Medical Informatics
Improving Health Care Through Information

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HEALTH CARE IS AN INFORMATION-based science. Much of clinical practice involves gathering, synthesizing, and acting on information. Medical informatics is the field concerned with the management and use of information in health and biomedicine. This article focuses on the problems that motivate work in this field, the emerging solutions, and the barriers that remain. It also addresses the core themes that underlie all applications of medical informatics and unify the scientific approaches across the field.

There is a growing concern that information is not being used as effectively as possible in health care. Recent reports from the Institute of Medicine have reviewed research findings related to information use and expressed concerns about medical errors and patient safety,[1] the quality of medical records,[2] and the protection of patient privacy and confidentiality.[3] The latest Institute of Medicine report on this topic ties all these problems and potential solutions together in a vision for a health care system that is safe, patient-centered, and evidence-based.[4] A variety of solutions is required to address the information-related problems in health care; many solutions involve the use of computers and computer-related technologies.

The Field of Medical Informatics

Medical informatics is a heterogeneous field, composed of individuals with diverse backgrounds and levels of training. Although virtually all health science universities have some entity with the word "informatics" in its title, there are fewer than 25 that carry out research in medical informatics and offer educational programs.[5] At some institutions, medical informatics is viewed as a service (eg, helping clinicians implement informatics applications), but it is more appropriately considered a science that addresses how best to use information to improve health care. The government leader in funding research and education in medical informatics has been the National Library of Medicine (www.nlm.nih.gov).

Some have argued that the adjective *medical* in front of informatics is inappropriate because it implies the work of physicians and not the remainder of health care and biomedical science. However, this name has achieved widespread usage. In the article by Kukafka et al,[6] Shortliffe described medical informatics as the broad term representing the core theories, concepts, and techniques of information applications in health and biomedicine, with the other adjectives preceding the word *informatics* denoting the specific application area (BOX). Core themes that emerge from informatics science (standards, terminology, usability, and demonstrated value) are relevant across all levels of medical informatics, not solely clinical informatics.

Applications of Clinical Informatics

There is a variety of classification types for the different applications of clinical informatics; one approach is by the type of information used. There are essentially 2 types of information used in clinical informatics: patient-specific and knowledge-based. Patient-specific information is generated by and used in the care of patients in the clinical setting, whereas knowledge-based information comprises the scientific basis of health care.

Electronic Medical Records

The core application using patient-specific information is the electronic medical record (EMR). The paper-based medical record has its tradition and virtues; however, research has shown it can be illegible, incomplete, difficult to access in more than one place, and insecure from unauthorized uses and users.[2] Although the EMR overcomes some of these problems, there are challenges to implementing the EMR at the levels of the individual and the organization.

The main challenge to individual use of the EMR has been its integration into the busy clinical workflow. The few studies that have been performed show computerized physician order entry (CPOE) adds time for the clinician, although other time savings are usually gained elsewhere through error reduction or the automation brought about by other features of the EMR (eg, accessing test results).[7-9] A related challenge is determination of the optimal computing device for the clinical setting. Handheld computers (also called personal digital assistants) are increasingly popular, as documented by their use by internal medicine[10] and family practice physicians.[11] While their portability is of great value, most usage has focused on entry and retrieval of simple data (eg, prescription writing and drug information) and it is unclear whether other usage (eg, image viewing and literature access) is amenable to these por-

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Box. The 4 Levels of Medical Informatics and Their Respective Foci From the Cell to the Population*

Bioinformatics—molecular and cellular processes, such as gene sequences and maps
Imaging informatics—tissues and organs, such as radiology imaging systems
Clinical informatics—clinicians and patients, including applications of nursing, dentistry, and other clinical specialties
Public health informatics—populations, such as disease surveillance systems

*Adapted from Kukafka et al.[6]

table devices or whether larger devices might be required.

At the organizational level, the key challenges have been managing complex informatics applications and the computer networks upon which they run. Although individual computers are relatively inexpensive, maintaining large networks of them and training the myriad of health care workers who use them are not. Berg[12] has noted that the interpersonal challenges to large organizations in implementing EMRs is much more daunting than managing the technology itself. Research has shown that involving users in the implementation process and providing features of benefit to them, such as time-saving measures like specialty-specific order sets, widespread implementation across the organization, and engaging the clinical leadership, are the most important keys to success.[13] Organizational challenges are not limited to hospitals and other large institutions. A particular problem in the outpatient setting is that small practices usually lack the minimal technical capabilities and financial resources necessary to implement EMRs.[14] A final challenge to all involved with the EMR is the protection of patient privacy and confidentiality, with the Health Insurance Portability and Accountability Act legislating their protection at substantial cost and effort.[15]

Information Retrieval

The field concerned with the organization and retrieval of knowledge-based information (not limited to medicine) is called information retrieval.[16] This area has seen tremendous growth due to the Internet and World Wide Web. More than 50% of the US population uses the Web regularly, and of those who do, more than 50% search for personal health information.[17] Physicians have embraced the Web as well, with 90% using it on a regular basis.[18] A large variety of online resources are now available to both patients and physicians. The oldest of these is MEDLINE, the bibliographic database of journal literature with more than 11 million references to approximately 4000 journals dating from 1966.[19] Produced by the US National Library of Medicine, MEDLINE is freely available to the entire world via the PubMed system on the National Library of Medicine Web site (http://pubmed.gov). Bibliographic databases only contain titles and abstracts of articles; however, users increasingly want the full text of journals online. The technical challenge of producing such journals has been supplanted by the economic question of how to increase availability when electronic publication is cheaper (ie, less printing and mailing costs) but still has some cost (due to value added in editing and production).[20] Another challenge is how to improve users' abilities to use such systems, as a systematic review has shown physicians do not always achieve optimal results with them.[21]

