AD___________________

Award Number: DAMD17-01-1-0696

TITLE: State of the Art Telemedicine/Telehealth

PRINCIPAL INVESTIGATOR: Rashid L. Bashshur, Ph.D.

CONTRACTING ORGANIZATION: University of Michigan
Ann Arbor, Michigan 48109-1274

REPORT DATE: December 2001

TYPE OF REPORT: Final Proceedings

PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 074-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	December 2001	Final Proceedings (1 Sep 01 - 31 Dec 01)

4. TITLE AND SUBTITLE
State of the Art Telemedicine/Telehealth

5. FUNDING NUMBERS
DAMD17-01-1-0696

6. AUTHOR(S)
Rashid L. Bashshur, Ph.D.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Michigan
Ann Arbor, Michigan 48109-1274

E-Mail:

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Report contains color.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 Words)***

14. SUBJECT TERMS
Telemedicine/Telehealth

15. NUMBER OF PAGES
115

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

NSN 7540-01-280-5500

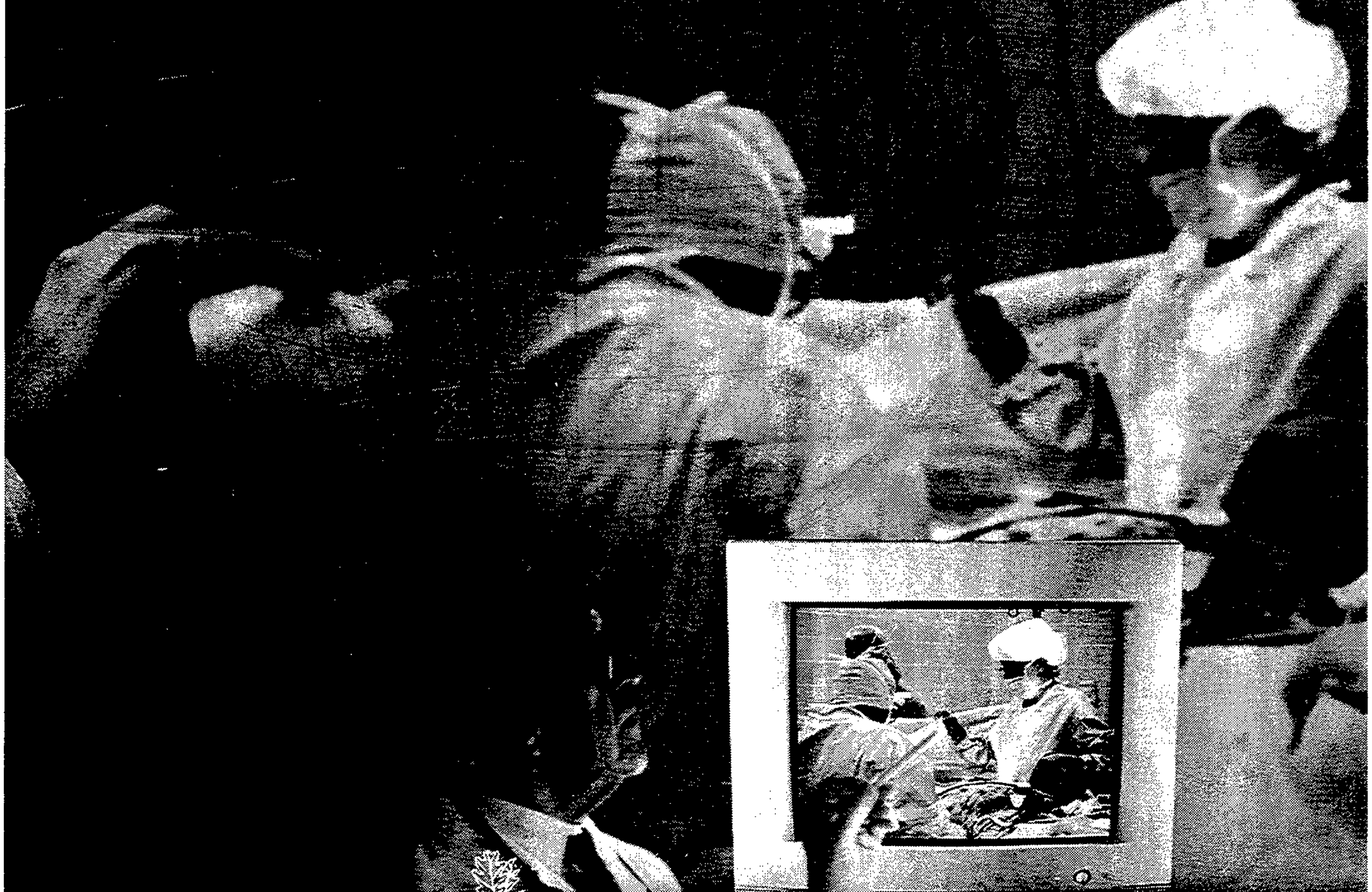
Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

STATE-OF-THE-ART

Telemedicine/Telehealth

AN INTERNATIONAL PERSPECTIVE

Editors
Rashid L. Bashshur, Ph.D.
Salah H. Mandil, Ph.D.
Gary W. Shannon, Ph.D.



Mary Ann Liebert, Inc. publishers
www.liebertpub.com

Committees

SCIENTIFIC PROGRAM

Michael Ackerman, Ph.D., *National Library of Medicine*
Norman Alessi, M.D., *University of Michigan*
Rashid L. Bashshur, Ph.D., *University of Michigan*
Adam Darkins, M.D., *Veterans Health Administration*
James Grisby, Ph.D., *University of Colorado*
Joseph Kvedar, M.D., *Harvard University*
Salah Mandil, Ph.D., *World Health Organization*
James McGee, M.D., Ph.D., *University of Oxford*
Douglas Perednia, M.D., *Association of Telehealth Services Providers*
Ronald Poropatich, M.D., *TATRC, United States Army*
Dena Puskin, Sc.D., *Office for the Advancement of Telehealth*
Tim Reardon, M.S., *ERIM/Altarum*
Jay Sanders, M.D., *Global Telemedicine Group*
Gary Shannon, Ph.D., *University of Kentucky*
Max Stachura, M.D., *Medical College of Georgia*
Ronald Weinstein, M.D., *University of Arizona*

ORGANIZING COMMITTEE

Norman Alessi, M.D.
Rashid L. Bashshur, Ph.D.
Deborah Biggs, J.D.
Amy Hooberman, M.H.S.A.
Rajesh Mangrulkar, M.D.
Michele Nypaver, M.D.
Tina Philip, M.H.S.A.
Tim Reardon, M.S.
Hasan Sapci, M.D.
Vanessa Kahl-Shultz, M.B.A.

INTERNAL COMMUNICATIONS

Deborah Biggs, J.D.
Tina Philip, M.H.S.A.

TECHNOLOGY AND EXHIBITS

Norman Alessi, M.D.
Rajesh Mangrulkar, M.D.
Michele Nypaver, M.D.
Hasan Sapci, M.D.
Gary Wautier, Ph.D.

HOSPITALITY AND LOGISTICS

Amy Hooberman, M.H.S.A.
Steve Jordan, B.B.A.
Vanessa Kahl-Shultz, M.B.A.
Michele Nypaver, M.D.
Tina Philip, M.H.S.A.
Lisa Williams

PUBLICATIONS

Rashid L. Bashshur, Ph.D.
Salah H. Mandil, Ph.D.
Gary W. Shannon, Ph.D.

STATE-OF-THE-ART

Telemedicine/Telehealth

AN INTERNATIONAL PERSPECTIVE

SYMPOSIUM REPORT

STATE-OF-THE-ART

Telemedicine/Telehealth

AN INTERNATIONAL PERSPECTIVE

Symposium Co-sponsors

University of Michigan
World Health Organization

Symposium Supporters

National Aeronautics and Space Administration
National Library of Medicine
Office for the Advancement of Telehealth
Agency for Health Care Research and Quality
RGK Foundation
Salinas Valley Memorial Healthcare System
Telemedicine and Advanced Technology Research Center
Environmental Research Institute of Michigan
Technology Opportunity Program
Internet2

Symposium co-chairs: Rashid L. Bashshur, Ph.D., and Salah H. Mandil, Ph.D.
Report editors: Rashid L. Bashshur, Ph.D., Salah H. Mandil, Ph.D.,
and Gary W. Shannon, Ph.D.

ISBN: 0-913113-97-2

Printed in the United States of America.

Introduction

State-of-the-Art Telemedicine/Telehealth: An International Perspective

RASHID L. BASHSHUR, Ph.D.,[1] SALAH H. MANDIL, Ph.D.,[2] and GARY W. SHANNON, Ph.D.[3]

THIS REPORT IS THE PRODUCT of a symposium entitled, "State-of-the-Art Telemedicine/Telehealth: An International Perspective," convened at the University of Michigan in August 2001. More than 200 participants took part in a series of formal presentations, panel discussions, and workshops/forums. (See the List of Participants on pages 109–110). Invited speakers, panel members, and other participants represented the leaders in experience and achievement in telemedicine/telehealth,[a] science, technology, and program and policy development and application. In addition to a comprehensive representation from the diverse sectors of telemedicine, speakers and participants reflected the international interest in telemedicine. Participants came from North and South America, Europe, Africa, Asia, and the Middle East. They represented telemedicine efforts underway or proposed in universities, medical centers and programs as well as in the private, public, and military sectors.

The diversity of participants is also reflected in the Symposium's cosponsors and supporters. The University of Michigan and the World Health Organization cosponsored the event. Other U.S. organizations providing support included the National Aeronautic and Space Administration (NASA), National Library of Medicine (NLM), Office for the Advancement of Telehealth (OAT), Agency for Health Care Research and Quality (AHRQ), Department of Commerce Technology Opportunity (TOP), U.S. Army Telemedicine and Advanced Technology Research Center (TATRC), RGK Foundation, Salinas Valley Memorial Health System, Internet2, and Environmental Research Institute of Michigan (now Altarum).[b]

Although from diverse interest and geographical backgrounds, participants in the symposium focused on two primary purposes:

---

[1]Director of Telemedicine, University of Michigan Health Center, Ann Arbor, Michigan.
[2]Director, HIT, World Health Organization, Geneva.
[3]University of Kentucky, Lexington, Kentucky.

[a]Acknowledging the debate over the terminology related to the use of various electronic communication modalities and the diverse health and health care-related content of the expanding field, the term "telemedicine" will be used throughout the report only in order to make the discussions more concise, and it includes telehealth. Broadly defined, "Telemedicine involves the use of modern information technology to deliver health services to remote patients and to facilitate health information exchange between providers and/or clients at some distance from each other. A telemedicine system is an integrated health care network offering comprehensive health services to a defined population through the use of telecommunications and computer technology."[1]

[b]The support of all these organizations and agencies is gratefully acknowledged. However, the findings, views, and perspectives presented in this entire report are those of the authors and editors, and not necessarily those of the sponsors.

(1) to assess the state-of-the art in telemedicine and (2) to arrive at a set of recommendations and action plans that, if enacted, set the stage for a robust and directed move forward for telemedicine at the regional, national, and international levels.

THE SYMPOSIUM

The symposium was organized into a progressive series of formal presentations, panel discussions, workshops, and a summary plenary session. Workshop participants were assigned on the basis of their respective interest and expertise, and included those who made formal presentations and participated in panel discussions on the selected topics. Reports were derived for the following topics: network organizational models, technology development and application, clinical applications, public health, disease surveillance and personal health, education, and telemedicine diffusion. It is hoped that the symposium's organization, focus, and agenda make it unique and, more importantly, make this report critical to a well-conceived advancement of telemedicine based on the best information available.

More specifically, the symposium had several related objectives. The first was to convene an international gathering based on invited position papers prepared and presented by leading experts in the field of telemedicine. A second objective involved examining and assessing the "state-of-the-art" of telemedicine. Based on these first two objectives, the third objective was to achieve a consensus on the major issues facing the development and diffusion of telemedicine. The fourth and, perhaps most critical, objective was to propose recommendations for research agendas and action plans directed toward moving telemedicine forward in the service of improving health and medical care at regional, national, and international levels.

THE REPORT

This report addresses selected critical aspects of telemedicine. It focuses on issues related to the development of integrated regional, national, and international networks; clinical applications of telemedicine as well as the application of telemedicine in public health, disease surveillance, personal health, and health education sectors; telemedicine technology; and the diffusion of telemedicine.

Accordingly, the report is organized into topical chapters, as follows.

- Chapter 1 provides a brief introduction to the evolution of telemedicine and its role in the health care system.
- Chapter 2 provides a general assessment of clinical telemedicine applications and a discussion of clinical applications in various stages of development.
- Chapter 3 examines the role of telemedicine in public health, epidemiological surveillance, and health promotion/disease prevention.
- Chapter 4 focuses on the role of telemedicine in medical education.
- Chapter 5 examines the role and development of regional, national and international telemedicine network models and reviews several alternative models.
- Chapter 6 focuses on issues pertaining to telemedicine technology.
- Chapter 7 examines issues pertaining to the diffusion of telemedicine.
- Chapter 8 concludes the report and provides a general summary and conclusions.

Each chapter concludes with a series of recommendations pertaining to research needs, related research agenda, and recommended action.

REFERENCE

1. Bashshur, R. Telemedicine and the Health Care System. In: Bashshur R, Sanders J, Shannon G, eds. Telemedicine Theory and Practice. Springfield, IL: Charles C Thomas, **1997**;9.

