Clinical information systems: their application in the ICU

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"From the earliest times, the notions of ill health and its treatment have been wedded to those of observation and interpretation of data."[1] Indeed, one could say that health care in general and Intensive Care in particular are information intensive enterprises. Medical Informatics involves the broad fields of management and use of biomedical information. Although based on medical computing, Medical Informatics incorporates the knowledge of the origin, nature, synthesis, and utility of the medical information itself. For Medical Informatics systems to be successful in improving health care, the skills of the interested physicians, nurses, computer scientists, researchers, and other medical professionals must be combined in a collaborative effort. The expectations of society for medical progress and increased use of computers for diagnosis and treatment are fuelled by the increased use of computers in everyday life.

Patients in ICUs are the most seriously ill of hospitalised patients and, therefore, require the most responsive care to assure their recovery. As a result, they present the team of care givers with the most 'raw' data needed to optimise their care. Whether these data include frequent vital signs, such as systolic and diastolic pressures along with heart rate derived from bedside monitors, or the results from magnetic resonance imaging scans or chest X-rays, all of these data must be acquired, stored (charted) and transmitted to the team of caregivers in a prompt and accurate manner.

WHAT IS A HEALTH INFORMATION SYSTEM?

A hospital information system, or more broadly, a health information system, is a system that gathers clinical as well as administrative data for and about the patient. Clinical data may be derived from observations and measurements by physicians, nurses, therapists and other caregivers, or from bedside monitoring devices, the clinical laboratory, medications given, and information from other ancillary services. Administrative data include information about scheduling of procedures, the costs and charges associated with various procedures, coding and documentation of the procedures performed on a patient, charges for medications given, classification of diseases using a coding systems, such as ICD-9, and a variety of other sets of information about whom and how to bill for the services. Computerisation of both the administrative and clinical aspects of care giving have become more and more common in recent years.

In the 1960s there was a rapid growth in the development of 'order entry and charge capture' administrative computer systems. However, in the 1960s, virtually all of the clinical parts of the medical records were based on hand-written notes and records. Since that time, the computer has been used as an aid to gathering, collating, and displaying patient information with the promise of improving the care of the patient as well as improving the efficiency and effectiveness with which the care is given.

WHAT DO MOST HEALTH INFORMATION SYSTEMS DO?

In 1998, most Health Information Systems have been designed to carry out administrative functions, such as order entry, charge capture and scheduling. While assisting with these 'administrative' functions is important for a health care organisation to be effective and efficient, a far greater potential for benefit is to use the computer to gather and process clinical data. Computer systems needed in the ICU are those which can help the physicians, nurses and other care providers with gathering, storing and presenting clinical data so as to optimise patient care.

DISADVANTAGES OF THE TRADITIONAL PAPER CLINICAL RECORD

Shortliffe and Barnett have outlined the disadvantages of the traditional hand-written medical record.[1] The issues involved are pragmatic and logical problems, redundancy and inefficiency, influence on clinical research and the passive nature of paper records.

Pragmatic and logical issues

Positive answers to the following questions with the current hand-written paper record can seldom be made. Can I find the data I need when I need it? Can I read and interpret the data once I find it? Can I reliably update the data with new observations so that others in the future can access the data?

Redundancy and inefficiency

Current hand-written records have a multitude of redundantly recorded data. Such 're-entry' of data is not only inefficient, but in many cases, results in transcription errors.

Influence on clinical research

Much of the current clinical research is based on 'manual chart review.' Such 'abstraction' of records is arduous, inexact, and very expensive. As a consequence, current record systems are an 'untapped' resource for clinical research.

Passive nature of paper records

The paper record 'sits there' waiting for someone or something to be done with it. Computer records can be active – as illustrated in the computerised decision-support example shown later in this paper.

ADVANTAGES OF THE COMPUTER-BASED PATIENT CLINICAL RECORD

The primary disadvantages of the traditional paper record are overcome by the computer-based record and there are other advantages too.[2]

Inaccessibility is a major drawback of any paper based patient record system. In emergencies, the patient's record may be unavailable because it is in a physicians office, distant hospital, or in the same hospital, but being used by someone else or might even being lost. With computer-based patient records the information can be retrieved from remote locations, for example in an ambulance via radio/cell-phone communications. Further, the records can be accessed simultaneously by several people, for example, a physician, a nurse, a therapist and an admitting clerk.

