

## INFORMATION SYSTEMS AT THE JOHNS HOPKINS HOSPITAL

Computers are playing an increasingly important role in patient care. Ten years ago, systems were limited primarily to processing data; today they are becoming an integral part of the medical decision-making process. This article reviews the Johns Hopkins Medical Institutions' experience with clinical information systems and describes two applications in detail.

### INTRODUCTION

The potential benefit of computers in health care delivery was recognized in the early 1960's. It had already been established that about one-fourth of all activity in a hospital was dedicated to information processing.<sup>1</sup> Clearly, the computer could be used to manage this function, provide surveillance and reminders, and assume some of the labor-intensive activities. Unfortunately, the technology of the 1960's could not economically and reliably support the concepts of the early visionaries. The result was overpromise, under-delivery, and a decade of skepticism.

By the early 1970's, the diligence of researchers and developers had been rewarded. Systems were in operational use; in many cases the cost of operation was fully supported by patient care revenues. Progress continued, and 1975 represents something of a watershed year in the scientific literature of medical information science. Prior to that year, most papers were either speculative or descriptive. Since the operational half-life of the early systems was shorter than the normal publication cycle, many papers presented defunct applications. By 1975, however, key contributors reported on five years' experience with a system. Data were evaluated and system benefits were identified. Although most applications still were supported by research funds, progress was made in the development of transportable systems that could be justified on the basis of cost or benefit.

Building on newer, less expensive equipment, the use of computers proliferated. The 1982 market for hospital information systems is projected to be close to \$1 billion.<sup>2</sup> Over 95% of all hospitals of 100 beds or more use or plan to use computers.<sup>3</sup> Of course, much of this use will be for financial and administrative management. Nevertheless, computers are playing an increasing role in the process of patient care.

In what follows, we trace the use of information systems at the Johns Hopkins Hospital. This history records both success and failure. Because the primary focus is the impact on patient care, the discussion is limited to clinical information systems. These are defined as applications that manage clinical data and that also retain an extended data base. Systems in-

cluded in this category are the hospital information system, the clinical laboratory system, and surrogate medical record systems. Excluded from consideration are financial information systems, embedded computers (e.g., the CAT scanner), and systems with limited data base facilities (e.g., digital physiological monitoring systems and EKG stations).

### THE JOHNS HOPKINS HOSPITAL

The Johns Hopkins Hospital (JHH) is an 1100-bed hospital located in the inner city of Baltimore, Md. The hospital annually provides about 320,000 days of inpatient care; there are also over 350,000 outpatient visits per year, of which 77,000 are emergency cases. As part of the Johns Hopkins Medical Institutions, the hospital is also involved with teaching, research, and specialized medical care.

### Hospital Information Systems

In 1974, JHH organized itself into a group of largely independent units.<sup>4</sup> Each unit (e.g., the Section of Surgical Science or the Department of Medicine) was given broad financial responsibility and authority in the formulation of its individual budget. The reorganization led to dramatic reductions in cost growth and provided a model for other hospitals. With respect to information systems development, this reorganization implied that JHH would provide central facilities, such as financial management systems and an admission, discharge, and transfer system. Individual functional units, on the other hand, would be free to purchase or develop local systems if they could be justified. The result was a major commitment to a central system that supported all JHH units plus the independent development of smaller systems that would meet specialized needs.

Figure 1 is a diagram of the clinical computer complex at the East Baltimore campus. The JHH central computers are located in the basement of the Rutland Avenue garage. They consist of one IBM 3031 and two IBM 4341 computers with 3.5 gigabytes of mass storage. This system supports 350 video terminals throughout the hospital; it also provides batch sup-

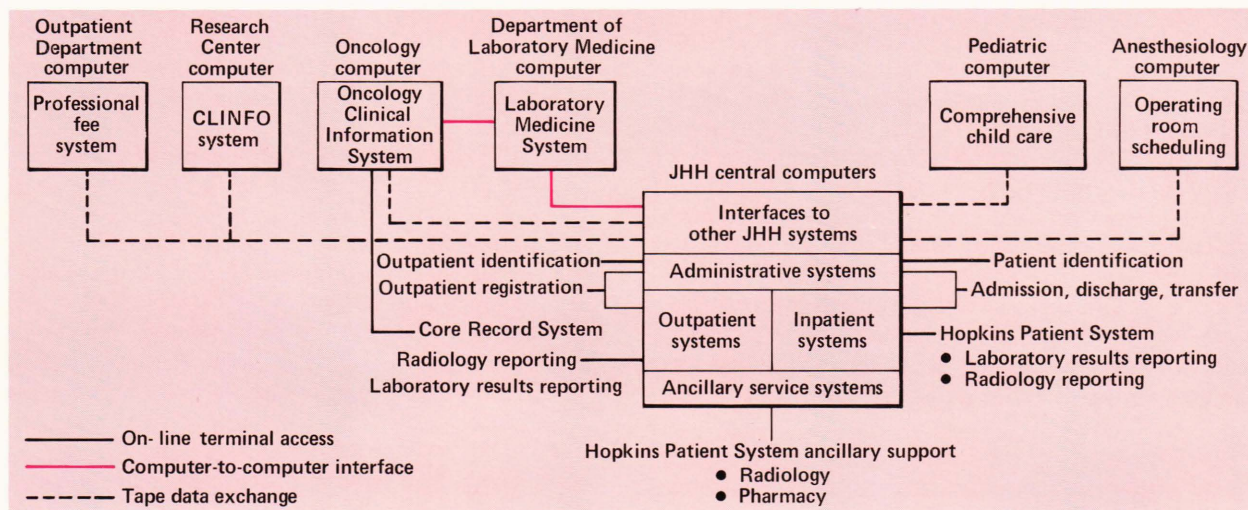


Figure 1 — Johns Hopkins Hospital clinical information systems.

port for all of the hospital's administrative systems and some of the School of Medicine's research needs.

The clinical functions supported by the JHH central computers are divided into four general categories:

1. Administrative systems. These include the identification of patient history numbers from the name and demographic information; the recording of such general information as address, next of kin, and insurance coverage; and patient location within the hospital.
2. Inpatient systems. All hospital-wide inpatient functions are now being merged into a single integrated unit called the Hopkins Patient System.
3. Outpatient systems. As in most large hospitals, the large number of outpatient visits limits the scope of the automated support. Access to some current information is available through the Hopkins Patient System.
4. Ancillary services. A hospital is normally divided into patient care services (e.g., surgery, pediatrics) and ancillary services (e.g., pharmacy, radiology, clinical laboratory). Each system that provides a patient care service also includes functions that are uniquely directed to the management of the ancillary service units (e.g., work lists for the clinical laboratory).

In addition to the JHH central computer complex, there are several smaller computer facilities that are dedicated to the local needs of specific functional units:

1. Department of Laboratory Medicine. A network of computers manages the processing of information within the clinical laboratory. This involves interfacing with automatic analyzers, processing requisitions, preparing laboratory

reports, and communicating with the JHH central computer.<sup>5,6</sup>

2. Oncology Center. A pair of computers supports a 56-bed tertiary care facility for cancer patients that also handles 500 outpatient visits a week. The computers are also used to operate the prototype Core Record System.
3. Department of Pediatric Medicine. This system is dedicated to the Comprehensive Child Care program. It is used to manage administrative data, present clinical information, and support quality assurance and research analysis.<sup>7,8</sup>
4. Department of Anesthesiology and Critical Care Medicine. A small computer is being used to manage scheduling for the operating rooms and critical resources. There are plans to integrate this system into a much larger resource scheduling system.

In addition to these patient care systems, other systems throughout the Medical Institutions are used for research and administration. Of particular note are the following:

1. CLINFO. This system has been specially designed to allow individual investigators to manage and analyze data from clinical trials.<sup>9,10</sup>
2. Professional Fee Billing. A commercial system is used for professional fee billing. This system can support new clinical applications for the outpatient units.

### Development of the Systems

Under the leadership of Richard Johns and Donald Simborg, the Department of Biomedical Engineering was instrumental in developing several major clinical systems in the late 1960's and early 1970's.

A prototype ward management system<sup>11</sup> was implemented in the early 1970's. It was designed to organize and assist in carrying out physicians' written

nonpharmaceutical orders in a 30-bed acute inpatient ward. The system processed all physician orders and produced action sheets for each nursing team and patient. Special action sheets dealt with diets, utility rooms, weight, specimens, intake and output, and vital signs. Standing order sheets were also printed.

During its trial period, the system was well received by the users. A detailed analysis that compared automated and nonautomated 30-bed units demonstrated that the system was able to reduce errors.<sup>12</sup> A summary of the findings is given in Table 1. Unfortunately, the cost of equipment was too great to justify full-scale implementation, and the system was abandoned after the concept had been demonstrated.

