Medical Applications of Computers: An Overview

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AMA/NET, CADUCEUS, ONCOCIN, COSTAR, MYCIN, MUMPS: a strange medical upper-case computer vocabulary that introduces a new dimension in medical practice. Inexpensive microcomputers, the reduction in cost of larger minicomputers and mainframe computers, and the growth of communication networks have created information management capabilities to refine and enhance the way the physician practices medicine. To the degree that caring for patients involves an orderly process of securing, processing, communicating, and applying information, the computer brings efficiencies to established routines and creates altogether new clinical capabilities. Medical practice is not entirely a rational process, however. Much that occurs in the clinical interaction cannot be described in precise objective terms, and in these areas, which are central to the physician's human qualities, the computer is not likely to introduce change. Computer applications as powerful tools can expand the physician's effectiveness, but only under the physician's direction.

Computer is an imprecise term blending concepts of digital electronics, data processing, and information management. Few of the applications involve mathematical computing: information processing and data processing more accurately describe what most computers do. This review will focus primarily on information-processing programs that interact directly with the clinician. Physiological monitors and automated instrumentation will not be discussed, and only brief mention will be made of computers for office and hospital management. Distinctions between microcomputers, minicomputers, and mainframe computers are not emphasized, since current hardware technology and flexible software allow wide areas of overlap. Knowing what goes on inside a computer is useful, but it is not necessary to be a computer expert to understand its applications.

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Hospital and Office Management

Hospital Management Systems

Hospitals must coordinate the services of many specialized personnel to achieve effective and affordable care. The technical capabilities of modern medicine create logistic demands that exceed traditional hospital administrative and management abilities. To meet these demands, comprehensive computerized hospital management systems—often mainframe systems costing millions of dollars, sometimes smaller minicomputers—are capable of the many following management functions: (1) patient registration, admission, internal transfer, and discharge; (2) financial assessment, billing, insurance, accounting, payroll; (3) bed census, surgery scheduling, supply inventory and ordering, personnel scheduling; (4) physiological monitoring and alerting intensive care units, emergency rooms, operating rooms; (5) nursing care plans, charting, reports; (6) pharmacy ordering, dispensing, patient drug profiles, and drug interaction alerts; (7) laboratory test ordering, processing, reporting; (8) radiology procedure ordering, scheduling, reporting; (9) medical record storage, delivery, updating, report generation; and (10) audit and supervision of all aspects of hospital operation.

Ambulatory-Care Management Systems

Clinical offices, whether serving a solo practitioner or a group practice, can benefit from the same type of management help that hospital systems provide. A number of companies offer office management systems using microcomputers or, for large facilities, in-house minicomputers. Frequently provided services include patient registration, billing, accounting, insurance, payroll, patient scheduling, recall notices, medical records, practice profiles (age, sex, diagnoses, medications, etc), and correspondence or reports (word processing).

The decision to automate office operations requires expert advice about the type of system to purchase or whether to automate at all. Pegboard and other manual systems have been around a long time; replacing them with a computer may only increase operating costs without providing significant benefits. A professional consultant is often a wise investment, although a physician or business manager who takes the time to study available books and articles can arrive at a sound decision.

Clinical Information Systems (Medical Records)

Methods of acquiring, processing, and applying clinical information (the patient medical history, physical examination, laboratory studies, assessment, and plans for further diagnostic procedures, therapies, and patient education) have been among the first applications of medical computing and remain areas of vigorous development by commercial firms, universities, and public health agencies.[1] To separate clinical information (ie, medical records) from hospital or office management is to some degree artificial. Entering "history of penicillin sensitivity" in a medical record, for example, requires management steps to ensure that nursing and pharmacy personnel do not, through error or orders of another physician, administer that medication. Similarly, ordering an upper gastrointestinal x-ray examination requires that the dietary service not provide breakfast the day of the examination, that the radiology service schedule the procedure and bill for it, and that the radiologist's report be recorded and entered into the patient's record promptly—basically clerical operations rather than clinical activities. A breakdown in any of these routines may result in the expense and inconvenience of an additional hospital day. Even the simple matter of prescribing during an office visit involves making a note in the chart and writing a prescription. At each step there is duplication of effort and the possibility of error; in larger facilities the physical record may be missing, in use by others, illegible to anyone but the person making the entry, disorganized, or lacking recent reports.[2] A truly paperless, computer-integrated health care system does not exist. There are no technical problems that cannot be solved; more often the problems are in the area of psychological flexibility in adapting to new routines.

