

The Internet, Medicine, and Clinical Informatics

Craig F. Feied, MD
Mark S. Smith, MD
Jon A Handler, MD
Michael Gillam, MD

The advent of the Information age has transformed and is transforming all of society, and it will change all of medicine in no less measure. Four aspects of this transformation are particularly interesting for their likely future effects in the field of medicine: ubiquitous connectivity, cyberspace communities, object orientation, and the development of trusted advisors.

Connectivity and the Internet

Connectivity is the cornerstone upon which the future of medicine is being built, and the Internet is the most visible manifestation of modern connectivity. What do we mean when we say ‘the Internet’? Do we mean the wires that connect one computer to another? The fiber-optic cable that connects local area network hubs from city to city? The satellite linkages that connect hubs from country to country? Do we mean the low-level protocols that allow us to send packets of information across those wires with confidence that they will arrive where we want them to go? Do we mean mid-level protocols that let computer programs send files and messages across those wires, using the low-level protocols? Perhaps we mean the end-user computer programs that give us an easy-to-use interface that lets us get text and pictures from some remote location, across those wires, using those mid-level and low-level protocols?

The fact is, all of these definitions are wrong. No matter which of these definitions we were to adopt, we would be forced to accept the fact that the Internet, as defined, would cease to exist in the near future. The cabling, hardware, and software that we use when we use the Internet

are all undergoing rapid change as we move towards the “next-generation Internet” (NGI).{refs}

No matter how the underlying transport and the top-level interfaces change, the essential power of the ability to connect to other people's information resources using the Internet will remain the same. This is what is essential about the Internet: the ability to give other people information that we possess and the ability to get from other people information that they possess, without regard to the distance that separates us. We use the word connectivity to describe this ability to exchange information at a distance. The Internet provides a previously unavailable level of connectivity to just about everybody who can get access to a computer and a telephone line.

It is not the mere existence of connectivity that is the key to the revolutionary changes that are coming in medicine. For more than two decades it has been possible to create a connection between two computers at distant sites and to transfer documents and images at high speeds, but the utility of this connectivity was tempered by limited availability. This type of connection was quite expensive, and required a high degree of specialized knowledge. The usefulness of these early remote connections was further reduced by compatibility problems and nonstandard file formats. An image could be sent from New York to San Francisco, but a complicated file conversion might be necessary before it could be viewed. The revolution that is occurring now in society and in medicine is made possible not by the mere existence of connectivity, but by the emergence of connectivity that is easy to use, inexpensive, compatible across many hardware and software platforms, and nearly ubiquitous.

The quality of connectivity

Of all the forces that are at work in today's Internet to produce unimagined change in the world of medicine, the most powerful is the increasingly near-ubiquity of connectivity. A person can walk up to any internet-connected

computer anywhere in the world and can exchange material with any other similarly connected computer, of any brand or type, anywhere else in the world. Connecting an existing computer to the Internet requires nothing but a \$50 modem and some free software, and asks nothing of the user but a willingness to learn something new. Attaining Internet connectivity is now so easy that the number of connected computers is increasing according to an exponential function. {refs }

Nearly as important as the ubiquity of connectivity are the ease of use and the unmetered payment system of the Internet. Today we face a reality that seemed unbelievable when posited just a few years ago: in many situations, making a computer connection is actually easier and cheaper than making a telephone voice connection. For example, to call Moscow via a voice telephone line it is necessary to know the long-distance company prefix, then the country code and the city code, the telephone number and the extension desired, and a 14-digit billing number. Once connected, a foreign language must be navigated in order to get a message to the wished-for correspondent. While connected, charges mount by the second. To connect to the same site in Moscow via the Internet, one merely clicks on an icon for the desired site and the connection is established without human intervention, virtually instantaneously. Because there are no 'message units' for computer connections, the connection to Moscow is essentially free, no matter how long it remains established. Of course the principle of *TANSTAAFL* ("there ain't no such thing as a free lunch") continues to apply, because each user pays a flat rate for unmetered Internet access, but the fact remains that there are no extra charges for individual connection transactions. The bill gets paid, but for the individual user, once connected to the Internet, there is no deterrent to regular heavy use.

Today, this combination of near-ubiquitous, fast, easy, inexpensive connectivity means that when a physician wants information about the latest experimental cancer treatment regimens,

or needs to know the current CDC recommendations for immunizations in travelers to Timbuktu, the information can be retrieved in a matter of seconds from anywhere on earth, at any time of the day or night. Tomorrow, ubiquitous connectivity will mean that specific medical records for an individual patient can be obtained just as easily.