**Table 1** — Summary of ward errors with and without a prototype ward management system.

	<i>Automated Units</i>	<i>Unautomated Units</i>
Orders examined (total no.)	856	857
Transcription errors (%)	1.7	7.3
Communication errors (total no.)	9	70
Uninterrupted communication errors (no.)	6	38
Failure to carry out order exactly (%)	5.8	14.7

A different application of a computerized clinical system was developed for the inpatient pharmacy in 1970.<sup>13,14</sup> Its goals were to reduce errors in the administration of medication, to lower the number of nursing hours required for medication-related activities, and to eliminate waste of medication. The system uses unit-dose drugs (that is, drugs that are prepackaged in the unit of use) and works as follows:

1. Physician drug orders are entered into the data base at a video terminal. This may be done by a medical professional or a clerk at the nursing station, or in the pharmacy. At JHH, all orders are entered in the pharmacy. The order entry program will not accept inappropriate doses, methods of administration, etc.
2. After the order is entered, a pharmacist reviews the order against the patient's current drug profile (i.e., a list of current orders and drugs administered). If there are questions, he will call the physician.
3. Periodically, the system processes all active orders and prints dose envelopes that contain the name and location of the patient, the time of scheduled administration, the drug description,

and any special instructions. These envelopes have a clear window on the reverse side so that a technician can check to see that the contents match the instructions printed on the front side.

4. After the envelopes are filled and checked, they are placed in a tray for delivery to the nursing unit. Each tray typically contains all drugs required for a two-hour period. One hour prior to the time of administration, a list of drugs is printed, and the pharmacy technicians adjust the trays to reflect any changes made since the envelopes were first printed. The tray and list are then delivered to the floor for administration.

By having the computer manage the current orders and by using multiple checks for accuracy, the number of medication errors was reduced by about 75% (see Table 2). Because the computer is used to process all orders, automatic billing and preparation of daily and discharge drug profiles are possible. The availability of the profiles reduces clerical activity and makes timely data available in an easy-to-read format.

**Table 2** — Summary of pharmacy errors with and without a computerized unit dose system.

	<i>Automated Units</i>	<i>Unautomated Units</i>
Observations (total)	1234	1428
Wrong route	1	2
Wrong dose	7	76
Extra dose	3	8
Unordered drug	5	18
Wrong form	4	1

The automated unit-dose system was in operational use from 1970 to 1983. Its scope was limited to the departments of Medicine, Pediatrics, and Oncology. The decision to discontinue its use was based upon its operating cost and the need to implement a new pharmacy system for the Hopkins Patient System. An equivalent pharmacy system with an identical flow was written for the Oncology Center and now operates on the Oncology Center's computer. A manual, unit-dose cart system is used in all other units; an automated pharmacy system is scheduled as part of the implementation plan for the Hopkins Patient System.

A third system, the Johns Hopkins radiology reporting system, was developed in the late 1960's to speed and facilitate the generation of radiology reports.<sup>15</sup> It is used throughout the hospital and follows this flow:

1. On completion of filming, each study is given an accession number, and the patient identifier

information is entered by a clerk into the system's data base.

2. In the reading room, the radiologist signs on to the reporting terminal. All reports generated after this sign-on will contain his name at the bottom.
3. To begin reporting, the radiologist enters the accession number of the case, and the terminal displays a frame with logically arranged lists of words and anatomic diagrams specific to each type of examination (see Fig. 2). The report is generated by probing (touching) selected words or phrases; colored probe points indicate the availability of more detailed frames.
4. Once the report has been generated, it is reviewed in text form at a video terminal. If it is accepted, END EXAM is probed and the process continues.
5. Periodically, the newly generated reports are printed, and the printed reports are distributed to the ordering physicians. On-line access to the report, however, is available at all designated video terminals in the hospital as soon as END EXAM is probed.

method of dictation and stenography. The system is easy to use. The radiologists generate reports almost as quickly as they can dictate, and the final report is immediately available for verification and retrieval. Finally, the availability of computer-stored reports is useful for research, medical audit, teaching, or regeneration of lost medical records. (A commercial version of the system was marketed by Siemens; because of limited sales, it is no longer available.)

In parallel with the development of these stand-alone systems, there has been a continuous effort to produce an integrated hospital system. One key component of such a system is the patient locator called the admission/discharge/transfer system. In the mid-1970's, such a system was developed at JHH, one that both maintained the current inpatient census and linked the various ancillary systems. The success of this approach led the hospital to evaluate its needs in the area of hospital information management. After performing an intensive analysis, JHH decided to install a comprehensive hospital information system. The system chosen was the IBM Patient Care System, which was originally developed by the Duke Medical Center and is marketed by IBM.<sup>16</sup>

This system has been in routine use since 1972. The cost of operation is comparable to the traditional

The needs of each hospital are different. A considerable period of time is necessary before the requirements are established and the system can be in-

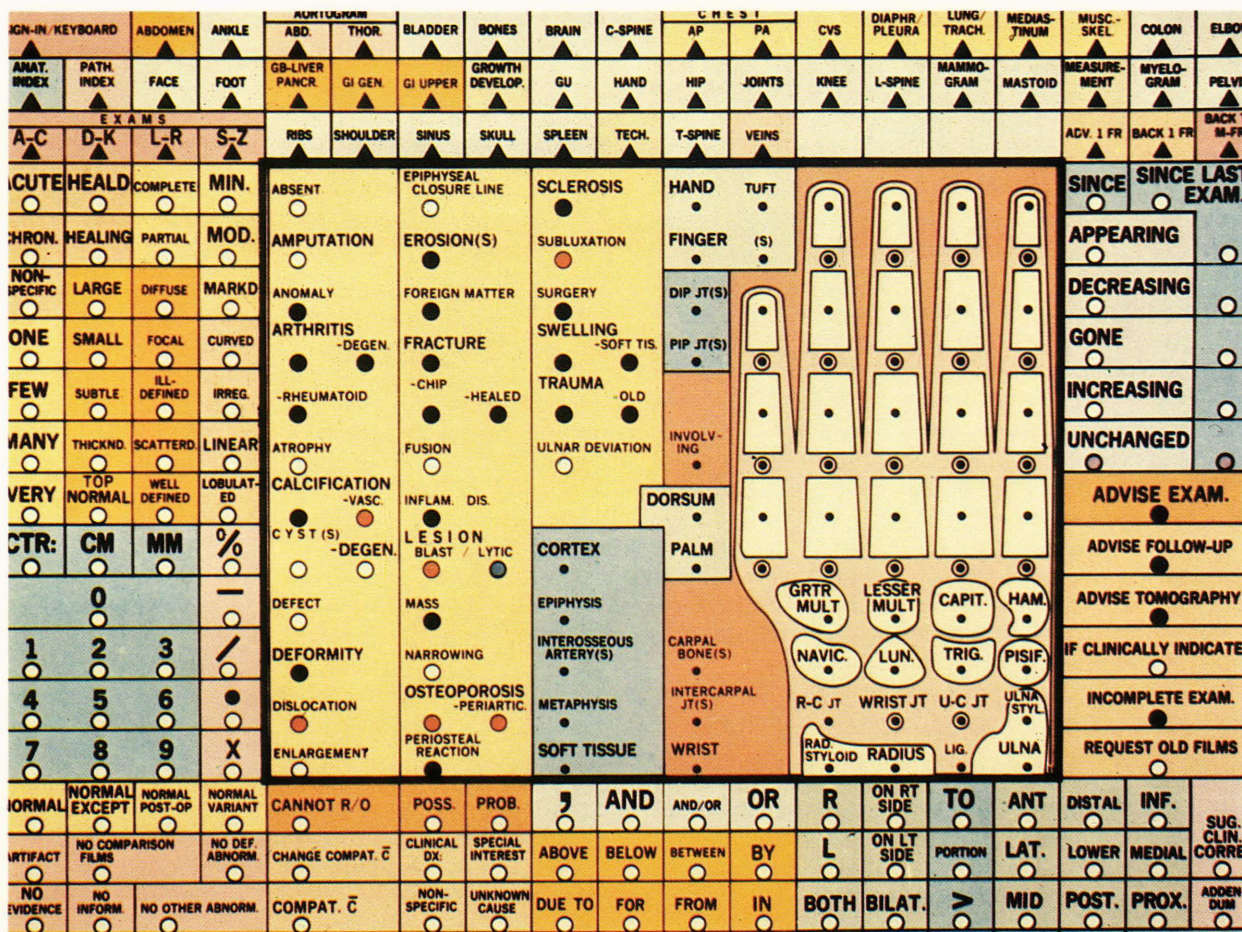


Figure 2 — Sample radiology display from the commercially available system.

stalled. At the present time, the Hopkins Patient System provides access to clinical reports in the nursing units and selected outpatient areas. New and replacement functions are being installed; several years will be required before the complete system will be implemented.

Along with the creation of a strong centralized system, several functional units developed systems for their local needs. Two of these systems provide an interesting contrast in requirements and scope. The first is the Oncology Clinical Information System, designed to manage data and to support decision-making for cancer therapy. The second is the Core Record System, designed to produce a low-cost summary medical record for use in ambulatory care. Both systems were cost justified on the basis of their contribution to patient care; neither development was supported by any government grants.

### THE ONCOLOGY CLINICAL INFORMATION SYSTEM

The Johns Hopkins Oncology Center is one of 22 Comprehensive Cancer Centers established as part of the National Cancer Plan initiated by the Cancer Act of 1971. The Center has major programs in laboratory and clinical research, education, and collaborative activities with community physicians. Care of adult patients is centered in a 56-bed facility that can also serve 500 outpatients per week. At any one time, 2000 patients are being treated under one or more of several hundred formally established treatment plans called protocols.

