

Patient Care and Monitoring Systems

After having heard this lecture, you should know the answers to these questions:

- What are the four major information-management issues in patient care?
- How have patient-care systems evolved during the last three decades?
- How have patient-care systems influenced the process and outcomes of patient care?
- Why are patient-care systems essential to the computer-based patient record? How can they be differentiated from the computer-based patient record itself?

- What is patient monitoring and why is it done?
- What are the primary applications of patient monitoring systems in the intensive-care unit?
- How do computer-based patient monitors aid health professionals in collecting, analyzing, and displaying data?
- What are the advantages of using microcomputers in bedside monitors?
- What are the important issues for collecting high-quality data either automatically or manually in the intensive-care unit?
- Why is integration of data from many sources in the hospital necessary if a computer is to assist in most critical-care—management decisions?

Patient care

Patient care is the focus of many clinical disciplines—medicine, nursing, pharmacy, nutrition, therapies such as respiratory, physical, and occupational, and others. Although the work of the various disciplines sometimes overlaps, each has its own primary focus, emphasis, and methods of care delivery. Each discipline's work is complex in itself, and collaboration among disciplines adds another level of complexity. In all disciplines, **the quality of clinical decisions depends in part on the quality of information available to the decision-maker.**

Patient care

The process of care begins with collecting data and assessing the patient's current status in comparison to criteria or expectations of normality. Through cognitive processes specific to the discipline, diagnostic labels are applied, therapeutic goals are identified with timelines for evaluation, and therapeutic interventions are selected and implemented. At specified intervals, the patient is reassessed, the effectiveness of care is evaluated, and therapeutic goals and interventions are continued or adjusted as needed. If the reassessment shows that the patient no longer needs care, services are terminated.

Discipline in patient care:

Patient care is a multidisciplinary process centered on the care recipient in the context of the family, significant others, and community.

- 1. Physician:** diagnose diseases, prescribe appropriate medications, authorize other care services.
- 2. Nurse:** assess patient's understanding of his/her condition and treatment and his/her self-care abilities and practices; teach and counsel as needed; help patient to perform exercises at home; report findings to physician and other caregivers.
- 3. Nutritionist:** assess patient's nutritional status and eating patterns; prescribe and teach appropriate diet to control blood pressure and build physical strength.
- 4. Physical therapist:** prescribe and teach appropriate exercises to improve strength and flexibility and to enhance cardiovascular health, within limitations of arthritis.
- 5. Occupational therapist:** assess abilities and limitations for performing activities of daily living; prescribe exercises to improve strength and flexibility of hands and arms; teach adaptive techniques and provide assistive devices as needed.

Information to Support Patient Care

As complex as patient care is, the essential information for direct patient care is defined in the answers to the following questions

- Who is involved in the care of the patient?
- What information does each professional require to make decisions?
- From where, when, and in what form does the information come?
- What information does each professional generate? Where, when, and in what form is it needed?

History

The genesis of patient care systems occurred in the mid-1960's. One of the first and most successful systems was the Technicon Medical Information System (TMIS), begun in 1965 as a collaborative project between Lockheed and El Camino Hospital in Mountain View, California.

Designed to simplify documentation through the use of standard order sets and care plans, TMIS defined the state of the art when it was developed. More than three decades later, versions of TMIS are still widely used, but the technology has moved on. The hierarchical, menu-driven arrangement of information in TMIS required users to page through many screens to enter or retrieve data and precluded aggregation of data across patients for statistical analysis.

Today's users have a different view of what can be done with data, and they demand systems that support those uses.

Part of what changed users' expectations for patient care systems was the development and evolution of the HELP system at LDS Hospital in Salt Lake City, Utah. (The HELP system by Pryor TA, Gardner RM, Clayton PD, Warner HR in J Med Syst 1983 Apr;7(2):87-102.)

Initially providing decision support to physicians during the process of care (in addition to managing and storing data), HELP has subsequently become able to support nursing care decisions and to aggregate data for research leading to improved patient care. Today, both vendors of information systems and researchers in health care enterprises are working to incorporate decision support and data aggregation features in systems that use the latest technologies for navigating and linking information.

Patient Care Components in Selected Information Systems

Patient-Care Component	Examples: Hospital	Examples: Ambulatory Care
Problem lists	Problem-Oriented Medical Information System (PROMIS), Medical Center Hospital of Vermont, Burlington, VT [Weed, 1975]; Tri-Service Medical Information System (TRIMIS), Department of Defense [Bickel, 1979]	Computer-Stored Ambulatory Record (COSTAR), Massachusetts General Hospital, Boston, MA [Barnett, 1976]; Summary Time-Oriented Record (STOR), University of California, San Francisco, CA [Whiting-O'Keefe et al., 1980]
Summary reports	Technicon Medical Information System (TMIS), Clinical Center at National Institutes of Health, Bethesda, MD [Hodge, 1990]; Decentralized Hospital Computer Program (DHCP), Department of Veteran's Affairs [Ivers & Timson, 1985]	Regenstrief, Regenstrief Institute, Indianapolis, IN [McDonald, 1976]; Computer-Stored Ambulatory Record (COSTAR), Massachusetts General Hospital, Boston, MA [Barnett, 1976]
Order entry	Health Evaluation Logical Processing (HELP), Latter Day Saints Hospital, Salt Lake City, UT [Kuperman et al., 1991]; Technicon Medical Information System (TMIS), Clinical Center at National Institutes of Health, Bethesda, MD [Hodge, 1990];	The Medical Record (TMR), Duke University Medical Center, Durham, NC [Hammond et al., 1980];

Cont.