Computer-based records provide a more legible and better organised report; better because the records are more legible than handwritten notes and more organized because of the structure computerised database systems place on the data stored within them. In addition, computer systems improve the quality of the patient data by providing range checks and prompting for additional information when it is appropriate.

Perhaps the greatest advantage of a computer-based record system is that the computer can use the gathered data to make decisions. Several examples of computerised decision-making applications will be illustrated later.

Maximising the advantages

To maximise the value of a clinical computer-based medical record system, four factors have been found to be key to designing and installing such systems:[3,4]

- Scope of information – does the record contain the data needed. For example, you may have all the vital sign information in an ICU and not know the medications a patient is receiving.
- Archival capability – if the computer-based record system has only the information for the current visit and not data from a previous hospital visit or a clinic visit, the incomplete record may be of marginal use.
- Coding of data – the current hand-written medical record is stored as simple narrative notes. Computerising the narrative notes via word processors will make the notes more legible and perhaps more accessible. However, uncoded information is not standardised and there is an inconsistent use of medical terminology that limits the ability to retrieve and process the information. For example, using the word processor, a doctor might state that the patient's blood pressure is 120/80 or 12O/8O. Superficially, to the human eye they both look the same. However, the second contains the capital letter O instead of a zero. The example shown is a simple one, but illustrates the point. Thus, only if controlled, pre-defined medical terminology and vocabulary are used will it be possible to aggregate, summarise, and share patient information. Establishment of standards for data definition and for sharing of data across institutions are still major challenges of the in establishing computerised records.[3,4]
- Accessability – to access a computerised record, one must have a computer terminal and access to the record system. While just 5 years ago having a computer available and interconnectable for every care-giver was a far-fetched thought, today internet technology and the world wide web (www) have totally revolutionized our thinking.

DISADVANTAGES OF THE COMPUTER-BASED RECORD

Although the computer-based record has many advantages, one must be prepared to deal with and solve some of the potential disadvantages. Listed below are some of the disadvantages.

Confidentiality of the record

A potential 'Achilles heel' of the computer-based medical record is the confidentiality of the record.[5,6] However, the paper-based record is also not immune from such unauthorised access. Policies and legislative mandates about who has access to patient records and which records are 'hot' political topics in the USA today. The computerised record has the potential of being much more secure, and in addition currently has automatic 'audit trail' and authorisation capabilities that are impractical to implement with paper record systems.

Large initial investment

One must make a large capital and 'social' investment to install and operate a computer-based record system. Recently, I heard on a local radio station that if the automobile industry had kept pace with the computer industry since 1960, an automobile would cost only $2.46 in the US today!! So the computer industry is one in which price is certainly moving in the right direction. The 'social' costs relate more to having a medical, nursing and administrative staff who have the vision and are willing to make the process and operational changes necessary to implement a computerised record system.

Potential for catastrophic failures

Everyone who has used computers is familiar with this consequence. However, redundant disks, backup computers and other technological strategies are minimising these consequences. The HELP system, which I use daily, is a hospital information system with computerised ICU and decision support capability with an availability of 99.85%. That means the system is unavailable for less than 2.2 minutes each day! The telephone companies in the USA look to have their systems available for all but 1 minute of the 1440 minutes of each day or an availability of 99.93% of the time – a laudable goal for clinical computer systems.

Physician data capture

The cost of entering all the data used by physicians that should be documented is still high. The two primary costs of physician data entry are:

- changing the format of data entry from a hand written 'free text' format to a structured format
- at this point computerised data entry typically takes a bit more time.

However, direct speech recognition systems along with natural language processing schemes are technologies that are progressing rapidly and offer great hope for fast, simple and effective physician data entry. In addition, integration of data from multiple sources and not having to 're-enter' them in a dictation will dramatically aid physicians in the amount of data they must enter into a computerised record system. See the 'Antibiotic Assistant' example below.

HOW DO CLINICAL DEPARTMENTS AND CLINICALLY ORIENTED COMPUTER SYSTEMS INTERFACE WITH THE ICU?