#### Development of the System

The development of the system was begun in the mid-1970's, when plans were made to consolidate various oncology activities into a single facility. Although there was no funding for a computer or for software, the facility's architecture and staffing projections were predicated on the assumption that a computer system would be available. Over 250 wall jacks were set into place, with cables terminating in a computer room.

During the period of planning, it was decided to develop a prototype system. At that time, outpatients were being treated in a Johns Hopkins clinic, and inpatients were being treated in facilities at Baltimore City Hospital. At each site, procedures had been established for patient management based on the careful evaluation and monitoring of clinical data.

Based on the Oncology Center's clinical practices, it was determined that an information system was required that would

1. Organize and display the clinical data as an integrated report that combined inpatient and outpatient data in ways that could indicate trends and facilitate decision-making.
2. Manage the basic patient record functions, including a hospital-wide tumor registry, sum-

mary patient records, current census, and appointments.

3. Schedule patient care activities and therapies as determined by clinical algorithms and research studies. Since most cancer therapies involve sequences of actions over long periods of time, the ability of the computer to provide reminders was considered an important asset in dealing with the problem of information overload.
4. Maintain clinical data for retrospective analysis.

In July 1975, one year before the Center was to open, work on a prototype began.<sup>17</sup> The first task in developing a prototype was to convert the existing automated tumor registry file into a format that could be expanded to meet the needs of the Center. The data base was transferred and programs were developed to produce patient abstracts such as that shown in Fig. 3. At the same time, work began on the development of formats that could display clinical data effectively. Flow sheets and printer plots were designed, and, after many iterations, the formats presented in the following sections were established.<sup>18</sup>

The prototype system operated on a computer at the Applied Physics Laboratory. The tumor registry was a functional system with a current data base. It ran in the batch mode and was used for searches, reports, abstract preparation, and quality assurance. The remainder of the prototype system was used on a

```

JOHNS HOPKINS HOSPITAL          HISTORY NO:
ONCOLOGY CENTER                TIME:
                                DATE: 4/2/82

                                PHONE          CLASS   DNC
                                SPOUSE         ORG 02121061
                                BIRTH DATE   PRR 030
ADMITTED 02/02/78             DISCHARGED 03/25/78
SEX F                           RACE WHITE   MAP. STATUS SINGLE
FOLLOW UP STATUS - 09/05/78   DECEASED

DIAGNOSIS PRIMARY - 1
-----
:
:   OUTSIDE DIAGNOSIS 12/77
: ANNE ARUNDEL GENL. HOSP.
:
:   JHH DIAGNOSIS 02/78
:
: 162.3 UPPER LOBE, LUNG
: 8047/23 DAT CELL CARCINOMA (T-162)
: GRADE: POORLY DIFFERENTIATED
: EXTENT: DISTANT
: LATENT: LT ORGAN INVOLVEMENT ONLY
:
: BASIS OF DIAGNOSIS: PATHOLOGY, CYTOLOGY, X-RAY, OTHER: OJHH REPORTS
: CARCINOMA OF LUL LUNG WITH MET.
:
: 78-1 - BONE MARROW BX.: METASTATIC SMALL CELL CARCINOMA CONSISTENT
: WITH LUNG PRIMARY, OSL 78-1759 - MEDIASTINAL LYMPH NODE (OSL):
: METASTATIC SMALL CELL CARCINOMA CONSISTENT WITH LUNG PRIMARY.
:
:
: TREATMENT PRIMARY - 1
:-----
: FROM : TO : TYPE : PURP : LOC : DESCRIPTION
: 12/77 : : BIOP : : OTH : BRONCHOSCOPY BX.
: 12/77 : : BIOP : : OTH : MEDIASTINOSCOPY BX.
: 02/02/78 : : CHEM : : JHH : NOTE 1
: 02/02/78 : : BIOP : : JHH : NOTE 2
: 06/14/78 : : BIOP : : JHH : BONE MARROW (POS. 78-9524)
:
: NOTES
: 1 J7719 - CYTOKAN, ADRIAMYCIN, AND VP16
: 2 BONE MARROW NEEDLE BX. (78-1937)
:
:-----
HISTORY
:-----
: MEDICAL HISTORY 1950 PEPTIC ULCER, 1965 TB
: SOCIAL HISTORY  SMOKE: 2 PPD X 25 YRS. 3-4 PPD X 8 YRS.
: ONSET OF SYMPTOMS 12/77: RT. FLANK PAIN
: OCCUPATION      TELEPHONE OPERATOR
: ALLERGY         PENICILLIN
: COMMENTS       RELIGION: BAPTIST
:-----

```

Figure 3 — Sample patient abstract, Oncology Clinical Information System.

limited basis. Because of the difficulty in establishing a current data base, the display system was most effective for retrospective studies; its primary contribution was the establishment of format requirements for outputs.

In 1976, in part as the result of a gift from the Educational Foundation of America, sufficient funds were available to purchase a computer and support the development of a system for the Oncology Center. Called the Phase I system, it would be a conversion of the prototype to an interactive system on a dedicated computer. A PDP-11 computer was selected with the MUMPS operating system. Work on the prototype stopped, and development of the new system began.<sup>19</sup>

Figure 4 presents a summary of the development activity. As can be seen, the prototype system was converted to an on-line system with the prototype's data base in nine months. The reasons that the system could be rapidly implemented were (a) the existence of a prototype so that the design requirements were well known, (b) the use of MUMPS with its powerful data access tools and interactive debugging capability, and (c) the fact that all activity was devoted to new applications with no effort spent on system maintenance.<sup>20</sup>

Development of the system continued and new functions were added: bacteriology reports sorted by date, organism, or specimen; appointment system, including scheduling of tests; pheresis system to manage blood product donation and transfusion; administrative functions such as charge capture and reporting of level of care; and protocol-directed daily care plans.<sup>21,22</sup>

The success of the Phase I Oncology Clinical Information System began to limit its effectiveness. The system became saturated at 20 concurrent jobs, production processing required 20 hours a day, and it was difficult to add new functions to the existing system. Further, during periods of computer downtime

there was no automated backup. It was therefore decided to add a second computer to permit adding functions and to provide backup.

The second computer was installed in 1980. Standard MUMPS was now available; the previous version was no longer used. Because the two versions were sufficiently different, it was decided to reprogram the system rather than convert it. This became known as the Phase II system. It also was decided to use a new programming tool, TEDIUM™, which would provide data base management system functions and improve system maintainability.<sup>23-25</sup> Unfortunately, TEDIUM was only in its initial stage of development, and the staff was faced with the following problems: (a) conversion of what was, by now, a complex system, (b) maintenance of the old MUMPS system, and (c) use of a new and poorly documented tool. The result was a major slip in the schedule and some user frustration. However, the conversion was successful. Parts of the new system were put into operational use in 1981, and the old MUMPS system was retired in 1982.

The two computers are now linked with distributed data base software; continuous clinical and administrative support is provided. There is a direct link to the Department of Laboratory Medicine's computer system, and all test results are automatically transferred to the Oncology Clinical Information System. The computer also supports an Oncology Center pharmacy with a common data base.

Because the system manages a very large data base, attention is now being directed to the implementation of tools to manipulate the data base for retrospective analysis. Called the Phase III system, parts are in operational use; all basic tools will be in place by the end of 1983.

### Data Display and Management

The data base contains information on about 37,000 patients, including 9000 who have been treated in the Oncology Center. For all patients in the data base, it is essential to have the basic identification (name and history number), demographic data (e.g., age, race, sex, place of birth), and diagnosis (e.g., location of disease, type of disease, date diagnosed). For the patients treated at the Oncology Center, additional information is required for therapy, administration, and evaluation.

The abstract, shown in Fig. 3, provides on-line access to much of the summary data required by the health care team. The abstract contains identification and administrative data. For each primary tumor site, there is a block that gives the diagnosis and a summary of treatment. These blocks combine both codes and text. For example, for the patient whose abstract is shown in Fig. 3, the disease is coded as 162.3, Upper Lobe, Lung. While this is effective for searches, there is a less precise text description that is more meaningful to the physician, i.e., "Carcinoma of LUL lung with met." A summary of the pathology report provides more detailed information.

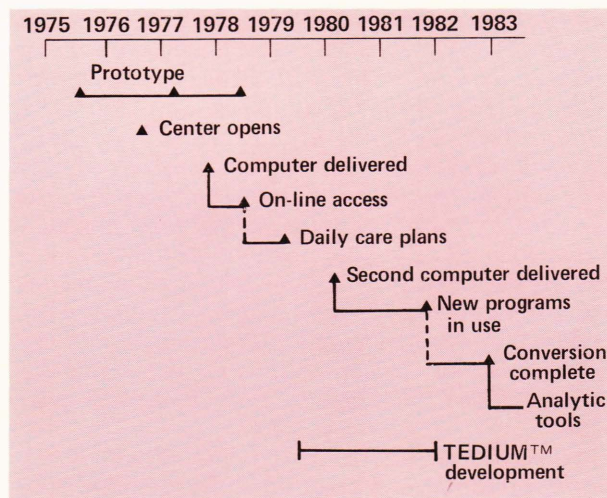


Figure 4 — History of the development of the Oncology Clinical Information System.