Short-term problems

An important limiting factor that is missing in today's Internet is dependability. It is impossible today to rely on the constant availability of Internet access to a particular cyberplace. Dependable availability is especially important in Medicine, where care must be available around-the-clock. Many current initiatives promise that dependability will increase over time, {refs } and significant benefits that seem futuristic today will seem quite natural when we take dependable Internet connectivity for granted in the same way that we now regard telephone connectivity.

A second limiting factor in today's Internet that will also be solved in the near future is the problem of insufficient bandwidth, which translates into relatively slow transfers when the amount of information to be transferred is very large. With improved bandwidth, we will see a change in the type of information that gets exchanged. Instead of just hearing a colleague read a cardiologist's interpretation of a patient's cardiac catheterization, it will be possible to view the actual catheterization itself, playing it forwards and backwards, zooming in and out, changing contrast and viewing angle as desired.

The principal initiative that promises a real solution to the problems of dependability and bandwidth is the "next generation Internet" (NGI) project of the xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx. {refs }

Cyberspace Medicine

Another fascinating aspect of the transformative processes of the Information Age is our transition to an existence in cyberspace. What is

cyberspace? Where is it to be found? What does it mean to say that something exists or occurs in cyberspace? It is easy to define precisely where a face-to-face conversation is taking place: in an office, in Washington DC, in the United States, on Earth, in the Milky Way galaxy. If one picks up a telephone and calls a colleague in another state, it's much more difficult to say where the conversation is taking place. Is it in the ear? In the handset of the telephone? In the wires between the two offices? Perhaps it's in the satellite that handles transatlantic telephone traffic. The question becomes even more interesting if the conversation is handled digitally over a packet-switched network, because in this case the millions of bits of data that describe a human voice is broken into discrete packets that may travel by completely different paths before being re-assembled at the other end. The answer, of course, is that the conversation is not occurring in any particular physical place, but it is useful to consider that the conversation occurs in cyberspace, an electronically defined nondimensional space that connects two or more real dimensional spaces.

The concept of cyberspace has special utility when applied to the incredible web of near-universal digital connectivity that we now know as the Internet. For one thing, documents, photographs, programs, and datasets can be transferred from place to place as easily as a voice can be sent by telephone. For another thing, unlike voice connectivity, Internet connectivity is free of the tyranny of concurrency: there is no need for concurrent involvement of both parties to an information transfer. If there is information to share, it can be made available in such a way that access to the information is at the discretion of the user. Routine or automatic information transfer can take place asynchronously with no active involvement on the part of the provider. Equally important, the Internet allows the 'publishing' of information in such a way that it 'exists' in multiple cyberplaces simultaneously. Because of this, the Internet also encourages the creation of virtual information sets, in which information that exists piecemeal at widely separated sites is

integrated together to produce a new cumulative information set, available through a single cyberspace location that may or may not have any physical counterpart. Many cyberspace 'sites' contain nothing more than 'pointers' to information that actually resides in fragmented form in multiple separate and physically distant locations.

The end result of all of these factors is a new reality: we have come to think of composite objects that exist only in cyberspace as if they had a physical reality. We think of sites accessible via the Internet as if they were actual physical locations, and when we exchange information with a site, we think of ourselves as 'going to' that site in cyberspace.

Of course, connectivity is not new, and cyberspace is not new -- physicians have enjoyed a high degree of connectivity for years, and many medical transactions already take place in cyberspace. Every time one physician picks up the telephone and hears from another physician that a patient's electrocardiogram was normal in the office last week, that's a little bit of medicine in cyberspace. The practice of medicine will be qualitatively different, however, when physicians routinely connect via the Internet in order to look at the old electrocardiogram directly.

Today, clinical practice is based on test interpretations that are performed by a consultant who never sees the patient. This will change. When sufficient bandwidth is widely available, all physicians will learn to interpret an increasing number of tests that now require consultation by another specialist. This will come to pass partly because of the 24-hours-a-day, seven-days-a-week nature of medicine, and partly because access to data is inextricably linked to empowerment.

This may seem to be an overly optimistic and unlikely prediction, but there is ample historical precedent for this development. The first complete protein sequencing, for example, won a Nobel prize. Within five years, the ability to perform successful protein sequencing was an

important criterion for university promotion and tenure. A few years later protein sequencing was considered an appropriate project for a doctoral candidate. Today, high-school students perform protein sequencing as part of a science fair project.