Gathering data, whether it be observational data collected by a clinician or by a bedside monitor or laboratory instrument, the data must be 'interfaced' or entered into the integrated computer system. Interfacing is one of the most difficult tasks in acquiring clinical data for use in a computerised medical record. Figure 1 illustrates a patient in an ICU with data being acquired by a bedside monitor. Although the bedside monitor seems to be one of the key factors that differentiates the ICU from other care sites in a hospital, the need for data from ancillary departments is still essential. In a study conducted by Bradshaw and colleagues[7,8] at our facility, it was found that data from the bedside monitor accounted for only about 13% of the decisions made on patients in a shock–trauma ICU. Data from the laboratory were used for 42% of the decisions made, while pharmacy data accounted for 22% and observational data for 21% of the decisions. Thus, even though the bedside monitor appears to be the key differentiator for the ICU, integration of records across an institution is essential for the care of the critically ill. Figure 1 shows that it is essential to have data from the clinical laboratory, ancillary departments, radiology and pharmacy, from outside the ICU. In addition, data from the bedside monitor (including data from ventilators and other support devices), observations made about the patient, medications given (including drip rates from intravenous pumps), and information about procedures performed are essential for optimum patient care.

WHAT IS A COMPUTERISED CLINICAL DECISION MAKING SYSTEM AND HOW DOES IT WORK?

Figure 2 shows data that have been acquired in coded form and stored in an integrated clinical database. From this database, data can be processed by a 'decision-support engine' or what is also known as an 'expert system.' The decision support engine uses knowledge or rules from a knowledge base to process the integrated data. The processing of the decision support engine can be either 'data driven', for example if a serum potassium is 6.2 meq/L, a life threatening situation, the knowledge base will indicate that an alert should be sent to the physician or nurse caring for the patient. So as the data flows into the database the knowledge base is 'data driven' to process the data and look for alerting conditions. Interpretation of data from a blood gas machine is also a data driven application. See Figure 3 for a blood gas report with computerised interpretation. A 'time driven' application might be to send a reminder to check a ventilator setting and patient condition status 30 minutes after after the FiO_2 has been decreased during a weaning process.

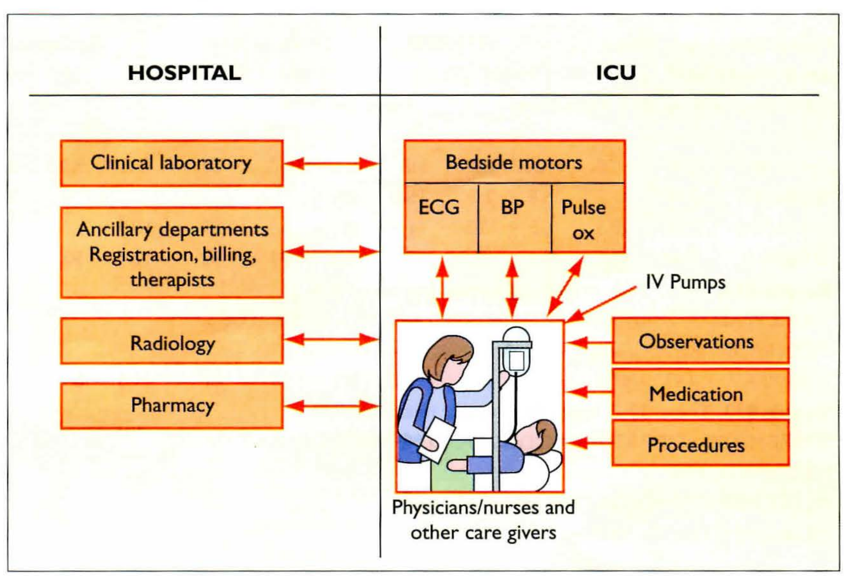
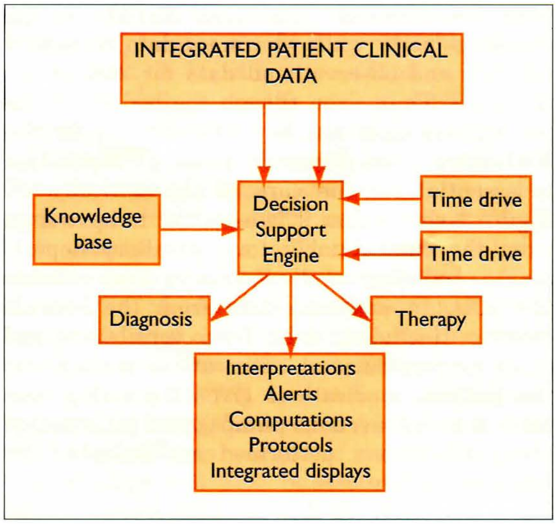


