# Health Care and the Next Generation Internet

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The Internet phenomenon, spurred on since the early 1990s by the creation of its most successful application, the World Wide Web, has had a remarkable impact on our global society in just a few short years (1). The penetration into our homes, schools, and workplaces has arguably exceeded the rate of adoption of earlier popular consumer technologies such as television and VCRs.

The world of medicine and health care has not escaped the Internet's impact, and health-related sites are among the most frequently accessed information resources on the Web. Medical observers are rethinking the optimal methods for implementing electronic medical-record systems based on Internet technology (2), and distribution of biomedical information via the Internet is increasingly commonplace and accepted (3). This issue of the Annals includes two articles describing both the promise and problems related to the expanding uses of telecommunications in health care. Grigsby and Sanders summarize the burgeoning activities in the area of telemedicine (4), acknowledging the logistical, fiscal, and regulatory barriers that have prevented more rapid adoption of these promising methods. In the second article, researchers from Mayo Medical School describe a clever Internet application that facilitates monitoring for sporadic diseases that previously would have defied efficient or comprehensive tracking (5). We should anticipate many more such applications as our horizons are broadened and more health workers realize how networking infrastructure can support new and innovative biomedical applications.

Biomedicine is not a recent initiate to the world of the Internet. Medical-research computers (such as the NIH-funded SUMEX-AIM resource at Stanford University) were connected to the ARPAnet (the predecessor to today's Internet) as early as the 1970s. Scientists began to realize that this marvelous, federally-funded network was potentially a great boon to biomedical research and allowed collaboration with scientists around the country in ways that would previously have been unthinkable (6). Some 25 years later, despite remarkable advances and the transfer of the network to the private sector, we see our fragmented health-care system only beginning to understand and adopt the Internet as a tool for health-care delivery and information access. With proper leadership, investment, and commitment, the networking technology already available to us will provide marvelous opportunities for innovative medical uses.

But despite growing enthusiasm for the Internet, any Web user can attest to its severe limitations. Recognizing that there are significant research questions to be addressed in promoting the continued growth and utility of the Internet in the decades ahead, the Federal government has committed significant incremental FY98 research dollars to the creation of the "Next Generation Internet" (NGI) program; ongoing investments are anticipated in FY99 and beyond. (Information about the Federal program is available on the Web at <http://www.ccic.gov/ngi/>.) The Federal research programs have strong bipartisan support in the Congress and are partnering with a consortium of academic institutions that are investing heavily in improving their own campus networks while they seek government support for test-bed experiments. The consortium, initially known as Internet-2, now has well over 100 U.S. member universities. It recently created a not-for-profit corporation, the University Consortium for Advanced Internet Development (UCAID; see <http://www.ucaid.org/>), which will continue to promote experimentation and demonstrations using high-speed networking of a sort not yet generally available to the Internet community.

What will the resulting future networking infrastructure mean to the practice of medicine, to personal health practices, and to health-science education?

Imagine the day when citizens will no longer have multiple medical records scattered in the offices of various physicians and in the medical-record rooms of numerous hospitals. Instead, their records will be linked electronically over the Internet so that each person has a single "virtual health record", the distributed but unified summary of all the health care they have received in their lives. Furthermore, this record will be secure, treated with respect and confidentiality, and released to providers only with the patient's permission or under strictly defined and enforced criteria at times of medical emergency (7). The work of DeGroen and colleagues (5) presages what will someday be possible in the area of clinical investigation. They have demonstrated that current Internet technology can already facilitate the secure sharing of patient information for purposes of data pooling and analysis, thereby supporting the integration of clinical practice with clinical research. With further standardization of patient-record formats and of clinical terminology (8), linkages to the Internet will in turn support cross-institutional research coordination and multi-center trials.