The list of medical diagnostic and therapeutic procedures that once were part of an exclusive and restricted domain is extensive. At one time, special certification was required before a physician was permitted to draw arterial blood. Electrocardiograms were once regarded as mystical tracings that could be obtained and interpreted only by specialists (in fact, many clinicians still are in practice who have never learned how to obtain or read an ECG).

Plain-film X-rays once were read only by radiologists, but every medical student and resident now learns to interpret plain-film x-rays of the chest and extremities, and is expected to recognize obvious or common clinically relevant abnormalities. This ability is gradually lost by physicians who do not have ready access to their patients' x-rays, but is retained and improved in physicians who routinely receive the x-rays for viewing. In a similar way, neurosurgeons routinely view their patients' computed tomographic scans and magnetic resonance images, and most would not care to rely exclusively upon the interpretation of a radiologist. When images are routinely and easily available for viewing, clinicians will become proficient at image interpretation. Ubiquitous connectivity will make all diagnostic images routinely and easily available to every clinician.

Today it is usual that a clinical decision is based upon a limited, but immediate, clinically-guided interpretation of diagnostic images. Much later, a complete interpretation is made by an expert radiologist, who unfortunately usually is not familiar with the past history and the clinical presentation of the patient. This system will not survive. In the future, for any complicated case, diagnostic images will be interpreted by the clinician in direct, real-time, connected consultation with a radiologist. In the same

manner, we will interpret our complicated ECGs in connected consultation with the cardiologist, V/Q scans with the nuclear medicine attending, complicated reductions with the pediatric orthopedist -- and it will all happen in real-time.

Distributed medical record in cyberspace

The distributed medical record is already here -- doctors just haven't recognized it yet. No patient has all of his or her medical records in one place. A typical patient may have bits and pieces of medical information scattered here and there in medical offices, laboratories, and hospitals across the country. Even if all of a patient's records are at one hospital, parts of the complete record are found in the Medical Records office, other parts in Radiology, some in Ultrasound, some in the Pyxis pharmacy computer, some in the Lab computer, another portion in a billing chart in the billing office, and other parts in many other places about the hospital. Even today, significant portions of a typical medical record literally have no existence in hardcopy. Any billing question, for example, will send a billing representative scurrying for the nearest terminal.

Many issues of security, privacy, and reliability are raised whenever electronic medical records are discussed, but these issues are neither new nor unique to electronically represented portions of a medical record. Sensitive financial data are routinely shared across portions of the Internet, even though the very survival of entire countries depends upon the integrity and security of this data. Although there have been breaches of security and losses related to electronic banking, it is a matter of record that opportunities for financial loss are much greater when manual systems are used to manage and transfer large sums. So shall it be with medical records. All of the real security issues are soluble, and many of the issues that are hotly discussed today are nothing more than expressions of discomfort with something new.

As soon as physicians get used to the Internet as a means of being connected, it will be accepted just as telephones and fax machines have been accepted. What happens today when a colleague calls to request an old ECG on a patient who is in a distant emergency department with chest pain? The old ECG is obtained and faxed through without much fuss, because clinicians also know that it is in the best interests of the patient to have an old ECG available for comparison. At many hospitals, it is now possible to call up an old ECG directly on a computer screen. It's a minor step to add the ability to put that ECG into a password-protected web page and to tell that distant colleague where to point a viewer. When this happens, the two physicians will have created (in a matter of seconds and with no official authorization) a distributed medical record in cyberspace. Today, a physician viewing the cyberspace ECG will probably print out a local hard copy to stay with the printed chart, but before the year 2000 the concept of a 'hard copy' will seem silly -- after all, the cardiologist on call will be looking at the ECG remotely, and the CCU will want to look at it too. Within a few years most of the patient's chart will not exist in hard copy, unless an extracted subset has been printed out for a particular purpose.

Here's how a simple distributed medical record might be implemented today. A patient suffering from new headaches is referred by her primary physician to a neurology center, where she has an EEG, some blood work, and an MRI scan. At the time of the visit, the neurology center gives the patient a card with the center's internet address along with a special patient identification number (PIN). The patient gives a copy of this card to her primary physician, and keeps the card in her wallet, alongside similar cards from her primary physician, from the pharmacy where she fills her prescriptions, and from the hospital in Chicago where she had a cardiac catheterization while visiting on a trip two years ago.

