5. Health Care

From rural India to state-of-the-art hospitals in the United States, information technology (IT) is transforming and revolutionizing health care. Health care practitioners focus increasingly not just on doing something right but on doing the right thing—and doing the right thing in health care depends on the availability of good information.

In the future, many of the improvements in health care will come not from better drugs or better doctors, but from better managing information. Indeed, we are on the cusp of witnessing a radical transformation of health care as health care practitioners and patients increasingly embrace the IT tools of the digital age.

Already the effects of IT can be seen in the rise of new applications such as telemedicine and the growth of emerging fields such as bioinformatics. In fact, so much is happening that all the IT applications in health care—ranging from applications to streamline paperwork and business processes to extremely advanced clinical applications of IT to drive major medical innovations—are far too numerous to catalog.

As discussed below, IT is helping provide four key benefits in health care:

- reducing health care costs
- increasing access to health information
- improving the quality of health care
- increasing access to health care

Challenges to the adoption and use of health IT adoption, including economic barriers and interoperability issues, have slowed the digital transformation of the health care industry, particularly in the United States, but many of the benefits of health IT can already be found among early adopters.[1] Many health IT applications are still in the early stages of development where their benefits have been tested and proven but have not yet been scaled.

Efforts to quantify the benefits of emerging health IT applications are nascent. Researchers have tried to measure the success of health IT applications. But many researchers focus on only one metric of their success—such as user acceptance, economic benefits, usefulness, or improvement in patient safety—rather than conducting a comprehensive evaluation.[2] It is important to note that evaluative studies of health IT with negative findings may reflect an improper implementation of a technology rather than a problem with the technology itself. It is also important to recognize that case studies of health IT with positive findings may be difficult to generalize to a broader context. Even with these caveats, however, available research overwhelmingly points to a future where improvements in IT will continue to open new opportunities for advancements in health care.

Reducing Health Care Costs

As health care costs continue to rise, finding ways to stem the increases in health care costs while improving the quality are critical. And given that much of health care involves generating, processing, and transmitting information, it is not surprising that IT can play a key role in reducing costs.

Many early IT initiatives by hospitals reflected a naïve vision of how IT should be integrated into their workflow processes. In many cases, hospitals began developing IT systems without defining clear strategic goals and metrics for measuring performance.[3] Health IT systems are not simply "plug-and-play" products. To avoid wasting money and effort, hospitals must consider the extensive training, support, and workflow process development that need to accompany any investments in health IT.[4] Some hospitals have already wasted millions of dollars on health IT systems that failed to generate cost-saving benefits. The Cedars-Sinai Medical Center in the United States for example, spent $34 million to develop its own in-house computerized physician order entry (CPOE) systems system that ultimately had to be shelved after a few months of use because clinicians found too cumbersome.[5]

Although the potential financial benefits of IT in health care have not been realized on a large scale to date, a growing body of evidence suggests that IT will introduce substantial cost savings in health care, which ultimately will be passed on to patients. Estimates of the overall cost savings vary, but most studies show the benefits of health IT greatly exceed the costs. Societal cost savings from implementing and using health IT in the United States, for example, have been estimated by two studies at approximately $80 billion per year.[6] Studies of European countries

Cost savings from implementing and using health IT in the United States have been estimated by two studies at approximately $80 billion per year.

echo the claims from U.S. studies that the cumulative benefits of IT projects in health care will far exceed the costs.[7]

Cost savings from health IT identified by researchers come from an array of sources, most related to using information more effectively. Much of the savings in available estimates comes from increases in efficiency, such as shorter hospital stays because of better coordination, better productivity for nurses, and more efficient drug utilization.[8] In particular, researchers expect investments in electronic health records (EHRs) to generate substantial savings. EHRs contain a patient's complete medical history, including a full listing of the patient's illnesses, treatments, laboratory tests, drugs administered, and allergies. EHRs provide doctors with more complete information about their patients, which reduces the need for duplicative and unnecessary medical tests.

Hospitals can save money by using IT-enabled operational decision support systems to analyze clinical and financial information, including resource utilization levels, component costs, and clinician performance.[9] Operational decision support systems that support administrative decisionmaking can help to ensure higher levels of efficiency and improved business processes.[10] In addition, some hospitals are implementing self-service kiosks and online portals to automate certain functions such as patient registration and payment, thereby reducing wait times and decreasing staff utilization.[11]

Another source of cost savings from health IT is electronic claims processing. In 2006, 75 percent of claims submitted by medical practices in the United States were received electronically, compared with 44 percent in 2002.[12] Electronic claims processing results in greater efficiency and lower costs.[13] The successful transition from paper-based claims processing to electronic claims processing illustrates the potential for improving other health care business processes.