Patient-Care Component	Examples: Hospital	Examples: Ambulatory Care
Results review	University of Missouri--Columbia System, Columbia, MO [Lindberg, 1965]; Decentralized Hospital Computer Program (DHCP), Department of Veteran's Affairs [Ivers & Timson, 1985]	Computer-Stored Ambulatory Record (COSTAR), Massachusetts General Hospital, Boston, MA [Barnett, 1976]; Summary Time-Oriented Record (STOR), University of California, San Francisco, CA [Whiting-O'Keefe et al., 1980]
Nursing protocols and care plans	Health Evaluation Logical Processing (HELP), Latter Day Saints Hospital, Salt Lake City, UT [Kuperman et al., 1991]; Technicon Medical Information System (TMIS), El Camino Hospital, Mountain View, CA [Watson, 1977]	
Alerts and reminders	Health Evaluation Logical Processing (HELP), Latter Day Saints Hospital, Salt Lake City, UT [Kuperman et al., 1991]; Beth Israel Hospital System, Boston, MA [Safran et al., 1989]	Regenstrief, Regenstrief Institute, Indianapolis, IN [McDonald, 1976]; The Medical Record (TMR), Duke University Medical Center, Durham, NC [Hammond et al., 1980]

The HELP hospital information system: update 1998.

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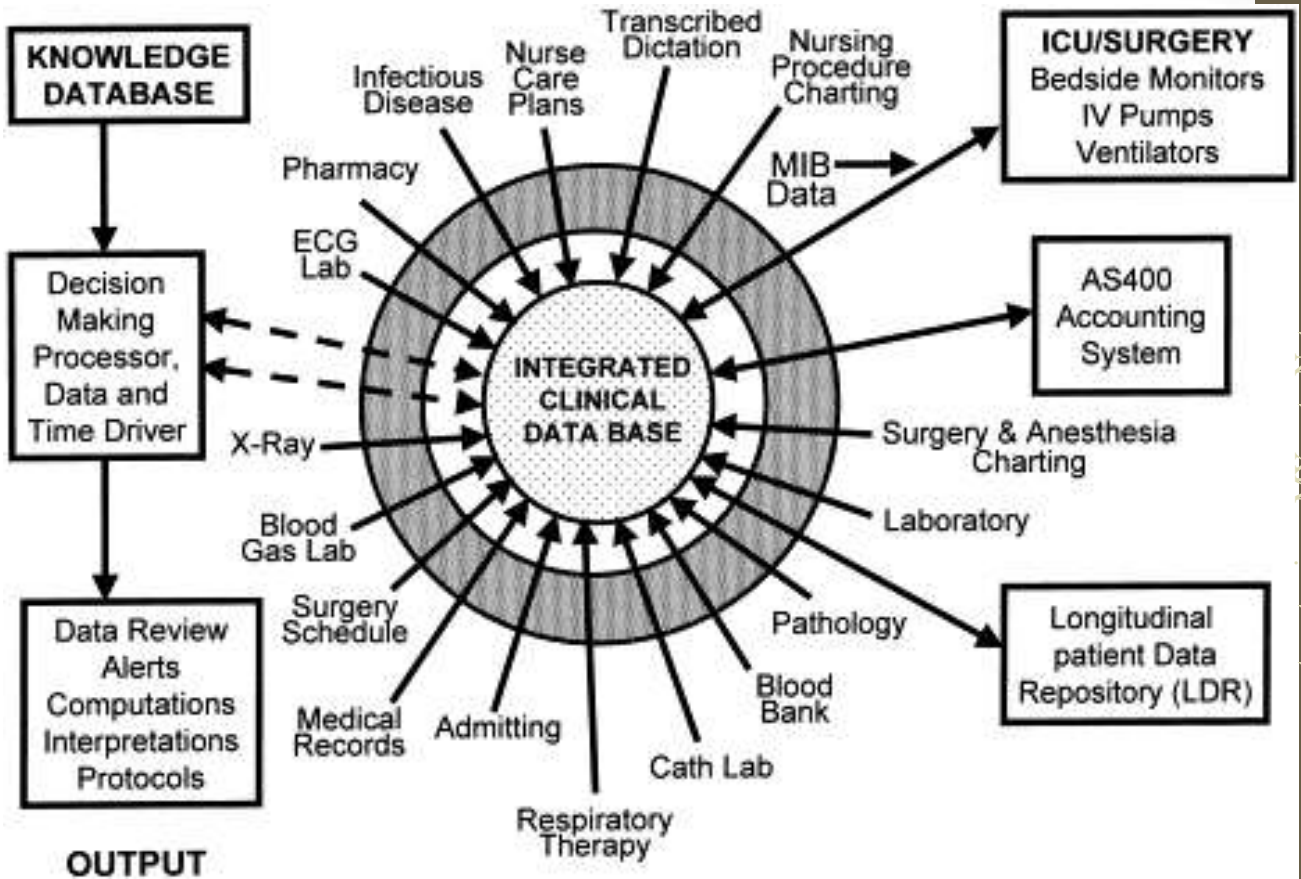
Int J Med Inf 1999 Jun;54(3):169-82