The presentation and searching of abstract data are generally straightforward. The management of clinical data, however, is more complex. Some patients are treated for many years, and all of their inpatient and outpatient test results, medications, and vital signs are retained. The data base now contains over 4.5 million data points for those patients treated at the Oncology Center. It is not uncommon for patients to have over 100 data points recorded in a single day. Clearly, special tools are required to present these data in formats that facilitate medical decision-making.<sup>26</sup>

The most common format for data display is a chronological tabulation called a flow sheet. The system provides a capability for ordering flow sheets (see Fig. 5) containing specific data for a given time period. This presentation is clearly superior to the collection of laboratory slips that usually confronts a physician; in fact, in most settings a physician generally transcribes the information on the laboratory slips onto his own flow sheet.

A major deficiency of the flow sheet is its inability to indicate the time axis. This deficiency is effectively overcome in a plot such as that shown in Fig. 6, which shows the first 36 days of therapy for a leukemia patient treated with a combination of two anti-tumor drugs. The platelet and white blood cell counts are plotted on a logarithmic scale. Below the plot are shown the chemotherapy administered, the anti-

otics given, the blood products transfused, and the temperature in degrees above normal.

To illustrate how such plots can be used in patient care, note how this single plot combines information to provide an overview of the patient's progress. Therapy for the leukemia with cytosine arabinoside and daunomycin was begun on February 16. With the convention used by this protocol, this date is re-numbered treatment day (TX DAY) 1. Based on a laboratory research model of cell kinetics, a second cycle of cytosine arabinoside chemotherapy is given beginning on day 8. The effect of this treatment is readily seen. A large number of malignant leukemic cells (W) are eliminated, falling from a pretreatment level of 80,000 to a level of 100 by day 5.

At the bottom of the plot, the patient's maximum daily temperature is indicated in degrees above normal (centigrade). The temperature is elevated at the outset of treatment. As a toxic reaction to the chemotherapy, bone marrow aplasia (signified by a white blood cell count of less than 1000) is added as an additional medical problem. Two antibiotics are begun; the temperature falls to normal. Protocols for the management of fever in the absence of normal white blood cells are a routine part of the organized approach to clinical management that must be taken into consideration in the design of this computer display

To continue with this illustration, the impact of a standard protocol for administration of blood platelets is also seen. Platelet levels, plotted as "P" on the graph, are monitored daily. When the number of platelets in the blood falls below 20,000/cubic millimeter, there is a danger of hemorrhaging, and platelet transfusions are given. This plot uses a horizontal line drawn at 20,000 to provide a visual guide to the medical management team. Transfusions of platelets and the responding rise to higher levels on the following day are indicated along the bottom of the plot and in upward deflections of the plotted line. In this patient, it is clear that platelet responsiveness exists and continues throughout the treatment.

By day 19, normal white blood cells are seen to be returning, and by day 32 the patient is shown to be in remission from his leukemia and ready for discharge.

The use of daily plots combined with composite plots of the same variables (mean and 95% confidence limits for ten or more patients treated with this cytotoxic regimen) help in assessing this patient's status and allow the physician to compare the patient's response to the combined experience of the total group under treatment. The availability of actual data to accurately describe past and current clinical experience is considered an important basis for rational clinical decisions. In addition, these features of the system support the Center's clinical research programs.

In this example, more than a month of therapy has been summarized in a graph to show the basic processes of tumor treatment, control of infectious disease, and blood product support. During this

JOHNS HOPKINS ONCOLOGY CENTER		HISTORY NO: 002830146							
		NAME: *****							
		DATE: 04/30/82							
STANDARD FLOW									
:	:	29MAR82:30MAR82:31MAR82:01APR82:02APR82:03APR82:04APR82:	:	:	:	:	:	:	:
:	J7R20	DAY 35:DAY 36:DAY 37:DAY 38:DAY 39:DAY 40:DAY 41:	:	:	:	:	:	:	:
:	J7914	DAY 21:DAY 22:DAY 23:DAY 24:DAY 25:DAY 26:DAY 27:	:	:	:	:	:	:	:
PAT STATUS									
:	TEMP	DEG C	37.5	37.4	37.4	36.9	37.4	37.3	37.3
:	PULSE		120	122	124	104	104	148	148
:	RKSPHAIN		24	20	24	20	22	12	24
:	BODY WT AM KG		61.3	61.0	61.4	61.2	60.7	61.0	61.0
:	FVC		3.50		3.70		3.6		3.5
:	CAFF LEVEL		4	4	4	4	4	4	4
:	FLUID (I.V.) ML		1465	1350	940	2115	1690	4110	2435
:	FLUID (P.I.) ML		940	1545	675	480	600	0	30
:	TOTL INTAK ML		2405	2895	1565	2595	2290	1235	2465
:	URINE OUT ML		2450	975	2075	1380	1000	1875	875
:	URI+STOOL CC		0	0	0	0	0	0	0
:	LIQ STOOL ML		50	250	0	850	275	0	800
:	FEMES OUT ML		0	0	350	550	0	0	50
:	TOTL OUT ML		2500	1225	2425	2780	1275	650	1725
:	IN/OUT DJF ML		-95	1670	-860	-185	1015	585	740
:	KCAL(I.V.) KCAL		1344	936					
:	PROT(I.V.) G		54	39					
:	KCAL(P.O.) KCAL		932	1430					
:	PROT(P.O.) G		45	57					
:	TOT CAL KCAL		2276	1691					
:	TOT PROT G		99	74					
HEMATOLOGY									
:	WBC	#/CU	3700	3600	3600	5400	5000		
:	HCT	%	33.6	34.0	30.0	33.0	33.0	34.0	32.0
:	RETICULOCYTE	%	2.4		5.0		3.2		
:	PLATELETS	/MM <sup>3</sup>	83000	85000	89000	92000	116000	105000	89000
:	WBC/DIETS	%							
:	MEIAT/ICLYT	%							
:	HANDS	%	3	5	1		5		
:	EUSI/PHIL	%	5				1		
:	BASOPHILS	%		1					
:	LYM/PHOCTP	%	16	10	13		9		
:	MONOCYTES	%	9	17	6		19		
:	NEUTROPH	%	72	62	80		64		
CHEMISTRY									
:	SER NA	MEQ/L	131	133	135	137	136	138	136
:	SER K	MEQ/L	4.0	3.7	4.2	4.0	4.8	4.9	4.6
:	SER CL	MEQ/L	95	95	98	101	99	105	102
:	SER CO2	MEQ/L	29	30	30	26	27	25	24
:	ANTON GAP		11	12	11	14	15	13	15
:	SER BK ALI	MG/DL	12	13	12	15	14	14	11
:	SER CHEAT	MG/DL	0.9	0.8	0.7	0.7	0.7	0.6	0.3
:	SUN/CHEAT		13	16	17	21	20	23	37
:	SER GLUC	MG/DL	144	149	138	106	169	148	154
:	TOT SER PT	MG/DL				5.2			
:	SER ALBMIN	GM/DL	3.2			2.5			
:	TOT BILI	MG/DL				0.3			
:	BTP BILI	MG/DL	0.1			0.1			
:	SGOT	IU/L	26			31			
:	SGPT	IU/L				48			

Figure 5 - Sample flowsheet.

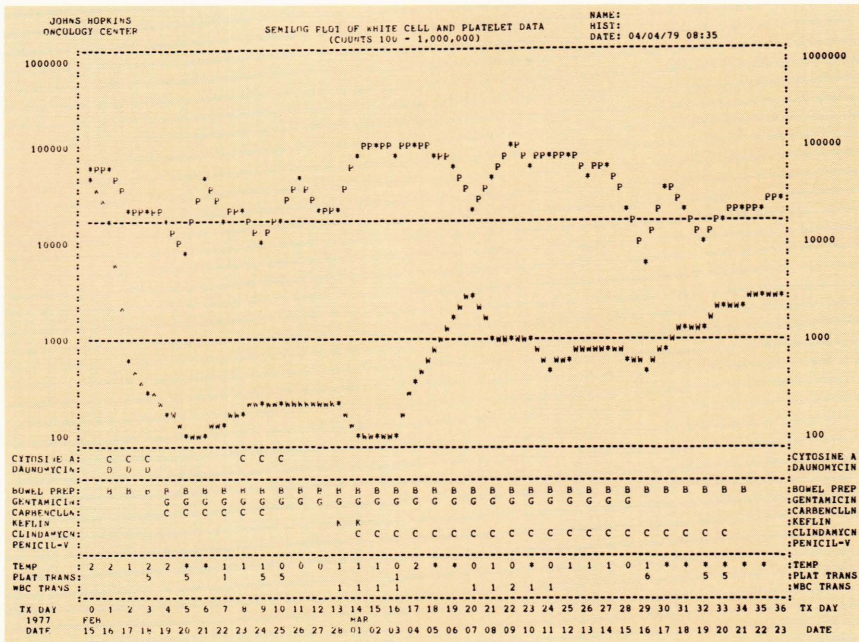


Figure 6 — Sample plot.

period, other organ systems are under stress, and similar plots may be used to monitor the function of individual organs such as kidneys or liver, selected general functions such as nutrition or fluid balance, or specific medical complications such as hypercalcemia. Each day approximately 100 plots are printed and distributed to the patient areas in time for morning rounds or an outpatient visit.