Increasing Access to Health Information

Ever since Hippocrates developed an oath for doctors, the model of health care has been one where the doctor had the information and the patient received it. But this model was always flawed because it failed to make patients active participants in their care and treatment. One reason that some individuals are not more actively involved in managing their own health and health care is that they have bought into the idea of the doctor as the expert, believing that "the doctor always knows best."

Now IT is fostering a radical transformation of health care by enabling patients to be much more empowered, both about the kinds of treatments that are available to them and about the quality of the health care providers they choose. By providing patients with access to more and better information, IT empowers them to make more informed health care decisions. By increasing patients' access to their own medical records and to a plethora of information to help patients make better decisions, IT has the potential to improve health care.

When patients have access to their personal medical records, they can take a more active role in their health care and routinely monitor their symptoms and treatment. Access to personal health records helps give patients a stronger sense that they have control of and responsibility for their own care. Many online applications, including WebMD, Revolution Health, and Microsoft HealthVault, have emerged to allow individuals to track and analyze their personal health information.

With online access to their personal health record and new Web-based tools, individuals can manage their health information online as easily as they manage their finances. Currently, for example, online applications allow patients to track health markers such as their blood pressure, cholesterol, and body mass index to see how these indicators changes over time and how they compare to healthy patients of the same age and sex. Patients can combine these online tools with medical home monitoring devices to track and compare their health between office visits.

Consumer demand for EHRs and personal health records is growing, and many people have embraced the technology when it is available. One of the leading EHR software companies reports that its product is used by more than 58 million people, mostly in large multispecialty practices.[14] Usage varies by country: In the United States, approximately 28 percent of primary care physicians have EHRs versus

79 percent in Australia, 89 percent in the United Kingdom, and 98 percent in the Netherlands.[15]

In the United States, Kaiser Permanente, the largest not-for-profit health plan in the country, has implemented an EHR system called KP HealthConnect, which allows patients and providers instant access to their medical information. Physicians use the system to place orders, review laboratory results, and access their patients' medical histories. Health plan members access the information using a secure Web portal that allows them to review laboratory results and office visits, as well as to communicate with their providers. As of mid-2007, 1.4 million Kaiser Permanente members had signed up for online access.[16] Kaiser Permanente has also partnered with Microsoft to allow its members to voluntarily manage their personal health records using Microsoft HealthVault.

Some health systems that have introduced EHRs have found that they helped reduce health care costs associated with visits to physicians. One study found that after introducing EHRs, Kaiser Permanente reduced visits to primary and specialist outpatient care by 5 to 9 percent.[17] Another study found that annual adult primary care visits decreased between 7 to 10 percent among patients who communicated with their providers electronically.[18] Secure Web portals also automate and simplify many health care transactions for the patient, including booking doctors' appointments, making copayments, filing for insurance reimbursements, and ordering prescription refills.

In addition to EHRs and personal health records, other IT tools also increase access to health information. Today, patients use health resources on the Internet to learn more about medical conditions, treatments, and prevention. Indeed, a survey in 2005 found that 80 percent of U.S. Internet users have looked for health information online.[19] Online health resources eliminate barriers to information by giving patients more convenience and privacy, access to online social networks, and the ability to communicate with specialists around the world.

In the United States, for example, the National Library of Medicine has indexed over 16 million health articles in PubMed (a free search engine of medical and life science journals) and maintains MEDLINE (a database of publicly available medical information).[20] These tools provide doctors and patients with access to the latest research from clinical studies, information on new medicines and treatments and explanations of illnesses and diseases. In a world where new health research is released daily, it is difficult for doctors to keep up with the latest findings. By giving patients access to the latest health research, the Internet enables patients to find information that often their own doctors are not aware of. This is one reason why multiple studies have found that Internet-based patient education is both useful and effective.[21]

By unleashing the power of information, health IT enables individuals not only to learn about medical conditions and treatments but also to obtain information about the quality of care from different health care providers. One of the realities of the health care system is that the quality of care between doctors and hospitals can vary widely and patients suffer for it. Yet, until recently, patients had few resources for distinguishing between different quality doctors. Most relied on imprecise indicators such as word of mouth or the name of the school on the doctor's diploma.

Now IT is enabling health care consumers to make more informed decisions about where they seek treatment. Tools available to help consumers make such decisions include public and nonprofit projects such as the U.S. Department of Health and Human Services' Hospital Quality Initiative[22] and the Leapfrog Group's hospital ratings.[23] Patients can now use these tools to receive objective performance metrics by which they can compare hospitals in their community. Thus, for example, patients can learn which hospitals in their community received the highest ratings on patient safety or have the most experience and positive outcomes with a particular high-risk treatment.

