Knowledge Integration: Insight Through the E-Portal

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ABSTRACT

Data become information when they can be summarized and organized into logical patterns; information becomes knowledge when it can be manipulated for actionable decision making; knowledge becomes insight when contextually relevant and temporarily appropriate. This article describes how information technology can now be used to provide clinicians with access to both insight and information that is context- and event-sensitive. Collaboration between the American College of Physicians, medical knowledge experts, Oregon Health Sciences University (OHSU), and shared medical systems for framework and infrastructure combine to create the ideal environment of complementary and synergistic competencies. This article describes the research that is under way at OHSU to determine how to deploy medical knowledge derived from these sources and integrate it into the clinical workflow; it also examines a vision of how medical knowledge can be integrated in the future.

KEYWORDS

- Knowledge
- Insight
- E-portal
- Contextual integration
- OHSU (Oregon Health Sciences University)
- Information

The vision looks something like this: Dr. Jones, an internist, examines a patient in the Emergency Department for admission to the hospital. It is July 4, 2000, and the patient, a fifty-four-year-old employee of a local nature preserve with frequent exposures to wildlife, presents with a four-day clinical history.

Symptoms began with a generalized, erythematous skin rash on the upper extremities that spread to the rest of the body. The patient subsequently developed a nonproductive cough and a fever to 104 degrees; he became increasingly lethargic and is now barely responsive. The infectious disease consultant is not currently available. Based on his knowledge of vector-borne diseases, Dr. Jones is concerned about a complicated differential diagnosis, including Lyme disease, rickettsial disease, and possibly recurrence of the West Nile encephalitis outbreak that occurred in the New York area in 1999.

Wanting to order only an appropriate workup and empirically correct treatment, Dr. Jones goes to the PC located in the ER and clicks on a "Prognosis Help" button; immediately, patient-relevant knowledge sources from best-evidence journals and clinical guidelines from the National Guideline Clearing House (NGCH) are sent to his desktop. Dr. Jones also receives a recommendation to send serum from the acute and convalescent phases to the Centers for Disease Control and Prevention (CDCP) to confirm the diagnosis. Although he never leaves the Emergency Department, Dr. Jones has access to the information he needs to expedite care for this patient.

One week later, a representative from the CDCP contacts Dr. Jones and thanks him for following through on the guideline and sending them the serum sample. They just received four additional hits to their Web site with similar queries and have determined that there might be another outbreak of the West Nile virus. Symptoms of all these patients are very similar to those of Dr. Jones's patient.

A Look at the Past

In the past, information technology (IT) was used as a means of automating manual clinical processes. The goal of this automation was to create a standard method for collecting data in a structured format to facilitate the measurement and analysis of the quality of care. These IT solutions, however, were focused on replicating the manual documentation process used to support the existing drivers of care management. The result was cumbersome and often redundant data entry, disconnected work processes, and ineffective access to results.

As IT capabilities are extended to support a knowledge-centric view rather than simply a data-centric view, clinical practice solutions must begin to take advantage of these new capabilities. In the past, data were king; today, data have become the commodity. Successful IT systems of the future will support and streamline workflow, not merely serve as data repositories. An added goal of systems designed to support clinical workflow must be the ability to support prospective clinical insight.

The terms *knowledge* and *insight* are used with careful consideration. They are not synonyms for *data* or *information* but are a natural extension of these terms along a continuum. *Knowledge* can be defined as the ability to make correct clinical decisions as a result of contextually relevant and temporally appropriate content. *Insight* takes this concept to the next level by incorporating the ability to make proactive decisions based on the same knowledge content. Knowledge and insight are inextricably tied together in an ongoing feedback loop, as illustrated in Figure 1. When knowledge is obtained, it can be fed back into the system, creating additional momentum for the application of insight. Systems that use this cycle can be viewed as "self-learning" applications.

Both knowledge and insight are made possible by the evolution of IT from simple databases to Web-based applications that can integrate disparate content into a format that enables clinicians to make critical time-dependent decisions. We can better understand the value of developing systems that support insight—not just data, information, and knowledge—by examining how the opening scenario can be rewritten *without* the support of IT systems along this value chain.