Address reprint requests to:
Rashid L. Bashshur, Ph.D.
Director of Telemedicine
University of Michigan Health System
C201 Medinn Building
1500 East Medical Center Drive
Ann Arbor, MI 48109-0825

E-mail: bashshur@umich.edu

Chapter 1

Telemedicine and Health Care

RASHID L. BASHSHUR, Ph.D.

THE RAPID EXPANSION of information technology and its applications in almost all aspects of modern society including commerce, industry, banking, education, entertainment, as well as health care mirrors the general expansion of the information age and the development and deployment of the so-called "information highway." It has created enormous opportunities for development in terms of improved efficiency, effectiveness, and productivity, and has provided unprecedented public and professional access to information and various sources of help dealing with a wide range of health and health-related issues. At the same time, it has produced several serious problems that must be addressed through voluntary and regulatory action. These problems include quality control, consumer protection and security, interoperability between systems, harmonization (universal standards), social equity, intellectual property rights, and investment strategies.

THE EVOLUTION OF TELEMEDICINE

The seemingly intransigent problems of increasing cost and inequitable access to quality health care, coupled with the merger of the information technology and health services sectors gave rise to the field of telemedicine. In broad terms, since its inception in the late 1960s and early 1970s, the history of telemedicine can be characterized as consisting of three major periods or eras. Each era has been closely linked to or derived from significant advances in associated information technology, telecommunications, and computers.

First was the telecommunications era, which spanned the 1970s and continued into the early 1980s. This era depended on broadcast and television technologies, which comprised complex, cumbersome, and often unreliable communication systems. In this era, with the exception of a few and very costly systems, audio and visual data were not fully integrated. The second or digital era emerged next in the late 1980s and continues. Digitization in telecommunications and computer advances mark the advent of this era. The integration of telecommunications and computer processing coupled with transmission of relatively large amounts of information on limited bandwidth has characterized this era. The Integrated Service Digital Network (ISDN) technology, which permits simultaneous transmission of voice, video, and biometrics data at relatively high speeds within a "universal" network, was the foundation. Telephone lines and sophisticated switches enabled point-to-point, point-to-multipoint, or multipoint-to-multipoint connections, the latter within designated networks.

In the continuing development of electronic communication technology, the digital era in telemedicine is now being challenged and, in many instances, succeeded by the third, or Internet era. This era uses the Internet, that complex, powerful, and ubiquitous communications "network of networks." The Internet allows open access to a global-communication environment. It constitutes a radical departure from the preceding eras in that the technology is less expensive, more ubiquitous and, therefore, more accessible to greater numbers of people. Extensive image, audio, and text information can be stored and retrieved at points of care and consultation through this technology. Internet services in health care (e-health) range from posted information about health issues and health resources, support groups and lay referral to the provision of professional services, including diagnosis, treatment, and drug prescriptions.

The inception of and interest in the Internet era of telemedicine derive, at least in part, from frustrations of telemedicine users with the inability to provide accurate and timely information at an affordable price using legacy systems.[a] However, problems with the Internet for telemedicine have already created considerable interest in the incipient era of the federally sponsored Next Generation Internet (NGI) or Internet 2 (I2) developed in the private sector. Because of its widespread distribution and popularity, access to the original Internet is often delayed or denied at peak use periods, although the predicted massive failures have not occurred. Also, limited bandwidth precludes storage and transmission of large data sets required for certain diagnostic and/or clinical applications. Other problems pertain to security, latency, synchronization, and quality of service.

The promise of NGI/I2 lies in the estimated 100/1000-fold increase in bandwidth and increased rate of information transfer. Federally and privately funded research initiatives in developing the infrastructure and test-beds for NGI/I2-based telemedicine are underway. However, even before the NGI/I2 experiments have been completed, the U.S. Department of Defense has initiated research and development of Intelligent Integration of Information (I*3) by the Defense Advanced Research Projects Agency (DARPA).

The I*3 is essentially a data management reconfiguration. Its goal is to expand data acquisition and integration capabilities, and to couple these with enhanced human-computer interaction and collaboration between analysts and decision makers. I*3 has been labeled by some as an enhanced "information food chain." While this development is taking place in the United States, public and private sectors in the European Community are cooperating in the development of Intelligent Information Interfaces (i3) directed toward moving computing power from the desktop and embedding it in everyday objects. The goal is to develop vertically and laterally "connected communities."

Ultimately, both i3 and I*3 may have large incremental impacts on the capability and distribution of electronic communication, and these developments must also be taken into account in this initiative. Regardless of improvements and innovations in technology, traditional problems of access or ubiquity, availability,[b] quality of service,[c] and security[d] remain.

THE RATIONALE FOR TELEMEDICINE

Logic dictates, and telemedicine advocates believe, that the appropriate use of telemedicine can redress the intransigent problems of constraints on access to care for large segments in the population, continuing health care cost inflation, and uneven geographic distribution of quality. Indeed, the pursuit of telemedicine is fueled by the fact that despite decades of other notable national and international efforts and programs:

- Access to health care, if anything, may have diminished for certain disadvantaged groups in many countries, including Europe and the United States.
- Cost inflation in health care has not abated.
- The gap in medical care between developed, emerging and re-emerging countries has widened in some respects.
- And, geographic variations in quality of care within and between countries have not diminished.

[a]Legacy systems are systems that use telephone lines with integrated switching devices. The legacy system does not permit alternative information packet routes and, therefore, information transfer may be interrupted and/or lost.

[b]Availability has been defined as the likelihood that a network is available for service and functioning properly.

[c]With regard to technology, Quality of Service (QoS) has been referred to as the capability of a network to provide a range of guarantees about its performance, measured in terms of sustained bandwidth, latency, and/or packet loss rates.

[d]Security refers to the capability of a network to ensure the confidentiality and integrity of information transmitted across it.

What then is the promise of telemedicine? How can we expect telemedicine to resolve these seemingly intractable and intransigent problems? What does telemedicine have to offer that was previously unavailable to enhance access, contain cost, and improve quality of health care? The basic assumptions and logic underlying the potential contribution of telemedicine in each of these are presented briefly below.

Accessibility enhancement

The potential and realized effect of telemedicine on access to care is most direct and measurable. In fact, to date the presumed increase in access to care for remote populations has been the cornerstone of telemedicine development. In all likelihood, its future is much greater in scope and application. Be that as it may, by virtue of its distributive capacity, telemedicine can obviate or reduce most travel distance, travel time, and some appointment delay to care. In theory, other things being equal, access to both specialty and primary care would be available regardless of the relative location of the patient. Thus, the need among patients to travel for specialty care, especially diagnosis, would diminish. The more remote and the farther away people live from medical care centers the more they can profit from this system.

Cost containment

Ironically, technology is a major culprit in the rising cost of care. Technological advances in testing, diagnosis, and treatment have produced significant improvements in health, not however, without increased cost. Telemedicine technology may be different. It can contain cost inflation by providing appropriate care to remote patients in their home communities. This care would be rendered at local health facilities by local health providers, but with ready access to and, when necessary, can work under the direct supervision of remote consulting specialists. This is likely to diminish the need for transporting certain patients to tertiary care centers; or, alternatively, reduce the need for specialists to travel to remote locations without compromising the quality of care patients receive. The cost of care at local facilities is likely to be less than that at tertiary care centers. Moreover, because of the ready availability of extensive information about patients in electronic form and reliance on efficient information technology, unnecessary replication of diagnostic tests, and the intensity of care or, in some cases, "over treatment" can be reduced. At the same time, efficiency and coordination of care may be enhanced.

Quality improvement

Views regarding the anticipated effects of telemedicine on quality of care are not as direct as those of access and cost containment. Nonetheless, the basic premise is that telemedicine would promote coordination and continuity of care by virtue of the ready availability of comprehensive information on the patient regardless of site of care. Additionally, telemedicine accords remote providers unique opportunities for targeted and highly effective continuing medical education, diminished isolation, and ongoing interactions with specialist colleagues from tertiary care centers. Finally, the technology can serve as a highly effective tool for clinical decision support for all providers, thereby reducing "medical errors."

While there are no reliable estimates for total U.S. investment in telemedicine, the American Telemedicine Association estimated federal (both military and civilian) expenditures on telemedicine in 1999 at about $240 million. This estimate does not include Medicare expenditures on teleradiology or patient monitoring. The total federal expenditures in the United States over the past 5 years could well have exceeded $1 billion. It is appropriate, therefore, to make a critical assessment of the status of this field and where it is going. A valid assessment of this field is neither simple nor straightforward, however. One problem is that we have yet to reach authoritative consensus on a clear and precise definition of telemedicine content and boundaries, that is, what it is and what it is not. And, although ultimately telemedicine may be fully integrated into the mainstream health care system, we have not resolved the interim question of whether telemedicine constitutes a new system of care or whether it is simpy an electronic adjunct to clinical practice and the dissemination of health information. Additionally, we are faced with continual and often dramatic changes in information technology that significantly alter the production process of health and health care. In turn, these changes alter the assessment matrix and the ultimate cost-benefit ratios of telemedicine.

This reality and potential, coupled with the continuing expansion of e-communication and its direct linkage to the development and expansion of telemedicine, require that, periodically, it is prudent and necessary to "step back" and take stock of telemedicine developments, problems, and prospects. Furthermore, it is necessary to make appropriate and timely recommendations based on these observations, and to develop appropriate research and actions agendas to support the future development and deployment of telemedicine.

Such assessments must include and integrate developments in each of the inclusive telemedicine sectors. While specific and individual sector reviews and critiques are useful, these efforts should be presented in a forum with participants from all major sectors. In this manner, the developments, problems and prospects from one sector are compared and contrasted to those in other sectors. What emerge, therefore, are common perspectives and integrated analytic schemes to help future development.

A VIEW TO THE FUTURE

Optimism about the future of telemedicine must be tempered with concern. It is important, for example, to note that this is not the first generation of telemedicine. As discussed earlier, the first generation appeared in the late 1960s and early 1970s—and lasted less than a decade. The reasons for the demise are numerous and include the following:

- Cumbersome, unreliable, and expensive technology.
- Short-term funding for research and development.
- Unrealistic expectations for short-term performance and evidence.
- Perhaps not surprisingly, lack of recognition and limited acceptance by mainstream medicine.

In many respects, the current situation of the second generation of telemedicine is substantially different from the first. Today, every state in the United States and almost every country in the world has some telemedicine activity and experience. The technology has taken giant strides in increasing functionality and restraining cost. Indeed, the current and rapidly expanding telemedicine and telematics technology was only a futuristic dream during the first generation of telemedicine.

Accelerated developments in bioinformatics, miniaturization, and computer chip design promise major advances in the prevention, diagnosis, and treatment of disease and the promotion of health and well-being. In addition, on the horizon are continued developments in genomics, miniaturization, artificial intelligence, and chip design. Some may question whether this is telemedicine, telehealth, e-health, health informatics, or biohealth informatics. It does not really matter what we call it or where we draw boundaries. The ultimate quest is to cure disease, prevent it if possible, reduce infirmity, and enhance the quality of life. Collective and collaborative efforts from various fields of science and technology, including what we now call telemedicine, are necessary.

While much is different today, there are some disturbing similarities with the past. Despite the widespread proliferation of telemedicine projects and programs, few would claim that the promise of telemedicine has been fully realized or that the research to date has confirmed claims made by advocates and supporters. This second generation of telemedicine faces some of the same uncertainties faced by the first generation:

- Many projects have been funded for the short term, and are based on incomplete or nonexistent plans for long-term sustainability.
- The lack of mature telemedicine programs prevents adequate and definitive cost-benefit analysis, particularly in terms of health outcomes, patient-borne costs, and total costs.
- With certain exceptions, such as teleradiol-

ogy and telepathology, and except for curiosity and lip service, health providers and health administrators have not embraced telemedicine enthusiastically. Few think of it as a possible integral component of the health care delivery system.

- The success and progress of telemedicine are being met, in the United States at least, by state-based protectionism, and inconsistent federal policies and financing regulations. Internationally, major challenges have yet to be overcome, including legal, ethical, economic, cultural and logistical issues.

At the same time, the technology has developed a life of its own that continues at an accelerated pace, the current setbacks in "dot-com" businesses notwithstanding. In fact, the current decline in "dot-com" business will result in an appropriate sorting and sifting, and a reality check. Market forces have created winners and losers. Perhaps, this is as it should be.

Information technology has permeated every aspect and every sector of society, including health care. The only questions we should raise about the future is how to position our health care institutions, ourselves, and our patients to maximize the benefits and minimize the drawbacks of this powerful tool.

Summing up, the second generation of telemedicine has made great strides in terms of technology, geography, and interest when compared to the first generation. There seems little doubt that the interest and the advancing technology have assured its future in some form or another. However, with an informed public policy and private action, we have the opportunity to derive more benefits, assure a more prudent investment, and improve health and well-being of people everywhere.

One of the unique and significant attributes of telemedicine technology is its integrative capacity for establishing networks and building partnerships. More benefits and more dividends can be achieved: (1) by establishing integrative telemedicine systems that incorporate all diagnostic and clinical services within health care institutions; (2) by encouraging states, provinces, and countries to develop comprehensive and ubiquitous networks within their boundaries; and, (3) by sharing health care resources among the countries of the world.

To think of telemedicine only in terms of serving remote or otherwise medically disenfranchised populations may be shortsighted, counterproductive, and basically incorrect. To do so has the potential to not only relegate telemedicine to a second tier or level of medical care, but it would also ignore its capabilities for greater system integration and coordination and more efficient production of health for all.

HEALTH AND HEALTH CARE CONTEXT

It is important to place the promise, goals, challenges, and progress of telemedicine within the context proposed health objectives for local, national, and international communities. Telemedicine has been proposed as a modality for delivering health when provider and client, or provider and provider, cannot meet face-to-face because of geography, convenience, or practicality. Hence, the appropriate starting point for understanding the role of telemedicine in health care is to describe the broader context of health care systems and their objectives.