Improving Quality of Care

Three important ways in which the quality of health care can be improved are by (1) reducing the number of medical errors; (2) improving our understanding of the effectiveness of health care interventions; and (3) introducing new, more effective diagnostic and treatment interventions. As discussed below, IT is playing a key role in all three.

Fewer Medical Errors

Most health care errors stem from limited or mistaken information. A drug is given to the wrong person. A pharmacist misreads the dose on the prescription and dispenses the wrong dose. A doctor does not know the most accurate medical tests for a patient. Health IT can reduce these and a host of other kinds of medical errors, thus increasing patient safety.

Health IT can help reduce medical errors by providing accurate information when it is needed. Medical practices, for example, can improve patient safety by using computerized physician order entry (CPOE) to eliminate the ambiguity of hand-written medical orders. To provide additional improvements in the quality of care, CPOE can be used in conjunction with clinical decision support systems (CDSS). These systems, which include automated diagnostic programs, computerized test result interpretations, and drug management systems, provide health care workers with real-time information to aid with treatment and reduce medical errors.[24] CDSS can provide expert medical guidance to doctors to help ensure that they follow protocol and adhere to medical best practices.

Investments in health IT applications such as CDSS also have the potential to improve care and reduce costs by increasing patient safety. Adverse drug events account for 19 percent of injuries in hospitalized patients in the United States and cost hospitals alone over $2 billion per year, not including malpractice costs or the costs of injuries to patients.[25] One study found that health IT could eliminate around 200,000 adverse drug events in the United States at a national savings of $1 billion annually.[26]

Medical practices have also found various uses of radio-frequency identification (RFID) technology to improve efficiency and patient safety. RFID allows the automatic identification of objects through the use of wireless RFID tags or transponders. Thus, for example, hospitals can use RFID to track and monitor patients and manage items in the supply chain. RFID helps hospitals achieve positive identification, thereby increasing patient safety. Health care providers can use RFID to automatically verify that the right patient receives the right drug at the right dose at the right time.[27]

One reason why doctors have relied on paper records is that they need to be able to carry patients' records from one room to another, from one facility to another. But now portable IT devices such as tablet PCs, handheld computers, or personal digital assistants (PDAs) can provide physicians and nurses access to more complete and accurate electronic health information at the point of care. Thus, for example, doctors can use PDAs to order and check lab tests, take notes, and electronically prescribe medication. In addition, health care providers can use portable IT devices to get quick access to medical reference information such as medical literature and pharmacopoeias, or drug information databases. Rapid access to information is especially important in the critical care environment, where providers can use their portable IT devices to look up information such as drug dosing.[28]

Health care providers can use RFID to automatically verify that the right patient receives the right drug at the right dose at the right time.

Improved Understanding of the Effectiveness of Health Interventions

IT can equip health care providers with new strategies and methods for preventing, diagnosing, and treating medical conditions. More generally, health IT can help improve medical care by making it easier for doctors to provide evidence-based medicine. Evidence-based medicine is the use of treatments judged to be the best practice for a certain population on the basis of scientific evidence of expected benefits and risks. Evidence-based medicine requires health care providers to have sufficient knowledge of both the patient and the scientific evidence to make informed decisions.[29]

IT is providing that information by digitizing health information to provide doctors with instant access to their patients' complete medical history and the latest medical research. One reason why health care is not as effective as it could be is that the relationship between medical interventions and patient outcomes is unclear. Information about efficacy is derived largely from clinical trials, which are by nature limited in scope and coverage. Doctors need not only information about what works in a clinical trial but also information about the effectiveness of various treatments in real-world settings with specific types of patients.

As medical research becomes digital, health researchers will be able to use data mining techniques for medical research. Thus, for example, doctors will be able to review the risks and benefits of a specific drug or medical procedure, not just based on clinical trials, but based on a population sample that matches the profile (age, sex, body mass index, etc.) of their patient. In addition, health care providers will be able to use rapid learning networks to spot dangerous side-effects from drugs or other treatments, as well as identify effective treatments more rapidly.[30] These rapid learning systems will also greatly increase the knowledge base for evidence-based care.