Figure 1. *The ICU in relationship to the hospital's clinical information system.*

Figure 2. *Illustration of an integrated clinical system used as a decision support system.*



One of the best applications of a computerised expert system is the 'antibiotic assistant' currently operational at LDS Hospital.[9] Figure 4 shows a computer screen presented to a physician as they consider caring for a patient with infections. The system acquires data from multiple departments and monitors. For example, the admitting diagnosis comes from the admitting clerk, the temperature and vital signs from bedside monitors or direct nurse observation. Multiple laboratory findings are automatically obtained from the laboratory computer system, allergies from physician or nurse queries of the patient or from data previously reported by the patient on an earlier visit, cost of medications from the hospital administrative system. Interpretation of radiological data is made by natural language processing of the chest X-ray reports. As a result, the operation of such computer applications, the care of patients has been improved and can be provided at lower cost.[9]

HOW DO YOU ACQUIRE AND RECORD RELIABLE PATIENT DATA INTO AN INTEGRATED COMPUTERISED RECORD?

Since valid and reliable data are essential to caring for a patient, unusual thought and care must be taken to acquire, code and store such data.[10,11] Strong and her associates have recently looked at the acquisition of data in a variety of situations, many of them clinical, where there are difficulties or 'potholes' on the road to high quality information.[11] Gathering data for an entire hospital or health care enterprise is usually a subset of the requirements for gathering data from an ICU patient. There are at least three separate considerations needed to acquire high fidelity data just from ICU monitoring equipment:[12]

- Properly ***designed*** transducers and data collection equipment
- Properly carried out ***procedures*** by the clinical staff
- Appropriate ***processing*** of the signals.

Recently the medical information bus (MIB) has become an Institute of Electrical and Electronic Engineers (IEEE) standard.[13] With the MIB acquisition from bedside devices will become easier and more reliable.[14–16] It is not unusual for a nurse or therapist in our modern ICUs to acquire data visually from a computerised monitor and ventilator and manually key the data into a ICU or hospital information system for clinical recording and billing purposes. Even in our sophisticated computerised ICU, I have nurses say to me "Dr Gardner, why do we have to read off one computer screen and enter the data into another computer?" I only hang my head low and say, "Just be patient it will happen!"

Dr Clement McDonald recently reflected on the

Figure 3. *Example of a computerised blood gas interpretation.*

Blood Gas
4/13/98.12:11 – 4/27/98.12:11

Patient: Lastname, Firstname #99999999 Room XXX Age/Sex: 62/F DOB: 00/00/1935
Admit Weight: 86.00 kg Height: 163 cm BSA: 1.92 SQM BEE: 1466 Dr: Jones, XXX
Admit Diag: CHF, ACUTE ABDOMIN Admit: 04/19/98

Apr 27 98	pH	pCO_2	HCO_3*	BE*	HB	CO/MT	pO_2	SO_2	O_2CT*	$\%O_2$	AVO_2*	VO_2*	CO	A-a*	Qs/Qt*	PK/PL/PP	MR/SR
Normal Hi	7.45	41.9	26.8	2.5	15.9	2/1					5.5	300	7.30	25	5		
Normal Low	7.35	28.5	16.5	-2.5	11.9	0/1	58	89	15.9		3.0	200	2.90		0		
27 06:00 A	7.48	60.1	44.6	19.5	9.3	4/0	71	92	12.1	50				157		/ /5	10/

Sample #14, Temp 37.0, breathing status: assist/control
SEVERE MIXED RESPIRATORY ACIDOSIS AND METABOLIC ALKALOSIS
MODERATELY REDUCED O_2 CONTENT