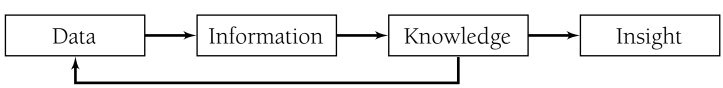
Dr. Jones Revisited

Imagine that it is July 4th, 1980, and Dr. Jones is examining a patient in the emergency department for admission to the hospital. The patient, a 54-year-old employee of a local nature preserve with frequent exposures to wildlife, presents with a four-day clinical history. Symptoms began with a generalized erythematous skin rash on the upper extremities that spread to the rest of the body. The patient subsequently developed a nonproductive cough and a fever of 104 degrees and became increasingly lethargic. The patient is now barely responsive. The Infectious Disease consultant is not currently available. Based on her knowledge of vector-borne diseases, Dr. Jones is concerned about a complicated differential diagnosis, including the recently described Lyme disease (named following an epidemic of arthopathy that occurred in the area of Lyme, Connecticut, in 1975), and rickettsial disease.

Following the prescribed protocol, Dr. Jones orders the appropriate workup, including a Chem 20, CBC, and urinalysis. Dr. Jones remembers reading reports about this new disease, as well as about treatment for it. To confirm his memory, he pulls the textbook, *Harrison's Principles of Internal Medicine,* from the bookshelf in the ER but discovers it is the 1979 edition. Lyme disease was just being considered a vector-borne disease in 1980. Because it is after hours, Dr. Jones has no access to journals in the library. Perhaps the CDC ("Prevention" was added after 1980) can help. However, the doctor's call produces a recording, because it is after normal business hours. Meanwhile, the patient loses consciousness and slips into a coma. Dr. Jones panics and starts ordering intensive treatment.

In the early 1980s, Dr. Jones would not have had on-line resources at his disposal; only previously published literature and possibly some patient data

Figure 1. The Insight Feedback Loop



(data points) would have been available. In fact, the content that was used to make a clinical diagnosis would most likely have been paper-based. Dr. Jones would certainly not have had point-of-care access to evidence-based research from recognized knowledge sources. The means of communication and access to knowledge to support decision making would have been derived from contacting peers or spending endless hours in the medical library sifting through card catalogues and medical journals.

Both the opportunity for medical error and the financial cost are significant in this situation. Dr. Jones might have ordered a more toxic combination of antimicrobial agents and a much broader range of laboratory tests, while spending several hours in the hospital medical library to research concerns about her patient. Not only is this an inefficient process but such inefficiency is among the reasons for the out-of-control costs that have plagued the medical industry.

Acquiring Knowledge

IT has finally evolved into the enabling infrastructure it has always promised to be. As Web-based systems become the norm, the barriers to transparent and accessible information are dissolving, and true clinical knowledge applications are beginning to emerge. The key to these knowledge applications is that integrated, decision-making content is delivered to the clinician when and where it is needed, without the traditional boundaries of space and time.

Technologies currently available allow for the development of systems that affect the entire professional experience of a physician. Physicians can now electronically link to many or all of the information and communication systems that influence their practice. These systems include patient medical records, research knowledge bases, prescription ordering, clinical decision support tools, and access to continuing medical education. The availability of these applications has introduced an opportunity for system designers to develop clinical practice systems that can support the full spectrum of knowledge needs for the clinician.

These systems can be represented by a model of information delivery that is based on clinical workflow processes, as well as the need to provide information to clinicians at varying levels of detail, as needed. We are now envisioning omnipresent clinical support systems (OCSSs). Given the wide array of pertinent information sources that can be integrated and accessible from almost any point on the globe, we can now design and develop information and communication models that provide practitioners clinical information where, when, and how they want it. Further, these can be personalized to provide only the information deemed necessary by the user-clinician.

The next challenge for the designers and builders of these OCSSs is to make them relevant and cost-effective. This may seem simple, but the medical field is littered with underused and discarded clinical information systems (CISs). Lack of quality, completeness, and practicality are among the reasons these systems have failed to become part of physicians' professional experience. The history of clinical information systems provides system designers a rich source of things *not* to do, as well as an endless resource for academic and barroom debate.