In the future, public health officials will also be able to use IT to more effectively detect outbreaks of infectious diseases and monitor treatment efforts. Already researchers have used increases in computing power to study various pandemic models. Thus, for instance, scientists have been able to evaluate the effectiveness of different public health strategies to respond to the outbreak of a worldwide influenza pandemic.[31] At the U.S. Department of Defense, the Electronic Surveillance System of Early Notification of Community-based Epidemics (ESSENCE) collects health data in real time from more than 400 facilities around the world and helps medical teams identify early-warning indicators of a possible disease outbreak, even if the system cannot identify the disease.[32] As medical research becomes increasingly data-intensive, IT will play an even greater role in storing, transmitting, and processing medical data.

New and Better Methods of Diagnosis and Treatment

IT is playing a key role in introducing new, more effective diagnostic and treatment interventions. As described below, researchers have developed or are developing IT-enabled medical devices that can be used to perform sophisticated diagnostic tests outside a doctor's office; IT-enabled prosthetic and orthotic devices far more sophisticated than any used in the past; IT-enabled "smart" implants that permit doctors to monitor and treat patients remotely; robotic surgical techniques; and many other technologies that improve diagnosis and treatment. Advances in IT and bioinformatics also enable the processing and storage of vast amounts of biological data.

Given that integrated circuits are in everything from cars to cell phones, it should come as no surprise that they are increasingly part of all types of medical devices. IT-enabled medical devices that have been developed or are being developed include portable devices that can be used outside the doctor's office. BrainScope, for example, is a portable medical device developed by researchers to measure brain electrical activity to diagnose concussions from head trauma. Although traumatic brain injuries are common, emergency workers have few tools with which to assess the severity of the injury. Portable devices such as BrainScope can aid emergency workers in performing triage.[33]

Researchers are also working to miniaturize existing medical devices such as electrocardiographs (ECGs) and sonographs to make them more portable. A compact ECG to enable doctors to bring the device to their patients, for example, has been developed by General Electric. Previous ECGs weighed around 15 pounds and cost $10,000, but by reengineering the ECG with low-cost materials and off-the-shelf electronics, engineers were able to shrink the device to less than 3 pounds and only $1,500. In

Health care providers will be able to use rapid learning networks to spot dangerous side-effects from drugs or other treatments, as well as identify effective treatments more rapidly.

rural India, this level of portability means that doctors can carry the compact ECG device with them as they travel from village to village, thereby ensuring that all patients receive better care.[34]

One of the most amazing uses of IT in medical devices is in increasingly sophisticated prosthetic and orthotic medical devices. A wide range of prostheses from artificial limbs to cochlear implants that allow hearing have emerged because of a combination of factors including faster low-power processors, improved biosensors, and a better understanding of the human brain.[35] Scientists have even designed an artificial silicon retina (ASR) microchip to restore lost vision. In one pilot project, scientists designed and implanted a 2-mm-diameter ASR microchip that used electrical stimulation to simulate how light would affect certain membranes; perhaps even more impressive, this microchip is powered entirely by incident light.[36] By restoring or improving their vision, this technology has dramatically affected the lives of individuals afflicted with blindness or visual impairments.

Although the bionic man was once something seen on a 1970s science fiction TV show, a wide array of IT-enabled advances in robotics has led to unprecedented advances in artificial limbs and orthoses, bringing the fantasy of creating a bionic man or woman closer to reality. Exoskeletal orthoses, or wearable robots, have been developed that provide adaptive robotic assistance to stroke survivors with weak muscles. These devices help stroke survivors relearn muscle control through therapeutic exercise. Patients control these devices though noninvasive electromyography biosensors that measure the electrical potential of muscle activity.[37] Many patients find that controlling these exoskeletal devices is intuitive, but such devices must piggyback on existing muscle groups and nerve signals rather than using brain activity.

As researchers continue to develop faster and more accurate brain-computer interfaces, patients may eventually be able to directly control a prosthesis with their brain.[38] Doing so should give patients more control over their artificial limbs and enable additional patients to benefit from this research. Already scientists have succeeded in training monkeys with electrodes implanted in their motor cortex to move a robotic arm to feed themselves using only their brains.[39] In addition, scientists have begun to develop methods to recreate the lost sensations in paraplegics and amputees by providing these patients with sensory feedback. Currently, most patients must use visual feedback to operate their artificial limbs. The goal is to develop prostheses that provide biofeedback by, for example, sending heat signals if temperature sensors indicate that an object is hot.

IT is also bringing us closer to another science fiction vision we saw in the 1960s in the Raquel Welch film "Fantastic Voyage." Rather than miniaturizing people in a submarine to travel inside a patient's body, however, IT is enabling a host of miniature implantable devices to do the same job. Advances in embedded systems, or special-purpose computers with a single task, have led to the development of microelectromechanical systems (MEMS) that integrate mechanical elements, sensors, and electronics on a silicon substrate. MEMS enable the development of "smart" implantable medical devices that allow health care providers to monitor or treat patients remotely and with minimal imposition on the patient.

