A Commentary on Technology and the Future of Health Care

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In his book, *The Lexus and the Olive Tree*, Thomas Friedman[1] describes a "fast world," where nearly all humans on earth are touched in some way by high-speed Internet connections, worldwide telecommunications, interconnected financial markets, and ubiquitous fast-food restaurants. One only needs to hear the ring of a cell phone, the buzz of a fax machine, or the awkward diction generated by voice simulation software to recognize plentiful and sometimes painful examples of life in this fast world.

As health care professionals, we can easily believe that we have already glimpsed the future and are already living in the fast world Friedman describes. We recognize that we must become more familiar with the Internet and incorporate computing power into our practice. We are also aware that the widely publicized genetics revolution will soon bring a large number of screening and diagnostic tests our way. We understand—and generally believe—that new technology can greatly assist us in preventing, treating, and curing disease.

But recent developments in computing and genetics are important not only because they bring new possibilities for health care. The combination of computing power, biotechnology, distance technology, and sensor technology will make delivery of health care in the United States unrecognizable from the care we deliver today. As startling as this prediction seems, it describes the challenge that health care systems must face directly and without delay. This article briefly surveys this new technology and previews its future role in health care.

Genetics

These days, we cannot pick up a scientific journal, a newspaper, or a magazine without finding articles that view the accomplishments of the Human Genome Project as the "biological equivalent of landing a man on the moon."[2] Nor is it a large leap to appreciate that the ultimate goal of genetic medicine is to prevent or treat disease with gene therapy or with a drug developed specifically for any given underlying defect.[2]

Using rapidly emerging discoveries in genomics (the study of all genes that make up an organism), scientists are perfecting methods of turning raw biological information into drugs, vaccines, and diagnostic tests. In the future, instead of wasting time on trial-and-error treatment, physicians will be able to use a genetic test to identify patients with the potential to respond to a drug. Pharmacogenomics will become key to individualized prescribing: A unique DNA signature will identify disease susceptibility, current disease status, and optimal drug treatment for a given person. Indeed, genotyping (or functional analysis) has already become standard practice in major cancer treatment centers such as the Mayo Clinic and St Jude Children's Research Hospital.[3]

Major developments in computer chip technology, nanotechnology, and combinatorial chemistry are signaling development of the "lab-on-a-chip."[4:729] Chip technology will enable quantitation and complex analyses on surfaces smaller than one square centimeter.[4,5] Today, most molecular genetic tests are not automated, are labor-intensive, and are extremely expensive.[4] Chip technology applications are already being tested to use cervical fluid, blood, buccal mucosal cells, and saliva.[6]

Genetics operates under the conceptual framework that disease is an individual event and that all subjects are truly individual. The enormous genetic variability among humans suggests that the more we know about genetics, the more apparent will become the observation that "each pathological event is unique in the same individual, and unique on different occasions, because of the variables with the environmental conditions of each instance. Environmental factors include not only the natural world but also the selection of lifestyles, foods, work conditions, family interactions, pets, etc. This, of course, means the death of nosology as we know it."[7:3]

How will a focus on unique individuals and individualized therapy comport with the population-based perspective of Permanente Medicine? What impact does individualized therapy have on health care delivery systems? For example, how will we reshape current pharmacy services for an era when drugs are tailored to the biochemistry of a single individual? Powerful computers will be at the hub of instant DNA analysis as well as subsequent design, formulation, and even dispensing of drugs.

In the 21st century, we will be able to detect the risk of genetically caused diseases from the moment of conception throughout the lifespan. As part of structuring our health care system, we will have to decide if we will test the blood of all newborns as well as other current Health Plan members for all known diseases. We will have to address the fact that these children, adults, and their families may have the gene for the disease but may never manifest symptoms of the disease. We will struggle even harder with the cost of offering fruitless medical interventions (including those that become "community standards") and with the ethical dilemma of telling patients that they have genetic mutations.

