	MEQ	IV	10.000
FUROSEMIDE, INJ	MGM	IV	200	GLUCONATE	MEQ	IV	9.000
FAMOTIDINE (PEPCID), INJ	MGM	IV	40.000	ELECTROLYTE VOLUME	ML	IV	122.000
DIPHENHYDRAMINE (BENADRYL), INJ	MGM	IV	50	MVI-12 , INJ	ML	IV	10.400
POTASSIUM	MEQ	IV	0	PHYTONADIONE (AQUA-MEPHYTON), INJ	MGM	IV	10
CALCIUM	MEQ	IV	9.000				

-ANAER CULT- **-PRELIMINARY REPORT-** 24DEC 18:50
SOURCE: OTHER, PELVIS
SMEAR TYPE: GRAM STAIN
STAIN: FEW WBCS,

-ROUTINE CULT- **-PRELIMINARY REPORT-** 24DEC 18:50
SOURCE: OTHER, PELVIS
SMEAR TYPE: GRAM STAIN
STAIN: FEW WBCS,
RESULT: NO GROWTH IN 24 HOURS,

-ANAER CULT- **-PRELIMINARY REPORT-** 24DEC 18:40
SOURCE: OTHER, PLEURA
SMEAR TYPE: GRAM STAIN
STAIN: NUMEROUS GRAM NEGATIVE BACILLI, MODERATE NUMBER OF WBCS, FEW YEAST,

-ROUTINE CULT- **-PRELIMINARY REPORT-** 24DEC 18:40
SOURCE: OTHER, PLEURA
SMEAR TYPE: GRAM STAIN
STAIN: NUMEROUS GRAM NEGATIVE BACILLI, MODERATE NUMBER OF WBCS, FEW YEAST,
RESULT: GRAM NEG. BACILLI MODERATE GROWTH

-ANAER CULT- **-PRELIMINARY REPORT-** 24DEC 18:15
SOURCE: FLUID ABDOMEN
SMEAR TYPE: GRAM STAIN
STAIN: FEW WBCS, FEW YEAST,

-ROUTINE CULT- **-PRELIMINARY REPORT-** 24DEC 18:15
SOURCE: FLUID ABDOMEN
SMEAR TYPE: GRAM STAIN
STAIN: FEW WBCS, FEW YEAST,
RESULT: NO GROWTH IN 24 HOURS,

-ANAER CULT- **-PRELIMINARY REPORT-** 24DEC 18:00
SOURCE: FLUID ABDOMEN
SMEAR TYPE: GRAM STAIN
STAIN: FEW WBCS, FEW YEAST,

-ROUTINE CULT- **-PRELIMINARY REPORT-** 24DEC 18:00
SOURCE: FLUID ABDOMEN
SMEAR TYPE: GRAM STAIN
STAIN: FEW WBCS, FEW YEAST,
RESULT: GRAM NEG. BACILLI FEW

-ANAER CULT- **-PRELIMINARY REPORT-** 24DEC 17:05
SOURCE: FLUID ABDOMEN
SMEAR TYPE: GRAM STAIN
STAIN: MODERATE NUMBER OF WBCS,

-ROUTINE CULT- **-PRELIMINARY REPORT-** 24DEC 17:05
SOURCE: FLUID ABDOMEN
SMEAR TYPE: GRAM STAIN
STAIN: MODERATE NUMBER OF WBCS,
RESULT: GRAM NEG. BACILLI FEW
(END)