ABSTRACT:

The HELP hospital information system has been operational at LDS Hospital since 1967. The system initially supported a heart catheterization laboratory and a post open heart Intensive Care Unit. Since the initial installation the system has been expanded to become an integrated hospital information system providing services with sophisticated clinical decision-support capabilities to a wide variety of clinical areas such as laboratory, nurse charting, radiology, pharmacy, etc. The HELP system is currently operational in multiple hospitals of LDS Hospital's parent health care enterprise- Intermountain Health Care (IHC). The HELP system has also been integrated into the daily operations of several other hospitals in addition to those at IHC. Evaluations of the system have shown:

- (1) it to be widely accepted by clinical staff;
- (2) computerized clinical decision-support is feasible;
- (3) the system provides improvements in patient care; and
- (4) the system has aided in providing more cost- effective patient care. Plans for making the transition from the 'function rich' HELP system to more modern hardware and software platforms are also discussed.

HELP System at LDS Hospital



Block Diagram of the HELP System with its integrated centralized database, interface to the IBM AS400 billing system and newly implemented longitudinal patient data repository (LDR). As data flows into HELP's integrated database either by a 'data drive' mechanism or a 'time drive' mechanism the knowledge base and decision support capabilities of the HELP system are activated.

Conclusions:

The HELP system is one of the longest running and most successful clinical information systems. Concepts developed with the HELP system have shown:

1. that clinical care can be provided with such a system;
2. that computerized decision-support is feasible;
3. that computerized decision-support can aid in providing more cost-effective and improved patient care; and
4. that clinical user attitudes toward computerized decision-support are positive and supportive.

What is Patient Monitoring?

“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 management decisions, including when to make therapeutic interventions, and assessment of those interventions” [Hudson, 1985, p. 630].

A patient monitor may not only alert caregivers to potentially life-threatening events; many provide physiologic input data used to control directly connected life-support devices.

History of Physiological data measurements:

- 1625 Santorio-measure body temperature with spirit thermometer. Timing pulse with pendulum. Principles were established by Galileo. These results were ignored.
- 1707 Sir John Foye published pulse watch.
- 1852 Ludwig Taube Course of patient's fever measurement
- At this time Temperature, pulse rate respiratory rate had become standard vital signs.
- 1896 Scipione Riva-Rocci introduced the sphygmomanometer (blood pressure cuff). (4th vital sign).
- Nikolai Korotkoff applied the cuff with the stethoscope (developed by Renee Lannec-French Physician) to measure systolic and diastolic blood pressures.
- 1900s Harvey Cushing applied routine blood pressure in operating rooms.
- He raised at that time the questions:

(1) Are we collecting too much data?

(2) Are the instruments used in clinical medicine too accurate?

Would not approximated values be just as good? Cushing answered his own questions by stating that vital-sign measurement should be made routinely and that accuracy was important [Cushing, 1903].

History (Cont.)

- 1903 Willem Einthoven devised the string galvanometer to measure ECG (Nobel Prize 1924)
- World war II Development of transducers.
- 1950 The ICU's were established To meet the increasing demands for more acute and intensive care required by patients with complex disorders.
- 1963 Day reported that treatment of post-myocardial-infarction patients in a coronary-care unit reduced mortality by 60 percent.
- 1968 Maloney suggested that having the nurse record vital signs every few hours was "only to assure regular nurse-patient contact".
- Late '60s and early '70 bedside monitors built around bouncing balls or conventional oscilloscope.
- '90 **Computer-based patient monitors** - Systems with database functions, report-generation systems, and some decision-making capabilities.

Patient monitoring in Intensive care Units

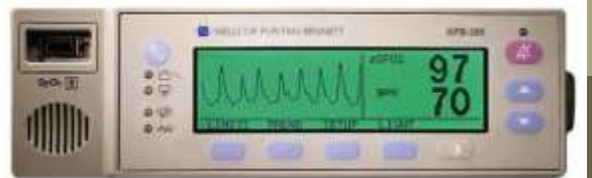
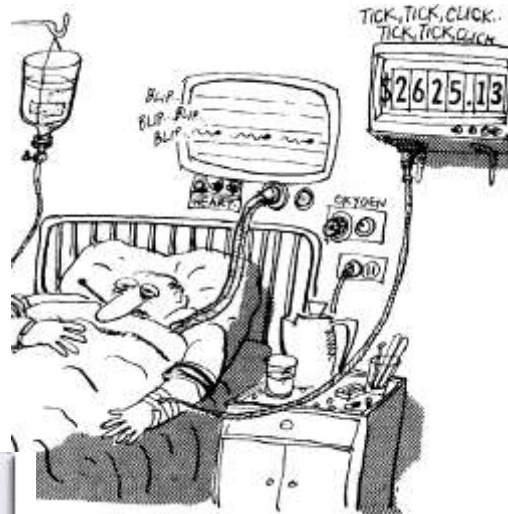
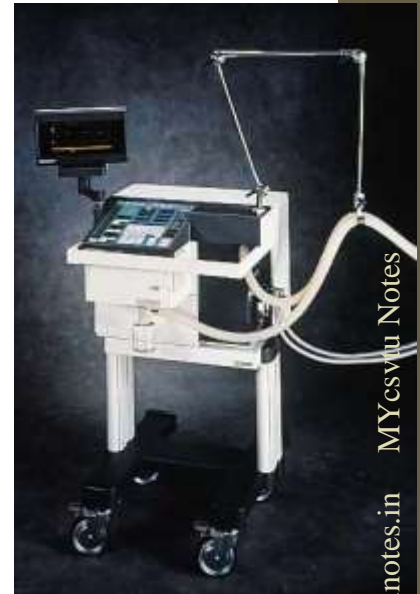
There are at least four categories of patients who need physiologic monitoring:

1. Patients with unstable physiologic regulatory systems; for example, a patient whose respiratory system is suppressed by a drug overdose or anesthesia.
2. Patients with a suspected life-threatening condition; for example, a patient who has findings indicating an acute myocardial infarction (heart attack).
3. Patients at high risk of developing a life-threatening condition; for example, patients immediately post open-heart surgery, or a premature infant whose heart and lungs are not fully developed.
4. Patients in a critical physiological state; for example, patients with multiple trauma or septic shock.

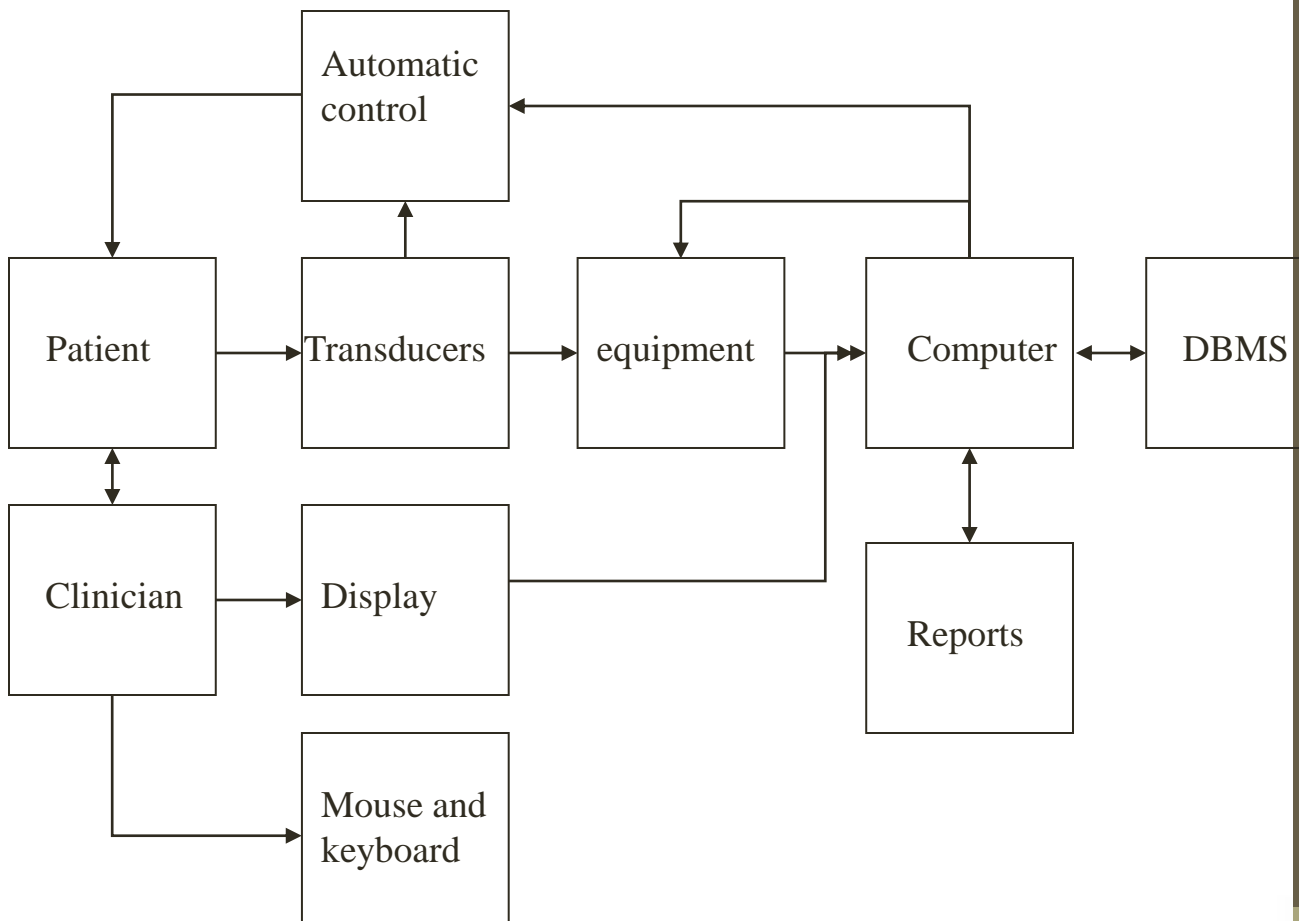
Care of the critically ill patient requires prompt and accurate decisions so that life-protecting and lifesaving therapy can be appropriately applied. Because of these requirements, ICUs have become widely established in hospitals. Such units use computers almost universally for the following purposes:

- To acquire physiological data frequently or continuously, such as blood pressure readings
- To communicate information from data-producing systems to remote locations (for example, laboratory and radiology departments)
- To store, organize, and report data
- To integrate and correlate data from multiple sources
- To provide clinical alerts and advisories based on multiple sources of data
- To function as a decision-making tool that health professionals may use in planning the care of critically ill patients
- To measure the severity of illness for patient classification purposes
- To analyze the outcomes of ICU care in terms of clinical effectiveness and cost-effectiveness

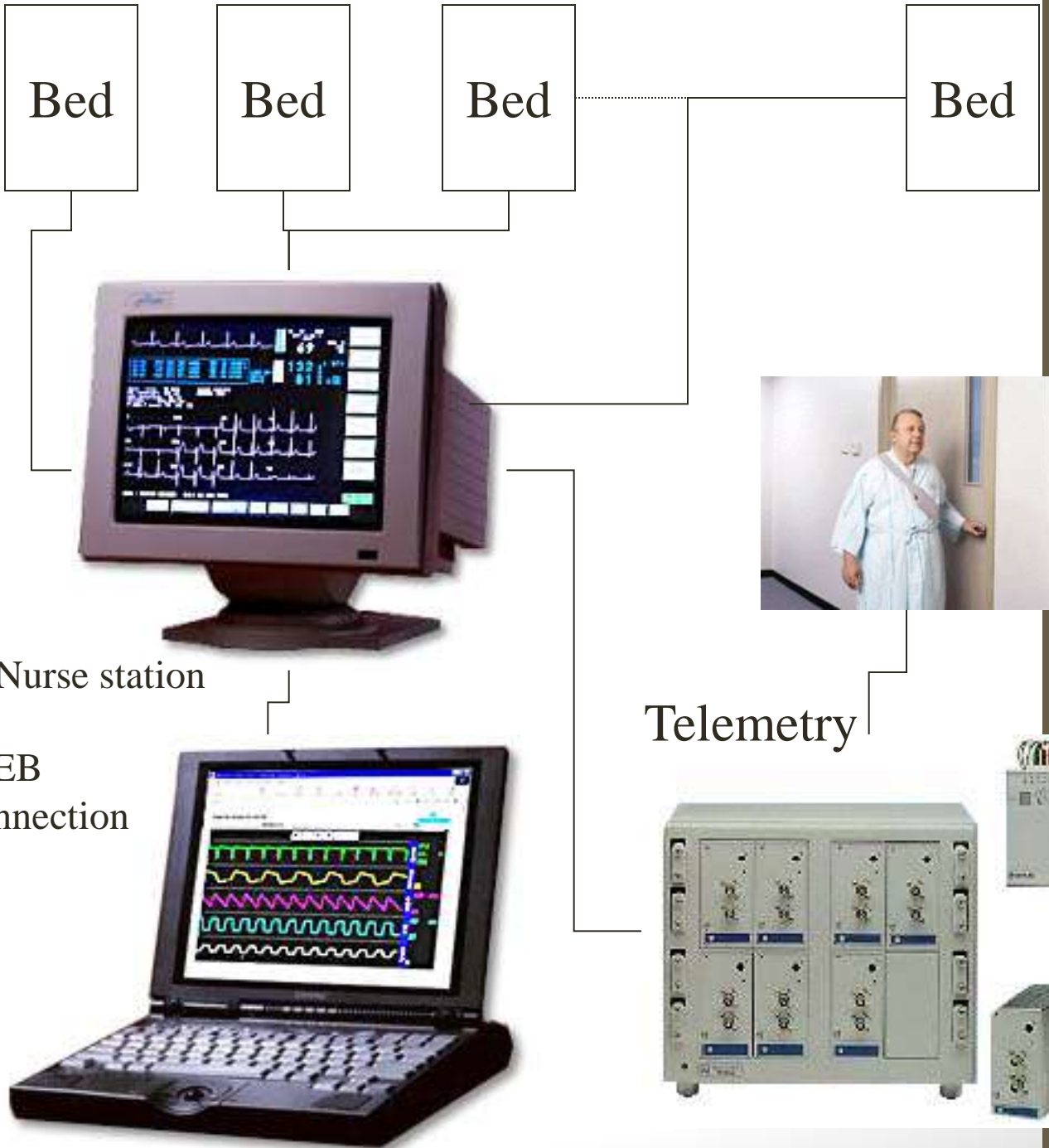
Intensive care Unit Bed



Use of computers for patient monitoring.



ICU



Some instruments in mind



And more...



Types of Data Used in Patient monitoring in different ICU's

Continuous variables	Sampled variables	Coded Data	Free Text
Cardiac ECG Heart rate (HR) HR variability PVCs	Temperature Central Peripheral	Patient observation Color Pain Position Etc.,	All other observations or interventions that cannot be measured or coded
Blood pressure Arterial/venous Pulmonary Left/right atrial/ventricular Systolic/Dyastol Per beat/average Systolic time intervals	Blood Chemistry Hb PH PO ₂ PCO ₂ Etc.,	Interventions Infusions Drugs Defibrillation Artificial ventilations Anesthesia	
Respiratory Frequency Depth/vol/flow Pressure/Resist Respiratory gases	Fluid balance Infusions Blood plasma Urine loss		
Neurological EEG Frequency components Amplitudes Coherence			

Patient monitoring



Features Matrix

ECG 3 leads

ECG 5 leads

ECG 10 leads

Respiration

Invasive BP

Dual Temp/C.O.