In addition to the journal literature, other knowledge-based information is available on the Web, including many of the traditional medical textbooks, clinical practice guidelines (National Guidelines Clearinghouse [http://guideline.gov]), and a growing number of Web sites aimed at patients and consumers, many of which can be found using the National Library of Medicine's MedlinePlus database (http://medlineplus.gov). One concern about Web sites is their quality, as peer-review mechanisms that normally control print literature are often not present, and sites purporting to provide balanced views may well be promoting a point of view or a product to sell.[22]

Concomitant with the growth of online information resources has been the emergence of tools to use them more effectively. Probably the most important of these is evidence-based medicine.[23] The original focus of evidence-based medicine was to train clinicians to find and critically appraise individual studies. Few clinicians have ready access or the time required to search MEDLINE, read articles, and synthesize their findings in the busy clinical setting. As a result, the focus has changed toward approaches that provide highly concise information in the context of the specific patient and clinical problem.[24] This has led to a change in the emphasis of evidence-based medicine toward the production of syntheses of clinical topics and concise synopses of their findings.[25]

Decision Support Systems

One clinical informatics application, the decision support system, crosses the boundary of patient-specific and knowledge-based information. These applications, which apply knowledge to patient data, emerged from artificial intelligence and expert system research in the 1970s and 1980s that attempted to model the clinical diagnostician. However, the goal of building an electronic diagnostician never materialized and the resulting systems were too time-consuming for use in the clinical setting.[26] These applications have reemerged in the form of decision support systems, which are embedded in the EMR and aim to detect critical situations and errors in care and then notify the clinician, provide appropriate information accordingly, or both.[27]

Several systematic reviews have documented the effectiveness of decision

support applications within the EMR. A variety of approaches, including reminders that increase adherence with ordering preventive measures, hospital admission order sets and display of costs, and interventions to detect medication prescribing errors, has been found beneficial.[28-30] Additional work has demonstrated the value of clinical practice guidelines to standardize care.[31] One interesting finding of decision support systems applications is that their benefits do not appear to be educational (ie, they do not result in clinicians learning how to provide better care). This is illustrated by the fact that when decision support systems applications are removed, the adherence to specific recommendations returns to the presystem baseline.[32] Decision support systems provide timely reminders for busy clinicians.

Core Themes

There are a number of core themes that underlie medical informatics, not limited to clinical informatics: standards, terminology, usability, and demonstrated value. As most applications in medical informatics interact with others in a federation of different systems, standards are essential to facilitate integration of data, especially across systems from different vendors.[33] One area in which standards are particularly important is terminology.[34] While most individuals know that an upper respiratory tract infection, a cold, and a viral syndrome are similar, computers do not inherently know this. If the benefits of data aggregation are to be achieved (eg, comparing patient outcomes and resource utilization across practices, institutions, and regions), then standard terminology is essential. Standardizing the structure of clinical documents will also make aggregation and movement of data across systems easier.[35]

Another core theme in medical informatics is usability. Systems must be integrated into the clinical workflow and demonstrate other benefits when they require more time or effort on the part of the user. One example of research focused on usability found that a CPOE system that allowed physicians to type in orders in free text and mapped them to known order sets was faster and more acceptable than a standard system based on a point-and-click interface.[36] Related to usability is the need to demonstrate value. One study of CPOE demonstrated that use of guidelines and dose selection menus resulted in significantly increased adherence to prescribing regimens known to optimize patient safety and reduce cost.[37]

Future Directions

Although considerable challenges remain, the impact of medical informatics will certainly grow. The imperatives of improving documentation, reducing error, and empowering patients will continue to motivate use of information technology in health care. There is plenty of evidence that clinical informatics applications can address these imperatives to enhance patient outcomes, reduce costs, and provide access to knowledge. Evidence alone will not be enough to ensure their widespread adoption. For example, one concern is that most of the studies documenting the effectiveness of decision support have been carried out in academic medical centers with institution-specific EMRs and may not be generalizable. Another concern is that while the correction of a small number of clinical anomalies (eg, improper drug doses) is feasible, the increase of this process might lead to cognitive overload of the clinician. It is also too early to know the true cost of widespread use of these applications.[38]

The optimal use of clinical informatics applications will require some reengineering of the health care system. It will be crucial for the medical informatics field to account for the needs and concerns of all parties who participate in the process: patients, clinicians, payers, and governments. Clinicians will have to accept some impact on their practices, particularly as the individual physician becomes more accountable to document increasingly expensive care and demonstrate avoidance of error. They will have to accept CPOE, because this is the only place to effectively apply decision support. Society as a whole will need to determine who will pay the costs of EMRs and CPOE, because even if they save money in the long term, the up-front investment will be substantial. The key challenge across all applications will be adherence to the basic goals of the science of medical informatics: developing systems that are easy to use and provide demonstrable benefit.

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> The whole purport of literature . . . is the notation of the heart. Style is but the contemptible vessel in which the bitter liquid is recommended to the world.
> —Thornton Wilder (1897-1975)