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FIG 18–5. Continued

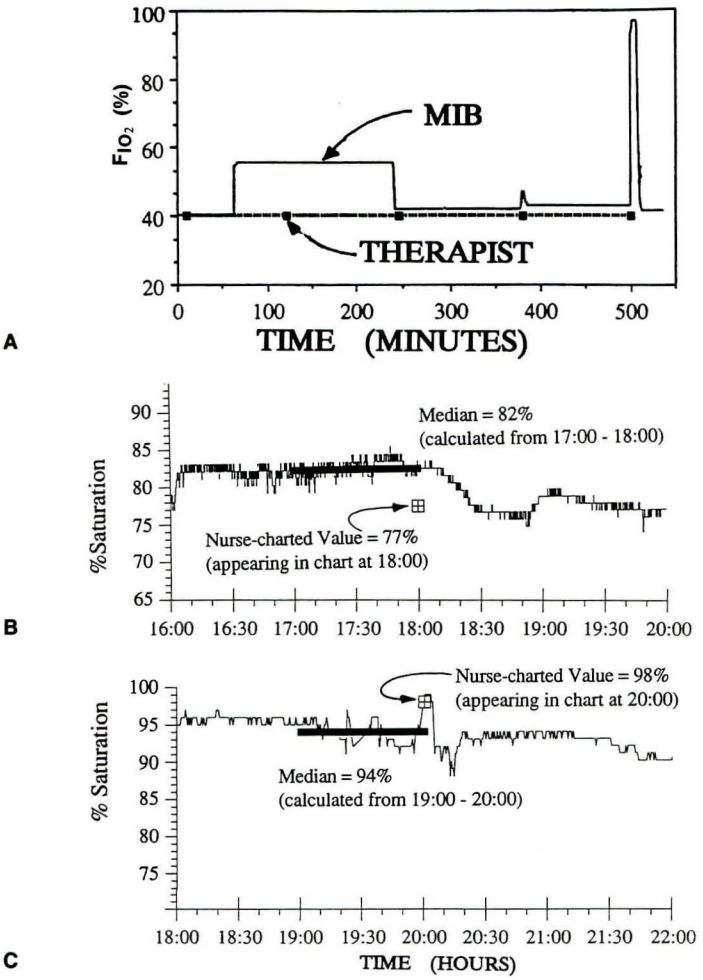

FIG 18–6.
Data recorded by the MIB. **A** shows MIB-recorded and therapist-charted F_{IO_2} data. Note the therapist *did not* chart the almost 3-hour increase in F_{IO_2}. **B** shows nurse- and MIB-charted O_2 saturations from a pulse oximeter. The nurse charted a saturation of 77% and said it occurred at 18:00. Most likely this was a "timeliness" error and the nurse made the measurement at 18:15. **C** shows that the nurse chose "atypical" for entry of saturation to put into the computer record. (*From Gardner RM, Hawley WH, East TD, et al: Real-time data acquisition: Recommendations for the Medical Information Bus.* Intl J Clin Monit Comput *1992; 8:251–258. Used by permission.*)

"electronic" medical record. Figure 18–9 shows a comparison of the data recorded by respiratory therapists and MIB for a 24-hour time interval. Therapists are instructed to record data at 2-hour intervals. As can be seen in Figure 18–9, the therapists have done an excellent job of data recording. However, at about 07:00 they increased the F_{IO_2} to 100% for a very short time interval and did not record it in the record. Later, at about 23:00 they increased the F_{IO_2}