NIBP

SpO₂

ECG

Standard leads available: I, II, III, V, aVR, aVL and aVF

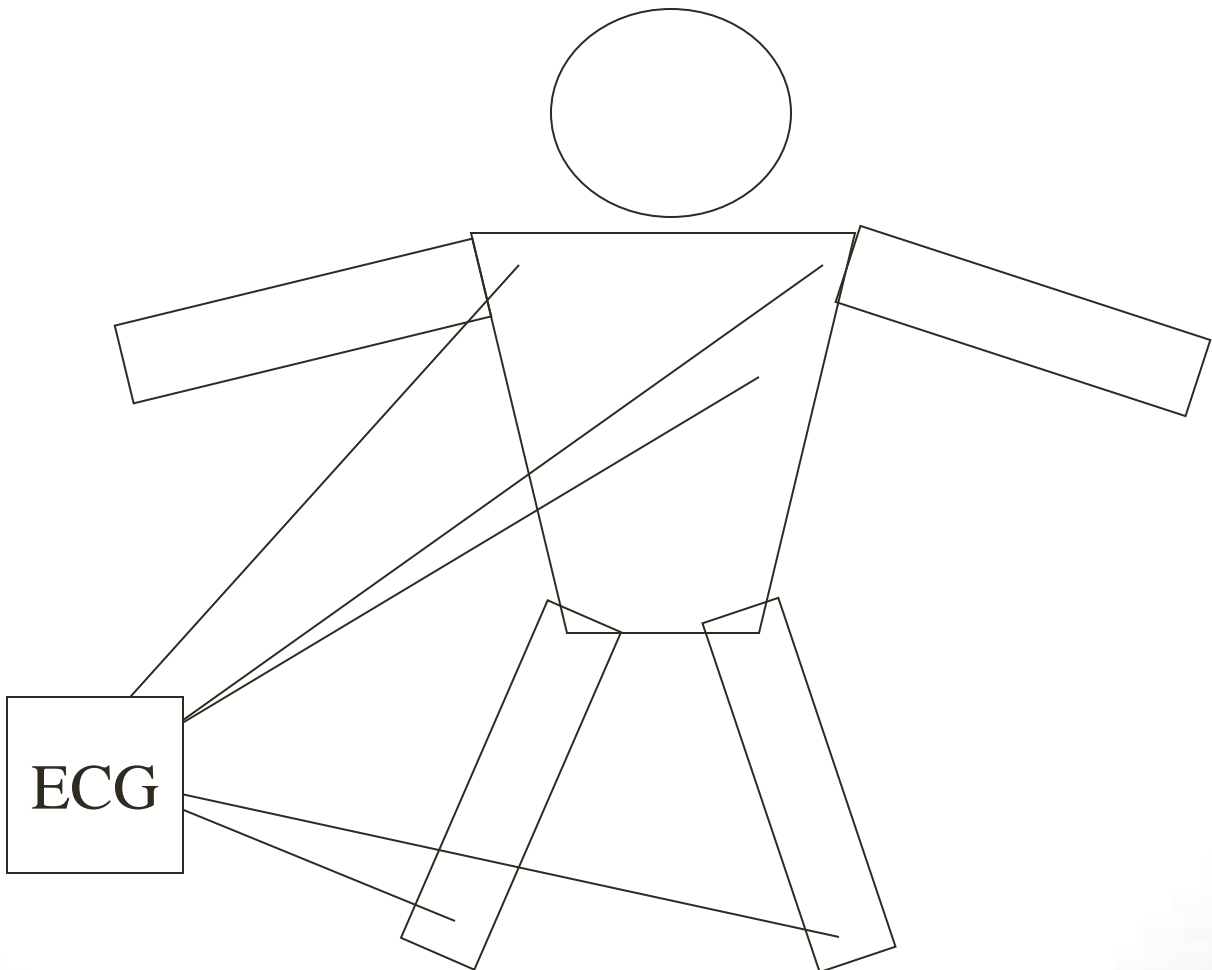
V₁ V₆

Heart rate detection, QRS detection range)