These are only the first-order effects of these developing technologies. Imagining the second-order effects is difficult, but these effects undoubtedly include the requirement that physicians, pharmacists, and nurses become computer-savvy technologists whose daily work may be far removed from the "laying-on of hands" common in traditional patient care.[8,9]

The World Wide Web

Much has now been written about the impact of the Internet on health care.[10-12] Medical information is one of the most-retrieved types of information on the Web—with well over 100,000 medical Web sites. Entering the single word "health" into any of the major Web-based search engines will result in millions of "hits."

The Web is now a commonly used tool in health care. A 1998 survey showed that 87 percent of health care organizations are using the Internet[10]—a figure that by now has undoubtedly increased substantially. But although an estimated 80 percent of hospitals use the Internet, fewer than 20 percent use it to give information directly to patients.[12] Consumers are obtaining medical information—lots of it—from the Internet, but not from us. This situation is a problem, and it will get worse.

One of most powerful developments in Web technology is the role of consumers. The

Internet is an engine for change because it provides an infrastructure for health professionals and consumers to access resources and databases. Universal access to this vast store of knowledge—without regard to its quality or content—has made medical practice more complex. But the most potent part of the Internet's power comes from the ability of consumers to gain access to the same knowledge base as providers of health care; in particular, this knowledge base includes peer-reviewed medical journals. For better or for worse, this access has increased consumers' involvement in health care decisions.

This development has provoked a debate about whether the typical patient can translate science-based information into better health or will instead become lost in a stew of information ("cyberhypochondria"). At a minimum, patients use information to challenge the evidence base of physicians. This use of information can put new strains on the physician-patient relationship but can also serve as incentive for doctors to learn how to use electronic resources, remain up-to-date on knowledge, and become better informed about patients' needs and preferences.

Meanwhile, outpatient care will be heavily influenced by the Web. Interactive video conferencing, educational programs, and the Internet will provide health care at a distance.[13] A report of a cost-effective program featuring remote video technology for home monitoring of chronically ill members of Kaiser Permanente in Sacramento has recently been published in the scientific literature.[14] Web technology will be used to match patients with ongoing clinical trials, far beyond the current capability of www.clinicaltrial.gov. The Internet will be used with greater frequency to transmit clinical data, to support Web-based consultations, and to communicate directly with patients via e-mail. A Web-based monitoring system for electrocardiography has been used successfully to collect clinical data from patients at home.[15] Current research featuring recruitment of at-risk teens for cognitive behavioral therapy may become a common method for outreach, treatment, and follow-up with hard-to-reach populations (Greg Clarke, PhD, personal communication, November 2000).[a] Eventually, health care providers such as Kaiser Permanente will help consumers and clinicians synthesize the cacophony of information generated by a "wired" world.

Distance Technology and Sensor Technology

The genetics revolution and the power of the Internet are widely recognized as the transforming technologies of the future. Another transforming technology on a more distant horizon is application of sensors or electronic monitoring devices and other "distance" technology in health care.[13,16] Today, these technologies are at the same level of development as computers were in the 1970s but are advancing very rapidly.[16]

Today's advanced technology unites sensing capability and data processing into a single integrated-circuit chip. Sensors detect physical, chemical, and biological signals[16,17] and can also measure and record a wide range of physical properties (eg, temperature, pressure, sound level, intensity of light, weight, amplitude of magnetic and electronic fields, and concentration of substances such as gases, liquids, or solids).[16]

Americans have become accustomed to using a wide range of electronic sensor devices in homes, cars, and offices. Sensors are all around us—in alarm and security systems, timers, household appliances, and elsewhere. In the future, sensors will be embedded in walls and ceilings of homes and offices, woven into clothing,[18] and given new applications not yet imagined.

Many applications are now being applied to health care. Remote transmission of pulse rate and blood pressure from the homes of patients with chronic illnesses is already available.[19] Developers are awaiting commercialization of in vivo glucose sensors for detection of hypoglycemia in diabetic patients.[20] In another small venture, diabetic patients wear a glucose sensor that looks like a watch and that produces small electric shocks which open a patient's pores so that fluid can be extracted to monitor tissue glucose concentration.[21] Other developers are working on an electronic "nose" that detects and differentiates the odors of growing bacteria that cause ear, nose, and throat infections.[22]