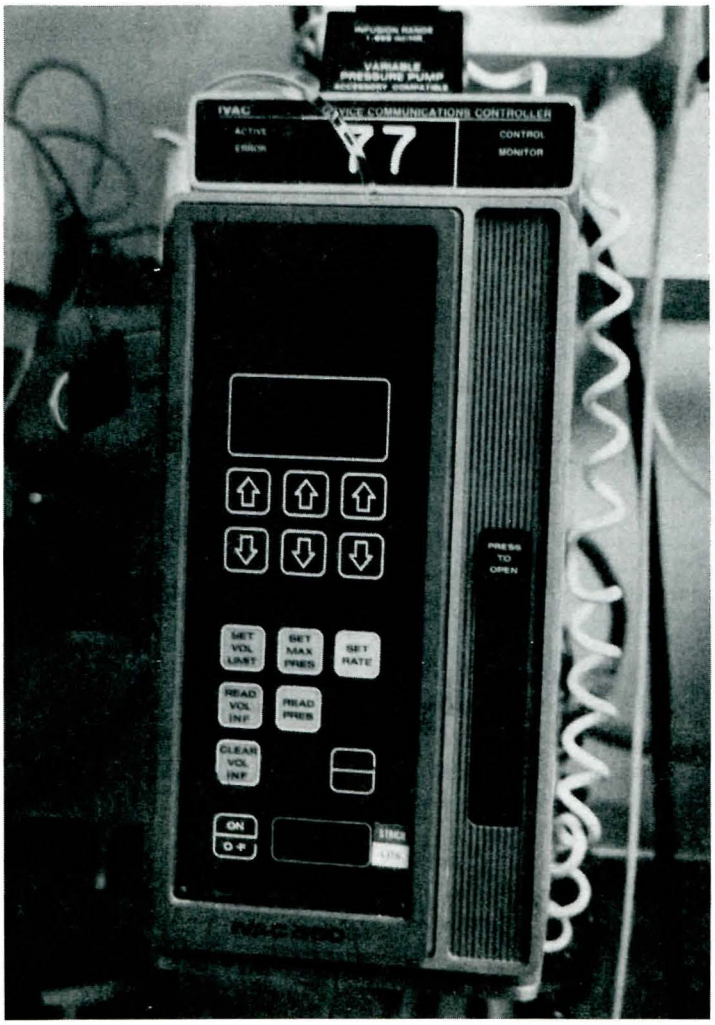

FIG 18–7.
Photograph of patient bedside IV pump indicating the medication lidocaine running at 3.0 mL/hour. Note the small MIB "box" with number 77 mounted on the top of the IV pump.

to 100% again and this time they did record the data. As can be seen from Figure 18–9, respiratory therapists record considerable "redundant" ventilator setting data. Nurses do not record the IV drip rates every hour or two, but only when they change the rate. Unlike IV drips, ventilators are commonly "played with" by physicians and others who *do not* record what they do, especially the change in ventilator settings. Therefore, there is a need to set up recording strategies to make sure these data are properly recorded. The MIB provides a method

FIG 18–8.
Photograph of a Puritan-Bennett 7200 ventilator with an MIB data interface box number 2003 on top. Also a pulse oximeter located next to the MIB interface box.

for acquiring the data, but does not completely solve the problem of *who* made the ventilator setting change.

Figure 18–10 shows measured tidal volume data recorded by the MIB and that manually entered by respiratory therapists. As can be seen, the therapists faithfully recorded the data every 2 hours. Unfortunately, they did not always record "representative" data as can be seen by several of the data points. In an attempt to record more representative data with the MIB, we have experimentally used a moving median for a 3-minute interval to acquire data. The MIB collects data from the ventilator every 10 seconds and then records a median every 3 minutes only if there is greater than a 50-mL change in corrected tidal volume. The bold line in Figure 18–10 is the computer's selection of the "representative" values for the 24-hour time interval. Although this methodology for recording of values is not yet widely reviewed and accepted, it is likely to be useful in clinical practice.[7]

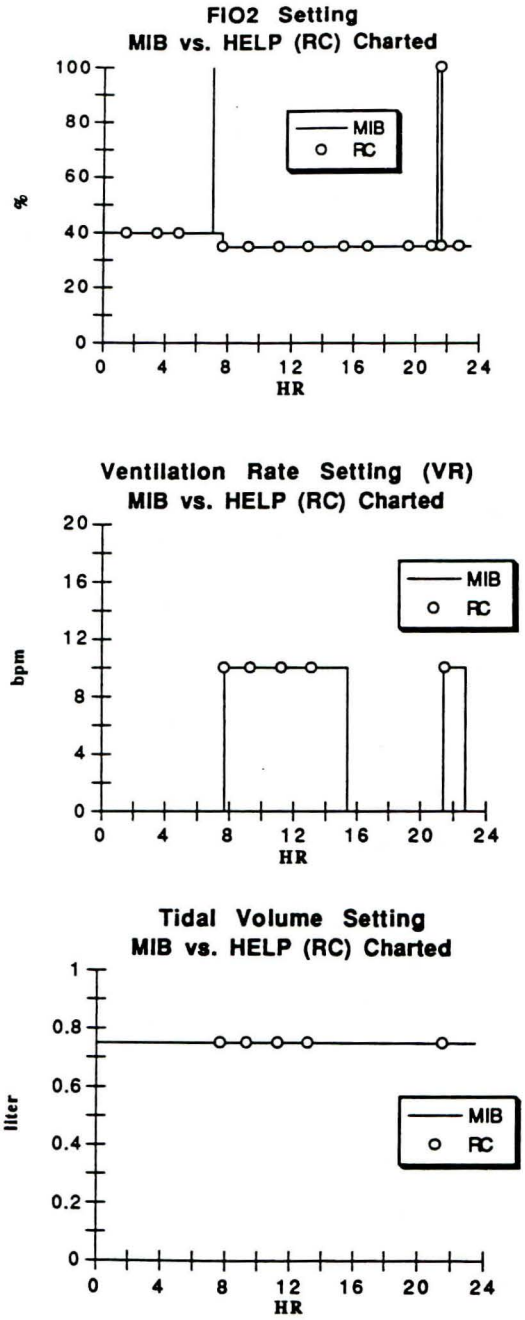

FIG 18–9.
MIB and respiratory care (RC) ventilator settings recorded for 24 hours from a Puritan-Bennett 7200 ventilator. Notice for the most part that the manually charted data follow the MIB data record (see text).