Office or Ambulatory Record Systems

Ambulatory care is a less complex information management challenge than hospital care. Office-based record systems, some operational for more than a decade, are successfully serving solo practitioners as well as large multioffice groups.[3]

COSTAR (COmputer-STored Ambulatory Record), developed for outpatient use, is the most widely used medical record system. COSTAR coordinates appointment scheduling, patient registration, insurance forms production, business and revenue analysis, complete clinical records, and quality assurance activities. The system was developed at the Laboratory of Computer Science, Massachusetts General Hospital, and employs MUMPS, a computer language specially developed for large data base applications. It is currently in use in about 100 locations, from small private practice offices to large public health departments. Centralization of patient records allows access to information from many separate locations within a health delivery system. A national users group meets regularly to develop enhancements for COSTAR. The system was developed with funds from the National Center for Health Research and is in the public domain; thus the software is available at little cost. Commercial firms offer a variety of enhancements to the basic system. COSTAR is designed for medium to large computers, but some versions for microcomputers are available.

Among many other systems in ambulatory settings are the following:

TMR (The Medical Record). TMR is a modular system that, when fully developed, will support office management (appointments, billing, etc), complete patient medical histories with some free-text capabilities, provide a comprehensive pharmacy system (prescription writing, drug interaction alert, drug information for patients, etc), and generate reports. TMR was developed and became operational at some Duke University clinics and affiliated Veterans Administration Hospital clinics, and it is expanding into hospital settings.

RMIS (Regenstrief Medical Information System). Developed at the Regenstrief Institute and St. Vincent's Hospital outpatient clinics, Indianapolis, RMIS provides a comprehensive patient summary, an extensive clinical reminder system, clinic scheduling, monitoring of laboratory results, comprehensive pharmacy service, and billing.

PCIS (Patient Care Information System). Developed at the Papago Indian Reservation, Tucson, Arizona, and operational since 1968, PCIS provides comprehensive medical summaries and an age- and sex-specific health maintenance program, and generates reports for Papago Indians who receive care at any of several widely scattered health care facilities. PCIS also supports health care to Alaska natives through computer-generated microfiche.

Integrated Systems

Lack of integration of clinical information between hospital and outpatient facilities is a major barrier to optimal health care delivery. Separate record systems introduce opportunities for error, omission, and duplication of effort. A computerized record system is essential for informational continuity at the hospital-ambulatory care interface, but few such systems are in existence.[4] The two following unique integrated systems should be noted, although neither is operating at this time.

The Kaiser-Permanente Medical Information System is designed to provide integrated outpatient and inpatient records at the Kaiser-Permanente Plan in northern California. Coordination of hospital and ambulatory care clinical services is a major reason health maintenance organizations such as Kaiser-Permanente achieve significant economies—their hospitalization rates are substantially below those of most fee-for-service medical care programs. Large-scale information systems have a rationale in both economics and optimal health care. High developmental cost and loss of federal funding caused (it is hoped temporarily) abandonment of the Kaiser-Permanente system.

TRIMIS (Tri-Service Medical Information System) addresses the needs of the military services. TRIMIS development was initiated in 1975, and some interim components have been installed. When fully operational, the system will include the following computer-assisted service modules: hospital and outpatient information system, appointment and scheduling, cardiology, medical records, pharmacy, food service, laboratory, radiology, and supply.

Record Security

A high level of patient-information security is maintained by requiring password identifiers and electronic keys to enter a computer, but no system can be made totally secure. The present paper-based record system, however, offers almost no security, and the risks of the computer must be compared with the benefits to the patient of having legible information available whenever and wherever needed.

Patient-Carried Records

Computer technology will soon enable patients to have their personal medical history with them at all times, a great benefit if they become ill away from their usual source of care or if they are unable to provide information because of severe illness or injury. Several systems that imbed a microchip in a small card or a plastic key are in limited trials; they differ primarily in the amount of memory and the degree to which they can be updated. Initial use will probably be to replace the military personnel dog tag, but as costs decrease, widespread applications, including personal medical information, are probable.

Medical Education

Education and computer use are basically cognitive activities; their integration has been explored for a decade. Various educational applications are described in subsequent papers in this issue.

Biomedical Literature and Information Utilities

The applications described so far, with few exceptions, employ computers with the program entered from a floppy disk. Once the program is loaded into internal memory, all interaction is between the user and the computer. It is also possible to use the same computer to reach out through standard telephone lines to a variety of biomedical literature data banks.[5] Almost all microcomputers have, or can easily be equipped with, an RS-232 circuit necessary for telecommunications; all that is needed to complete this capability is a modem (costing as little as $100) that converts analog telephone transmission signals to the digital form used by all computers. The computer allows access to data bases in which much of the published scientific literature is now recorded. By using a modem and connecting to the National Library of Medicine's MEDLINE, more than 4.0 million articles from 3,200 biomedical journals can now be searched from the home or office. Dozens of other data banks, including Excerpta Medica, the Science Citation Index, and Psychological Abstracts, are of professional relevance.