### Daily Care Plans

Daily care plans were designed to assist the physician who must treat many patients over long periods of time using complex treatment modalities in both an inpatient and an ambulatory setting. In a less complex environment, McDonald has shown<sup>27</sup> that there is a problem of physician information overload that can be alleviated by use of an automated system. Automated pharmacy systems have illustrated how routine surveillance for drug-drug interactions causes physicians to modify their therapeutic orders.<sup>28,29</sup> Wirtschafter *et al.* have demonstrated that automated procedures used in a community physician outreach program can produce very high rates of compliance with a research protocol.<sup>30</sup> The purpose of the daily care plan, therefore, was to introduce automated support for therapy decision-making.

In order to understand how an automated system may be used in a facility such as the Oncology Center, it is necessary to appreciate the general process of patient care. Patients are treated for their cancer, as well as for disease or therapy-related medical complications. Much of this therapy follows predefined protocols (clinical algorithms or treatment sequences) that may be grouped into four categories:

1. Research protocols. These define a set of therapeutic actions to be followed for a specific pop-

ulation in order to produce a consistent set of data to evaluate a hypothesis.

2. Individual therapy. This involves the use of antitumor drugs generally in multidrug combinations administered using complex time-sequenced relationships. Therapy may extend for months or years. An example is the use of a drug sequence demonstrated to be effective by a previous research protocol.
3. General support and response to life-threatening crises. These involve the use of established procedures to deal with anticipated reactions and problems associated with the antitumor therapy. In many cases, these actions are specified in each research protocol. Examples are (a) the use of antibiotic drugs to treat infections when it is known that the antitumor drug will severely lower the white blood cell count and (b) management of fluid balance.
4. Disease-specific continuing care. This entails the recommended long- and short-term care and patient monitoring associated with a specific disease independent of the therapy selected. These actions may also be included in the research protocol documentation. Examples are (a) routine six-month chest X rays for all patients with breast cancer and (b) routine three-month monitoring of serum protein electrophoresis results for certain multiple myeloma patients.

At any given time, an individual patient may be treated by one or more research protocols (e.g., an antitumor protocol and an antibiotic protocol). The patient whose flow sheet is shown in Fig. 5 is being treated by two protocols. (The day of treatment under each is given in the heading.) These research



protocols may be supplemented by other support protocols (e.g., a hypercalcemia protocol to help manage high levels of serum calcium) and long-term follow-up (e.g., annual battery of tests). The situation is further complicated by the fact that (a) protocols may have branches for preselected groups or outcomes in which patients are given different doses of the same drug or combinations of different drugs, (b) the Oncology Center is a teaching institution and thus subject to house-staff rotation, (c) at any one time, there are over 2000 patients being actively treated by the Center, and (d) there are currently more than 125 formal research protocols active in the Center.

The daily care plan system operates by first breaking down the protocol into logical therapy units called treatment sequences. The system then provides tools to allow the physician to assign these sequences to patients starting on a given date. This is called a standing order. Each day the standing orders are examined, redundant orders are removed, and a set of recommended orders is produced. These are printed as the plan that the physician uses to order tests and procedures. The results of these orders are then entered into the data base so that the next day's plan can be derived from both what the standing order requires and what was actually done.

The daily care plan is printed in several different formats. A physician plan summarizes information about the patient's status and tests to be ordered, a general plan contains more complete information, and an order guide is used by the ward clerk to process test requisitions and by the phlebotomist to obtain specimens.

The general daily care plan is illustrated in Fig. 7. It contains:

1. Data about patient status. Examples include height, weight, body surface area, admission weight, and blood type.
2. Therapy summary. This contains protocols with associated starting dates, names of physicians, and general comments.
3. Comments generated by treatment sequence. These are grouped into several categories, with the most important printed in a box to command attention.
4. Tumor measurements. Where there are solid tumors, a section of the plan records initial and current dimensions and computes total cross-sectional area and percent of change since the start of treatment.
5. Clinical findings. These are functions of the clinical data, such as percent of change in the patient's weight since admission, cumulative drug dose, or a maximum recorded laboratory value.
6. Chemotherapy orders. Where a treatment sequence indicates that a drug is required, this fact is listed. The notice may also include the

```

JOHNS HOPKINS ONCOLOGY CENTER          HISTORY NO:
                                           NAME:
                                           PLAN DATE: 08/06/80
                                           WEDNESDAY

GENERAL DAILY CARE PLAN

20 M F  HODGKIN'S DISEASE
HT 155  ADM WT 44      BAS 1.4  IDEAL WT 45  WT(08/05/80) 43.2
BLOOD TYPE  O+      HLA
PROTOCOL  E1475  BLEO-HOPP-XET  DAY 29  STARTED  07/09/80
                SECOND CYCLE - BLEO HOPP  8/6/80

PROVIDER  LENHARD, DR R

PROTOCOL GENERATED INSTRUCTIONS
*****
* MAX CUMULATIVE DOSE OF BLEOMYCIN IS 36 MG/M2 *
*****

ENTER PERFORMANCE STATUS
ENTER TUMOR MEASUREMENTS
MEASURE LONGEST DIAMETER & ITS PERPENDICULAR DIAMETER IN CM
SEE PROTOCOL (SECTION 5.21) FOR CHEMO DOSE MODIFICATION IF WBC <
4000 OR PLTS < 100000
SEE PROTOCOL (SECTION 5.12) FOR DOSE MODIFICATION IF TOTAL BIL >
1.5

MEASURABLE TUMOR SITES

      ID  GRID  D/T  M/METHOD  SIZE (CM)  DATE  SIZE (CM)  DATE
      A          7.4  07/09/80  9.7  7.4  07/09/80

      TOTAL AREA  71.78  71.78

RECENT CLINICAL FINDINGS
VALUE  DESCRIPTION  LAST FINDING  STARTING  THROUGH
5.6    CUMULATIVE TOTAL BLEOMYCIN  07/16/80  07/09/80  08/07/80
44     INITIAL BODY WT AM  07/09/80  07/09/80  07/09/80
43.2   LAST BODY WT AM  08/05/80  07/10/80  08/07/80
97     PERCENT BODY WT AM BASED ON 44  08/05/80  07/10/80  08/07/80
0.7    MAXIMUM SER CREAT  08/04/80  07/09/80  08/07/80
9100   MINIMUM WBC  07/16/80  07/09/80  08/07/80
704000 MINIMUM PLATELETS  07/16/80  07/09/80  08/07/80

CHEMOTHERAPY DRUG HISTORY
NAME  DOSE  GIVEN  % BASELINE
NITR MUST  8.3 MG  07/16/80  100 % OF 6 MG/M2
PROCARB  120 MG  07/22/80  85% OF 140 MG
VINCRIST  1.9 MG  07/16/80  95% OF 2.0 MG
PREDNISONE  56 MG  07/22/80  100% OF 40 MG/M2
BLEOMYCIN  2.8 U  07/16/80  100% OF 2.8 U

DRUGS TO BE ORDERED ON 08/06/80
2.80 MG BLEOMYCIN I.V., BASED ON 1.4 M2 X 2 MG/M2.
8.40 MG NITROGEN MUSTARD I.V., BASED ON 1.4 M2 X 6 MG/M2
1.96 MG VINCRISTINE I.V. MAX SINGLE DOSE 2.0 MG.
BASED ON 1.4 M2 X 1.4 MG/M2.
140 MG PROCARBAZINE P.O., BASED ON 1.4 M2 X 100 MG/M2.

TESTS AND PROCEDURES WITH DATE LAST PERFORMED (> INDICATES ORDERED 08/06/80,
* ORDERED STAT 08/06/80)

BLOOD AND SERUM TESTS
>HCT  HEMATOCRIT  08/05/80  >DIFF  WBC DIFF  08/05/80
>PLTS  PLT CNT  08/05/80  >WBC  WBC  08/05/80
>HGB  HEMOGLOBIN  08/05/80  H12  SMA-12  08/01/80
IGSV  IG SURVEY  07/04/80  SEU  SER COPPER  07/04/80
M6    SMA-6  08/04/80  >SALK  S ALK PHOS  08/04/80
>SGOT  SGOT  08/01/80  >SGPT  SGPT  08/01/80
>TBILI  TOT BILI  08/01/80  >SUN  S UREA NIT  08/04/81
>SCR  SER CREAT  08/04/80  >SURC  S UR ACID  08/01/80

RADIOLOGY PROCEDURES
CYR  CHEST XRAY  07/08/80

PHYSICIAN PROCEDURES
REPEAT ANY X-RAY TO DOCUMENT RESPONSE OR PROGRESSION
P.A. PROCEDURES
MUMP  MUMPS SKIN  07/04/80  TRIC  TRICH SKIN  07/04/80
FPD  FPD SKIN  07/04/80
DATA COORDINATOR INSTRUCTIONS
HAS DISEASE PROGRESSED? CHECK WITH M.D. RE: STOPPING TX SEQUENCES
    
```

Figure 7 — Sample general daily care plan (see Note 31).