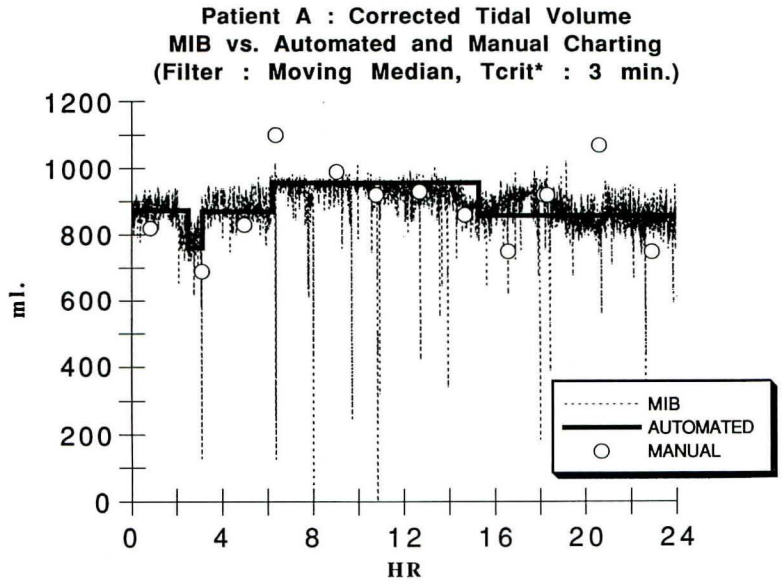

FIG 18–10.
MIB and respiratory care (manual) measurement data recorded for 24 hours from a Puritan-Bennett 7200 ventilator. The open circles are the 2-hour respiratory therapists' recordings, the jaggy vertical lines are the breath-by-breath MIB data recordings. In addition a 3-minute median is plotted. The 3-minute median data plot is the recommended data recording method for recording data into the patient record.[7]

COMPUTER-ASSISTED QUALITY ASSURANCE

Webster defines quality as "The degree of excellence which a thing possesses."[9] Demming, a pioneer in producing high-quality products who helped the Japanese become the world leaders in producing quality products, points out that "Reliable service reduces costs. Delays and mistakes raise costs."[10] Berwick tells us that "Real improvement in quality depends, according to the Theory of Continuous Quality Improvement, on understanding and revising the production process on the basis of data about the processes themselves. Every process produces information on the basis of which the process can be improved."[11] James tell us that quality is roughly equivalent to medical outcomes.[12] He further states that quality is "one of those things that is difficult to define, but that anyone can recognize—I know it when I see it." These and others have shown that medicine, like any other process, can be improved and that among other things the transfer of information is key to improving health care systems.[13] In the late 1700s the great English writer Samuel Johnson said "Men more frequently need to be reminded than informed."

McDonald has stated that most adverse events in health care are preventable, particularly those due to errors or negligence.[14] He has shown that computers are able to help in the process of improving quality.

Medical decisions have traditionally been considered a scientific, as well as intuitive, process. In recent years, however, formal methods for decision-making have been applied to medical problem-solving and computer-assisted medical decision-making has gained wider acceptance.[3, 15–17] Computers can be used to interpret data (e.g., interpretation of the ventilatory status based on blood gas data). Computers can also be used to alert physicians, nurses or pharmacists that a medication may be contraindicated.[18, 19] Computers can also be used to provide physician guidance using patient treatment protocols. What follows is a brief description of several computerized activities using the HELP system.