Context-Sensitive OCSS: A Model

The proposed model is clinician-centric, addressing a clinician's workflow across several axes: the context of the clinical event, temporal urgency, location, and X factors (factors to be determined).

The notion of a clinician-centric information system is more than a reference to a single view of medical information. If databases are properly designed (and occasionally even if they are not), appropriate tools can be used to harvest the data to create many different views. However, the goal is to develop systems that go beyond just user-centric views. We must develop systems that (1) support clinicians' information needs in the context of clinical practice, (2) provide knowledge, and (3) integrate seamlessly into clinicians' workflow.

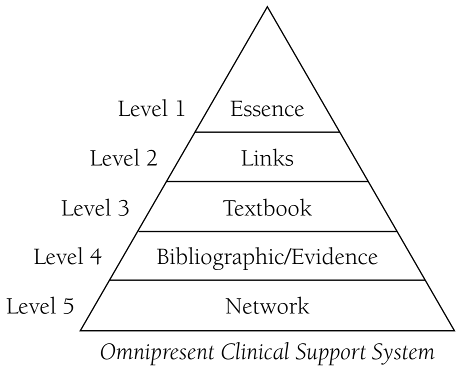
Clinical practice is mobile. In a given day, a clinician may work in more than one hospital, several clinics, many hospital rooms, and various labs, as well as at numerous workstations and offices. For an OCSS to be relevant, it must be situation-sensitive, that is, it must provide clinicians with usable information that is relevant to the environment (or context) they are in. For example, at the bedside a clinician needs highly abstracted, credible clinical information that provides complete answers to clinical questions in the fewest possible words. If the clinician posed the same clinical question at grand rounds, for example, a more detailed answer with references, tables, and charts would be desirable. And in a rare free moment in a clinician's day, an even broader or deeper understanding might be sought from the CIS.

Such a system would require access to clinical information that is written at different levels of abstraction, each level being supportive and internally consistent with related materials in the system. The various levels of information would be linked and the topics searchable at the word and concept levels. In addition, an OCSS would act as a personal information assistant, with features like bookmarking, content-specific continuing medical education, and calendar and scheduling integration.

At the application level, one can imagine the OCSS underlying a context-sensitive CIS as a multilayered pyramid. In this model (Figure 2) the top of the pyramid is Level 1 (Essence).

Essence. Level 1 represents the OCSS level that holds the information in its most abstracted form. For example, Level 1 information might consist of

Figure 2. Candidate Search Terms and Sources from the Context of the Electronic Medical Record



the minimum steps that a clinician must take to stabilize a patient with rickettsial disease or the appropriate dosage of a given medication.

Links. Level 2 provides information about Level 1 topics but in greater detail and with references and links to related and relevant topics. Level 2 would provide the clinical rationale to support Level 1.

Textbook. Level 3 provides a more traditional, textbook level of detail. Here the author could provide the context for Levels 1 and 2, as well as the clinical thinking that brings focus and meaning to the information, for example, about rickettsial disease, Lyme disease, or West Nile encephalitis.

Bibliographic/Evidence. Level 4 is the bibliographic or evidence layer. This OCSS level links the clinical rationale and thinking of the previous levels to the scientific literature. Level 4 provides the full text of requested articles. It also provides a bibliographic linkage that medical researchers use to support (and refute) medical writing. In addition, it can help medical researchers identify gaps in the medical research literature.

Network. Level 5 is the network level; links to relevant information sources and smart software agents that search the Internet would provide the ability to continuously update Level 4. Level 5 is also where the CIS clinical-alert systems would live—the network connections and smart agents that search the Internet for relevant and trusted sources. For example, the CDCP might alert OCSS administrators of new and important information that must be considered for inclusion in the OCSS information databases.

Arbitrary Boundaries. The boundaries between the levels are a bit arbitrary. The levels are a representation of how we need to organize and develop information to support the clinical decision-making process, which will vary, depending on the clinician's needs. For example, the needs of a medical student are different from those of a resident, attending physician, or specialist. Needs also vary with context, in the sense that a specialist may want one level of information for his or her specialty area and another level for other areas. For example, an endocrinologist may want only Level 4 information about diabetes but Level 2 or 3 information about a patient's peptic ulcer or hip replacement surgery.