Currently, for example, implantable medical devices that permit continuous monitoring of glucose levels in patients with diabetes are marketed by several companies. The traditional approach to monitoring diabetic patients' blood glucose levels, using finger sticks, provides only a few data points. Continuous monitoring allows both patients and doctors to track diabetic patients' glycemic patterns over time and also helps patients better understand the effect of certain behaviors on their glucose level.[40] Health care providers can also use implantable medical devices to deliver drugs that might otherwise require a trip to the doctor's office.[41]

Even the brain is not off limits for IT-enabled medical implants. Doctors are using brain implants that provide deep brain stimulation to treat medical conditions such as Parkinson's disease, Tourette's syndrome, depression, and obsessive-compulsive disorder. These devices monitor brain activity and help the patient by sending or blocking electrical activity in the brain.[42]

Other microelectronics used in health care include a pill-sized, ingestible thermometer that can monitor the body's core temperature and wirelessly transfer the readings to a nearby computer. Developed by the National Aeronautics and Space Administration (NASA) for astronauts and now used by athletes, firefighters, and divers, the ingestible thermometer provides an effective mechanism to continuously monitor the core body temperature of individuals exposed to extreme heat or cold.[43] Similarly, engineers have developed a pill-sized camera that patients can swallow to view their digestive tract and eliminate the need for a more intensive endoscopy which requires sedation.[44]

When Wilhelm Conrad Röntgen discovered X-rays in 1895 he could not have imagined the transformation in health care that this discovery would bring about. Medical imaging is now a widely used diagnostic tool for anything from colon cancer to pneumonia. In addition to using traditional film-based X-rays, health care providers now use a variety of newer forms of medical imaging such as digital X-rays, computed tomography (CT) scans, magnetic resonance imaging (MRI), positron emission tomography (PET), and photoacoustic imaging. Some forms of medical imaging are more advanced than others. CT scans, for example, use computers to compose a high-resolution cross-sectional view of an area of the body from multiple images that traditional X-ray methods cannot provide.

Advances in IT have led to advances in medical imaging techniques that let health care providers see into the body in much more accurate and detailed ways. Although the underlying technology for many of these medical imaging techniques has not changed, recent advances in IT have introduced a number of benefits. Thus, for example, patients using an EHR benefit from digital images as they can easily access, store, and share their lifetime history of medical scans with any of their health care providers.

Other benefits of IT can be seen in areas such as digital mammography. Digital mammograms use the same X-ray science as older mammograms, but using a digital receiver in lieu of film yields a number of benefits, including less radiation exposure for the patient, immediate lab results, and most importantly, more accurate readings. In addition, electronic storage and transmission of mammograms allows doctors to easily compare mammograms from multiple years or patients to provide more accurate diagnosis.[45] The European MammoGrid project created a European-wide geographically distributed database of digital mammograms, which allowed radiologists to make comparative diagnoses with other images from the databases.[46] Breast cancer is the second most common form of cancer in the world, and IT-enabled advances such as these ensure that more accurate screening for the condition helps save lives.

Another advantage of digital images is that they can be analyzed and manipulated by computers after processing. Projects such as the Visible Human Project, for example, have created detailed, three-dimensional representations of the human body.[47] In addition, researchers have used medical imaging to develop virtual reality animations of the human body.[48] These virtual reality experiences enable researchers and students to better visualize different human systems. Researchers also can model diseases in these virtual environments and help improve research on better treatments.

Advances in the fields of medical imaging and robotics have even enabled computer-assisted surgery. The da Vinci Surgical System, for example, allows surgeons to use a robotic eye and robotic arms to conduct minimally invasive surgeries such as removing the gall-bladder, removing the prostate, and conducting other various surgical procedures on the chest. Surgeons control the da Vinci Surgical System through a special console that gives them an enhanced view of the operating table and precise control of the electronically controlled medical instruments. By allowing surgeons to make only small incisions, computer-assisted surgery reduces patients' postoperative scarring and pain and improves patients' recovery time and safety.[49]

Computer-assisted surgery has also led to the development of telesurgery. Using high-speed networks to transmit real-time audio, video, and health data, surgeons can remotely operate robotic arms in an operating room thousands of miles away. The first transatlantic surgery occurred in 2001, with the surgeon in New York City and the patient in Strasbourg, France. Telesurgery has the potential to improve care for residents in rural locations by providing them access to the best medical experts. Telesurgery can also be used by patients too sick to travel or in locations without a doctor, such as a war zone or the International Space Station.[50]