Respiratory Care

The respiratory care charting and monitoring system was developed to be a computer-assisted quality assurance monitor.[5, 20, 21] The system addresses the immediate needs of patients through a daily medical director's alert report, which allows the medical director to intervene in acute situations as they arise.[20, 21] The department's quality assurance program monitors and evaluates clinical indicators of staff performance in terms of stated policies and procedures. The integrated data base of the HELP system is crucial to allow these functions, which would not be feasible using manual chart review.

Computerized, real-time quality assurance can be used to improve quality and reduce the cost of care. Most hospitals in the United States do quality assurance by defining a criteria for quality and then, via a random chart review, determine the compliance with this predetermined level. Then using educational or procedural mechanisms they attempt to improve the quality. Following that they study the problem with a second random chart review to determine the success rate. Using the computerized data base, criteria designated for quality care can be explicitly described and when breeches in that "standard" are found via computer surveillance an immediate report can be generated and the problem corrected immediately. This allows real-time improvement of care. Computerized quality monitoring can be used on every patient for every situation; thus, it is far superior to conventional quality assurance activities.

Computer monitoring also can dramatically improve the identification of problems. For example, when adverse drug reactions are detected by a continuous computer surveillance program, the rate of detecting adverse reactions was 80-fold higher than when reported by hand.[22] These types of audits are only achievable with an integrated computerized clinical decision-making data system.

Computerized respiratory care charting is efficient because it has streamlined the process of documentation while extracting the most "useful" information from the recording process. Without having to provide costly cumulative paper reports, the computer system provides better access for data entry and review. Overall, computer charting is preferred by therapists over manual charting, because it makes their jobs easier and improves the quality of information charted. Computer charting has added a high degree of confidence that there will be good correlation of clinical, administrative, and financial records. Such a system has demonstrated its value to the therapists, their department, the hospital, and most importantly to the patient.[5, 9]

COMPUTERIZED BLOOD GAS INTERPRETATION

Figure 18–11 illustrates the use of the computer to acquire and interpret a patient's blood gas results. With the increased sophistication of laboratory instruments, physicians, nurses, and respiratory therapists are being presented with large amounts of clinical data that they are expected to interpret and use to formulate therapeutic actions. Since this new information can be derived from blood gas instruments, we have connected blood gas machines to the HELP computer using the MIB. Error rates have decreased from 0.28% to *no* errors as a result of this electronic interface.[23] In addition, the computer uses its "knowledge base" to provide an interpretation of the results. Experience with the computerized blood gas interpretation system has shown that[24]:

1. The interpretation is accurate and appreciated by physicians and nurses.
2. The interpretations provide better care to a growing number of patients.
3. Quality control in the blood gas laboratory is enhanced.
4. Computerization has lead to standardization of classification criteria.
5. Terminology of blood gas interpretation has been standardized.
6. Computerization provides educational benefit to the medical staff, nurses, and others.
7. Turnaround time between sample taking and result reporting has decreased.

COMPUTERIZED PROTOCOLS DIRECT PATIENT CARE

Under the medical leadership of Drs. Alan H. Morris and Terry P. Clemmer of the pulmonary/ICU group at LDS Hospital, extensive computerized protocols have been developed.[25] Morris has said: "The explosion of medical information has found clear expression both in the proliferation of medical publications and in the staggering amount of information collected from critical care patients. A recent morning rounds review of a critically ill patient produced a list of 236 different variables."[25] With such a huge amount of data it is not surprising that Dr. David M. Eddy, in a recent JAMA commentary, stated " . . . all confirm what would be expected from common sense: The complexity of modern medicine exceeds the inherent limitations of the unaided human mind."[26]

With the able medical informatics assistance of Drs. Thomas D. East and Dean F. Sittig, the pulmonary division has developed, tested, and validated several computerized ventilatory care protocols.[27, 28] Computer protocols for the management of mechanical ventilation (respiratory evaluation, ventilation, oxygenation, weaning, and extubation) in patients with Adult Respiratory Distress Syndrome (ARDS) have been developed and validated at LDS Hospital.[27] These protocols use the bedside computer terminals (Fig 18–3) to prompt the clinical care team with therapeutic and diagnostic suggestions. The protocols, in both paper flow diagram and computer form, have been used for over 40,000 hours in more than 100 patients. The computerized protocols directed patient care 94% of the time. The remainder of the time, patient care was *not* protocol controlled because the current protocol logic did not include events such as transport for x-ray studies. The survival of these patients has been four times greater than was expected from historical controls.[27, 28]