Three days later, the patient travels to Washington DC on business, and develops another terrible headache. She comes to the

emergency department and presents all of her medical cards to the registration clerk. The emergency department clerk passes each card through a card reader and either the patient or the clerk types in the PIN number. A database representation of the information needed to generate a web page is created for the patient, with active links to each of the outside sites where a piece of the patient's records is found. Pointers connect to all of the records kept online by each of the patient's outside medical care providers: the past medical history, prior ECG's, the medication list, the cath report and a video of the cath, the MRI scan and interpretation, and all the rest.

In fact, to a user of the emergency department record in Washington DC, it will not be obvious which parts of the record reside where. The whole thing will seem so natural that nobody will think twice about looking at a sonogram from St. Louis alongside an MRI from Juneau. The era of the cyber-medical-record will have truly arrived.

Cyberspace communities

Another way in which the Internet is changing society, and emergency medicine along with it, is in the development of cyberspace communities -- people with shared interests who live in different locations all around the world, but who are in daily communication just as though they all lived in the same small town. The concept of peer review takes on a whole new meaning when it is carried out on a regular daily basis in a secure forum with open discussion among many interested members of the same profession.

Examples of the impact of this sort of community abound: a query recently went out on a popular emergency medicine mailing list: the author was seeing a large number of patients with symptoms of influenza, and wondered where else it was cropping up, and how other clinicians were dealing with it. Pooled information from many different practitioners gave a clinical picture of the current epidemic

that was very different from the official reports published in the Mortality & Morbidity Weekly Report. The use of recently-introduced antiviral agents was discussed and reviewed online in this context, with the result that a number of physicians altered their routine practice. The publication of an interesting article in a prominent journal often leads to a lively online discussion among a number of interested and knowledgeable people, providing a timely online review of the material from several different viewpoints.

An outgrowth of specialized cyberspace communities are specialized registries of clinical information. Such specialized registries have proven their worth in the field of cancer therapy, where constantly updated pooled clinical data from many practitioners and many clinical trials helps us to decide on the optimal therapy for an individual patient. Of special interest to emergency medicine, collaborative registries have been being founded for trauma, for complications of AIDS, for thrombolytic regimens as used in the transcatheter lysis of deep vein thrombosis, for tracking infectious epidemics, and for several other types of clinical data.

Object Orientation

It is often said that smart 'info-agents' will have a transforming effect on society. It is true that with near-ubiquitous connectivity we have already gained access to a mind-numbing variety of information resources. It is also true that modern information technologies can already allow us to develop 'smart' programs that can search multiple resources to find the answers to specific questions. In fact, the first of these 'information agents' have just begun to appear on the Internet. Information agents will indeed be an important aid to clinical decision making, but a much more fundamental change is coming, again riding the coattails of ubiquitous connectivity. This fundamental change is based upon the concept of object orientation, a concept that will forever change the way we practice. The third development that will arise from the extension of cyberspace through

ubiquitous connectivity and will have a tremendous power to transform medicine is the development of intelligent objects. Intelligent objects will come about because not only will physicians be ubiquitously interconnected, but machines will be ubiquitously interconnected as well.

Ubiquitous machine-to-machine connectivity and object orientation in systems design will add narrowly focused 'intelligence' to what are now real-life inanimate objects. This intelligence will reside in a portion of cyberspace that is closely associated with the physical expression of an object or a class of objects. The appearance of intelligent objects will change our life in profound ways, and medicine will be no exception. An example will illustrate the concept.

Today, a medication is just a powder in a bottle. In a typical emergency department, that medication may be prescribed hundreds of times a year. Each time it is prescribed, a clinician must take active steps to seek out and acquire information about the correct dosing and administration of the drug, and those steps must be repeated by every clinician every time the drug is given. Before an unfamiliar drug is administered in the Emergency Department, similar information has been looked up by a student, an intern, a senior resident, an attending, a nurse, and a pharmacist. Each of these clinicians seeks and finds information about the drug from a different source: subsets of information about the medication exist in a variety of locations, and must be actively sought with 'secret' knowledge of where to look and what questions to ask. The hospital pharmacy guidelines tell the nurse how to mix it and with what other infusates it is compatible. The resident's survival guide tells how much to prescribe. To find out whether it can be given to a pregnant patient, a consultant usually is called by telephone. The dosing for patients in renal failure is found in the Physician's Desk Reference (PDR). Updated manufacturer's information is found in the PDR supplements, although these usually are not available in a clinical environment. Any potential interactions

with other drugs the patient may be taking will be noticed only by the pharmacist, and only if the interactions are well-known and well-documented.