Consistent with the mission of the World Health Organization (WHO), the World Health Assembly has repeatedly addressed global strategies for optimizing health conditions worldwide. For example, in 1977 at Alma Ata, the Assembly developed a consensual proclamation on global health, which was endosed by 192 member countries. It affirmed that the major social goal of governments and the World Health Organization should be attainment of a particular "level of health" by all people of the world by the year 2000. The intended level of health would permit each person to lead a socially and economically productive life. The definition of health implied by this statement was much more realistic than that adopted in the 1948 WHO Constitution as "A state of complete physical, social and mental well-being, and not merely the absence of disease or infirmity." Still, the lofty goal of achieving even this modest level of health among people of the world by 2000 was not practicable.

In 1981, the Assembly adopted a more reasonable and concrete plan under the title, "Global Strategy for Health for All by the Year 2000." In this new strategy, "health for all" did not imply an end to disease and disability nor that doctors and nurses would care for all citizens in all countries. Rather, the statement focused on equity of access to essential health care services as a desideratum in national health policy. The underlying premise and promise of "health for all" was that available health resources should be equitably distributed and that no one would be denied access to essential health care. In 1994, the Assembly again focused on the issue of equity of access to health services. Indeed, equity of access to health services emerged as the dominant ethical concern of WHO member states and administrators.

The importance of access derives from the uneven distribution of need for health care in every society and in every community. Typically, those in greatest need tend to have the least resources. At the international level, this problem is further aggravated by the persistent disparities between nations in terms of economic, geographic, cultural, and technical capabilities; uneven distribution of resources in relation to need; poor management: and, inefficient use of existing resources.

Echoing similar concerns for the U.S. population, the Office of Disease Prevention and Health Promotion of the U.S. Department of Health and Human Services published *Healthy People 2010*,[1] in November 2000. This publication builds on and expands similar initiatives of the previous two decades.[e] *Healthy People 2000*[2] presented a set of health objectives and targets to be achieved throughout the nation over the first decade of the new century.[e] The national health objectives were established through a "broad consultative process, built on the best scientific knowledge and designed to measure programs over time" (see *www.health.gov/healthypeople*). The detailed objectives can be essentially grouped into two sets:

- Those aimed at increasing quality and years of healthy life for individuals of all ages, and
- Those aimed at eliminating health disparities among different segments of the population.[f]

To achieve these general goals, the report lists 28 action areas, each containing concise goal statements and specific objectives. These areas range from "Access to Quality Health Services" (including preventive care, primary care, emergency services, long-term care and rehabilitative services), through "Mental Health and Mental Disorders" (including mental health status improvement, treatment expansion, and state activities) to "Vision and Hearing."

For two decades, various editions of *Healthy People* have served as strategic planning tools for the federal and state governments as well as other private and public partners. The single overarching purpose is to promote health, prevent disease, and provide care for the sick and disabled as well as to ameliorate pain and suffering and to provide palliative care for the dying. Such a health care system necessarily includes the entire range of health-related activities aimed at these objectives.

It is important to recognize, however, that health systems are unique to each society and culture—even within countries. In each instance, the system reflects: (1) a combination of cultural values and practices, (2) the extent to which science and technology are incorporated into the practice of medicine, (3) the level of health sophistication, (4) relative affluence, and (5) each society's investment in health and health care. Indeed, the health system of each country or region is the unique blend of public and private, organized and unorganized, and formal and informal services directed toward the production of health.

THE ROLE OF TELEMEDICINE

Telemedicine has developed concurrently with, but until the last decade, largely separate from the development of global, national, state,

[e]Preceded by Healthy People, 1979, Surgeon General's Report; Promoting Health/Preventing Disease: objectives for the Nation (1980); The 1990 Health Objectives for the Nation: A Midcourse Review. Health of the Nation: Highlights of the Healthy People 2000 Goals—1995 Report to Congress.

[f]*Healthy People 2000* included a third objective, namely, "Achieve Access to Preventive Health Services for All." Prevention and Health Promotion, April 1999.

and local health objectives such as those described above. Nevertheless, the impetus for telemedicine development correlates with issues and obstacles facing health objectives in the larger context, namely inequity of access, uneven quality and cost inflation on the one hand, and increased use and continuing development of information technology, miniaturization, and telemetry, on the other hand.

It is not surprising that today we are witnessing the confluence of telemedicine and the many functions of health care systems. The range of specific functions that telemedicine or interactive health communication (IHC) can provide, as identified by Eng and Gustafson,[3] includes the following:

- Information transfer—on demand provision of individualized health information.
- Informed decision making—to facilitate health decision making process of individuals or to facilitate communications between health care providers and individuals.
- Health behaviors—to promote adoption of and maintenance of positive health behaviors by individuals and communities.
- Peer information and emotional support—through providing wellness information and explaining associated benefits and costs.
- Self-help and self-care—to help users manage health problems without direct intervention from a health care professional or to supplement existing health services by facilitating remote health monitoring and information.
- Demand for health services—to enhance the use of effective health care services and reduce the use of unnecessary services.

Therefore, in the context of regional, national, and international health goals, telemedicine can play a critical role in achieving both short- and long-term objectives. The trend to contain and reduce health care costs will be supported by systems that promote self-help, manage demand for care, and replace or supplement face-to-face interactions with electronically mediated ones. In geographically and functionally fragmented health care systems, telemedicine can help integrate care delivery by enhancing provider communication and centralizing information sources. As health care systems continue with attempts to contain costs, some components of care delivery may be reassigned from relatively expensive professionals, such as physicians, to less costly providers, such as nurses and other health professionals. In addition, information technology will let more patients receive care in their local health care facilities rather than in most costly and often distant medical centers, while geographically remote specialists supervise care in local facilities electronically.

At another level, with improvements in the technical capacity of health departments, information technology, and interactive health communication can become a central strategy for community health education, community outreach services, and social marketing for positive health behaviors.

CONCLUSION

This discussion has focused on the development of telemedicine vis-à-vis global, national, regional, and local goals for improving the "health for all." In this context, telemedicine can facilitate and enhance the progress toward these goals by improving access to health services and health-related information, improving the quality of health care, and containing the rising costs of health care. It can also contribute to increased awareness of health problems, preventive health behaviors, public and community health education, and improved self-care.

Central to telemedicine's potential for contributing to current and future efforts to achieve many of the health objectives discussed above, however, is its performance in the clinical setting. Clinical telemedicine applications can be found in practically all clinical specialties and subspecialties. Regardless of specialty, telemedicine, advanced telemetry, and telecommunications technology have the potential to reconfigure the medical care landscape, making high-quality specialty care accessible regardless of provider and patient location. Telemedicine can, thus, succeed in electronically redistributing and providing a more equitable distribution system of clinical services than is possible with the conventional modality of medical care delivery. Telecommunications and information technology can also reduce the risk of clinical "error" by providing improved, expanded, and readily accessible patient information. Finally, telemedicine can give remote providers access to the lastest medical information in the literature or consultative sources.

Thus, as a new modality of medical care and health care delivery, telemedicine is optimally situated to make major contributions to the universal health care goals and objectives. As such, it represents an efficient instrumentality for achieving health care goals nationally and internationally. And yet, after more than a decade of active research and development activity in telemedicine, we have not yet adequately summarized, critiqued, and presented in a systematic and cogent fashion what has been learned from research, development and evaluation. Once again, the purpose of this symposium (and this report) is to consolidate the knowledge gained to date; to frame the issues to be addressed and the methodologies to be used; and to chart the future direction for policy development, both nationally and internationally. It is only upon this firm foundation that telemedicine can fulfill its considerable promise efficiently and effectively.

REFERENCES

1. *Healthy People 2010.* Office of Disease Prevention and Health Promotion, U.S. Dept. of Health and Human Services, November 2000.
2. *Healthy People 2000.* Office of Disease Prevention and Health Promotion, U.S. Dept. of Health and Human Services, 1991.
3. Wired for health and well-being: The emergence of interactive health communication and health. Eng T, Gustafson D, eds. Science Panel on Interactive Communication and Health. Office of Disease Prevention and Health Promotion, April 1999.

Address reprint requests to:
Rashid L. Bashshur, Ph.D.
Director of Telemedicine
University of Michigan Health System
C201 Medinn Building
1500 East Medical Center Drive
Ann Arbor, MI 48109-0825

E-mail: bashshur@umich.edu

Chapter 2

Clinical Applications in Telemedicine/Telehealth

Contributors:

Elizabeth Krupinski, Ph.D., University of Arizona
Michelle Nypaver, M.D., University of Michigan
Ronald Poropatich, M.D., TATRC, USAMRMC, Fort Detrick
and
David Ellis, M.D., University of Buffalo
Rihab Safwat, M.D., Gezira University, OAE
Hasan Sapci, M.D., University of Michigan

THIS CHAPTER: (1) summarizes the state of the art in selected clinical applications of telemedicine; (2) identifies basic issues pertinent to expanding clinical applications; and, (3) presents a research agenda and related action plans to promote the integration telemedicine into mainstream clinical care. For the purpose of this report, clinical telemedicine is defined as the exchange of health information pertaining to a patient, via telecommunications technology and computers, between geographically separated providers or providers and patients, for the purpose of evaluation, diagnosis, treatment or education.

THE STATE OF THE ART IN CLINICAL APPLICATIONS

Clinical telemedicine applications reflect the spectrum of clinical specialties and subspecialties found in conventional clinical medicine. That is, telemedicine has been applied in practically all areas of clinical medicine as well as medical education. Hence, clinical telemedicine is represented in the vast majority of medical specialties, although the stages of development and maturity vary substantially by specialty.

Detailed treatment and discussion of each and every type of clinical telemedicine specialty is neither feasible nor necessary here. The following synthesis of the literature is based on a selection of applications (Table 1). While not totally inclusive, the vast majority of literature on clinical telemedicine derives from this group of applications. Therefore, the assessments, conclusions, and subsequent recommendations presented here may be considered applicable to the entire field of clinical telemedicine. The discussion of clinical telemedicine applications is based on a matrix made up of two parameters. The vertical axis represents the level of maturity of the application. Maturity is defined on the basis of several factors, including the quantity and quality of research pertaining to the application, the degree to which the application has been accepted by the profession, and the development of standards and protocols for the application. Subsequently, each clinical application, classified by level of maturity, was reviewed in terms of several performance attributes, as evidenced by data availability in published literature. Therefore, the horizontal axis of the matrix reflects performance attributes common to each clinical application. These attributes include technical feasibility; diagnostic accuracy, sensitivity, specificity, clinical outcome, and cost effectiveness.

Teleradiology and telepathology rank high on the maturity scale when evaluated on the

TABLE 1. SELECTED CLINICAL APPLICATIONS OF TELEMEDICINE BY LEVEL OF MATURITY

Radiology Pathology	MATURE
Psychiatry Dermatology Cardiology Ophthalmology	MATURING
Surgery Pediatrics Emergency medicine Rare Diseases	EMERGING

basis of the attributes listed above. In contrast, telemedicine has only recently been applied and minimally evaluated in emergency medicine, pediatrics, and rare diseases. These characteristics place them in the "emerging" category of clinical telemedicine.

The ultimate merit of these applications has to be determined on the basis of their performance and positive impact in three basic areas: quality, cost, and access, as discussed in Chapter 1. The prevailing presumption in assessing clinical telemedicine is that the clinical applications of telemedicine will manifest results at least equal to, if not better than, those obtained in the traditional forms of clinical practice.

MATURE APPLICATIONS: TELERADIOLOGY AND TELEPATHOLOGY

Teleradiology and telepathology represent the most mature and well-established clinical specialties within telemedicine.[1–5] There are several reasons for this. Specifically, in each specialty there is considerable continuity or similarity between them and traditional or conventional practice modalities. For example, both radiologists and pathologists rely heavily on imaging, rather than direct patient contact, to make a diagnosis or identify abnormalities. Perhaps because of this, for the most part, both diagnostic services are reimbursable under government rules. Also, the wide acceptance and recognition of the benefits of teleradiology and telepathology have led to explicit standards for quality assurance that protect both the patient and the provider. Finally, there is a wealth of scientific evidence in a large volume of research on image display and image interpretation available before and after the deployment of telemedicine. Taken together, these conditions facilitated the transition to and acceptance of teleradiology and telepathology.

Typically, in the traditional clinical setting, the radiologist and pathologist do not work directly with patients. Hence, viewing patient images for diagnostic purposes via telemedicine is not substantially different, in many respects, from the traditional mode. The fact that both radiology and pathology rely heavily on the interpretation of images may be the most significant factor that has placed them at the forefront in telemedicine deployment. There is an image to be interpreted. How the image gets to the radiologist or the pathologist, and how it is presented, are certainly different in telemedicine. But, the essential task—the diagnostic interpretation of image data—is the same.

For radiology in particular, the early development of methods for distributing clinical images within a hospital or clinic setting set the stage for teleradiology and the distribution of radiographs across longer distances. Indeed, a number of issues, such as image display and resolution and gray-scale, which are related to the electronic distribution of large image data sets, had been resolved in radiology and pathology prior to the development of telemedicine. Ongoing research in these specialties in computer-aided detection and diagnosis, digital compression, and the display, storage, and transfer of digitized images also contributed substantially to the smooth and early transition to telemedicine. Digitization and the acquisition of digitized images constitute the initial step in the electronic transmission of images from one site to another. The subsequent step of image presentation, once they have reached their destination, has also been studied extensively.