7. Chemotherapy history. This is a flow sheet containing the date and dose of the last administration of each antitumor drug. If a recommended dose has been defined, the percent of the recommendation is computed.
8. Tests and procedures. Depending on the format, this portion of the plan will contain tests and procedures to be ordered as determined by the active treatment sequences. STAT (immediate) tests are flagged, and the date the test was last ordered is given.

Daily care plans have been used to order tests and procedures for all bone marrow transplant and leukemia patients since April 1980. They have recently been extended to cover all inpatients and outpatients treated at the Center.<sup>32,33</sup>

## Evaluation of the Oncology Clinical Information System

Three criteria are used to evaluate a clinical information system:

1. **Utilization.** This is a measure of how and where the system is used. Clearly, extensive use indicates that the system is an integral part of the health care process. Furthermore, extensive use would suggest that the system is perceived to be beneficial.
2. **Cost.** This is the cost of the system both for one-time development and for operations. It includes all costs associated with the information system within the organization.
3. **Cost benefit.** This is a measure of the net cost impact of the system, i.e., the difference between the operating costs with the information system and the estimated cost of operations if no computer system existed.

With respect to utilization, the system operates seven days a week and is the primary support for clinical data displays, clinic scheduling, patient admission, tumor registry operation, the pheresis program, and test ordering. One aspect of use is how well the system fits into the Oncology Center's operation; Table 3 presents some summary statistics. A second measure of utilization is the number of new projects. During the past 12 months, a parallel system was established for Pediatric Oncology, all radiation therapy activity is being processed by the system for both charge capture and reporting, a unit-dose pharmacy system was implemented, and forms for starting new protocols have been developed.

Support for the system and its Information Center is taken from different cost centers within the Oncology Center. With the exception of some separately funded research activities, all operating costs are derived from patient care revenues. The Information Center assessment is based on a guideline of 3% of the charges for the services supported. (The 3% figure includes a five-year write-off of the capital investment.) Units supporting the Information Center include Medical Oncology, Pediatric Oncology, Radiation Oncology, the Pheresis Center, the Oncology Pharmacy Center, and the Administrative Offices.

The measurement of cost benefit is a more difficult task. In evaluating the system, it is clear that no manual system could provide the capabilities of the automated system. Thus, a cost benefit analysis would be comparing different capabilities. Furthermore, it must be recognized that the traditional methods for cost benefit analysis consider only those items appearing in the institution's budget. Cost savings to other segments of the economy usually are not tabulated. Yet, some of the most dramatic cost savings benefit patients and third-party payors and may have a negative cost impact on the Oncology Center. By way of example, the system component that was used

**Table 3** — Weekly utilization statistics (1981) for the Oncology Clinical Information System.

	<i>Printed</i>	<i>On-Line Requests</i>
Plots	500	50
Daily clinical sets	*	1000
Flow sheets	750	230
Abstracts	375	280
Bacteriology reports	130	25
Other reports (searches, queries, special requests)	50	*

\*Not applicable.

to support the Pheresis Center enabled the Oncology Center to reduce morbidity and mortality; at the same time, it produced a cost avoidance to patients of \$240,000 a year.<sup>22</sup> Yet, in this case at least, the computer's contribution to realized cost savings within the Center's budget cannot be isolated.

## THE CORE RECORD SYSTEM

The Core Record System is a prototype automated ambulatory medical record system designed for multiclinic use in outpatient departments. Like many other large urban hospitals, JHH frequently serves as a primary source of health care for a large segment of the local population. The visit patterns of these patients are characterized by repeated use of walk-in facilities (particularly the Emergency Department), continuing care for the chronically ill, uncoordinated and overlapping use of multiple specialty clinics, and occasional inpatient admissions.

Each year, 100,000 patients are seen in 350,000 visits. In an institution of this size and complexity, the continuity of care for ambulatory patients is frequently complicated by the difficulty of finding and extracting information from the medical records. There are approximately 1500 requests for medical records made each day by the outpatient clinics. While many requests are satisfied in a timely manner, it is clear that the rapid delivery of records on short notice presents a considerable challenge and expense. In addition to the problem of medical record availability, there is also the need to coordinate patient care within the institution. Duplication of tests should be avoided, prescription of medication by specialty clinics must be integrated, and patient follow-up and referral must be coordinated.

The Core Record System is designed to meet many of the information needs of an ambulatory setting at a cost that is low enough to be acceptable by an outpatient department unit. This is in marked contrast to the Oncology Clinical Information System, where the high cost of tertiary care provides an economic justification for a complex (and costly) information system.

## Development of the System

The initial model for the Core Record System was the Minirecord System. This system was initiated as the result of a grant from the Applied Physics Laboratory to produce a prototype demonstration of how medical care could benefit from the use of information systems.

Begun in 1974, the Minirecord System was designed to support the needs of the Hamman-Baker Medical Clinic, which provided long-term care for 7000 chronically ill patients. It had already been demonstrated that the availability of patient problem lists improved follow-up and continuity of care,<sup>34</sup> and it was hypothesized that the availability of an automated problem list would have a beneficial effect on patient care. Consequently, a system was specified that would provide

1. Better treatment and follow-up of problems identified within the Medical Clinic through the use of a problem and medication summary;
2. Improved follow-up of problems identified and treated outside the Medical Clinic;
3. Immediate access to a *minimal medical record* to expedite medical evaluations during visits to the Emergency Department or Primary Care Walk-In Clinic;
4. Availability of on-line data to evaluate abnormal laboratory test results and unscheduled requests for prescription refills;
5. An appointment system for the clinic's 100 health-care providers.

Following the implementation of a prototype system on the Applied Physics Laboratory computer, a data base was developed and the system was modified to operate on the JHH central computer. Access to the Minirecord was available in the Medical Clinic, the Emergency Department, and selected inpatient units. The system was well received and remained in place until 1982, when the Hamman-Baker Medical Clinic was closed and replaced by the Johns Hopkins Internal Medicine Associates.<sup>35,36</sup>

The Core Record System grew out of a series of task forces organized in 1978 and 1979. These groups were directed to identify areas in which automation might improve operations in the Outpatient Department and the Medical Records Department. A solution proposed by these groups was the Core Record System. Designed as a multiclinic expansion of the Minirecord, the new system would support the following functions:

1. Maintenance of a minimal automated ambulatory medical record. This would be available on-line at strategically located terminals and be printed as part of the physician's visit record. It would contain the minimal information necessary for providing patient care when a more complete record is not available. The

minimal record would also aid in coordinating care among clinics.

2. On-line patient registration and processing of charges. Terminals and printers would be installed in each participating clinic.
3. Operation of a clinic-oriented appointment system. Management reports would be prepared and a data base would be maintained for retrospective analysis.
4. Integration of the system with existing hospital administrative systems. Since the hospital is starting to install an inpatient hospital information system, the Core Record System must be capable of being integrated with it.

Development of the system began in 1979, and the system was in production use in 1981. An evaluation of the system has been completed, and the hospital is considering expanding it to support all Outpatient Department clinics.<sup>37,38</sup>

## Description of the System

The principal component of the Core Record System is its medical record; a sample record is shown in Fig. 8. The record contains four basic sets of data:

1. Standard identification and registration information (e.g., age, address). This is maintained in a format compatible with the hospital administrative and business systems.
2. Active problem list, inactive problem list, and medication summary. This information is stored in free text, but there are plans to code the text by a computerized coding scheme.
3. Information extracted from other hospital systems. This includes lists of outpatient visits and current appointments with any outpatient clinic.
4. Clinic-specific data. This includes patient instructions, work release information, and other clinic-defined data.

Data also are listed on a computer-printed encounter form. This form contains the basic registration data, a summary of the current problem list and medications, and space to record the progress note and the tests and procedures performed. The encounter form is either preprinted (for clinics using an appointment system) or printed on demand (e.g., for the Emergency Department). The registrar and provider each uses the encounter form to record his actions. The original becomes the progress note that is stored in the medical record; a copy is used for the entry of the charges and to update the summary of the problem list and medications.