Each clinician believes his or her portion of the information is complete and correct, and after a number of tedious look-ups, each clinician believes he or she 'knows' all important information about the drug, at which point the information becomes frozen in memory. After this point any changes in the published recommendations for that medication will not be noticed. If memory fails, an incorrect dose can be (and often is) given.

Looking back from the future, this present state of practice will seem primitive or even barbaric. To begin with, in the future, all of the information for a drug will be integrated together and uniformly available everywhere: no drug will be marketed without a centrally-administered data resource that provides a publicly available up-to-date version of all known information related to that drug. What is more interesting, though, is that it will not be physicians, nurses, and pharmacists who use the data resource. In the future, the data resource will principally be used by the drug itself.

This is not a typographical error, nor is it a fanciful dream. In the future, a medication and its cyberspace data-self will be tightly linked. A medication will 'know' to whom it is being administered, and each medication will 'know' its own list of indications and contraindications, interactions and side effects. In computer-speak, the things an intelligent object knows how to do are referred to as its 'methods', thus a dose of medication will become a 'real-world instance' of a class of 'cybermedication objects' that possess 'methods'.

Even today, many hospitals keep all medications in locked, computer-controlled pharmacy supply carts, from which medication must be requested for a specific patient. Today the computer knows a lot about the patient's billing charges, but nothing about the clinical conditions for which the drug is being ordered. In the future,

when the cyberspace representation of a medication is 'drag-n-dropped' on a particular patient, the medication object will examine its new environment (the patient data record) and will send system messages containing the correct dose for that patient, the necessary adjustments in any other medications for compatibility, the method of mixing, which infusate to piggyback it into, and so forth. If a medication knows it shouldn't be given in pregnancy, it won't allow itself to be given to a pregnant patient unless you explicitly force the issue with an override. If the medication can't tell from its environment whether the patient might be pregnant, then if there is already urine in the lab, it will order and check a pregnancy test. If there is no urine available, it will ask for some.

Medications will not be the only 'objects' with 'methods' in the emergency department of the future. Lab tests will have 'methods', and will order companion tests if needed for meaningful interpretation. An order for a CSF glucose, for example, might look for a recent serum glucose, and if none was found, might proceed to order one. It is entirely possible that an ECG might read itself, compare itself to its younger self, order a set of cardiac enzymes, request the pharmacy cart to release a thrombolytic agent, and put in a page for the CCU resident, notifying the clinician of these actions as they are performed.

The advent of object orientation and of ubiquitous connectivity among all components of our local environment will bring changes that may leave very few aspects of modern medicine untouched.

The computer as 'trusted advisor'

So far as decision assistance is concerned, it seems apparent that our practice will be changed in one more small, but still important way. Because it is reliable and can be incrementally improved until we are satisfied, it is inevitable that the computer will become a 'trusted advisor'.

of increasing connectivity and the current trends towards object orientation, intelligent agents, and expert advice systems.

The concept of 'trusted advisor' is best explained through example. If a medical student tells an attending that a patient's vital signs are stable, the attending will most likely take the chart and look at the vital signs directly. If a nurse reports that the vital signs are stable, the attending may inquire "what are the most recent vital signs?" If a trusted colleague signs out with a statement that "the patient's vital signs have been normal," that information may be accepted with neither verification nor expansion. The reason one statement is accepted but the others are expanded or verified is not that students or nurses are suspected of failing to notice an abnormal vital sign. The reason one statement is more credible is because the colleague is trusted to have applied the same perceptual filters to the data that the attending herself would apply. In other words, the vital signs are accepted as normal according to shared criteria and taking into account the clinical setting. The statement "the vital signs are normal" becomes a "trusted observation" from a 'trusted advisor'.

The computer can become a 'trusted advisor' because it can be relied upon to apply criteria that the physician would accept, and can be counted on to inform the physician of any important exceptions. When such trusted advisor programs become available, physicians will be freed from much of the busywork of modern medicine. For example, if we can accept it when the computer says "all the labs are back, and they are all normal," we will be free from the need to examine each and every lab result from every patient. Similarly, if we can trust the computer to make sure antibiotics that have been ordered are actually being administered before a septic patient leaves the emergency department, we can turn our attention to other matters.

Conclusion

Many of the changes that are coming in the next few decades will be so fundamental that they are beyond our ability to predict, yet some version of the changes that have been discussed here seems almost inevitable, given the current pace