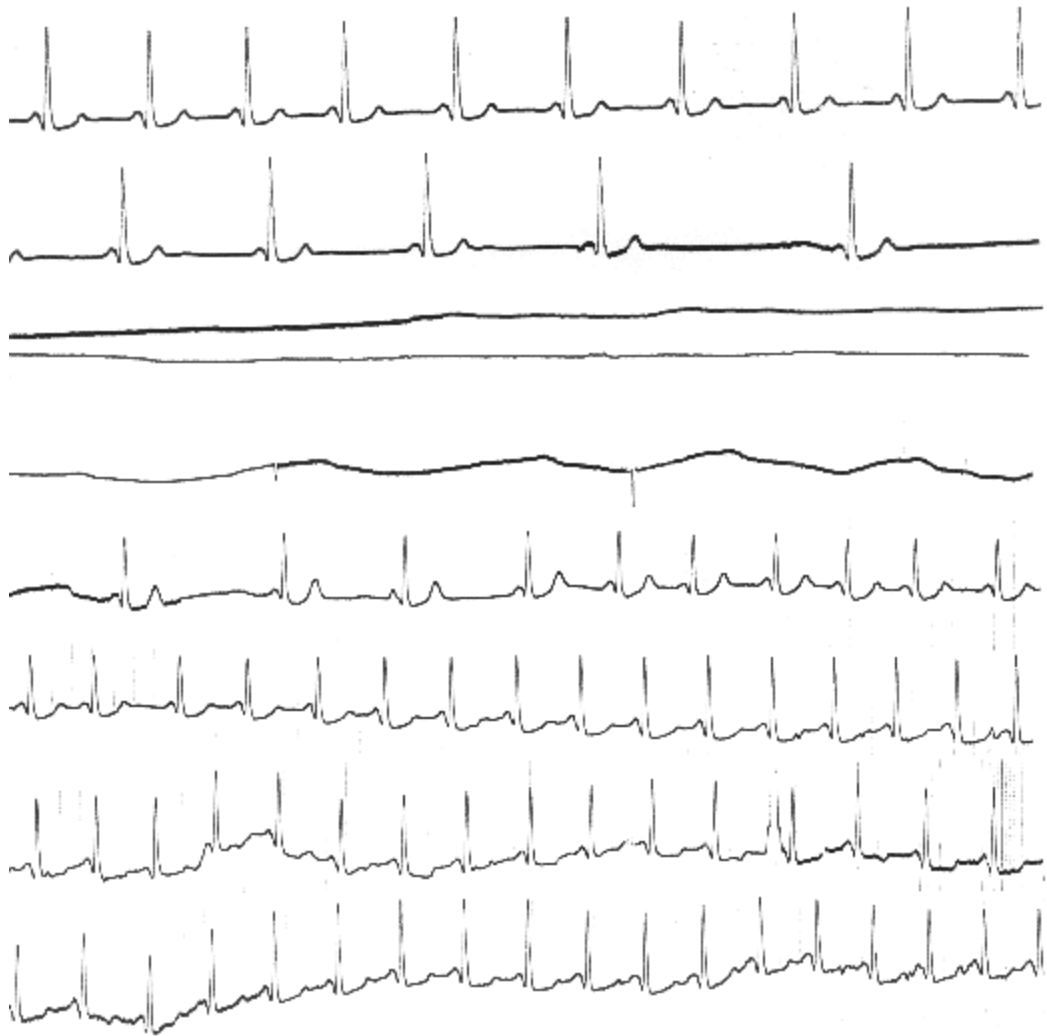
Pacemaker detection/rejection.

Lead fail: Identifies failed lead and switches to intact one

Trends: 24 hours with 1-minute resolution



ECG Strip



Respiration

Rate range: 1 to 200 breaths/min

Impedance range: 100 to 1000 ohms at 52.6 kHz

Detection sensitivity range: 0.4 to 10 ohms impedance variation

Low rate alarm range: 1 to 199 breaths/min

High rate alarm range: 2 to 200 breaths/min

Apnea alarm rate: 0 to 30 seconds in one-second increments

Cardiac artifact alarm

Waveform display bandwidth: 0.05 to 2.5 Hz (-3 dB)

Analog output: Selectable

Trends: 24 hours with 1-minute resolution

Invasive Blood pressure

Catheter sites: Arterial, pulmonary arterial, central venous, left atrial, intracranial, right atrial, femoral arterial, umbilical venous, umbilical arterial, and special.

Trends: 24 hours with 1-minute resolution

Temperature

Number of channels: 2

Range: 0°C to 45°C (32°F to 113°F)

Alarms: User-selectable upper and lower limits for T1, T2

Resolution: $\pm 0.02^\circ\text{C}$

Displayed parameters: Temperature 1, temperature 2

Trends: 24 hours with 1-minute resolution

Pulse oximetry

Saturation range: 0 to 100%

Saturation accuracy

SpO₂% Accuracy

90 to 100% 1.5%

80 to 89.9% 2.1%

60 to 100% 2.4% (overall range)

Below 60% Unspecified

Pulse rate range: 40 to 235 beats/min

Displayed frequency response: 1.5 to 10.5 Hz

Alarm limit range:

SpO₂: 1% to 105%

Pulse: 40 to 235 beats/min

Displayed parameters: Oxygen saturation, pulse rate

Trends: 24 hours with 1-minute resolution

Noninvasive blood pressure

Measurement technique: Oscillometric

Displayed parameters: Systolic, diastolic and mean pressure; time of last measurement, cuff size, countdown to next measurement

Heart rate detection: 30 to 300 beats/min

Measurement modes: Manual, auto and stat. Stat measurement is 5 minutes of continuous measurements.

Trends: 96 stored events

Cardiac output

Cardiac output range: 0.2 to 15 liters/min

Blood temperature range: 30°C to 42°C (86°F to 107°F)

Injectate temperature range: 0°C to 30°C (32°F to 86°F)

Waveform display frequency response: 0 to 10 Hz (-3dB)

Displayed parameters: Cardiac output, blood temperature, injectate temperature, trial number

CareVue

The HP CareVue In-Patient Charting System is a point-of-care system which directly supports the patient-care delivery process of the care unit by facilitating the documentation and management of the electronic patient chart.