The system is currently in use in the Emergency Department (60,000 visits/year), the Primary Care Walk-In Clinic (23,000 visits/year), the Orthopedic Clinics (4500 visits/year), and the Oncology Center's Radiation Therapy and Outpatient units (35,000

```

JHH CORE RECORD  EMERGENCY DEPARTMENT  09/08/81
REGISTRATION INFORMATION
BALTIMORE MD 21218  BIRTHDATE 12/27/27 CLINIC
PHONE 301  RACE B SEX F
MAR STAT

MEDICAID DATA
NUMBER  NAME  FROM 02/76 TO 12/81
**** NO ALLERGIES RECORDED ****
----- ACTIVE PROBLEMS -----
2-A BILATERAL CARPAL TUNNELS (MINIREC, 04/11/80)
4-A HYPERTENSION (MINIREC, 04/11/80)
5-A MORBID OBESITY (MINIREC, 04/11/80)
6-A ARTHRITIS L KNEE (MINIREC, 12/05/80)
11-A TORN L KNEE LIGAMENT (ORTH, 06/04/81)
12-A DEGENERATIVE JOINT DISEASE LEFT LEG (ER/INT, 07/31/81)
13-A RT FLANK PAIN (ER/INT, 08/26/81)
----- INACTIVE AND OTHER PROBLEMS -----
1-I DISCH FROM WIL-3 ON 012861 (MINIREC, 08/26/81)
(C)CONTINUE OR (Q)UIT

JHH CORE RECORD  EMERGENCY DEPARTMENT  09/08/81
3-I S/P R PAROTID EXCISION (MINIREC, 08/26/81)
9-I GEN MED CLINIC PROV: BASCOM, REBECCA (MINIREC, 06/19/81)
10-I NEXT GEN MED APPOINTMENT ON 08/07/81 (MINIREC, 06/19/81)
----- MEDICATIONS -----
1 ALDOMET (MINIREC, 04/11/80)
2 HCTZ (MINIREC, 04/11/80)
3 ELAVIL (MINIREC, 04/11/80)
4 KCL (MINIREC, 04/11/80)
5 NALTON (MINIREC, 12/05/80)
6 DARAVON (ER/INT, 07/31/81)

RECENT PATIENT OPD VISITS
GEN MED 09/26/80 ORTH 10/03/80 PLAS SUR 10/17/80 ER 10/29/80
ORTH 10/30/80 ER/PCC 11/05/80 ORTH 12/04/80 GEN MED 12/05/80
PLAS SUR 12/05/80 PLAS SUR 12/22/80 PLAS SUR 02/23/81 GEN MED 02/27/81
ORTH 04/09/81 P.T. 05/06/81 ORTH 06/04/81 PLAS SUR 06/26/81
ER/INT 07/31/81 PLAS SUR 08/17/81 ER/INT 08/26/81
**** NO APPOINTMENTS ****

----- END OF CORE RECORD -----
(D)ISPLAY (P)RINT (N)EXT PATIENT

```

Figure 8 — Sample core record.

visits/year). Clinic-specific data have been defined by individual clinics. For the Emergency Department, there are instructions to the patient and information regarding the patient's disposition. This disposition information is particularly useful to the Emergency Department in that an automated "locator" file is maintained and the status of a patient can be determined by querying the system. For the Orthopedic Clinic, work release information and instructions to the patient represent the clinic-specific components.

In addition to the medical record, the system provides two other services: an appointment system and a charge capture system. The appointment system is designed as an inter- and intra-clinic system with on-line capabilities for entry, update, and display of appointments. Appointments can be displayed by patient, health care provider, or clinic. The appointment system allows scheduling of ancillary tests and procedures that need to be performed at the time of the next appointment. The charge capture function allows each clinic to process all of its charges. The Outpatient Business Office can then process the clinic's bills and create a tape that is input to the billing system on the main hospital computer.

## Evaluation

The Core Record was evaluated in 1982 based on data from 32,500 encounters in four clinics over a nine-month period.<sup>39</sup> (The actual period varied among the clinics, depending on the date a clinic came on the system.) Four factors were considered: medical information, process integration, new functions, and cost.

With respect to the medical data, it was shown that the Core Record contained information about visits to more than one clinic in over 30% of the cases. Such information normally would be available only through the complete medical record. The availability of Core Records was next considered. The results were biased by the fact that there was only a limited period of data collection prior to the evaluation. Nevertheless, within the Emergency Department and Primary Care Walk-In Center, over one-third of all patients entering the clinic were already in the system. (Over half the Emergency Department cases are walk-in patients with no current record.) Of those identified, two-thirds had a Core Record.

An evaluation of the Core Records showed that they tended to contain more than one problem and—depending on the Outpatient Department unit—less than one medication. Physician compliance in completing the records ranged from 75% in the Emergency Department to 96% in the Orthopedic Clinic. Availability of information was a function of type of patient and treatment; repeating patients with chronic problems required—and had—better documentation. A brief comparison of the Core Record with the complete medical record showed that the Core Record tended to contain more summary information. Where data were available from the medical record, of course, the documentation was more complete.

The evaluation of both process integration and new functions was anecdotal. It was demonstrated that charge capture and medical summary processing could be integrated. New functions such as a patient locator, appointment system, and management reports could be provided. The cost analysis focused on the cost to operate the system. A target of \$1.00 per encounter was considered reasonable. The actual cost was \$0.91 per encounter plus a charge of \$0.15 to \$0.20 for forms. Potential cost savings were identified, but realization of the savings would be dependent on reorganization within the hospital.

Finally, a subjective evaluation by 21 clinicians, administrators, and support staff in two clinics found that

1. The Core Record concept is easy to understand (20 of 20 responding);
2. Provider use of the system is not time-consuming (providers only, 10 of 11 responding);
3. Despite the added burden to users, the Core Record System was worth the effort (19 of 20 responding);
4. If such a system were implemented, there would

be an improvement in health care delivery (18 of 21 responding);

5. If the system were not continued, health care delivery would be adversely affected (providers only, 9 of 12 responding).

## CONCLUSION

The use of computers to manage clinical information systems has undergone tremendous change in the past decade. It is now clear that computers can be used to control costs<sup>40,41</sup> and improve patient care.<sup>42</sup> Equipment prices are falling and our experience base is growing. Five years ago, few major systems could be started without external financial support; the next five years should bring into the marketplace a broad spectrum of validated clinical information systems.

The history of clinical information systems at Johns Hopkins reflects the progress in the field. Starting with some grant-supported projects in radiology and the pharmacy, systems were put into operational use that continue to serve as integrated components of the care process. In the mid-seventies, new systems were initiated in the clinical laboratory, Pediatrics, Oncology, and the Outpatient Department. Each continues to play an essential role in the hospital's operation. Finally, in the early 1980's, the hospital committed itself to providing a comprehensive inpatient system.

Future work will most certainly involve the expansion of current capabilities and networking of the systems. (A model for hospital system networking has been developed at the Applied Physics Laboratory and is in use at the University of California Hospital in San Francisco.<sup>43,44</sup>) The availability of powerful desk-top computers suggests that applications will proliferate. Portions of larger systems such as the Oncology Clinical Information System will become available to support the management of other chronic diseases. Finally, the ability to link and merge data and algorithms among systems will dramatically improve utility. Thus, one can expect even more exciting developments in the application of computers to medical care.