Given the relatively advanced development and deployment of teleradiology and telepathology, several issues associated with network technology are no longer the focus of major research efforts in these fields. Beyond the technological requirements for image acquisition, transmission, display, and storage, other advances in these two fields apply to other clinical applications of telemedicine generally. Of particular note are clinical standards and protocols. While practitioners and administrators in other clinical telemedicine fields have attempted to establish clinical standards, as yet, there are no agreed upon, scientifically tested standards to support real-time video and audio services.

Neither are there explicit guidelines for seamless integration, communication, and interoperability for integrating different vendor-based systems.[6] Here too, teleradiology has been the leading clinical application in developing the Digital Imaging and Communications in Medicine (DICOM) standards.[7] The DICOM standards were developed jointly by the American College of Radiology (ACR) and the National Electrical Manufacturers Association (NEMA). These standards facilitate the integration of hardware and software from various vendors for the transmission of clinically acceptable data, for data security, and for image display. The ACR[8] has also developed specific display and compression standards and guidelines for teleradiology. Interestingly, telepathology benefited greatly from adoption of a version of the DICOM standards because many of the hardware and software requirements were comparable.[9] (Information about the ACR-NEMA DICOM standards is available at medical.nema.org/.)

Image acquisition is quite advanced in these two applications. In radiology, for example, most procedures, including mammography, are provided in digital form. Images can be transmitted directly to a viewing workstation within the same institution or at a remote location. When only film is available, high-quality digitizers are available. In telepathology, the raw data are biologic specimens, often not rendered in digital form. Thus, large-area, high-resolution charge-couple device color cameras are used routinely to digitize specimen images for both static and dynamic telepathology transmissions.[10–13]

Of course, real-time interaction and audio capabilities related to image acquisition, transmission, and display are fundamental to teleradiology and telepathology. For example, telepathology[10–12] uses robotic systems and real-time transmissions to circumvent errors in field selection and depth of focus and to improve diagnostic accuracy. Fluoroscopy[14] and ultrasound[15] in teleradiology also require real-time capabilities. Synchronous transmission of video and audio signals are especially crucial in Doppler ultrasound applications and echocardiography. New developments in these areas should focus on ways to make these systems faster and user-friendlier.

Teleradiology and telepathology have also made substantial progress in data display. In both fields, image review proceeded from the traditional modality (film or light microscope) to digital display. For the most part, teleradiology requires high-luminance monochrome display rather than color to maximize the dynamic range and contrast resolution for identifying small, low-contrast objects. High-resolution displays are needed because of the inherently large size of radiographic images. With the advent of digital mammography that acquires images up to 5000×6000 pixels in size, the spatial resolution requirements of the monitor are also much greater than in most other applications.[16,17] Recent advances in three-dimensional display are quite promising for teleradiology and telepathology, but performance standards have not been developed for these new approaches.[18,19]

The requirements for telepathology display more closely match those for display in most other clinical applications than do those for teleradiology. For example, color performance and fidelity are very important parameters,[20] and they are crucial in certain clinical areas such as teledermatology. Good initial calibration followed by periodic assessments assures color fidelity on digital displays.[21,22] Again, the DICOM standards in radiology[7] incorporate calibrating monitors based on principles of perceptual linearization. Research studies have demonstrated this calibration scheme to improve diagnostic performance.[23]

The diagnostic efficacy of teleradiology and telepathology is well documented. However, static-image telepathology in certain instances may not deliver the required level of diagnostic accuracy to be acceptable in routine clinical practice.[15,24–27] It may be difficult for the remote provider/sender to choose the precise set of static images out of all possible images (e.g., slides and magnifications) to send to the consulting pathologist. Using dynamic-robotic systems, pathologists achieved substantially higher levels of diagnostic accuracy when they were able to control image fields and depths.[11,28,29] In one study, for example,[29] no statistically significant differences were observed between conventional light microscopy and video microscopy in discriminating benign from malignant breast lesions. Another study[11] evaluated the relative diagnostic accuracy and confidence levels using a dynamic-robotic telepathology system and traditional light microscopy. Diagnostic concordance between the two modalities was higher than 98%. Moreover, the misdiagnosed cases in telepathology were also misdiagnosed using conventional light microscopy. Hence, general errors of interpretation could not be attributed to telepathology. A follow-up study[28] reported concordance rates between light microscopy and telepathology interpretations that approached 100%. Another study reported high diagnostic accuracy using dynamic-robotic telepathology equivalent to conventional light microscopy.[30] Moreover, with increased experience, time required for image interpretation in telemedicine decreased to levels comparable to those in the conventional mode.

Several studies have demonstrated comparable diagnostic accuracy between teleradiology and conventional radiology.[31–33] In at least one instance, Full-Field Direct Digital Mammography, actual improvement of results using teleradiology was noted as it simultaneously expanded the diagnostic capabilities in mammography. Formerly, these capabilities had been restricted because of the very high spatial and contrast resolution requirements.[34–36]

A recent series of studies assessed the accuracy of teleradiology consultations.[36–40] Lee et al.[38] compared the diagnoses of 956 urologic radiology examinations on film versus remote computer-based viewing. Diagnostic decisions were the same in 97% of the cases. Radiologists trained in teleradiology, however, performed better than untrained radiologists, demonstrating the significance of training. Eng et al.[39] investigated the relative performance of teleradiology and conventional radiology in resident coverage of emergency cases in terms of the comparative accuracy of radiograph interpretation. Their findings suggested that teleradiology coverage by faculty radiologists and radiology residents would improve radiograph interpretation, compared to that provided by emergency medicine faculty alone. Another study demonstrated that teleradiology consultations by subspecialty radiologists significantly improved the quality of the radiology reports.[40] In some cases it improved patient care by eliminating unnecessary procedures or by suggesting more specific follow-up examinations. Subspecialty teleradiologists provided more accurate diagnoses in 21% of the cases.

A study in Finland investigated whether teleradiology consultations would reduce unnecessary patient transportation and thereby save on opportunity and treatment costs.[41] Of the patients examined via teleradiology, 81% avoided unnecessary transportation, and 75% of those transported to a central hospital were operated on immediately on arrival without further radiological study.

MATURING APPLICATIONS: TELEPSYCHIATRY, TELEDERMATOLOGY, TELECARDIOLOGY, AND TELEOPHTHALMOLOGY

"Maturing" clinical applications include telepsychiatry, teledermatology, telecardiology, and teleophthalmology. There has been substantial research and development work in these specialties. Research evidence to date, however, is not reflected proportionately in the acceptance and diffusion of the technology in these applications. In part, these applications have not achieved more professional and institutional acceptance because national and international standards for technology and clinical protocols have not been developed, tested, and disseminated.

Telepsychiatry

Pioneering experiments in psychiatric teleconsultation in Boston, Massachusetts, and Omaha, Nebraska, were among the earliest demonstrations of the feasibility and clinical efficacy of telepsychiatry.[42,43] Today, telepsychiatry is one of the most frequently used clinical applications of telemedicine, and it is estimated that more than 12,000 telepsychiatric consults are conducted annually in the United States.[44] Moreover, research in this field has consistently demonstrated a high degree of concordance in clinical assessment between telepsychiatric and traditional in-person consults. For instance, a retrospective case control study using Global Assessment of Functioning scoring found no significant differences between the evaluation of patients in this mode versus in-person evaluation.[42] Another study investigated well-being and quality of life, as measured by the Mental Health Inventory and Health of the Nation Outcome Scale; it found no significant differences in outcomes between the two modes of consultation.[46] In the same study, telepsychiatric consultation costs were less than those associated with conventional psychiatric care, regardless of whether these consultations were done by private or public mental health care teams.

Telepsychiatry has been tested in both asynchronous and synchronous modes.[46–49] Although clinically feasible, the asynchronous mode and low bandwidth (128 kbps) transmission tend to limit interpersonal interactions, as would be expected. For rather obvious reasons, real-time or synchronous interactions and higher bandwidth (384 kbps) are preferable[45–47] because this is a discipline that relies heavily on interpersonal interactions between patient and therapist and where symptoms include emotional and behavioral manifestations.

Similar to other clinical applications, cost analyses in telepsychiatry suggest that positive returns on investment are achieved, but only after the capital investments in equipment are recovered through the initial stages of use. However, because the cost of videoconferencing equipment continues to decline, it is difficult to determine the exact costs that will be incurred in these systems. In reality, there can be no accurate answer to the question of the return on investment because a significant portion of the cost continues to be a moving target. Moreover, recurring costs for transmission, maintenance, and personnel are recoverable from recurring revenue, which depends volume.[46,47]

Research on the acceptance of and satisfaction with telepsychiatry suggests that both patients and providers are satisfied with this modality of care. There is evidence that familiarity breeds comfort, as acceptance is positively associated with frequency of use. That is, there seems to be a learning curve for both providers and patients resulting in increased acceptance with prolonged and frequent use.[45–53]

Teledermatology

Teledermatology has to be a considered a reasonably mature application by virtue of the quantity and quality of the published literature on the topic. The development of teledermatology has been aided by the heavy reliance of this specialty on viewing skin images, which can be transmitted electronically. For the most part, good-quality pictures can provide realistic renditions of skin conditions for diagnostic purposes, especially when viewed by skilled dermatologists.

Substantial information is available about technical specifications, clinical effectiveness, and cost analysis of teledermatology.[54–62] Numerous scientific studies have demonstrated relatively consistent (67–88%) diagnostic concordance between conventional (in-person) dermatology and in both synchronous (real-time) and asynchronous (store-and-forward) teledermatology.[54–63] Several randomized clinical trials in the United Kingdom focused on clinical effectiveness and relative cost of teledermatology in comparison with in-person care.[54,56–58] The findings from these studies were generally positive for clinical effectiveness. In one study, however, the cost-benefit ratio of teledermatology was less favorable than conventional dermatology because of the high cost of equipment and longer general practitioner time. Yet, if the same equipment were purchased at current rather than previous market prices and the distances that patients traveled were greater, teledermatology would be a cost-effective alternative to conventional care.[54] That is to say, cost effectiveness was sensitive to price of equipment and patient travel distance. A teledermatology program in Norway proved less costly than any of three conventional care alternatives: (1) visiting service plus patient travel to dermatologist; (2) individual patient travel to a hospital; or (3) patient to dermatologist visit, assuming a minimum annual volume of patient visits.[60]

Another study reported low rates of misdiagnosis (5%) and of suboptimal management plans (8%). The differences between these rates and those of conventional dermatology were not statistically significant.[54,58] Moreover, asynchronous teledermatology produced fewer definitive findings than either synchronous or conventional modes. Sixty-nine percent of patients in the asynchronous consultation group were referred for subsequent conventional dermatological evaluation, compared to 46% of patients in synchronous and 45% in conventional treatment groups.[54] Barnard et al.[55] reported comparable rates of referral for biopsies between patients evaluated by asynchronous versus conventional modes.

Teledermatology research is moving forward by identifying those factors needed to sustain clinical applications. These include external, or situational, factors, such as minimum thresholds of patient volume, aggregate patient travel distances, and patient opportunity costs. Internal, or clinical, factors include concordance rates, misdiagnosis, and inappropriate treatment.

The majority of providers who tried teledermatology reported being satisfied with this mode of practice. For instance, in two separate studies, 75% of the consultations were judged by dermatologists to be "satisfactory."[63] The same studies also reported several limitations in teledermatology; among them the inability to palpate lesions; the potential for violating patient privacy or confidentiality of the patient history; and some hesitancy on the part of some patients to have lesions in their genital areas photographed. A few providers complained about the time required for capturing images during live consultations. Finally, some found that papulo-squamous lesions were particularly difficult to assess as was evaluating dark-skinned individuals.

Telecardiology

Telecardiology has at least two attributes that make it especially appropriate for telemedicine, namely the critical importance of the time interval between the onset of symptoms and the initiation of treatment and the overall high incidence of morbidity and mortality of heart disease. Indeed, heart disease is the leading cause of mortality in the United States, hence the importance of telecardiology for the remote diagnosis, prompt treatment, and appropriate management of heart disease. In many instances, the time delay from onset of certain symptoms to treatment is critical to survival.

Research in telecardiology has evolved from early studies of the feasibility of electronic cardiac auscultation and the reliability of the electronic stethoscope to remote interpretation of real time diagnostic imaging. A substantial international body of literature pertaining to the transmission of echocardiograms, cineaortography (angiograms), remote blood pressure monitoring, and electrocardiography is available.[64–77] Today successful transmission of echocardiogram images is feasible in both real time and asynchronous modes.[64,66,68–70] Real-time data exchange is preferable to assure accurate image capture and to provide immediate clinical decision support.[64,68] This operational aspect has obvious ramifications for scheduling, work flow, and bandwidth availability at the sending and receiving sites. The minimal transmission speed is 128 kbps, using T1 lines and integrated service digital network (ISDN). The use of 384 kbps is becoming more common and exploration of Internet transmission is underway.[75]

With regard to diagnostic accuracy, one study noted a 6.5% rate of misdiagnosis, including three small ventricular septal defects and one pulmonary stenosis.[67] Patient transfer was avoided in 75% of patients, which resulted in net overall savings. In another study, a smaller rate of misdiagnosis (only 2%) was reported. Improved quality of care derived from more timely diagnosis of congenital heart disease, prompt transfer of patients needing surgical interventions, and more appropriate utilization of services.[61,63–67] These studies do not address the question of misdiagnosis rates relative to conventional or in-person care. However, the misdiagnoses in these studies were not clinically significant because they had no effect on clinical outcome.[64,67]

A study of diagnostic accuracy of remote cineaortography (angiograms) that used satellite technology (13 MB/s) reported an enhancement of image display capabilities, which resulted in a more effective analysis of blood flow and pinpointing lesions, as compared with the conventional mode.[65] Experiments in transmitting cineaortogram images via high bandwidth are currently under way in the Next Generation Internet (NGI).[76] This research is expected to expand the technical capabilities of telecardiology consultative services to remote patients on secure routes, while containing cost.