In many ways CareVue is not much unlike a point-of-sale retail or ATM system in that it was designed with a highly-available, centralized department-level database server and many distributed client workstations to accurately and efficiently serve this OLTP (i.e., On-Line Transaction Processing) predominately, data-entry, update-intensive activities of the nurse.

How does one determine if the patient-care delivery process is as efficient and effective as it should be? This is generally not the responsibility of the immediate care-provider, the unit nurse. It is the concern of management; the case management team, unit and departmental managers, clinical peer-review committees, accreditation organizations, and the hospital administration. Since the CareVue system is in a sense a detailed recorder of the activity surrounding the patient's care, it is an obvious source of the answers to many of these questions. With careful construction of the questions, the appropriate data can be extracted and transformed; mined into meaningful business information. This data mining process enables analysis of the patient-care delivery process and is a necessary activity in today's healthcare enterprise.

During a patient's stay, multiple CareVue systems cooperate to transfer a patient's electronic record as the patient moves from the domain of one system to another. However, over time, the system maintains only a recent, thinned, albeit, detailed, set of the patient's chart data and only for this current hospital visit.

In the late half of the 1980s, when CareVue was designed, there were too few or otherwise incomplete healthcare informatics standards available. HP's database developers were concerned, and rightly so, with designing a database subsystem and data model that would satisfy the demands of OLTP and work around this lack of standards. Formalizing a standards initiative prior to the beginning of application development would only unnecessarily have delayed market entry. An object-oriented data model was an obvious way to proceed and provided an environment of flexibility to assuage the concerns regarding compliance to otherwise inadequate clinical informatics standards. It would not be until 1995 however, that HP would learn the full impact of that early decision. The greatest impact was not on the development of applications that supported the primary objective of CareVue, the OLTP patient charting function, but more on the influence it would have on deploying such a system throughout the enterprise and on developing a complete clinical data management strategy. With the consolidation of hospitals into growing enterprises, the easy exchange and retrospective analysis of patient-care data had become a priority need of all customers. This could simply not be met with the current CareVue architecture alone.

Data analysis in general, but specifically, On-Line Analytical Processing (OLAP) of CareVue patient chart data requires a separate infrastructure than that which can be met with the CareVue (OLTP) architecture. Additionally, the dynamics and semantic ambiguities of CareVue data must be resolved to be transformed into meaningful information which is easy to understand and navigate.

History

The earliest foundations for acquiring physiological data date to the end of the Renaissance period.² In 1625, Santorio, who lived in Venice at the time, published his methods for measuring body temperature with the spirit thermometer and for timing the pulse (heart) rate with a pendulum. The principles for both devices had been established by Galileo, a close friend. Galileo worked out the uniform periodicity of the pendulum by timing the period of the swinging chandelier in the Cathedral of Pisa, using his own pulse rate as a timer. The results of this early biomedical-engineering collaboration, however, were ignored. The first scientific report of the pulse rate did not appear until Sir John Floyer published “Pulse-Watch” in 1707. The first published course of fever for a patient was plotted by Ludwig Taube in 1852. With subsequent improvements in the clock and the thermometer, the temperature, pulse rate, and respiratory rate became the standard **vital signs**. In 1896, Scipione Riva-Rocci introduced the sphygmomanometer (blood-pressure cuff), which permitted the fourth vital sign, arterial blood pressure, to be measured. A Russian physician, Nikolai Korotkoff, applied Riva-Rocci's cuff with a stethoscope developed by the French physician Rene Laennec to allow the auscultatory measurement of both systolic and diastolic arterial pressure. Harvey Cushing, a preeminent U.S. neurosurgeon of the early 1900s, predicted the need for and later insisted on routine arterial blood pressure monitoring in the operating room. Cushing also raised two questions familiar even at the turn of the century: (1) Are we collecting too much data? (2) Are the instruments used in clinical medicine too accurate? Would not approximated values be just as good? Cushing answered his own questions by stating that vital-sign measurement should be made routinely and that accuracy was important [Cushing, 1903].

Since the 1920s, the four vital signs—temperature, respiratory rate, heart rate, and arterial blood pressures—have been recorded in all patient charts. In 1903, Willem Einthoven devised the string galvanometer for measuring the ECG, for which he was awarded the 1924 Nobel Prize in physiology. The ECG has become an important adjunct to the clinician's inventory of tests for both acutely and chronically ill patients. Continuous measurement of physiological variables has become a routine part of the monitoring of critically ill patients.

At the same time that advances in monitoring were made, major changes in the therapy of life-threatening disorders were also occurring. Prompt quantitative evaluation of measured physiological and biochemical variables became essential in the decision-making process as physicians applied new therapeutic interventions. For example, it is now possible—and in many cases essential—to use ventilators when a patient cannot breathe independently, cardiopulmonary bypass equipment when a patient undergoes open-heart surgery, hemodialysis when a patient's kidneys fail, and intravenous (IV) nutritional and electrolyte (for example, potassium and sodium) support when a patient is unable to eat or drink.