The same role-based scenario applies to all constituents in an organization—executives, managers, employees, and consumers. Different levels and types of content are required for users, depending on their situation. Clinicians need access to results and professional medical knowledge; executives need access to policies and procedures and regulatory information; managers need operational figures; and all want comparative information on industry-recognized best practices.

Employees and consumers also need access to information and knowledge but from a different array of sources. They require access to internal knowledge sponsored by the organization, such as event notices and education seminars, as well as access to human resource data that are specific to their needs. For example, "Change of Life" events might require the addition of a child or a change in marital status. Employees and consumers also need access to individualized information, such as their own medical records. Consumers often want to track health information, access health news and drug-interaction data, complete health assessment surveys, receive follow-up and preventive care information, schedule health appointments, and communicate with their physicians on-line. Such information and knowledge are essential to empower the consumer to manage his or her own health. If this can be accomplished, a primary prevention capability is provided that can facilitate complete population healthcare management.

Current Research

Research is already under way at Oregon Health Science University (OHSU) to investigate the various levels of medical knowledge that must be integrated into clinical workflow. This challenging effort involves processes to understand the information needs of clinicians, questions most commonly posed, environmental constraints, and essential integration entry points. The only way this form of research can occur is if the necessary collaboration exists between users of the system, medical knowledge experts, and CIS architects. This research is occurring at OHSU through a joint development alliance with Shared Medical Systems (SMS, a Siemens company) and various providers of medical knowledge.

In another research effort, under the leadership of Dr. William Hersh and Dr. Susan Price, OHSU has begun the daunting task of cataloguing health-related content and providing that content at the right time and place for the clinician. The major goal of this work is to provide context-sensitive links from the electronic patient record to various information sources such as electronic textbooks, bibliographic resources, and electronic clinical guidelines.

The current system identifies terms from three sources within the electronic medical record (EMR): (1) the patient problem list, (2) concepts identified in the most recent history and physical report, and (3) laboratory results. The identified terms, as well as the available information resources, are available to the user (see Figure 3), with the appropriate results returned (see Figure 4).

Figure 3. Results of the Search from Figure 2

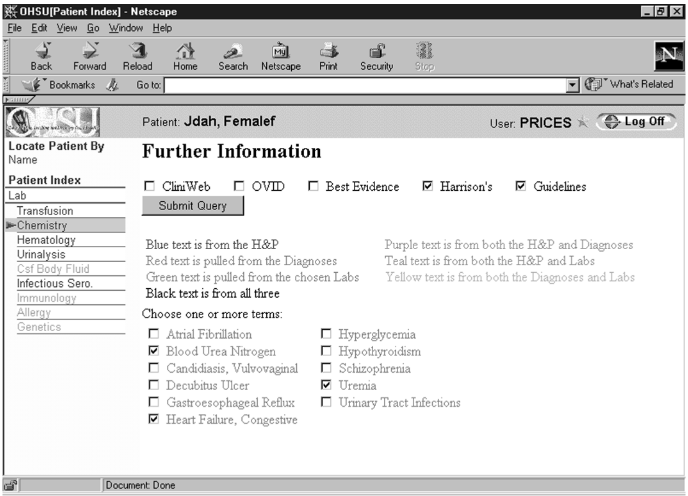
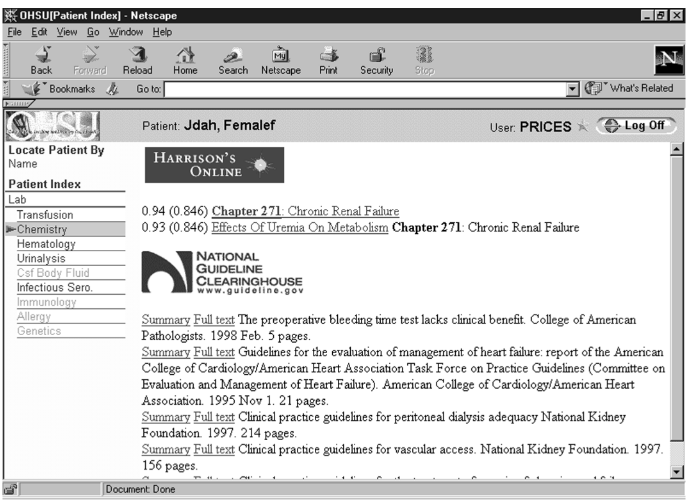