Several advances in commercially available home monitoring devices for blood pressure and electrocardiogram transmission have been reported.[73,77,78] Research in this area has been prompted by potential improvements in hypertension control and reductions in morbidity and mortality from cardiovascular disease. A randomized clinical trial compared conventional clinic-based hypertension care to a computerized home-based system where blood pressure measurements were transmitted to providers at regular intervals, and also made available to patients themselves.[73] Blood pressure (systolic, diastolic, and mean arterial pressures) decreased in patients who used the home service, compared with those who were cared for by conventional means. A reduction in mean arterial blood pressure of almost 10 mm Hg was achieved among African American patients using the home system, versus an increase of 5.25 mm Hg in similar patients using conventional care. Two other randomized clinical trials using remote blood pressure monitoring devices corroborate these findings in the general population without regard to race/ethnicity.[77,78] In addition, these findings demonstrate the benefits in disease management that may derive from the use of tele-home care services.

Twelve-lead electrocardiograms (ECGs) and pacemaker monitoring are also available as individual home monitoring devices or as ongoing monitoring services linked with health providers.[67,79,80] There are several other examples (one provider offers 24 hour per day, 7 days per week, real-time remote interpretation of ECGs by cardiologists).[79] The ECGs can be transmitted via satellite or via cellular or terrestrial telephones available commercially. Another monitoring system that broadcasts ECG signals over the Internet was developed in Singapore.[81] ECG monitoring instruments (3-lead versus 12-lead) that transfer data over wireless means have now been developed.[74] Wireless devices typically tend to enhance patient compliance without compromising data collection.

The U.S. Veterans Health Administration (VHA) has been using telemedicine extensively for a number of years, including a system for remote surveillance of pacemakers (at a rate of more than 30,000 observations per year).[82]

In a study of telemonitoring pediatric patients, Vincent et al.[83] found that telemedicine was effective for correlating subjective patient complaints with the presence or absence of pacemaker problems, regardless of age. Also, financial charges for telemedicine consultations were significantly lower than comparable outpatient visits. This is a unique study because it focuses on remote surveillance of pacemakers in a pediatric population.

Peripheral devices distinguish between simple videoconferencing and comprehensive clinical consultations. They let the clinician approximate an on-site physical examination, and they use electronic versions of standard examination tools, such as stethoscopes, otoscopes, ophthalmoscopes, haptic devices, as well as other sense-extending implements that are almost exclusively electronic, including close-up cameras and document stands, dermascopes, and robotic microscopes.[84] Among these peripheral devices, the electronic analog and digital electronic stethoscopes are essential to telecardiology, and they are particularly important to remote general practitioners who need specialist consultation.

Research findings on the reliability of telecardiology in transmitting the information needed for good clinical decisions have been reported from five telecardiology programs in North America. They ranged in scope from the simple use of an electronic stethoscope in physical examinations of remote patients to comprehensive cardiology programs offering store-and-forward and real-time systems using broadband, ISDN, fractional T1, and standard telephone lines. Data from these studies reveal rather consistent findings for the clinical effectiveness and cost-effectiveness of transmitting diagnostic-quality information in both real-time and store-and-forward systems.[85]

Finally, pediatric echocardiography transmission remains the most studied clinical telemedicine application for children. Interobserver reliability and diagnostic validity of a commercial electronic stethoscope for pediatric telecardiology have been investigated.[85] The study concluded that this device provided reliable screening for congenital heart disease. Although highly reliable, however, the use of the electronic stethoscope reduced diagnostic reliability. This finding might be explained, at least in part, by methodological and technical artifacts, such as the absence of blinding, bandwidth limitations, and other artificial restrictions on the remote assistants. Absent these conditions and restrictions, the electronic stethoscope remains a highly promising tool for pediatric telecardiology.[84] Pediatric cardiology patients have been examined remotely since 1991.[86] In addition to the electronic stethoscope, the system used interactive real-time video. However, according to one study, only 51% of parents were willing to use the system for follow-up care for their children.[74]

Because the stethoscope is a fundamental device in clinical cardiology as well as in most other fields of medicine, including general clinical use, medical education, and paramedic use in ambulances and mobile units, the electronic device is central to much of clinical telemedicine. The electronic stethoscope appears to be cost-effective and relatively easy to use, when compared with complex echocardiography and ultrasonography equipment.

Teleophthalmology

Teleophthalmology is the final "maturing" clinical application of telemedicine discussed here. Teleophthalmology incorporates primary diagnosis and management, screening, consultation, and comanagement. Here again, telemedicine seems to be especially suitable because optical and imaging devices provide the basis for most patient evaluations, and ophthalmologists tend to rely heavily on diagnostic images. Indeed, they diagnose, prescribe, and treat on the basis of images of eye pathology.

The majority of research studies in teleophthalmology in the United States and Europe have focused on clinical effectiveness and, to a lesser extent, clinical feasibility. One such feasibility study, conducted among teleophthalmology providers in the European Community's Telematics in Ophthalmology Project (OPTHEL),[87] focused on the detection of moderate, nonproliferative/non-sight–threatening diabetic retinopathy in a screening program. Digital fundus photography was successful (85% median sensitivity and 90% median specificity) in detecting this retinopathy.[88] However, it failed to exclude macular edema, which requires analysis of ongoing visual acuity for full interpretation of diabetic retinopathy.

Teleophthalmology research results are available from several studies in the United States, especially the Joslin Vision Network (JVN), the Department of Defense, and the VHA.[88,89] For example, a comparative study determined the level of diabetic retinopathy observed in standard 35-mm imaging techniques and digital images using the JVN nonmydriatic, low-light video camera. High agreement was observed between the two methods ($\kappa = 0.67$). Furthermore, the nondilated images using the JVN camera were an acceptable alternative to ascertain clinical level of diabetic retinopathy and appropriate follow-up care.

Other teleophthalmological studies have assessed the use of remote slit-lamp examination in the detection of acute eye problems; the use of fiberoptic digital cameras to screen for retinopathy among children; and surgical follow up in corneal transplantation.[90–92] Overall, teleophthalmology improved access to scarce ophthalmologic services, and it enhanced the management of chronic diabetic eye care.

EMERGING APPLICATIONS: TELESURGERY, TELEPEDIATRICS, AND EMERGENCY MEDICINE

The final set of clinical applications includes telesurgery, telepediatrics, and emergency medicine. This set is labeled as emerging because of the combination of recency of application, limited research, and limited professional acceptance of these clinical applications.

Telesurgery

Many consider telesurgery a true "frontier" in telemedicine. This is primarily because of the demanding technological requirements, including robotics and reliable broadband transmission and redundancy, as well as the skill needed at both ends in the foreseeable future for safe and effective administration.

Since 1992, in varying degrees, the surgical specialties[94–119] of orthopedics, general surgery, neurosurgery, urology, otolaryngology, pediatrics, and plastic surgery have used telemedicine in various surgical procedures.[97] Numerous studies have investigated the feasibility of surgical teleconsultation, telementoring (surgical instruction), teleproctoring (overseeing surgical procedures), and remote or virtual-presence surgery (active control of remote surgical instrumentation). These studies have demonstrated the vigorous interest in applying telemedicine by innovators in the surgical community. Significantly, the development and evolution of telesurgery coincides with the expansion and success of laparoscopic and arthroscopic surgical procedures. Phillipe Mouret performed the first video-laparoscopic cholecystectomy in Lyon, France, in 1987. Recent strides in these minimally invasive techniques have improved patient outcomes, reduced the length of hospital stays, increased outpatient surgeries, and reduced postsurgical discomfort and pain, in the hands of skilled surgeons, although not without new risks. The natural progression to telemedicine occurred because the equipment used to perform these operations involves remote operating techniques.[94,102,103]

Research in remote surgery remains largely descriptive and somewhat anecdotal, often based on single or few cases. At the same time, the field is undergoing rapid change as a result of dramatic developments in robotics and related technologies and enhancements in the quality of service and the reliability of broadband Internet.[93–103] Telementoring has gained wide professional appeal for assisting and facilitating surgical education, including advanced surgical skill training for established surgeons in arthroscopic and laparoscopic techniques.[94,100] To date, however, no randomized clinical trials have been conducted on telementoring, teleproctoring, or virtual-presence telesurgery.

A number of successful virtual-presence surgeries have been demonstrated, however, including laparoscopic hernia repair, gastric banding, upper pole nephrectomy, orchiectomy, and bladder reconstruction.[94,100] A recent example of a successful robotic gallbladder surgery received international attention because the patient was in Toulouse, France, and the surgeon was in Boston, Massachusetts. Another demonstration simulated virtual surgery while sharing tactile sensations between Japan and Germany.[120] Questions of patient safety, surgeon liability, and the cost of robotic equipment and instruments are currently limiting scientific investigations and broader diffusion of this field.

In contrast with remote telesurgery, the literature discusses a variety of teleconsultative applications in several surgical specialties. Not surprisingly, image-based applications, such as neurosurgery and orthopedics, have received the most attention. Clinical teleorthopedic consultations have been demonstrated in the United States and Europe (France, Finland, and the United Kingdom) that support geriatric rehabilitation and trauma/fracture consultation.[109–111] The clinical feasibility of accurate vascular surgical evaluation has been demonstrated, and it has been accepted well by patients.[112–114] Teleconsultation in otolaryngology is more widely available in Europe than in the United States.[115–119] From the financial perspective, one study reported a net cost savings of more than a half million dollars from a telemedical emergency neurosurgical network, resulting from a reduced need for and cost of patient transfer for care.[108] Perhaps disturbing to some, it has been speculated that information science will change the practice of surgery, "pushing the limits beyond the bounds of human performance."[121] Be that as it may, the future application of telesurgery in all its forms simultaneously offers many challenges and opportunities.

Telepediatrics

As with other clinical specialties and subspecialties, the demand for and development of telepediatrics derives, in some measure, from the geographic imbalance in the distribution of specialty providers. In many communities in the United States as well as in some countries as a whole, certain pediatric subspecialties are either nonexistent or in short supply.

Major pediatric telemedicine clinical consultative initiatives in the United States are directed, for example, toward the care of chronically ill children and those with special health care needs.[122] Yet, the bulk of the literature pertaining to the use of telemedicine to provide subspecialty support for this population is largely descriptive and primarily focused on patient, family, and provider attitudes and perceptions. In a randomized clinical trial evaluating the effect of Internet videoconferencing to support families during neonatal hospitalization, however, researchers reported reduced hospital costs associated with care of very low birthweight infants.[123] In this instance, cost reductions resulted entirely from discharging these infants directly to homes equipped with Internet videoconferencing, compared with control infants who required triage to an intermediary community hospital step down unit after hospital discharge.

Work in school-based telemedicine has focused on children with limited access to health care because their parents were poor, uninsured, or lived in remote areas. Providing care for these children while they are at school via telemedicine has proven to be both feasible and well accepted by the community. In some instances, these programs were less costly than ambulatory care pediatric visits to the school setting.[124,125] Other pediatric telemedicine initiatives included school-based projects to assist in triage and transport of children who fall ill or injured at school.[126]

Emergency telemedicine

The earliest applications in emergency medicine were based on telephone triage and call centers to manage patients in managed care organizations.[127–129] Until recently, most of the research literature on emergency telemedicine (ET), which includes emergency medicine and triage, consisted of feasibility studies and demonstrations.[127–147] In 1994, the potential for positive ET cost/benefit ratios warranted further study and demonstration.[148] Early applications of ET began in Norway, but progress has been slow there as elsewhere.[149]

Telemedicine has been used successfully in several areas of emergency medicine, including teleradiology for remote and after-hours interpretation of emergency radiographs and computed tomography (CT) scans[130–132]; mentoring of and providing consulting with remote trauma teams;[145–147] and follow-up care of trauma patients returned to their community after initial management in tertiary care trauma centers.[135] Similarly, a telemedicine network established for neurosurgical patient management proved to be effective in coordinating care and reducing costly and unnecessary transfers for neurosurgical evaluation.[108] Live, synchronous videoconferencing has been used extensively in the United Kingdom to supervise nurse practitioners in remote, minor trauma centers.[137,138]

In the United States, telemedicine has been used to direct physician assistants and nurses in Oklahoma, Minnesota, and New York. It has also been used to provide emergency psychiatric services.[139] In a randomized clinical trial, patients were more satisfied with their emergency telemedicine experience, compared with their most recent visit to an emergency department.[150] Other settings where the efficacy and efficiency of emergency telemedicine applications have been demonstrated include nursing homes,[140] correctional facilities,[141] and islands remote from mainland tertiary care centers.[142]

Onsite (prehospital) care and emergency medical services constitute an essential component of emergency medicine. The transmission of 12-lead ECGs prior to a patient's arrival to the emergency room has decreased the initiation time of thrombolytic administration[143] and led to more timely evaluation of possible stroke victims, thereby aiding in the evaluation of cerebral thrombolysis.[144]

One of the earliest international applications of telemedicine in a natural disaster was the National Aeronautics and Space Administration's (NASA's) "Spacebridge to Armenia" to aid earthquake victims.[145]

Advances in miniaturization and portability of telemedicine equipment have led to mobile, wearable computers[146] and real-time data transfer systems that can relay critical patient information and coordinate medical emergency response.[147]

In brief, in stark contrast to its potential benefits, the diffusion of ET has been slow. ET has some problems not typically encountered, or not encountered to the same degree, in other clinical specialties. These include the need to coordinate, in an often unpredictable yet timely fashion, a number of participating providers at both remote and consulting sites, the need for continuous consultative services during the emergency episode, the high-risk presentation of many patients, and the lack of a defined reimbursement structure.