## REFERENCES and NOTES

- <sup>1</sup>R. A. Jydstrup and M. J. Gross, "Cost of Information Handling in Hospitals," *Health Serv. Res.* 235-371 (Winter 1966).
- <sup>2</sup>Report by the U.S. General Accounting Office, *Computerized Hospital Information Systems Need Further Evaluation to Ensure Benefits from Huge Investments*, AFMD-81-3 (Nov 1980).
- <sup>3</sup>D. A. B. Lindberg, *The Growth of Medical Information Systems in the United States*, Lexington Books, D. C. Heath and Co., Lexington, Mass., p. 98 (1975).
- <sup>4</sup>R. E. Gibson and R. J. Johns, *A Study of the Management of the Johns Hopkins Medical School and the Johns Hopkins Hospital*, JHU Internal Report (25 May 1971).
- <sup>5</sup>R. E. Miller, G. L. Steinbach, and R. E. Dayhoff, "A Hierarchical Computer Network: An Alternative Approach to Clinical Laboratory Computerization in a Large Hospital," in *Fourth Ann. Symp. on Computer Application in Medical Care*, **IEEE 80CH 1570-1**, pp. 505-513 (1980).
- <sup>6</sup>B. I. Blum, R. E. Miller, and R. E. Lenhard, Jr., "Distributed Laboratory Data Processing in a Large Hospital: The Johns Hopkins Experience," in *Informatics in Health Facilities: Vol. I. Computerization and Automation*, M. Rubin, ed., CRC Press, Inc., Boca Raton, Fla. (in press).
- <sup>7</sup>R. H. Drachman, M. J. O'Neill, and K. V. Ledford, "Implementation of a Medical Information System in an Ambulatory Care Setting," in *Third Ann. Symp. on Computer Applications in Medical Care*, **IEEE 79CH 1489-3C**, pp. 225-228 (1979).
- <sup>8</sup>R. H. Drachman, M. J. O'Neill, and K. V. Ledford, "Computer Review of Ambulatory Care—The "CARE" System," in *Fifth Ann. Symp. on Computer Applications in Medical Care*, **IEEE 81CH 1696-4**, pp. 213-218 (1981).
- <sup>9</sup>J. C. Mabry *et al.*, "A Prototype Data Management and Analysis System (CLINFO): System Description and User Experience," in *MEDINFO 77*, North-Holland Publishing Co., New York, pp. 71-75 (1977).
- <sup>10</sup>J. B. Johnson, Jr., *et al.*, "Five Years' Experience with the CLINFO Data Base Management and Analysis System," in *Sixth Ann. Symp. on Computer Applications in Medical Care*, **IEEE 82CH 1805-1**, pp. 833-836 (1982).
- <sup>11</sup>D. W. Simborg, "The Development of a Ward Information-Management System," *Meth. Inform. Med.* 12, 17-26 (1973).
- <sup>12</sup>D. W. Simborg *et al.*, "Ward-Information Management System: An Evaluation," *Comput. Biomed. Res.* 5, 484-497 (1972).
- <sup>13</sup>H. J. Derewicz and D. D. Zellers, "The Computer-Based Unit Dose System in the Johns Hopkins Hospital," *Am. J. Hosp. Pharm.* 30, 206-212 (1973).
- <sup>14</sup>D. W. Simborg and H. J. Derewicz, "A Highly Automated Hospital Medication System, Five Years' Experience and Evaluation," *Ann. Intern. Med.* 83, 342-346 (1975).
- <sup>15</sup>P. S. Wheeler and D. W. Simborg, "The Johns Hopkins Radiology Computer Reporting System," *Electromedia* 2-3, 104-108 (1975).
- <sup>16</sup>IBM Health Care Support/DL/1, *Patient Care System: Terminal Operators Guide. Program Number: 5796-ANY, SH20-1956-0* (Nov 1977).
- <sup>17</sup>B. I. Blum and R. E. Lenhard, Jr., "A Prototype Clinical Patient Management System," in *ACM Tech. Symp.*, Washington, D.C., pp. 5-12 (Jan 1977).
- <sup>18</sup>B. I. Blum *et al.*, "A Clinical Information Display System," in *First Symp. on Computer Applications in Medical Care*, **IEEE 77CH 1270-8C** pp. 131-183 (1977); reprinted in V. Sondak and H. Schwartz, *Computers and Medicine*, Artech House, Inc., Dedham, Mass. (1979).
- <sup>19</sup>B. I. Blum and R. E. Lenhard, Jr., "Design of an Oncology Clinical Information System," *ACM 77*, 101-107 (Oct 1977).
- <sup>20</sup>B. I. Blum *et al.*, "The Johns Hopkins Clinical Information Systems: A Study in MUMPS Productivity," in *1978 MUMPS Users' Group*, College Park, Md., pp. 6-17 (Jun 1978).
- <sup>21</sup>B. I. Blum and R. E. Lenhard, Jr., "An Oncology Clinical Information System," *Comput. Mag.*, 42-50 (Nov 1979).
- <sup>22</sup>R. E. Lenhard, Jr., *et al.*, "The Johns Hopkins Oncology Clinical Information System," in *Sixth Ann. Symp. on Computer Applications in Medical Care*, **IEEE 82CH1805-1** pp. 28-43 (1982).
- <sup>23</sup>B. I. Blum, "A Tool for Developing Information Systems," in *Automated Tools for Information Systems Design*, H. J. Schneider and A. I. Wasserman, eds. North-Holland Publishing Co., New York, pp. 215-235 (1982).
- <sup>24</sup>B. I. Blum and C. W. Brunn, "Implementing an Appointment System with TEDIUM," in *Fifth Ann. Symp. on Computer Applications in Medical Care*, **IEEE 81CH** pp. 172-181 (1981).
- <sup>25</sup>B. I. Blum, "MUMPS, TEDIUM and Productivity," in *First IEEE Computer Society Int. Conf. on Medical Computer Science/Computational Medicine (MEDCOMP)*, **IEEE 82 CH1797-0** pp. 200-209 (Sep 1982).
- <sup>26</sup>B. I. Blum and R. E. Lenhard, Jr., "Displaying Clinical Data for Decision Making," *J. Clin. Eng.* 8, 61-68 (1983).
- <sup>27</sup>C. J. McDonald, "Protocol-Based Computer Reminders, The Quality of Care and the Non-Perfectability of Man," *N. Engl. J. Med.* 295, 24 (1976).
- <sup>28</sup>R. K. Halse *et al.*, "Computerized Medication Monitoring System," *Am. J. Hosp. Pharm.* 33, 1061-1064 (1976).
- <sup>29</sup>A. M. Weissman *et al.*, "Computer Support of Pharmaceutical Services for Ambulatory Patients," *Am. J. Hosp. Pharm.* 33, 1171-1175 (1976).
- <sup>30</sup>D. D. Wirtschafter, J. T. Carpenter, and E. Mesel, "A Consultant-Extender System for Breast Cancer Adjuvant Chemotherapy," *Ann. Intern. Med.* 90, 396-401 (1979).
- <sup>31</sup>This plan is for the first day of the second cycle of therapy. The comment in the box warns the physician that one of the drugs to be administered, Bleomycin, has a maximum cumulative dose. The sections on measurable tumor sites, recent clinical findings, and chemotherapy history are automatically updated from the clinical data base each day. The actual drug dose is computed on the basis of a body surface area (BSA, see top of plan) of 1.4. The general plan includes a list of all tests and procedures required for the protocol. Twelve tests are to be ordered from this plan. General physicians comments are listed at the beginning of the plan. Messages related to a procedure are listed in the procedure ordering section. Most messages tend to be reminders. The next version of the system will be able to generate warning messages based upon data trends.
- <sup>32</sup>B. I. Blum, R. E. Lenhard, Jr., and E. E. McColligan, "Protocol Directed Patient Care Using a Computer," in *Fourth Ann. Symp. on Computer Applications in Medical Care*, **IEEE 80CH 1570-1** pp. 753-761 (1980).

- <sup>33</sup>E. E. McColligan *et al.*, "The Human Element in Computer Generated Patient Management Plans," in *Tenth Ann. Conf. of the Society for Computer Medicine*, San Diego (Sep 1980); reprinted in *J. Med. Syst.* **6**, 265-276 (Jun 1982).
- <sup>34</sup>C. J. Johns, B. I. Blum, and D. W. Simborg, "The Minirecord Approach to Continuity of Care for a Large Population of Ambulatory Patients," in *Third Illinois Conf. on Medical Information Systems*, pp. 121-132 (1976).
- <sup>35</sup>C. J. Johns *et al.*, "A Minirecord: An Aid to Continuity of Care," *Johns Hopkins Med. J.* **140**, 277-284 (1977).
- <sup>36</sup>B. I. Blum *et al.*, "A Low-Cost Ambulatory Medical Information System," *J. Clin. Eng.* **4**, 372-378 (1979).
- <sup>37</sup>B. I. Blum, R. J. Johns, and E. E. McColligan, "An Approach to Ambulatory Care Medical Records," in *Int. Conf. on Systems Science in Health Care*, Montreal, Canada, pp. 1025-1033 (1980).
- <sup>38</sup>E. E. McColligan, B. I. Blum, and C. W. Brunn, "An Automated Core Medical Record System for Ambulatory Care," in *1981 SAMS/SCM Joint Conf.*, Washington, D.C., pp. 72-77 (1981); to be published in *J. Med. Syst.*
- <sup>39</sup>E. E. McColligan and B. I. Blum, "Evaluating an Automated Medical Record System for Ambulatory Care," in *American Medical Informatics Assoc. (AMIA)*, San Francisco, pp. 206-215 (May 1982).
- <sup>40</sup>R. J. Johns and B. I. Blum, "The Use of Clinical Information Systems to Control Cost as Well as to Improve Care," *Trans. Am. Clin. Climatol. Assoc.* **90**, pp. 140-152 (1978).
- <sup>41</sup>B. I. Blum and R. J. Johns, "Computer Technology and Medical Costs," in *Information Processing 80*, S. H. Lavington, ed., North-Holland Publishing Co, New York, IFIP, pp. 903-906 (1980).
- <sup>42</sup>B. I. Blum, "Review of the Established Benefits of Automated Information Systems in Patient Care," *Applications of Computers in Medicine*, M. D. Schwartz, ed., IEEE Catalog No. TH0095-0, Vol. 1, pp. 234-240 (1982).
- <sup>43</sup>S. G. Tolchin *et al.*, "Progress and Experience in the Implementation of a Hospital Local Area Network at UCSF," in *IEEE MEDCOMP 82*, pp. 291-298 (Sep 1982).
- <sup>44</sup>S. G. Tolchin *et al.*, "A Distributed Hospital Information System," *Johns Hopkins APL Tech. Dig.* **3**, 342-354 (1982).

---

ACKNOWLEDGMENTS—The author served as the director of the Clinical Information Systems Division (CISD) of the Department of Biomedical Engineering from 1975 to 1983. Working essentially full-time in the School of Medicine, it is natural that my contributions are closely linked to those of the people at JHMI with whom I worked. Now that I am returning to APL, I would like to express my appreciation to all those in JHMI who were so helpful to me.

Richard J. Johns, is both a friend and a teacher. Dick helped me transfer my experience to this new application area, found the financial support I needed, and taught me to be uncompromising with respect to my standards. My other departmental director, Albert H. Owens, was equally inspiring and supportive. He provided a secure, stable environment in which sound accomplishments flourished.

In the technical area, I have had special relationships with two people. Raymond Lenhard, Jr., provided the perfect complement in the development of the Oncology Clinical Information System (OCIS). By identifying the requirements and testing the results in a clinical setting, Ray helped transform a collection of programs and people into a useful system. Elizabeth McColligan joined CISD in 1977 and was instrumental in making both the Minirecord System and the OCIS care plans effective clinical tools. Liz manages the Core Record project and has succeeded me as director of CISD. There are, of course, many others who contributed greatly to this work. Some of them are listed as authors in the references.