Apr 27 98	pH	pCO_2	HCO_3*	BE*	HB	CO/MT	pO_2	SO_2	O_2CT*	$\%O_2$
27 04:20 A	7.43	61.4	40.4	14.3	11.7	3/1	59	87	14.3	6

Sample #13, Temp 37.2, breathing status: nasal cannula
SEVERE MIXED RESPIRATORY ACIDOSIS AND METABOLIC ALKALOSIS
MILD HYPOXEMIA
MILDLY REDUCED O_2 CONTENT
PULSE OXIMETER SO_2 88.0

barriers to computerised patient records.[17] He indicated that interface standards for gathering data from laboratory systems, pharmacy systems and physician dictations systems that reside in what have previously been isolated systems are now available in the form of standards: HL7/ASTM, DICOM, LONIC, SNOMED, and others.[17] To make computerised patient records a reality, we must embrace these standards and 'share' data.

WHERE FROM HERE?

We have only begun to gather the data needed in the computerised clinical patient record and use these computerised records for decision support and quality improvement. We must not only come up with better ways of getting data into computer systems, we must be more clever (as with the antibiotic assistant illustrated in Figure 4), in making these systems more practical and supportive of physician functions as well as enhancing the quality of patient care with decision support systems based on the computerised records.

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Program Run at 14:10 on 04/27/98
12345678 Last, First Middle   E6XX 50 yr M Dx: CP, Acute Renal Failure
Max 24 hr WBC+ 0.4 Æ ( 0.4) Admit: 03/22/98.00:39  Max 24 hr Temp=38.5 Ø (38.7)
Renal Function: Impaired, CrCl = 31,  Max 24 hr Cr = 3.1≠ (2.5) IBWeight: 77 kg
Antibiotic Allergies: None reported
Current Antibiotics:
 1. 04/20/98.09:03 Tobramycin (Nebucin), Vial 100.          Q48 hrs
 2. 04/27/98.13:14  Ciprofloxacin (Cipro I.V.), Vial 400    Q24 hrs
Identified Pathogens            Site     Collected
 Pseudomonas aeruginosa         Sputum 04/20/98.04:31

Therapeutic Suggestion  Dosage Route  Interval
Ciprofloxacin   400mg  IV        *q24hrs
Suggested antibiotic duration: 10 days
*Adjusted based on patient's renal function
<1> Micro <2> OrganismSuspect <3> Drug Info <4> ExplainLogic <5> Empiric Abx,
<6> Abx Hx <7> ID Rnds <8> Lab/Abx Levels <9> Xray <10> Data Input Screen
To Order <*> Suggested Abx, <Enter>Other Abx </>D/C Abx <-> Modify Abx

EXPLANATION LOGIC
Patient should receive IV antibiotics.
Suggested antibiotics are not one of patient's known antibiotic allergies.
Renal function dictates that dosage should be adjusted.
Coagulase negative Staph. in sputum or urine is not considered a pathogen.
Cultures show isolated bacteria that were not considered pathogens.
Erythromycin may decrease the pharmacological effects of digitalis.
Antacids will decrease absorption of Ofloxacin.
A Staph or Gram+ cocci reported in blood was considered a contaminant.
Positive respiratory culture was supported by Xray of 04/27.
Prophylactic antibiotics are not suggested for this patient at this time.
Identified pathogens are covered by the suggested antibiotic(s).
Suggested antibiotic(s) are the least expensive of the appropriate antibiotics.

The antibiotic suggestions should not replace clinical judgement.
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Figure 4. *Display from a computer screen from an 'Antibiotic Assistant' used at LDS Hospital. Adapted from the recent work of Evans RS and colleagues.[9] The upper part of the display shows the relevant patient data needed to make a antibiotic therapeutic recommendation. The computer and its knowledge base have recommended ciprofloxacin, 400 mg i.v. every 24 hours for 10 days while the physicians have also chosen the same antibiotic and tobramycin in addition. If the physician chooses to order the ciprofoxacin he has only to enter an * and 'Enter' on the bedside terminal keyboard. The computer presents the data shown in about 5 seconds, while a manual review to acquire the same information takes about 15 minutes.[9] The lower part of the display shows the 'explanation logic' used to justify the therapeutic recommendation given.*

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