A special form of computer-assisted surgery uses a visualization technique called Augmented

Reality, which supplements the real world with three-dimensional virtual objects that appear to coexist in the same space as the real world in order to enhance the user's perception of and interaction with the real world. The use of a head-mounted display that enhances the sense of sight by combining virtual objects with real-world objects is the most common example of this technique.[51] In medicine, Augmented Reality has a variety of applications. By providing surgeons with virtual X-ray vision, for example, Augmented Reality can allow minimally invasive or noninvasive surgery. Minimally invasive surgery is more difficult than traditional surgery (because small incisions reduce the ability of a surgeon to see inside), but it reduces trauma to the patient and shortens recovery times.[52]

Augmented Reality can also be combined with traditional vision to give physicians a better understanding of the patient. A surgeon could create a three-dimensional model of a tumor from ultrasound images, for example, and then superimpose the tumor model onto real-time images of a patient. This technique would allow the surgeon to perceive the exact position of the tumor in the patient's body and make better decisions regarding treatment.[53] It would also allow a doctor to conduct a needle biopsy of a breast tumor, for example, using Augmented Reality to visually guide the needle.[54]

IT is enabling researchers to develop more advanced pharmaceutical treatments. In particular, researchers have looked to grid computing as health care research becomes more data and processor intensive. By distributing storage, data analysis, and data processing across a grid, grid computing enables participants to build better, more advanced, system together than they would have been able to build alone. Traditionally, health researchers conduct *in vivo or in vitro* studies—medical studies using either living organisms or test tubes. But grid computing has opened up the possibility of in silico studies, or medical studies conducted by computer simulations. Using grid computing, a researcher may conduct a simulation to evaluate which drug or combination of drugs will likely be most effective on a patient given a set of genetic markers. These simulations require vast amounts of computing power to analyze not only large data sets but also drug interactions, drug resistance, immune responses, and mutations.[55]

One of the most successful examples of grid computing in health care is the cancer Biomedical Information Grid (caBIG).[56] This initiative, overseen by the U.S. National Cancer Institute, is the result of a collaborative effort by health care researchers to build an flexible, online platform for cancer research. The caBIG infrastructure consists of multiple tools, applications, and data repositories that facilitates research, encourages collaboration, and makes data from disparate sources more accessible. Applications include a clinical trial case management system, an *in vivo* imaging system, tissue banks and pathology tools, and numerous biomedical data analysis tools. The caBIG infrastructure helps researchers generate and validate hypotheses, record and share valuable research results, and speed the transition of research findings into clinical practice to help cancer patients.[57]

Using high-speed networks to transmit real-time audio, video, and health data, surgeons can remotely operate robotic arms in an operating room thousands of miles away.

Finally, it should be noted that the most important medical breakthrough of our era—the unlocking of the human genome—would not have been possible without IT, in particular, the enormous processing power found in today's supercomputers. The Human Genome Project sought to correctly analyze and sequence the 3 billion chemical base pairs that make up human DNA. Traditionally, biologists use a technique known as chain termination for DNA sequencing. The problem with this method is that it allows only short strands of DNA to be sequenced. The process of sequencing each strand in order proved to be too slow for sequencing the entire human genome. For that reason, researchers devised a new technique known as whole genome shotgun sequencing in which they segmented DNA into small, random fragments, and then used a network of computers operating in parallel to reassemble these fragments into the correct sequence.[58] Further research in genetics will rely on advances in IT and bioinformatics to successfully store, manage, and analyze biological data.

Telemedicine systems can also be used to provide access to health care for individuals in remote locations who would otherwise not receive care.

Currently, one of the biggest challenges for researchers is to better understand proteins, the organic compounds responsible for many of the essential functions in cells. Understanding proteins will help researchers fight diseases such as HIV/AIDS, malaria, cancer, and Alzheimer's disease. It is important to understand the three-dimensional structure of a protein because the shape of a protein determines how it interacts with other molecules. Although scientists can find the sequence of amino acids that constitute a particular protein, predicting the shape of the protein requires testing an enormous number of possibilities to discover which structure is most stable.

Yet solving the problem by computer still presents an enormous opportunity over the more costly alternative of discovering protein structures in the lab. To help speed this process, researchers at the University of Washington created the Rosetta@home project—a distributed computing project that allows Internet users donate their spare computer processing power to help with this research.[59] As of May 2008, the project had over half a million computers working on the project at any given moment.[60] However, the research team realized that while the computers were making important progress, human problem-solving skills and intuition might help find the solutions faster. In response, they developed Foldit, an online, multiplayer game that allows Internet users to compete against each other to find the best protein structure. Future plans include allowing participants to design new proteins that might treat or prevent diseases.[61]

Increasing Access to Health Care

If you want access to the best health care in the world, you should live close to a major world-class research hospital, usually located in an urban area. Right now, if you do not live near such a facility, you may not get the best treatment. The good news, though, is that IT is helping to break down geographical barriers to health care by enabling patients to have access to top-quality care without necessarily being physically close to it.