LDS HOSPITAL BLOOD GAS REPORT

[redacted] NO. 12032[redacted] DR. BELNAP, LEGRAND P. SEX M AGE 44 ROOM E60[redacted]

DEC 26 91	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	40.6	26.0	2.5	17.7	2/ 1					5.5	300	7.30	22	5		
NORMAL LOW	7.35	27.2	15.8	-2.5	13.7	0/ 1	63	91	18.5		3.0	200	2.90		0		
26 04:01 V	7.35	47.6	25.8	.5	9.7	3/ 1	44	71	9.8	40						/ / 5	25/
26 04:00 A	7.36	44.7	24.9	-.2	10.3	2/ 1	58	85	12.3	40			21.60	127		/ / 5	25/
	SAMPLE # 53, TEMP 37.9, BREATHING STATUS : ASSIST/CONTROL																
	HB ERROR SUSPECTED, AV-O2, SHUNT, O2 EXTRACT RATIO NOT CALCULATED																
	MODERATE ACUTE RESPIRATORY ACIDOSIS																
	MODERATE HYPOXEMIA																
	SEVERELY REDUCED O2 CONTENT (12.3) DUE TO ANEMIA (LOW HB)																
	HYPOVENTILATION NOT IMPROVED																
	PULSE OXIMETER SO2 87.0																
25 22:09 A	7.34	46.3	24.5	-.9	10.3	3/ 1	64	87	12.7	40				120		/ / 5	25/
	SAMPLE # 52, TEMP 37.8, BREATHING STATUS : ASSIST/CONTROL																
	MODERATE ACUTE RESPIRATORY ACIDOSIS																
	MILD HYPOXEMIA																
	SEVERELY REDUCED O2 CONTENT (12.7) DUE TO ANEMIA (LOW HB)																
	HYPOVENTILATION (PREVIOUSLY NORMAL)																
	PULSE OXIMETER SO2 88.0																
25 17:43 V	7.36	46.9	26.1	.8	10.6	3/ 1	47	74	11.1	40						/ / 5	24/
25 17:42 A	7.38	43.9	25.6	.9	10.9	2/ 1	63	88	13.4	40	2.03			124	46	/ / 5	24/
	SAMPLE # 51, TEMP 37.9, BREATHING STATUS : ASSIST/CONTROL																
	MILD ACID-BASE DISORDER																
	MODERATE HYPOXEMIA																
	SEVERELY REDUCED O2 CONTENT (13.4) DUE TO ANEMIA (LOW HB)																
	HYPOVENTILATION CORRECTED																
	PULSE OXIMETER SO2 88.0																
25 04:08 V	7.39	44.3	26.5	1.8	11.3	1/ 1	44	78	12.4	40						/ / 5	25/
25 04:07 A	7.40	44.3	27.1	2.6	11.1	2/ 1	59	89	13.9	40	1.79	347	19.40	127	48	/ / 5	25/
	SAMPLE # 50, TEMP 36.8, BREATHING STATUS : ASSIST/CONTROL																
	MODERATE CHRONIC RESPIRATORY ACIDOSIS																
	MODERATE HYPOXEMIA																
	SEVERELY REDUCED O2 CONTENT (13.9) DUE TO ANEMIA (LOW HB)																
	HYPOVENTILATION IMPROVED																
	PULSE OXIMETER SO2 89.0																
24 21:51 V	7.33	54.3	28.1	1.9	10.2	2/ 1	45	76	11.0	70						/ / 5	24/
24 21:50 A	7.36	48.2	26.8	1.5	10.3	2/ 1	67	91	13.2	70	2.12	332	15.70	296	46	/ / 5	24/
	SAMPLE # 49, TEMP 36.6, BREATHING STATUS : ASSIST/CONTROL																
	MODERATE CHRONIC RESPIRATORY ACIDOSIS																
	MILD HYPOXEMIA																
	SEVERELY REDUCED O2 CONTENT (13.2) DUE TO ANEMIA (LOW HB)																
	HYPOVENTILATION MARKEDLY IMPROVED																
	PULSE OXIMETER SO2 91.0																
24 20:25 A	7.30	59.5	28.6	1.7	10.2	2/ 1	66	90	13.0	80				346		/ / 5	18/
	SAMPLE # 48, TEMP 36.5, BREATHING STATUS : ASSIST/CONTROL																
	SEVERE MIXED CHRONIC AND ACUTE RESPIRATORY ACIDOSIS																
	MILD HYPOXEMIA																
	SEVERELY REDUCED O2 CONTENT (13.0) DUE TO ANEMIA (LOW HB)																
	HYPOVENTILATION MUCH WORSE																
	PULSE OXIMETER SO2 90.0																
24 09:45 A	7.47	45.4	32.9	9.2	9.2	2/ 1	58	88	11.5	40				127		48/ 32/ 5	23/
	SAMPLE # 47, TEMP 36.9, BREATHING STATUS : ASSIST/CONTROL																
	MODERATE MIXED RESPIRATORY ACIDOSIS AND METABOLIC ALKALOSIS																
	MODERATE HYPOXEMIA																
	SEVERELY REDUCED O2 CONTENT (11.5) DUE TO ANEMIA (LOW HB)																
	HYPOVENTILATION (PREVIOUSLY NORMAL)																
	PULSE OXIMETER SO2 87.0																