Several other important issues must be addressed and questions answered before ET moves from the emerging to the more mature status of telemedicine clinical applications. These include meeting the considerable technological requirements for on-site assessment of various types of trauma; reliable modes of transmission; and coordination of on-site and en-route care between remote personnel and specialists in emergency departments. It must also include an assessment of the clinical capabilities of the remote personnel and the level of procedural skills as well as the availability of medications and diagnostic and therapeutic equipment on board. In addition, the locus of equipment control must be determined; that is, whether the equipment is controlled onsite or from a remote location.

The location and accessibility of the trauma center, the overall organizational setting and how it is structured, and the relevant characteristics of the population served by the remote emergency treatment setting all need to be evaluated. The total technological solution includes the specification of telecommunications requirements, the communications protocols, the videoconferencing equipment, and the design of the videoconferencing system as well as the adjunctive video equipment that is used to communicate between the provider and the patient.

The clinical practice of emergency telemedicine depends on managing certain presentations or chief complaints. Substantial clinical experience and a literature base provide evidence for developing ET protocols in patient management. These clinical guidelines must be developed within emergency medicine, simultaneously with guidelines for nursing practices in this context.

There appears to be only one study addressing emergency telemedicine using a randomized clinical trial comparing telemedicine and non-telemedicine evaluations.[151] It reported no significant differences between the experimental and control groups in terms of return visits, need for additional care, physician–patient interaction, nurse–patient interaction, and overall patient satisfaction. Other studies have investigated patient outcomes for telephone triage systems[152] and follow-up of remote trauma teleconsultations.[153] Overall satisfaction in the triage study was 90%. A small proportion (11%) of callers scheduled a subsequent office visit, and 1.5 % used the emergency room for further care. The follow-up study reported a misdiagnosis of only 2% of original telediagnosis in minor trauma cases.

Another study investigated satisfaction and return on investment of a nurse triage service.[154] Positive return on investment was reported as a result of reductions in emergency department and physician office use, in addition to high levels of satisfaction. A number of ET studies have focused on technology issues, including video resolution, compression, color depth, and display[155] as well as depth perception in a mono-camera system, particularly for wound management.[156]

Scientific research targeted at demonstrating the clinical effectiveness and cost effectiveness of ET is essential for the orderly growth of this application and for fulfilling its potential for improving health outcomes for trauma patients everywhere.

SPECIAL APPLICATIONS AND SETTINGS

Rare diseases

A brief comment on an important application of clinical telemedicine services for patients with rare diseases is appropriate here. The National Institutes of Health Office of Rare Diseases defines an orphan or rare disease as one that affects fewer than 200,000 individuals in the United States (some diseases with more than 200,000 affected individuals are included, but subpopulations of these conditions would be lower than the prevalence standard for rare disease). The Office recently listed almost 2400 diseases of this type (rarediseases.info.nih.gov/diseases.html). Therefore, while the people with any single rare disease may be relatively few, in the aggregate, the total number of people suffering from rare diseases is considerable. This sector of clinical telemedicine represents an opportunity to contribute significantly to the health care of large numbers of afflicted children and adults.

In some instances, patients afflicted with certain diseases receive special assistance from the government or from private voluntary organizations. These types of diseases, for example, victims of adrenal hormone deficiency (Addison's disease), sickle cell anemia, and cystic fibrosis, are particularly suitable candidates for telemedicine. Cystic fibrosis is a severe disease of the lungs with such related complications as malnourishment, diabetes, liver problems, infertility, and premature death.[157] Care for patients afflicted with many of these diseases is often complex because it involves teaching them techniques appropriate to their problem, such as how to loosen mucous buildup, how to avoid infection, how to use special diets to improve nutritional status,[158] and how to deal with specific complications.[159] Providers must have special expertise in the treatment methods unique to each of these diseases, and such expertise is often available only in large medical centers. Consequently, patients who need these services often have to travel far or simply forgo treatment or even diagnosis.

Travel costs are recognized as being important enough that special agencies provide air transportation to get patients to distant specialty medical centers. For example, the National Patient Travel Center's stated goal is "to ensure that no financially needy patient is denied access to distant specialized medical evaluation, diagnosis, and treatment for lack of a means of medical air transportation."[160]

Telemedicine applications[161] for patients with rare diseases include the actual medical consultation and diagnosis, maintenance of patient records, dissemination of information and educational materials, electronic (chat rooms) with other patients or caregivers, and home health visits. Teleconsultations can be for acute episodes or emergencies, regular visits, transfers to the hospital, second opinions from experts, or just meetings with the patient and family. The potential benefits include greater continuity of care, more treatment at home rather than in a hospital, better knowledge of the disease and appropriate treatment, hence greater compliance, improved health outcomes, and potentially diminished costs.

Telemedicine in the home

Home-based telemedicine, typically referred to as "telehome care," represents a special application, albeit not a unique clinical one, that is growing in significance. In this type of care, the patient and the caregivers in the home environment assume a much greater role in the treatment and care of chronic illness. They may be away from medical institutions, but they have electronic links to them. This approach is discussed here to focus on an important new application of telemedicine that foretells a changing paradigm in health care delivery for many people.

Ironically, the new emphasis on treating chronically ill and disabled individuals in the homes reflects the locus of care for the majority of illnesses during the first half of the 20th century. The major difference, of course, is that interactive media has replaced the traveling physician's little black bag.

The aging population and limits on hospitalization time add to the importance of the home as a health care setting. Indeed, trends in medical care are moving away from hospitals and toward outpatient settings. Home health care telemedicine initiatives, therefore, are particularly important to present and future medical care needs of ever increasing segments of the population everywhere, including the United States and Europe.

Remote home health devices can capture and transmit such vital information as blood pressure and ECGs[162] from home-based clients. Reductions in cost of home health equipment, ease of integration to standard home-based PCs, and increasing patient access to the Internet have created new opportunities for home-based chronic disease management.

Research literature endorses the concept of telehome care. For instance, home blood pressure monitoring and other devices have been effectively used in managing chronic diseases such as asthma and diabetes.[162–165] In a randomized clinical study, Tsang et al.[165] reported significant reductions in mean Hb A_{1C} (glycosylated hemoglobin, assessment of long-term glucose control) using home glucose monitors as part of a home diabetic management program. Preliminary data, however, from a pulmonary home health application that measured peak flow and forced vital capacity[163,164] reported patients having initial difficulties in using flow devices, which interfered with their definitive remote management.[164] On the other hand, one small study used a new forced vital capacity home monitoring device connected to a palmtop computer and ultimately to a Web server to give providers full access to vital information about their patients.[164]

In a landmark study, researchers reported positive health outcomes from a prospective, randomized clinical trial of home health services in terms of quality, patient satisfaction, and cost savings.[166] Patients received either standard home care with periodic visitation and back-up telephone availability to health personnel, or they received standard home care with telephone and teleconferencing access from the home. No differences between the two groups were noted in quality indicators. On the other hand, the average direct costs were higher for the intervention group versus the control group ($1,830 vs. $1,167 USD). However, these costs included start-up equipment costs. Subsequent analysis that controlled for continued utilization and depreciation of equipment yielded savings of approximately $900 per patient in the intervention group. Based on these findings, a major health insurer is now integrating telehome services within its organization.

A special platform based on a hybrid fiber-and-coaxial network in Taiwan demonstrated the clinical feasibility of this technology in transmitting biomedical data, including three-channel electrocardiograms, blood pressure, and video and audio signals from the home.[167]

Nurses and ancillary health care providers are the mainstay of home health services in most countries.[168,169] In Hong Kong, for example, it was reported that 89% of geriatric nurse outreach services could be accomplished using telemedicine.[168] This finding has been supported by a recent retrospective study in the United States that assessed procedures performed by home health nurses.[169] It was observed that 46% of the procedures currently being performed by home health nurses could have been achieved remotely through teleconsultations.

RECOMMENDATIONS FOR FUTURE ACTION AND RESEARCH

Clinical telemedicine applications face several core issues that must be addressed appropriately if telemedicine is to be integrated into mainstream medical care. For purposes of efficiency and clarity in this discussion, these issues are grouped into four sets: policy and regulatory issues, technology, human factors, and research.

Policy and regulatory issues include credentialing and privileging, reimbursement, interstate licensure, and intellectual property rights. These issues must be resolved in ways that serve the public interest and the well-being of patients and their families A recent report to the U.S. Congress addressed this in detail, and gave thoughtful analysis to each of these issues and more, including payment, legal/regulatory, safety and standards, privacy and security, infrastructure, and evaluation and research. The complete report is available at telehealth.hrsa.gov/pubs/report2001/main.htm.

Technology supporting clinical telemedicine is progressing rapidly, and several basic issues have been addressed comprehensively in selected sectors, such as physical attributes of displays for use in teleradiology and telepathology, spatial resolution, contrast resolution, dynamic range, color, luminance, and tone scale.

Future developments in support technology for other clinical applications take the lead from these more mature applications. Extant technologies can be adopted or adapted if appropriate, and the general evaluation methods and principles can be used as a guide for research. To be sure, there are established ways to evaluate displays that can easily be adapted to newer display technologies.[170–172]

Data compression, particularly in radiology,[173–176] has been thoroughly researched to determine diagnostic accuracy at different compression ratios. Still, more research is needed to develop definitive guidelines for specific clinical applications. For the most part, programs have tried to limit themselves to "lossless" or reversible compression schemes for clinical and legal reasons.[6] Both the type and levels of compression adopted for a particular modality are probably task-dependent. Hence, no single type or level of compression is appropriate for all clinical applications. For example, the task of detecting a micro-calcification cluster in mammography may be less affected by a given compression scheme and level than by the task of subsequently deciding (based on subtle, small features) whether that cluster is benign or malignant.

Telepathology and teledermatology are also concerned with detection and classification of small, subtle features, but there is the added complication of compression effects on image colors. If, for example, subtle shade changes are important for diagnosis and if compression blurs the boundaries between subtle color changes, then the ability to diagnose might be affected adversely.[177]

Important technological issues remain to be resolved, and the following recommendations are offered to provide some direction and guidance in this area.

- Research must integrate human and technical evaluations as they pertain to specific clinical applications and clinic telemedicine generally.
- An accessible repository of technology research literature should be developed and maintained to foster synergistic cooperation both nationally and internationally.
- Technology standards must be developed for each clinical telemedicine application pertaining to telecommunications, data storage, data compression, data display, data security, quality assurance and control, interoperability and seamless communication between systems, and institutional organization infrastructure to support clinical telemedicine.

Human factors issues in clinical telemedicine are critical, and they need to be emphasized in any future research agenda. An improved and comprehensive understanding pertaining to technology-based barriers for patients and providers in clinical telemedicine is needed.

Research on the display of information for consulting clinicians extends beyond the technology itself and focuses on image processing and manipulation.[178] Often image processing and manipulation technologies are incorporated into a workstation without having been evaluated by the providers who have to use them. When technologies either appear difficult to use or are perceived to be of little utility, they often are ignored. Scientific studies of provider (both consulting and referring) performance are needed to determine which technologies are useful and workable and how existing ones can be improved. Results from this type of research can be translated into tailored or customized telemedicine workstations. In addition to examining provider performance, research must determine how specific technological configurations affect the manner in which information is processed[179,180] and the degree and direction in which it influences workflow.[181–183]

The more mature clinical telemedicine applications of teleradiology and telepathology have brought to the forefront another area of research that is crucially important for telemedicine in general, namely the evaluation of how the clinician interacts with the digital display and the impact of this new modality on diagnostic performance. Researchers have done numerous well-controlled empirical studies to confirm that diagnostic accuracy is equivalent, in most circumstances, in conventional and digital display environments.[184–190] Indeed, in instances where this was not true, the remedy was available in a higher order technology.

Analyses are being undertaken to determine which specific clinical specialties are suited to telemedicine, and to what degree.[188] These must continue.

Research[191–193] has shown that radiologists and pathologists with more clinical experience tend to perform better diagnostically with the traditional display modalities than with newer telemedicine display modalities, but that those with lesser clinical experience tend to do better with the newer modalities. In teleradiology, not surprisingly, it has also been found[193] that experience is positively associated with increased accuracy and reduced case-study time. This type of research needs to be expanded. Moreover, it must include not only the consulting and referring physician, but the patient as well.

The importance of user-interface relationships for both providers and patients using teleconsultative equipment should be mentioned. This is particularly relevant in light of rapid progression to multimedia presentation of various clinical consultations. However, the focus here is more on how well the technology integrates with the current and future clinical environments. Research that assesses the integration of diagnostics and clinical presentation and management of data is needed.

Research needs in telemedicine vary widely. Clinical telemedicine applications vary in focus and technological requirements. Whereas significant strides in research have been achieved to date, many issues and questions could be more effectively and efficiently studied through coordinated and cooperative, multi-institution research. With limited notable exceptions, there are few examples of coordinated research efforts.[54,89] Coordinated institutional, regional, national, and international research should be promoted to obtain scientifically valid and policy-relevant results. Cooperative multicenter participation should identify relevant issues and problems and develop effective research strategies. Large-scale, coordinated research requires institutional and financial support to develop an appropriate infrastructure that will support and be conducive to research.