Hospital and Other Applications of Telemedicine

Recent advances in IT that enable large amounts of data to be quickly transferred anywhere in the world have give rise to telemedicine—an application of clinical medicine where medical information is transferred via telephone, the Internet, or other networks for the purpose of consulting and sometimes performing remote medical procedures or examinations. Telemedicine allows patients to have access to medical experts even when they are geographically separated from them.

Some applications of telemedicine offer patients benefits including more convenient care, better access to specialists, and an alternative to office visits for patients with minor medical questions. One application called Cisco HealthPresence, for example, uses the network as a platform that allows patients and doctors to interact over a secure connection through high-definition audio and video; it also allows doctors to obtain vital signs and diagnostic information from their patients using special network-enabled medical devices.[62] To take advantage of this service, patients visit a Cisco HealthPresence pod staffed by an attendant who assists with the technology and ensures the cleanliness of the pod.

Telemedicine systems can also be used to provide access to health care for individuals in remote or other locations who would otherwise not receive care.

In Australia, for example, the Broadband for Health Program connected indigenous and rural communities with health care providers in urban areas. In the United States, telemedicine systems have also been used to bring access to low-income residents in urban areas of the United States. Fort Wayne, Indiana, which has an extensive fiber-optic broadband system deployed by Verizon, for example, has set up a system where retired nurses help provide health evaluations for low-income residents without health insurance through means of two-way broadband connections.[63]

The conversion of health images into digital forms that can be sent over telecommunications networks has allowed the development of another application of telemedicine known as teleradiology. Teleradiology is the electronic transmission of radiological patient images such as X-rays, CTs, or MRIs from one location to another for interpretation and consultation. In 2003, two-thirds of all radiology practices in the United States reported using teleradiology.[64] Medical practices use teleradiology to transmit medical images electronically to radiologists located in another region or country, at home or simply another wing of the hospital. Teleradiology may also be used to send medical images to a specialist or provide a second opinion. Benefits from teleradiology include better quality radiology in small and rural hospitals and faster turnaround on interpretations.[65]

Some hospitals have used telemedicine to improve care for critically ill patients via remote electronic intensive care units (eICUs). The provision of around-the-clock care to critically ill patients in ICUs by physicians who specialize in their care (intensivists) is considered key to improving outcomes for such patients, but some hospitals cannot provide such care because of a shortage of intensivists. Remote eICUs address this challenge by allowing a team of intensivists to monitor critically ill patients in the hospital continuously using streaming video, EHRs, and remote sensors, so that they can coordinate care with the physicians and nurses who are caring for these patients in the hospital. A health system in Kansas City implemented an eICU to leverage its limited intensivists and standardize clinical practices and processes in its seven hospitals. Researchers found that this initiative reduced the health system's ICU and hospital mortality rates.[66] In addition, it reduced patients' ICU and hospital length of stay, a factor that strongly influences hospital costs.[67] A study of the first major eICU installation similarly found that the hospital reduced

Box 5-1: Per Capita Investments in Health IT by the United States and Other Countries

Investment in health IT varies by country, but overall government investment in health IT in the United States significantly trails many European countries. As shown in the table below, total per capita investment in health IT by the federal government in 2005 was only $0.43 per capita in the United States versus an astounding $192.79 per capita in the United Kingdom. Yet the United States spends more on health care than any other nation, with health expenditures reaching $2.0 trillion per year.[68]

Total government investment per capita[69]
(as of 2005)

United States	$0.43
Australia	$4.93
Canada	$31.85
Germany	$21.20
Norway	$11.43
United Kingdom	$192.79

While these numbers demonstrate the disparity between investments in health IT among different countries exact comparisons are never perfect because of differences in each country's health care system. For example, investments in electronic claims processing for health services may be included in the figures for some countries, such as the Canada which has a single-payer health system, but not others.