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;
ECCO2R (I=INFLOW, M=MIDFLOW, O=OUTFLOW)

KEEP FULL PAGE FOR RECORDS
(END) #696 - pg1

FIG 18–11.
Blood gas report for a patient in the Shock Trauma ICU. Note the computerized interpretations following the reported data as well as the reporting of ventilator settings and F_{IO_2}. The arterial sample interpretation at 04:00 is interesting because there is a large (0.6) difference in the hemoglobin measures from the arterial (A) sample (9.7) and the venous (V) sample (10.3).

The success of these computer protocols and their acceptance by the clinical staff clearly establishes the feasibility of controlling the therapy of severely ill patients. We have now refined the process for generating computerized protocols. Six steps were found to be essential in developing these protocols[27]:

1. Develop protocol logic by consensus.
2. Test the logic at the bedside.
3. Computerize the protocol logic.
4. Validate the protocols with archival computerized data.
5. Clinically validate and refine the protocols.
6. Prepare to use the protocols in routine clinical applications by training the clinical staff and generating appropriate instructional material.

Figure 18–12 gives some examples of "expert system" computer output derived from the HELP system. The top line indicates a "weaning failure" from the ARDS protocol. The second line points out, based on laboratory data, that the patient may be having an adverse drug reaction (ADR). The line with time mark 04:16 is an indication from the ARDS protocol that the F_{IO_2} should be increased. The final line on the report indicates that the patient may have a nosocomial wound infection, based on data contained in the computerized data base, such as microbiology data.

THE FUTURE OF COMPUTER CHARTING AND MONITORING

The quantity of data available on any one patient in the ICU is phenomenal. With the ability to sample data continuously and automatically, it is possible to gather thousands of data points each day for each monitored parameter from each of the monitoring devices. This presents to the clinical and medical informatics team an enormous challenge of determining what data are needed, how often it is necessary to sample, and what data should be stored. If data are redundant, do we need to store the output from all the devices? If so, do we use the same codes for redundant data? If the redundant data are not identical, which data point takes priority? If we have redundant data, which should be used for decision-making, quality assurance, and alerts? These are fertile areas for research activities and crucial to future monitoring system development. Currently these decisions are arbitrarily made with little or no scientific validation.[29, 30]

We must discover what data are needed for decision-making.[31] Typically in the acute care setting we generate enormous volumes of data. However, Knaus and his associates, using the APACHE scoring system, have shown us that they can do very well at making patient prognosis using only a few key data items.[32, 33]

It is time for physicians and other health care professionals to interact with the computer. Any computer system used by clinical staff must be fast, reliable, and user friendly. With little or no training the user should be able to find the desired clinical information and generate reports.[29] The Stanford University Medical Informatics group has recently developed some

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PATIENT IDENTIFICATION                          12032XXX  E60X

HELP DECISIONS

DATE TIME
26 DEC  07:38  WEANING ASSESSMENT FAILURE AT 7:30, BLOOD PRESSURE OUTSIDE
               LIMITS [90/50 < 200/120].   REMAIN IN POSITIVE PRESSURE
               VENTILATION.