The prevailing funding model for telemedicine research in the United States is short-term, competitive, and typically based in a single institution. Funding agencies must comply with Congressional mandates, which are sensitive to geographic equity issues. Competition encourages creativity, and geographic equity reduces the disparities between areas, but this model has the unintended effect of producing mostly small-scale, limited-purpose, and inconclusive research. Projects have typically been too small in terms of sample size, limited in funding, methodologically flawed, and of too short duration. This precludes producing a volume of definitive scientific results sufficient to inform prudent public policy and contribute to a scientific knowledge level in the professional community that can generate widespread acceptance. In addition, the demands for immediate financial returns by private industry and sponsoring organizations have precluded large-scale and long-term coordinated research efforts.

Clinical telemedicine research must build on and expand from the established foundation. Research gaps must be identified and filled. This applies to each clinical specialty as well as the entire system. Six steps toward establishing diagnostic efficacy of clinical telemedicine have been suggested, ranging from demonstrating technological efficacy to societal efficacy.[194] To date, several clinical telemedicine applications are in the early, or technological efficacy, stage. Research questions must be addressed that facilitate and test the efficacy of applications at more advanced levels. Even the mature applications of teleradiology and telepathology have yet to investigate the final stage of societal efficacy.

Research in telemedicine clinical applications should proceed from simple "proof of concept" studies to more advanced approaches that promulgate evidence-based guidelines (Table 2).

Funding is required from external (international, federal, state, and private funding agencies) and internal (professional societies, institutions, and organizations) sources to initiate and sustain the necessary research in this field. The scope of the research and the requisite expertise would dictate the involvement of specialty professional societies. Such societies should include those concerned with interrelated aspects of telemedicine, such as technol-

TABLE 2. PROPOSED STAGES FOR CLINICAL TELEMEDICINE RESEARCH

Proof of concept	INITIAL
Technical feasibility	↓
Helps develop research questions	
Clinical efficacy studies	
Multicenter trials to include:	
Human factors (patient/provider considerations)	
Special settings (prisons/military)	
Organizational infrastructure	
Diverse cultural/economic/geographic settings	
Cost analysis studies—return on investment (ROI)	
After ROI proven:	
Promulgate evidence-based guidelines	
Develop standards through professional societies	ADVANCED

ogy, education, ethics, and finance. Each society can determine the extent to which it would promote, foster, fund, and participate in research directed at the successful implementation of clinical telemedicine. The result would be a synergy that would propel the research and application forward to the point where clinical telemedicine becomes a multispecialty care system that makes a strong contribution to providing total health care for all patients, regardless of geography.

In addition to sponsored research, the external and internal funding agencies should support education and training efforts in telemedicine. Training grants should be established, including fellowships in telemedicine clinical applications. These fellowships should not be limited to clinicians, but should be extended to all health care providers, researchers, managers, and technicians involved in telemedicine.

Scientific research should address and answer, as best it can, all pertinent questions regarding the effectiveness and safety of telemedicine. It must also address programmatic issues about optimal systems for the efficient delivery of health care and the overall effects of telemedicine on access to care as well as cost and quality. It must build on the existing body of knowledge, such as that documented in this report and elsewhere. It must consider the use of meta-analysis wherever permitted by study design and statistical power. To help accomplish this, professional societies need to support the use of telemedicine. However, for societies to be able to promote telemedicine applications, they need to have positive scientific evidence supporting its use, and be able to show their members that telemedicine will add value to their practice.

In summary, to facilitate development of these research efforts, a number of issues must be addressed, namely the following:

- Determine research priorities in clinical applications of telemedicine, the most pressing issues and their correlates. These priorities must include multifaceted investigations of clinical effectiveness and safety of a broad range of applications, with special emphasis on health outcomes, provider–client interactions, and systemic effects.
- Support large-scale, multi-institutional, and comprehensive research projects using randomized clinical trials with large samples and large data sets.
- Consider cost-sharing among funding agencies to support large-scale research and consortia for conducting the necessary scientific research.
- Develop appropriate patient privacy and safety guidelines, consistent with prevailing laws.
- Assess and monitor patient–provider relationships in clinical telemedicine applications.
- Develop proficiency and practice standards and certifications in clinical telemedicine.
- Develop clinical protocols for each clinical telemedicine application.
- Develop and integrate clinical telemedicine into medical school curricula.

- Establish clinical telemedicine boards within professional societies of each clinical specialty to conduct research and promulgate research findings and develop protocols and curricula that will foster the appropriate use and development of clinical telemedicine.
- Develop and test organizational models to support incorporation of clinical telemedicine in provider institutions and regional, national and international telemedicine networks
- Develop continuous monitoring and assessment tools for each type of clinical telemedicine application

REFERENCES

1. Bird K. Telemedicine concept and practice. In: Bashshur RL, Armstrong PA, Youssef ZI, eds. *Telemedicine: Explorations in the use of telecommunications in health care.* Springfield, IL: Charles C. Thomas Publishers, **1975:**89–112.
2. Park B. Communication aspects of telemedicine. In: Bashshur RL, Armstrong PA, Youssef ZI, eds. *Telemedicine: Explorations in the use of telecommunications in health care.* Springfield, IL: Charles C. Thomas Publishers, **1975:**54–86.
3. Riggs RS, Putillo DT, Connor AG. Medical consultation via communications. *JAMA* **1974;**228:600–602.
4. Jutra J. Teleroentgen diagnosis by means of videotape recording. *AJR* **1959;**82:1099–1102.
5. Gershon-Cohen J, Cooley AG. Telediagnosis. *Radiology* **1950;**55:582.
6. Lau C, Cabral JE, Haynor DR, Kim Y. Telemedicine. In: Kim Y, Horrii SC, eds. *Handbook of medical imaging: Display and PACS.* Bellingham, WA: SPIE Press, **2000:**305–331.
7. American College of Radiology, National Electrical Manufacturers Association, Digital Imaging and Communications in Medicine (DICOM): Version 3.0. American College of Radiology, Reston, VA, 1993.
8. American College of Radiology, ACR Standard for Teleradiology. American College of Radiology, Reston, VA, 1996.
9. Balis UJ. Digital imaging standards and system interoperability. *Clin Lab Med* **1997;**17:315–322.
10. Zhou J, Hogarth MA, Walters RF, Green R, Nesbitt TS. Hybrid system for telepathology. *Hum Pathol* **2000;**31:829–833.
11. Dunn BE, Almagro UA, Choi H, Sheth NS, Arnold JS, Recla DL, Krupinski EA, Graham AR, Weinstein RS. Dynamic-robotic telepathology: Department of Veterans Affairs feasibility study. *Hum Pathol* **1997;**28:8–12.
12. Walter GF, Matthies HK, Brandis A, Von Jan U. Telemedicine of the future: Teleneuropathology. *Technol Health Care* **2000;**8:25–34.
13. Halliday BE, Bhattacharyya AK, Graham AR, Davis JR, et al. Diagnostic accuracy of an international static-imaging telepathology consultation service. *Hum Pathol* **1997;**28:17–21.
14. Tobis J, Aharonian V, Mansukhani P, Kasaoka S, et al. Video networking of cardiac catheterization laboratories. *Am Heart J* **1999;**137:241–249.
15. Malone FD, Athanassiou A, Nores J, D'Alton ME. Effect of ISDN bandwidth on image quality for telemedicine transmission of obstetric ultrasonography. *Telemed J* **1998;**4:161–165.
16. Shtern F, Winfield D, eds. Report of the Working Group on Digital Mammography: Digital displays and workstation design. *Acad Radiol* **1999;**6:S195–S219.
17. Broderick TJ, Harnett BM, Merriam NR, Kapoor V, Doarn CR, Merrell RC. Impact of varying transmission bandwidth on image quality. *Telemed J e-Health* **2001;**7:47–53.
18. Nakajima S, Nakamura K, Masamune K, Sakuma I, Dohi T. Three-dimensional medical imaging display with computer-generated in-tegral photography. *Comput Med Imaging Graph* **2001;**25:235–241.
19. Golovkov AA, Erofeev NI, Kuznetcov SV. *Three-dimensional laser display for use in medicine.* St. Petersburg, Russia. Press release, May 24, 1999.
20. Doolittle MH, Doolittle KW, Winkelman Z, Weinberg DS. Color images in telepathology: how many colors do we need? *Hum Pathol* **1997;**28:36–41.
21. Shepherd AJ. Calibrating screens for continuous colour displays. *Spatial Vision* **1997;**11:57–74.
22. Gossiieaux F. Color calibration: Which approach is right for you? *Advanced Imaging* **1994;**9:Sept:67–70.
23. Krupinski EA, Roehrig H. The influence of a perceptually linearized display on observer performance and visual search. *Acad Radiol* **2000;**7:8–13.
24. Shimosato Y, Yagi Y, Yamigishi K, et al. Experience and present status of telepathology in the National Cancer Center Hospital, Tokyo. *Zentralbl Pathol* **1992;**138:413–417.
25. Weinberg DS, Allaert FA, Dussere P, et al. Telepathology diagnosis by means of digital still images: an international validation study. *Hum Pathol* **1996;**27:111–118.
26. Weinstein RS. Static image telepathology in perspective. *Hum Pathol* **1996;**27:99–101.
27. Bhattacharyya AK, Davis JR, Halliday BE, et al. Case triage model for the practice of telepathology. *Telemed J* **1995;**1:9–17.
28. Dunn BE, Choi H, Almagro UA, Recla DL, et al. Routine surgical telepathology in the Department of Veterans Affairs: Experience-related improvements in pathologist performance in 2200 cases. *Telemed J* **1999;**5:323–337.
29. Weinstein RS, Bloom KJ, Krupinski EA, Rozek LS. Human performance studies of the video microscopy component of a dynamic telepathology system. *Zentralbl Pathol* **1992;**138:399–401.
30. Dunn BE, Choi H, Almagro UA, Recla DL, Kru-

pinski EA, Weinstein RS. Routine surgical telepathology in the Department of Veterans Affairs: Experience-related improvements in pathologist performance in 2200 cases. *Telemed J* **1999;**5:4323–339
31. Elam EA, Rehm K, Hillman BJ, Maloney K, et al. Efficacy of digital radiography for the detection of pneumothorax: comparison with conventional chest radiography. *AJR* **1992;**158:509–514.
32. Scott WW, Bluemke DA, Mysko WK, et al. Interpretation of emergency department radiographs by radiologists and emergemcy medicine physicians: Teleradiology workstation versus radiograph readings. *Radiology* **1995;**197:223–229.
33. Krupinski EA, Lund PJ. Differences in time to interpretation for evaluation of bone radiographs with monitor and film viewing. *Acad Radiol* **1997;**4: 177–182.
34. Lou SL, Sickles EA, Huang HK, Hoogstrate D, et al. Full-field direct digital telemammography: Technical components, study protocols, and preliminary results. *IEEE Trans Inf Technol Biomed* **1997;**1:270–278.
35. Murphy JH, O'Hare NJ, Wheat D, McCarthy PA, et al. Digitized mammograms: A preliminary clinical evaluation and the potential for telemammography. *J Telemed Telecare* **1999;**5:193–197.
36. Maitz GS, Chang TS, Sumkin JH, Johns CM, et al. Preliminary clinical evaluation of a high-resolution telemammography system. *Invest Radiol* **1997;**32: 236–240.
37. Tachakra S, Hollingdale J, Uche CU. Evaluation of telemedical orthopaedic specialty to a minor accident and treatment service. *J Telemed Telecare* **2001;** 7:27–31.
38. Lee BR, Allaf M, Moore R, Bohlman M, et al. Clinical decision making using teleradiology in urology. *AJR* **1999;**172:19–22.
39. Eng J, Mysko WK, Weller GE, Renard R, Gitlin JN, et al. Interpretation of Emergency Department radiographs: a comparison of emergency medicine physicians with radiologists, residents with faculty, and film with digital display. *AJR* **2000;**175: 1233–1238.
40. Kangerloo H, Valdez JA, Yao L, Chen S, et al. Improving the quality of care through routine teleradiology consultation. *Acad Radiol* **2000;**7:149–155.
41. Maass M, Kosonen M, Kormano M. Transportation savings and medical benefits of a teleneuroradiological network. *J Telemed Telecare* **2000;**6:142–146.
42. Wittson, Cecil L, and Benschotter, RA: Two-way television: Helping the medical center reach out. *Am J Psychiatry* **1972;**129:136–139.
43. Dwyer, Thomas F. Telepsychiatry: Psychiatric consultation by interactive television. *Am J Psychiatry* **1973;**130:865–869.
44. Grigsby B, Brown N. Report on US telemedicine activity. *Am Telemed Service Provid* 1999.
45. Zaylor C. Clinical outcomes in telepsychiatry. *J Telemed Telecare* **1999;**5:S159–60.
46. Kennedy C, Yellowlees P. A community based approach to evaluation of health outcomes and costs for telepsychiatry in a rural population: preliminary results. *J Telemed Telecare* **2000;**6:S1:155–157.
47. Mielonen ML, Ohinmaa A, Moring J, Isohanni M. The use of videoconferencing for telepsychiatry in Finland. *J Telemed Telecare* **1998;**4:125–131.
48. Houston MS, Myers JD, Levens SP, McEvoy T, Smith SA, Khandheria BK, Shen WK, Torchia ME, Berry DJ. Clinical consultations using store-and-forward telemedicine technology. *Mayo Clin Proc* **1999;**74: 764–769.
49. Zarate CA Jr., Weinstock L, Cukor P, Morabito C, Leahy L, Burns C, Baer L. Applicability of telemedicine for assessing patients with schizophrenia: Acceptance and reliability. *J Clin Psychiatry* **1997;**58: 22–25.
50. Yellowlees P. The use of telemedicine to perform psychiatric assessments under the Mental Health Act. *J Telemed Telecare* **1997;**3:224–226.
51. Trott P, Blignault I. Cost evaluation of a telepsychiatry service in northern Queensland. *J Telemed Telecare* **1998;**4:66–8.
52. Dongier M, Tempier R, Lalinec-Michaud M, et al. Telepsychiatry: Psychiatric consultation through two-way television: a controlled study. *Can J Psych* **1986;**31:32–34.
53. Dossetor DR, Nunn KP, Fairley M, Eggleton D. A child and adolescent psychiatric outreach service for rural New South Wales: A telemedicine pilot study. *J Paediatr Child Health* **1999;**35:525–529.
54. Wootton R, Bloomer SE, Corbett R, Eedy DJ, Hicks N, Lotey HE, Mathews C, Paisley J, Steele K, Loane MA. Multicentre randomised control trial comparing real time teledermatology with conventional outpatient dermatologic care: Societal cost-benefit analysis. *BMJ* **2000;**320:1252–1256.
55. Barnard CM, Goldyne ME. Evaluation of an asynchronous teleconsultation system for diagnosis of skin cancer and other skin disease. *Telemed J* **2000;** 6:379–383.
56. Loane MA, Bloomer SE, Corbett R, Eedy DJ, Evans C, Hicks N, Jacklin P, Lotery HI, Mathews C, Paisley J, Reid P, Steele K, Wootton R. A randomized controlled trial assessing the health economics of realtime teledermatology compared with conventional care: an urban versus rural perspective. *J Telemed Telecare* **2001;**7:108–118.
57. Loane MA, Bloomer SE, Corbett R, Eedy DJ, Hicks N, Lotery C, PaisleyJ, Steele K, Wootten R. A comparison of real-time and store-and-forward teledermatology: A cost-benefit study. *Br J Dermatol* **2000;** 143:1241–1247.
58. Loane MA, Bloomer SE, Corbett R, Eedy DJ, Hicks N, Ltery HE Mathews C, Paisley J, Steele K, Wootton M. A randomized controlled trial to assess the clinical effectiveness with conventional care. *J Telemed Telecare* **2000;**6:S1–3.
59. Bergmo TS. A cost-minimization analysis of realtime teledermatology service in northern Norway. *J Telemed Telecare* **2000;**6:273–277.
60. Taylor P, Goldsmith P, Murray K, Harris D, Barkley