MINET (Medical Information Network) is devoted entirely to medical information services. The initial service on MINET is AMA/NET, an information utility of the American Medical Association. When fully operational, AMA/NET will provide subscribers with access to AMA data banks covering drug information, disease and diagnosis classifications, socioeconomic knowledge, and general medical news. A second MINET participant is PHYCOM, making available information about newly released pharmaceuticals as well as a variety of general medical news features. Telecomputing also offers access to more than 1,200 nonmedical data bases covering every aspect of daily living. Except for PHYCOM, which is supported by major pharmaceutical companies, all the information services must be purchased, usually by the on-line minute. Competition is vigorous and reductions in cost and increase in the number of available services can be expected.

Electronic Mail, Conferences, and Bulletin Boards

The same communication technology that makes it possible to interact with the biomedical literature permits the exchange of personal messages and information of all kinds. MED/MAIL of AMA/NET, and CompuServe, The Source, and DELPHI (low-cost general information services) all provide subscribers with a large amount of personal mainframe memory in which to store messages for retrieval by friends, associates, and designated others. The American Association for Medical Science and Informatics (AAMSI), for example, maintains 50 separate specialty interest groups (SIGs) by which persons around the country keep in touch. Protocol Data Query (PDQ), providing comprehensive information regarding cancer treatment protocols, names of experts in specific types of cancers, and general cancer information, has just been inaugurated by the National Cancer Institute, and many other clinical information networks are certain to be announced as progressively more physicians begin to use computers.

Artificial Intelligence and Medical Decision Making

Diagnosis and treatment—the heart of the clinical process—are the most challenging of all current computer applications. A few programs, applicable to very limited fields such as electrocardiogram (ECG) interpretation, are in daily use; many more, such as ONCOCIN for determining optimal treatment of lymphomas, or MYCIN for selection of antibiotic therapy, are available only in controlled settings while being refined; still others, such as CADUCEUS, a mainframe program that "diagnoses" a broad range of clinical problems, are still in the developmental stage.[6]

Computer programs that deal with diagnosis or therapy are of two general types. The first group depends on statistical probabilities or pattern matching, comparing the symptoms, findings, and laboratory values of a present patient with the recorded manifestations of large numbers of past patients whose diagnosis is definitely known. For example, the clinical data of a patient with acute abdominal pain would be compared with the compiled facts of patients who had surgically confirmed appendicitis, cholecystitis, or other abdominal conditions. The process is somewhat like weather prediction: today's weather conditions are fed to a computer, which then reviews patterns of past years seeking a match, assuming that what happened before will probably happen again. Note that this process requires no basic knowledge of medicine or meteorology—only the ability to gather appropriate data and recognize patterns.

The second approach involves a variety of cognitive strategies that to some degree simulate the thought processes of expert physicians. In its simplest form, algorithms or simple procedural rules are created that incorporate current clinical knowledge and agreed-upon standards of good practice. Such an algorithm would express in a series of simple "yes" or "no" questions the following situation:

> If a patient is aged over 40 years, smokes cigarettes, and has acute retrosternal chest pain and a normal ECG, but a past history of diabetes mellitus and a family history of coronary artery disease, then assume a diagnosis of myocardial infarction and admit to the hospital for further evaluation and treatment.

Thus, an appropriately programmed computer would interact with the clinician to make a sound decision about the sometimes difficult situation of a patient with chest pain and a normal ECG but a number of risk factors.

Much more sophisticated, and the approach to which artificial intelligence is most often applied, are programs that attempt to mimic the thought processes of clinicians of mature diagnostic skill. Exactly what is meant by thought processes is not easy to define, even by the experts themselves, but it involves a blend of lessons learned from past experience, logical reasoning, a substantial base of objective knowledge, and a variety of vaguely perceived mechanisms called intuition or good judgment. This approach is heuristic, which the dictionary defines as "helping to discover or learn, guiding or furthering investigation," but what others call simply "good guessing."