But the Internet's implications extend well beyond its impact on linkages among distributed medical-records. For example, today's early telemedicine experiments, such as those summarized by Grigsby and Sanders (4), are currently dependent upon specialized equipment and expensive communications lines. As the Internet evolves and supports higher-speed communications, we can anticipate that it will become the standard vehicle for linking medical experts with other clinicians and patients at a distance. Clear, full-motion video images will be transferred, high-fidelity audio links will support listening to the heart and lungs, and common computing platforms at both ends of the link will at last help to make this kind of medical practice cost-effective. Patients will avoid unnecessary travel from rural settings to major medical centers, primary-care clinicians will have personalized expert consultation delivered to them in their offices, and patients will accomplish in single office visits what now often takes multiple visits and major inconvenience.

Before long a medical student on her orthopedics rotation, preparing to observe her first arthroscopic knee surgery, will use the Internet to access and manipulate a 3-D "virtual reality" model of the knee on a computer at another location such as the National Institutes of Health. She will use new immersive technologies to "enter" the model knee, to look from side to side in order to learn the anatomic structures and their spatial relationships, and to manipulate the model with a simulated arthroscope, giving her a surgeon's-eye view of the procedure before she experiences the real thing.

Physicians will soon be able to prescribe for their patients specially-selected video educational programs that will be delivered to home television sets by a direct Internet connection. Our hospitals and clinics will use video servers over the Internet not only to deliver such materials to patients, but also to provide continuing medical and nursing education to their staff. Health-science schools will similarly provide distance-learning experiences via the Internet for postgraduate education, refresher courses, and home study by health-science students.

Furthermore, the video link into the home will be two-way, so that physicians can move beyond the simple use of telephones for managing patient problems at a distance to using visual senses as well. The infirm will have "home visits" via video links, avoiding unnecessary office or emergency room visits, and physicians will have important new tools for monitoring patients and putting new emphasis on prevention rather than on crisis management. Early experiments

show remarkable enthusiasm by patients when familiar physicians and nurses provide such videoconferencing or Internet-based interactions for disease management in the home.

The examples I have cited here have one thing in common: they could not be effectively and reliably implemented on today's Internet. Each requires transmission speeds that are currently unavailable, but the problems are more significant than speed alone and point to the research agenda that motivates the NGI projects. We clearly need higher speeds, but many applications will fail to be effective or accepted if the *quality* of that bandwidth is also not adequate. How do certain kinds of applications obtain *guaranteed*, reliable transmission speeds, even if they are only needed for a short period of time? How can we best deal with the problems of latency, the inherent delays due to the time required for transmission of signals? A surgeon attempting telepresence surgery over the Internet, bringing specialized expertise to an operating room possibly hundreds of miles away, will be unable to assist in the procedure if the movements he makes with hand devices at his end are not instantly reflected in what is happening, and what he sees happening, with the actual instruments at the other end of the link. How do we assure that the necessary bandwidth for the applications I have proposed is available not only on the major backbone networks, but also on the last segment of wire, cable, or wireless network that comes into our homes and offices?

The research agenda for the NGI is being defined, and as was the case in the early days of the ARPAnet, it will take an effective partnership between government and academia, informed by and coordinating with the changes that are occurring in industry. We would not have an Internet today if the government had not created the ARPAnet 30 years ago (9); industry would not have made the long-term investments necessary to create the technology and gradually to demonstrate its utility and practicality. It was 1995 before the national backbone network was finally fully handed off to the commercial sector. Leaders in the telecommmunications industry acknowledge that the innovations required for the NGI will not be undertaken if the investment is left to the private sector. Only the government and academia will take the long-range view needed to move the agenda forward, but industry will provide important partnerships in the process and the mechanism for transforming prototypes and experimental models into "industrial-strength" implementations that the NGI will require.

Many observers are eager to see developed the new technical and logistical capabilities that will enable the kinds of future health applications I have outlined above. The forces that are shrinking the world in other societal arenas, such as use of the Internet in entertainment, in scientific collaboration, and in travel planning, will also allow a globalization of health care and of health-information exchange. Our country's NGI effort will in turn influence the global information infrastructure and our ability both to provide advanced health-care services to others and to benefit from the information and experiences that they will make available to us using the same technologies (10). The biomedical computing community must accordingly participate in the NGI research agenda, creating the medical applications that will help to drive the development of advanced networking technologies while the medical community helps to evaluate their capabilities. The care of our citizens, and of people throughout the world, will ultimately benefit greatly from these efforts.

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