One reason for the relatively low investment in health IT in the United States is that while most private medical practices bear the cost of implementation, many of the benefits of these systems are received by the insurance companies and the patients. Although most researchers agree that investing in health IT yields a net societal benefit, the implementer does not always receive all of the benefits. It is not surprising then that single-payer systems, such as the United Kingdom, have much higher levels of investment in health IT.

mortality by 27 percent and reduced the costs per ICU case by 25 percent.[70]

Mobile devices are rapidly becoming an important platform for health care, as well. In 2007, for example, a Gartner study reported a worldwide total of 3.3 billion mobile connections from portable devices such as handheld computers and cell phones.[71] As a platform for health care, mobile devices have a number of benefits including low cost and widespread usage, even in underdeveloped regions. In addition, mobile devices can provide quick access to expert care even in remote or rural locations. Because of these advantages, researchers have begun developing health care applications for patients and providers using mobile devices as a platform.[72] Currently, for example, health care workers can use text messaging on cell phones as a tool to educate patients about diseases and send them medical alerts. In one study, health care workers experimented with an 11-week protocol to educate parents of children with type 1 diabetes using the mobile phone short message service (SMS) and received high user satisfaction.[73]

Many new applications of telemedicine are on the horizon. Recently, for example, researchers have begun developing a virtual speech therapist to help the estimated 40,000 people who suffer from a stroke every year in Malaysia. This application will address both the shortage of speech therapists in Malaysia and the difficulty patients face with traveling to therapy centers.[74] Other applications of telemedicine may make use of sensor networks and portable global positioning systems (GPS) to report personalized medical hazards to patients. Thus, for example, asthmatic patients may carry a GPS-enabled mobile device that can alert the patient when the ambient air quality reaches dangerous levels from allergens or pollutants.[75]

Remote Monitoring of Patients with Chronic Conditions

Health care providers use remote health monitoring of patients with chronic conditions to identify potential problems and recommend preventive treatment. Medtronic, for example, currently produces a number of implantable cardiac resynchronization therapy and defibrillator (CRT-D) devices that support remote monitoring.[76] Using a wireless data reader that connects to standard telephones, patients can securely transmit the medical data recorded by these medical devices to their health care provider. Their physicians can then review the patients' health information remotely, thereby reducing the number of office visits, a major benefit for patients with chronic diseases or who need frequent care.[77] Similarly, obstetricians can remotely monitor the blood pressure and fetal heart beat of their patients at home, rather than requiring the patients to be admitted to the hospital.[78]

The Renaissance Computing Institute in North Carolina has developed an Outpatient Health Monitoring Systems (OHMS) for patients with chronic conditions such as asthma. The OHMS uses multiple wireless sensors to monitor both a patient's condition and environmental factors that might affect that condition (such as pollution, allergens, temperature and humidity). Using an OHMS, patients can work with their doctors to more effectively manage their health before health crises arise.[79]

Remote monitoring gives patients with chronic conditions more flexibility to travel because their physicians can access their health information when the patients are away from home. In addition to convenience, home monitoring can lead to better quality care. A pilot project in Boston, for example, provided diabetes patients with a home health care monitoring system to help patients better manage their disease. The system recorded and analyzed daily health data for each patient. If any health problems were identified, such as high blood glucose levels, then the system alerted the patients and their doctors. Researchers have found that home monitoring leads to consistent improvements in clinical outcomes for patients with pulmonary conditions and cardiac diseases.[80] Such patients show a decrease in the number of emergency visits, hospitals admissions and average hospital length of stay. So far, however, researchers have not been able to conclusively quantify the magnitude and degree of the economic benefits of home telemonitoring of patients with chronic conditions.[81]

Box 5-2: National Strategies for Health IT Around the World

Health care providers around the world use IT to reduce health care costs by increasing efficiency. A survey as early as 2002 found that more than 90 percent of physicians in Finland, Sweden, Germany, the Netherlands, the United Kingdom, and the United States used a computer in their practice.[82] The same survey also found that approximately 79 percent of U.S. doctors and 61 percent of doctors in the European Union had Internet access in their practice.[83] Individual European countries such as Finland, Sweden, and the Netherlands had more than 90 percent of doctors connected to the Internet.

Many countries are implementing national e-health strategies. Canada, for example, has established Canada Health Infoway, a federally funded, independent organization with a mission to accelerate the adoption of health IT.[84] Sweden has developed a broad agenda for health IT that includes both establishing better conditions to promote health IT (e.g., a common information and technical infrastructure) and improving health IT applications (e.g., by facilitating more information sharing and making services more available to citizens).[85] Austria has made significant progress on its national e-health strategy by implementing an E-Card system, a smart card system for patient identification and payment. In addition, Austria is in the process of deploying "Elektronische Gesundheitsakte," a national decentralized EHR network.[86] Belgium has launched pilot projects such as Coplintho to study and develop IT that could improve the quality of medical care in the home.[87]

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