Perhaps even more stunning is the prediction that beds and tables in ICUs, hospital rooms, and operating rooms will soon be equipped with sensors and remote monitors to check vital signs and blood chemistry and with control sensors for mechanical ventilation, suction, intravenous transfusion, and cardiac defibrillation. In a 1999 issue of the *British Medical Journal* devoted to technology, Charles B Wilson, Director of the Institute of the Future, predicts that "inpatients may be implanted with tiny sensors as part of the admission process, and throughout the patient's hospital stay the chip will provide values instantaneously for the 40 or so laboratory tests that constitute 90 percent of a hospital laboratory's volume, thus changing the role of the central laboratory."[16:1288] Hospital lobbies can be vented with air monitors that detect and report any entrant who might transmit airborne infection.[23]

Once at home, patients may use a toilet (today designed by the Japanese company Toto) that analyses urine for glucose concentrations, patient weight, and other measures and sends reports to the clinical information system or directly to the health care team.[23] Clothing with embedded sensors will continuously monitor vital signs for patients at home or wherever else they may be.[16]

Issues Transforming Health Care

New technologies in health care are being introduced at blinding speed. These technologies are stunning in their breadth and scope and hold tremendous implications for the way health care will be delivered in the future. Although no one can guarantee exactly what the health care landscape will look like in the next 5, 10, or 20 years, several themes clearly emerge from the present trends.

Interdependence: An Outgrowth of the Information Explosion

No physician can practice medicine alone in this complex environment. The knowledge necessary to practice medicine has exceeded what any one individual can absorb. Most health care providers currently lack expertise in clinical or molecular genetics,[24,25] and greater familiarity with these areas of science and medicine will be required in the future.

Knowledge of genetics will not be enough, however. Computer technologies, interpretation of complex risk algorithms, robotics, and other technologies based on microelectronics and miniaturization will invade surgery, specialty care, and—most notably—primary care. These medical advances and technological breakthroughs will profoundly change our idea of group medical practice. Individual providers and entire health care systems must prepare themselves now for these developments.

Navigating a New Universe of Information

Systems must be developed to guide patients and physicians through the morass of available health information. This fact is perhaps most readily appreciated by every physician who has seen patients who are "armed" with information from many sources—scientific journals, newspaper ads, and the Internet, among others. Some patients are well informed about the risks and benefits of a treatment, whereas other patients have exaggerated expectations of receiving prompt medical benefits from an unproven or harmful treatment. This situation will become even more delicate and problematic as availability of genetic screening tests outstrips our ability to predict occurrence of disease.

We must build smart systems that evaluate and synthesize the content and quality of medical information and put it into usable formats. To cut through the forest of health-related information, patients and clinicians need guides based on good science and good sense. These guides must also reflect the value preferences of patients and physicians—the groups who will eventually accept one treatment choice over another.

The ability to express complex information face-to-face and through electronic means will be essential for clinicians. Because communicating and understanding these issues is so complex, genetic counselors and others who specialize in this work will be in great demand. However, primary care will remain the area where patients raise the most questions and demand clear and cogent answers.

Defining "Population-based" Health Care: A Future Dilemma

The individualization of medicine will complicate the notion of population-based care. Indeed, the ability to further identify individual human variation will eventually allow physicians to subclassify diseases and to adapt therapy to individual patients. Discoveries in genetics, combinatorial chemistry, and other developing scientific fields will reveal startling information about these individual differences. Pharmacogenomics will deliver on its promise to use information about genetic variation to predict responses to drug therapy. Gene therapy will be used to substitute healthy genes for nonactive or defective genes or to alter or control expression of a gene.[26]

The individualization of medicine will not eliminate the need to incorporate high-quality, empirically derived evidence into medical practice. Quite the contrary will be true. The need for "separating the wheat from the chaff" in analyzing evidence has never been greater. However, the individualization of medicine should increase the precision of prescribing and other types of medical decision-making. In the not-too-distant future, treatment "guidelines" may look more like instructions for highly specific, individually tailored treatment plans that reflect specific knowledge about a unique human being as well as about his or her environment.

Conclusion

Regardless of the accuracy of these specific predictions about the future, health care systems and physicians clearly have a great deal to do to prepare for a future where the only certainty is change itself. ❖

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