Figure 4. Additional Results from Search After Querying Harrison's Online



The system's development has progressed to the point that pertinent research questions can be addressed, such as how to extract information from a patient's medical record or select an appropriate resource type. In addition, clinicians can use patient data to formulate a query that will return information that is useful for enhancing the care of a particular patient. This project provides a fertile environment in which to demonstrate how metadata tagging of knowledge sources could significantly facilitate the retrieval of appropriate resources for answers to important clinical questions, based on the patient context in the EMR. (Metadata are data that describe the attributes of a resource. Typically they support a number of functions: location, discovery, documentation, evaluation, selection, and others. Human end users or their automated agents may carry out these activities.[1])

The OHSU-SMS project has recently extended to include Ovid Technologies (www.ovid.com), which has developed an alliance with SMS. Ovid is a content aggregator and IR system vendor whose search system is used by many major medical centers. The goal of the SMS-Ovid business agreement is to facilitate linkage between the EMR and Web-based information.

Hersh and his team are about to begin the next phase of this project, defining and evaluating new metadata standards for health-related content on the Web. Examples of metadata include the library card catalogue or the MEDLINE database of the National Library of Medicine (NLM). Both describe an information resource by various attributes, such as the name and location of its creator, subject matter, and physical or virtual location. A great deal of the activity of a library is devoted to the creation and maintenance of metadata to improve patrons' ability to find information.

If this effort is successful, the OHSU team will have created a new metadata standard for describing health-related Web content, which will enable the construction of a globally distributed knowledge base for healthcare. Not only will the team address major research issues related to metadata standards but their efforts will enhance the ability of Web users to find pertinent biomedical information. Such users may include, for example, (1) a healthcare provider seeking information about a disease, an image of a clinical finding, or a clinical practice guideline; (2) a healthcare researcher looking for datasets; or (3) a consumer looking for treatment alternatives for a serious disease. Another measure of success will be the adoption of this metadata approach so that it is accessible in the public domain for others to use and enhance.

Although the research draws on many bits and pieces of other work, the end result will be novel: a means for Web users to find a diversity of types of biomedical information on many topics. The work will also serve as a domain-specific test of metadata and other Web standards. Once these metadata standards are in place, common knowledge resources will be available for shared use by the global medical community, benefiting all parties and providing the necessary knowledge for insightful thinking that can promote proactive clinical decision making.

Achieving Insight

With the introduction of the e-portal, insight can be achieved. Insight is the use of knowledge to create proactive decision making and predictive forecasting to positively influence outcomes for the individual patient and for populations. The e-portal provides the means by which data, information, and knowledge from disparate sources can be aggregated to show a single relevant view. In its most dynamic form, the e-portal is a venue where information and knowledge are presented to the user, based on personal preferences and demographic changes.

A portal could be compared to a car's dashboard; it is a venue to deliver only information that is needed, such as fuel level, speed, mileage, and mechanical and electrical alerts. Concept cars in development today inform drivers well in advance of problems, letting them know, for example, that their vehicle's timing belt is wearing thin before the one-hundred-thousand-mile service is due to be performed. When the same paradigm is applied to the clinical environment, with the capability to *push* clinical alerts and results to the physician, the first leg of an insightful system is begun.

Preventive Care Through Insight. The value of the dollars spent on episodic, acute clinical care has increasingly come into question. In response to attempts to improve the quality of care, the focus has shifted to improving clinical outcomes, standardizing care processes, and analyzing variances. However, such efforts can result in cumbersome, labor-intensive processes for documentation and data collection with inconsistent and unproven benefits. The result has been dissatisfaction among healthcare delivery practitioners (physicians, nurses, therapists) and consumers (patients). In response to these concerns, many have focused on efforts to collect very limited, structured information that is based on preventive efforts in the inpatient (avoidance of falls, skin breakdown, infections and other adverse outcomes of care) and ambulatory (immunization, routine screenings, lifestyle changes) settings.