All of these approaches have not only strengths but also substantial theoretical and practical weaknesses. No single approach is applicable to all types of clinical problems. None seeks to replace the clinician; rather, the approaches create tools supporting the clinical process by ensuring complete data gathering, suggesting diagnostic considerations that may not occur to the attending clinician, reducing biases created by current experience or variable past experience, and ensuring that the latest information is available and given consideration. Also, algorithmic programs are helpful in assisting nonphysicians such as military medical corps personnel, who may be the only clinical resource in isolated areas. Finally, artificial intelligence research, by attempting to imitate human intelligence, may lead to insights about just what human intelligence really is.

Applications by Specialties

Documenting current clinical applications is difficult. Many clinicians create programs for their office microcomputer but do not publish. University-developed applications often require large computers, and the programs may not be applicable to nonuniversity settings. The published literature is of some help in knowing what is going on, but often articles are of the "show and tell" variety: describing work in progress rather than completed programs that have been carefully evaluated both from the technical aspect and from the aspect of their effectiveness in daily clinical settings. Effectiveness includes the ability to accomplish a task that has been shown to be clinically useful and cost effective. In addition, health care providers must be willing and able to use a new program. Insufficient attention to human factors is a major cause of program failure.[7]

The list of application programs presented in the Appendix is not complete; rather, it suggests the types of programs that have attracted interest. Some clinical areas are more suitable for computer applications than others, and there are great variations in the number of published reports according to clinical specialty. Heading references refer to review articles; other references are limited to a few programs of exceptional interest. Family medicine applications are described in some detail in subsequent papers in this issue.

Suggested Reading

Proceedings of the Symposium of Computer Applications in Medical Care. Silver Spring, Md, IEEE Computer Society Press (yearly, since 1977)

Van Bemmel JH, Ball MJ, Wigertz O: MEDINFO 83. Proceedings of the Fourth World Conference on Medical Informatics, Amsterdam. New York, North Holland, 1983

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18. Vanderheiden GC: The practical use of computers in rehabilitation. Rehabil Lit 44:66, 1983
19. Shiffman GS, Tobin D, Cassidy-Bronson S: Personal computers for the learning disabled. J Learning Disabilities 15:422, 1982
20. deDombal FT: Computers and the surgeon—A matter of decision. Surg Ann 11:33, 1979

Appendix
Medical Applications of Computers by Various Specialties

Anesthesiology
- Artificial intelligence critique or tutor program for preoperative anesthesia plan[8]

Clinical Genetics
- Epidemiological and demographic studies of genetic disease
- Family studies for risk and linkage
- Karyotype analysis

Health Care Delivery Process
- Clinician reminder system[9]
- Audit of quality of care
- Diagnosis-related groups (DRG) administration
- Personnel communication technology

Health Screening[10]
- Large organizations (health maintenance organization, the military), prevention, and early disease detection
- Industry (executive, pre-employment)
- Small-office systems

Internal Medicine
- Expert decision support

Cardiovascular Disease
- Electrocardiograph interpretation systems[10]
- Hypertension management[11]

Gastroenterology[12]
- Symptom diagnosis decision-making protocols
- Clinical dietary regimens
- Statistical analysis of disease groups (eg, chronic)

Inflammatory Disease
- Evaluation of alternative treatment protocols

Neurology
- Expert decision-making diagnostic system[13]

Pulmonary Disease
- Pulmonary function testing[10]

Mental Health[14]
- Crisis intervention protocols for nonphysician personnel
- Interactive psychotherapeutic programs
- Automated psychometric examinations
- Hypnosis induction
- On-line, electronic conferencing therapy

Occupational Health[15]
- Workers' medical records, appropriate content, confidentiality
- Long-term worker tracking
- Inventory and surveillance of workplace risks
- Epidemiologic or demographic studies of at-risk populations

Otolaryngology
- Support for the hearing impaired (excluding audio amplification)
- Strengthening of alternative sensory input, primarily visual skills
- Reading improvement skills
- Artificial speech

Ophthalmology
- Clinical decision-making program for diagnosis of strabismus
- Artificial intelligence program for glaucoma
- Automated refraction equipment

Pediatrics[16]
- Perinatal or neonatal facilities network coordination
- Individualized education for exceptional children
- Growth record evaluation

Pharmacy
- Interaction warnings: drug/drug, drug/food, drug/laboratory test
- Patient drug sensitivity alert
- Prescribing, labeling, dispensing, and transporting, records
- Exact dosage determination of narrow safety-margin drugs
- Patient drug profiles; refill control
- Hospital nursing support
- Drug information systems, poison control information

Radiology[17]
- Imaging
- Automated verbal reporting
- Digital image storage

Rehabilitation[18,19]
- Sensory and motor assist
- Learning and communication support

Surgery[20]
- Abdominal pain diagnostic protocols