26 DEC  06:59  ***** PATIENT WITH POSSIBLE ADR (LAB) ***** 13  12/26/1991.
               05:30

26 DEC  04:51  CONTINUE TO MONITOR AND DRAW AN ABG AT 6:36 FIO2 INCREASE AT
               4:36, WITH 1 HOURS AND 45 MINUTES REMAINING IN A 2 HOUR WAIT.

26 DEC  04:16  INCREASE FiO2 BY 10%, FROM 40% TO 50%.  DRAW AN ABG IN 15
               MINUTES.

26 DEC  04:00  HYPOVENTILATION NOT IMPROVED
               SEVERELY REDUCED O2 CONTENT (12.3) DUE TO ANEMIA (LOW HB)
               MODERATE HYPOXEMIA
               MODERATE ACUTE RESPIRATORY ACIDOSIS
               HB ERROR SUSPECTED, AV-02, SHUNT, O2 EXTRACT RATIO NOT
               CALCULATED
               SAMPLE #53, TEMP 37.9, BREATHING STATUS: ASSIST/CONTROL
               LV PARAMETERS ARE WITHIN NORMAL LIMITS

26 DEC  01:55  CONTINUE TO MONITOR PATIENT AND DRAW AN ABG IN 2 HOURS, AT
               3:55 PATIENT CURRENTLY AT MINIMUM THERAPY.

25 DEC  22:18  CONTINUE TO MONITOR PATIENT AND DRAW AN ABG IN 2 HOURS, AT
               24:18  PATIENT CURRENTLY AT MINIMUM THERAPY.

25 DEC  22:09  HYPOVENTILATION (PREVIOUSLY NORMAL)
               SEVERELY REDUCED O2 CONTENT (12.7) DUE TO ANEMIA (LOW HB)
               MILD HYPOXEMIA
               MODERATE ACUTE RESPIRATORY ACIDOSIS
               A-A GRADIENT 120
               SAMPLE #52, TEMP 37.8, BREATHING STATUS: ASSIST/CONTROL

25 DEC  21:45  CONTINUE TO MONITOR PATIENT AND DRAW AN ABG IN 2 HOURS, AT
               23:45 PATIENT CURRENTLY AT MINIMUM THERAPY.

25 DEC  18:00  LV PARAMETERS ARE WITHIN NORMAL LIMITS

25 DEC  17:56  TEST FOR VENTILATORY DRIVE (ALLOWED DURING WAIT TIMES):
               TITRATE VR (MAINTAIN CONSTANT Vt) DOWN TO 11 BR/MIN.  ACTIVATE
               PROTOCOLS AFTER CHARTING.  IF REASON NOT TO TEST, ENTER REASON
               USING OPT. #3 ON A

25 DEC  17:51  INCREASE FiO2 BY 20%, FROM 40% TO 60%.  DRAW AN ABG IN 15
               MINUTES.

25 DEC  14:11  CONTINUE TO MONITOR PATIENT AND DRAW AN ABG IN 2 HOURS, AT
               16:11 PATIENT CURRENTLY AT MINIMUM THERAPY.

25 DEC  10:25  ***** PATIENT WITH POSSIBLE NOSOCOMIAL WOUND ***** 83408
               12/24/1991. 17:05
PATIENT IDENTIFICATION                  12032XXX      E60X
HELP DECISIONS                                        #018 - pg1
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FIG 18–12.
Printout of the computerized medical decisions made for an ICU patient on the ARDS protocol. Also shown are blood gas interpretations, adverse drug alerts (ADR), interpretations of hemodynamic (cardiac output) parameters, and infectious disease monitoring statements (nosocomial wound).

innovative methods for presenting ventilator advice.[34–36] They used "participatory design" as the method of developing the user interface.[35] Such methods are exciting and innovative, but must be "battle hardened" in the clinical setting to validate them (steps 4 to 6 in the protocol development process noted earlier).

It seems to us that advances in the use of computers in charting and monitoring will be evolutionary rather than revolutionary. Changes will be needed in the health care system, as pointed out by the IOM report on computerized patient records, before use of such computer systems will be widespread. The expectations of society for medical progress and increased use of computers in clinical practice is fueled by increased use of computers in everyday activities. We have made great progress in using computers in medicine, but the opportunities to do more and provide better and more efficient care are astounding!

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