These preventive efforts can be divided into three areas: primary, secondary, and tertiary prevention.[2] *Primary prevention* is a proactive process to avert disease by immunization, lifestyle modification, and environmental manipulation. *Secondary prevention* includes processes to manage disease by early detection to allow curative treatments. Each of these has long been the purview of public health. Only recently, due to the insistence of the purchasers of healthcare (employers and government agencies such as HCFA), has attention been paid to these efforts on a broader scale. *Tertiary prevention* (sometimes used synonymously with *disease management*) is the management of ongoing disease processes to maintain or improve a patient's health status. Evidence shows that an individual's functionality and satisfaction can be improved; long-term cost savings are associated with such tertiary prevention efforts. However, many of these programs are labor-intensive, and showing short-term benefits to justify the start-up costs of such programs is problematic.

How the System Would Work. By revisiting the scenario used previously, we can now demonstrate how the system would work, that is, how informatics can be used to coordinate efforts based in the acute, episodic management of a clinical scenario with communitywide, preventive care activities.

Let's jump ahead in Dr. Jones's case and look at the feedback that could be received from the CDCP. The recommendation is that specimens be sent to the CDCP, including initial cerebrospinal fluid, as well as serum in acute and convalescent phases, to confirm a diagnosis. This feedback gives Dr. Jones, while still in the Emergency Department, the information he needs to manage his patient acutely. Within the next thirty-six hours, the patient awakens and begins to improve rapidly and will be discharged five days after admission.

The serum and cerebrospinal fluid sent to the CDCP are sufficient to provide a presumptive diagnosis of the same strain of West Nile encephalitis virus identified in the New York area the previous summer. Testing of mosquitoes in the area had previously been negative. Due to the early detection of the virus in the area, the CDCP is able to notify local health departments. The rapid deployment of primary prevention strategies includes a media blitz of public service announcements regarding mosquito control and avoidance; public awareness is heightened, and surveillance is increased for potential mosquito-breeding areas.

Notification is also being included as an alert on health-enterprise Internet entry portals for clinicians and consumers. Direct links from these alerts provide the individual with clinician- or consumer-specific information regarding prevention, detection, and treatment. Secondary prevention efforts also include notification to all physicians and emergency departments that the virus is present in the area so that new cases can be detected early.

As highlighted in this scenario, key elements of information can be collected to provide appropriate clinical guidance within a clinical workflow. Such guidance can serve to encourage appropriate treatments and clinical studies to speed diagnosis as well as decrease costs. In addition, the collection of appropriate information can serve to improve preventive care efforts, shown here with a new and emerging infectious disease.

The knowledge resources available to the clinician are vast, and with the emergence of healthcare professional vertical portals (vortals), there is certainly no shortage of information sources. These portals are the technology that enables knowledge to become aggregated and integrated into the clinical record. Portals have taken over the many functions that we have been accustomed to in our general workspace environment; they provide mechanisms that allow content and data from disparate systems to move in and out of repositories more easily in a form that users need. Portals enable enterprises to extend knowledge management and business intelligence initiatives within and beyond the walls of their organization in ways that could not have been envisioned two years ago.

Conclusion

Current technologies now allow for the development of systems that cover a physician's entire professional experience. Physicians can be electronically linked to many or all of the information and communication systems that influence their practice, including patient medical record systems, knowledge databases, prescription ordering, clinical decision support tools, and continuing medical education. With today's technology, we can achieve the next level in clinical workflow management—insight—by allowing the receiver of knowledge to instantaneously pull the precise nugget of information needed at the exact moment it's needed. This provides system designers with an opportunity to develop clinical practice systems that can support many (maybe all) facets of clinical practice.

With today's technology, we are at the precipice of a new era in medical knowledge management as revolutionary as Gutenberg's invention of the printing press more than six hundred years ago. Just as that invention, which made information widely available to the masses, changed the world, so will such clinical information systems forever change how medicine is practiced.

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