A. Evaluating a telemedicine system to assist in the management of dermatology referrals. *Br J Dermatol* **2001;**144:328–333.

61. Kvedar J, Edwards R, Menn ER, Mofid M, et al. The substitution of digital images for dermatologic physical examination. *Arch Dermatol* **2000;**136:249–250.
62. Krupinski EA, LeSueuer B, Ellsworth L, Levine N, et al. Diagnostic accuracy and image quality using a digital camera for teledermatology. *Telemed J* **1999;**5:257–263.
63. Phillips CM, Burke WA, Schechter A, Stone D, Balch M, Gustke S. Reliability of dermatology teleconsultations with the use of teleconferencing technology. *J Am Acad Dermatol* **1997;**37:398–402.
64. Sobczyk WL, Solinger RE, Rees Ah, Elb F. Transtelephonic echocardiography: Successful use in a tertiary pediatric referral center. *J Pediatr* **1993;**122: S84–88.
65. Julsrud PR, Breen JF, Jedeikin R, Peoples W, Wondrow MA, Bailey KR. Telemedicine consultations in congenital heart disease: Assessment of advanced technical capabilities. *Mayo Clin Proc* **1999;** 74:758–763.
66. Holland HC, Casey F, Brown D, Corrigan N, Quinn M, McCord B, Rogers J, Craig BG. Applications of a low cost telemedicine link to the diagnosis of neonatal congenital heart defects by remote consultation. *Heart* **1999;**82:217–221.
67. Casey F, Brown D, Corrigan N, et al. Value of a low-cost telemedicine link in the remote echocardiographic diagnosis of congenital heart defects. *J Telemed Telecare* **1998;**4:46–48.
68. Casey FA, Telemedicine in pediatric cardiology. *Arch Dis Child* **1999;**89:497–499.
69. Randolph GR, Hagler DJ, Khandheria BK, Lunn ER, Cook WJ, Seward JB, O'Leary PW. Remote telemedical interpretation of neonatal echocardiograms: Impact on clinical management. *J Am Coll Cardiol* **1999;**34:241–245.
70. Finley JP, Sharratt GP, Nanton MA, Chen RP, Bryan P, Wolstenholme J, MacDonald C. Paediatric echocardiography by telemedicine: Nine years experience. *J Telemed Telecare* **1997;3:**200–204.
71. McCue MJ, Hampton CL, Malloy W, Fisk KJ, Dixon L, Neece A. Financial analysis of telecardiology used in correctional setting. *Telemed J* **2000;**6:385–391.
72. Barbaro V, Bartolini P, Bernarducci R. A portable unit for remote blood pressure monitoring of pacemaker patients. *J Telemed Telecare* **1997;**3:96–102.
73. Rogers MA, Small D, Buchan DA, Butch CA, Stewart CM, Krenzer BE, Husovisky HL. Home monitoring service improves mean arterial pressure in patients with essential hypertension: A randomized, controlled trial. *Ann Intern Med* **2001;**134:1024–1032.
74. Orlov OI, Drozdov DV, Doarn C, Merrell RC. Wireless ECG monitoring by telephone. *J Telemed* **2001;** 7:33–38.
75. Firstenberg MS, Greenberg NL, Garcia MJ, Moorehead AJ, Carlson LA, et al. Image based transfer of cardiac ultrasound images. *J Telemed* **2001;**6:168–171.
76. Balch D. Internet2 for rapid transmission of cineangiograms. *J Telemed* **2001;**7:148.
77. Bondmass M, Bolger N, Castro G, Avitall B. The effect of home monitoring and telemangement on blood pressure control among African Americans. *Telemed J* **2000;**6:15–23.
78. Atinian NT, Washington OG, Templin TN. Effects of home telemonitoring and community-based monitoring on blood pressure control in urban African Americans: A pilot study. *Heart Lung* **2001;**30:191–199.
79. Rocci R. Telecardiogy. In Wooton R, ed. *European Telemedicine.* London, UK: Kensington Publications, **1999:**88–89.
80. Zaidi S. Recent experiences in trans-telephonic cardiac monitoring. In: Wooton R, ed. *European Telemedicine.* London, UK: Kensington Publications, **1999:**84–87.
81. Kong KY, Ng CY. Web-based monitoring of real-time ECG data. *Comput Cardiol* **2000;**17:189–192.
82. Smith JM. Future health care will depend upon telecom, VA predicts. *Govt Comp News* **1994;**13:87.
83. Vincent JA, Cavitt DL, Karpawich PP. Diagnostic and cost effectiveness of telemonitoring the pediatric pacemaker patient. *Pediatr Cardiol* **1997;**18:86–90.
84. Allen A, Wachter G. Peripheral devices. *Telemed Today* **1997;**5:22–23.
85. Belmont JM, Mattioli LF, Goertz KK, Ardinger RH, Thomas CM. Evaluation of pediatric telecardiology. *Telemed J* **1995;**1:133–149.
86. Mattioli L, Goertz K, Ardinger R, Belmont J, et al. Pediatric cardiology: Auscultation from 280 miles away. *Kansas Med* **1992;**326:347–350.
87. OPHTEL:http://tosca.gsf.de/OPHTEL/index.htm
88. Liesenfeld B, Hohner E, Piehlmeier W, Kluthe S, et al. A telemedical approach to the screening of diabetic retinopathy: Digital fundus photography. *Diabetes Care* **2000;**23:345–348.
89. Bursell SE, Cavallerano J, Cavallerano O, Clairmont AA, et al. Stereo nonmydriatic digital video color retinal imaging compared with Early Treatment Diabetic Study seven standard field 35mm stereo color photography for detection level of retinopathy. *Opthalmology* **2001;**108:572–585.
90. Birkmire-Peters DP, Coll KJ, Weldon A, Dunlap WA, Sakuda J. Joslin vision network initiatives: Tripler Army Medical Center and Honolulu Veterans Administration. *J Telemed* **2001;**7:143.
91. Shanit, KT Lifshitz T, Giladi R, Peterburg Y. A pilot study of tele-ophthalmology outreach services to primary care. *J Telemed Telecare* **1998;**4:1–2.
92. Shimmura S, Shinozaki N, Fukagawa KT, Tsubota K. Telemedicine in the followup of corneal transplant patients. *J Telemed Telecare* **1997;**3:227–228.
93. Schwartz S, Harrison S, Ferrone P, Trese MT. Telemedical evaluation and management of retinopathy of prematurity using a fiberoptic digital fundus camera. *Opthalmol* **2000;**107:25–28.
94. Link RE, Schulam, PG, Kavoussi LR: Telesurgery: Remote monitoring and assistance during laparoscopy. *Urol Clin North Am* **2001;**28:177–187.
95. Cheriff AD, Schulam PG, Docimo SG, Moore RG,

Kavoussi LR. Telesurgical consultation. *J Urol* **1999;** 156:1391–1393.
96. Bowersox JC, Cordts PR, Laporta AF. Use of an intuitive telemeanipulator system for remote trauma surgery: An experimental study. *J Am Coll Surg* **1998;**186:615–621.
97. Cadeddu JA, Stoianovici D, Chen RN, et al. Stereotactic mechanical percutaneous renal access. *J Endourol* **1998;**12:121–125.
98. Cadeddu JA, Staianovici D, Kavoussi LR. Robotic surgery in urology. *Urol Clin North Am* **1998;**25: 75–85.
99. Cadiere GB, Himpens J, Vertruyen M, et al. The world's first obesity surgery performed by a surgeon at a distance. *Obes Surg* **1999;**9:206–209.
100. Cubano M. Poulose BK, Talamini MA, et al. Long distance telementoring: A novel tool for laparoscopy aboard the USS Abraham Lincoln. *Surg Endosc* **1998;**13:673–678.
101. Docimo SG, Moore RG, Adams J, et al. Early experience with telerobotic surgery in children. *J Telemed Telecare* **1996;**2:48–50.
102. Kavoussi LR, Moore RG, Adams JB, et al. Comparison of robotic versus human laparoscopic camera control. *J Urol* **1995;**154:2134–2136.
103. Lee B, Cadeddu JA, Stoianovici D, et al. Telemedicine and surgical robotics: Urologic applications. *Rev Urol* **1999;**1:104–110.
104. Rovetta A, Bejczy AK, Sala R. Telerobotic surgery: Applications on human patients and training with virtual reality. *Stud Health Technol Inform* **1997;** 39:508–517.
105. Satava RM. 3-D vision technology applied to advanced minimally invasive surgery systems. *Surg Endosc* **1993;**7:429–431.
106. Satava RM. Virtual reality and telepresence for military medicine. *Ann Acad Med Singapore* **1997;**26: 118–120.
107. Schennib H, Bastawisy A, McLoughlin J, et al. Robotic computer assisted telemanipulation enhances coronary artery bypass. *J Thorac Cardiovasc Surg* **1999;**117:310–313.
108. Chodroff, PH. A three year review of telemedicine at the community level-clinical and fiscal results. *J Telemed Telecare* **1999;**5:S128–30.
109. Couturier P, Tyrrell J, Tonetti J, Rhul C, Woodward C, Franco A. Feasibility of orthopaedic teleconsulting in a geriatric rehabilitation service. *J Telemed Telecare* **1998;**4:85–87.
110. Aarnio P, Lamminen H, Lepisto J, Alho A. A prospective study of teleconferencing for orthopaedic consultations. *J Telemed Telecare* **1999;**5:62–66.
111. Tachakra S, Hollingdale J, Uche CU. Evaluation of telemedical orthopaedic specialty support to a minor accident and treatment service. *J Telemed Telecare* **2001;**7:27–31.
112. Bowersox JC, Shah A, Jensen J, et al. Vascular applications of telepresence surgery: Initial feasibility studies in swine. *J Vasc Surg* **1996;**23:281–287.
113. Endean ED, Mallon LI, Minion DJ, Kwolek CJ, Schwarcz T. Telemedicine in vascular surgery: Does it work? *Am Surg* **2001;**67:334–341.
114. Deaton DH, Balch D, Kesler C, Bogey W, Powell CS. Telemedicine and endovascular aortic grafting. *Am J Surg* **1999;**177:75–77.
115. Sclafani AP, Heneghan C, Ginsburg J, Sabini P, Stern J, Dolitsky JN. Teleconsultation in otolaryngology: Live versus store and forward consultations. *Otolaryngol Head Neck Surg* **1999;**120:62–72.
116. Stern J, Heneghan C, Sclafani AP, Ginsburg J, Sabini P, Dolitsky JN. Telemedicine applications in otolaryngology. *J Telemed Telecare* **1998;**4:S74–75.
117. Pederson S, Hartvisken G, Haga D. Teleconsultation of patients with otorhinolaryngologic conditions: A telendoscopic pilot study. *Arch Otolaryngol Head Neck Surg* **1994;**120:133–136.
118. Furukawa M, Furudawa MK, Mizojiri G, Matsuda H. Telemedicine in laryngology. *Telemed J* **1998;**4: 329–333.
119. Burgess L, Holtel MR, Syms MJ, Birkmire-Peters DP, Peters LJ, Mashima PA. Overview of telemedicine applications for otolaryngology. *Laryngoscope* **1999;** 109:1433–1437.
120. Hattori A, Suzuki N. Proceedings of the 22nd Annual EMBS International Conference: Tele-Virtual Surgery With Sharing Tactile Sensations Between Japan and Germany. 2000.
121. Satava RM. Information age technologies for surgeons: Overview. *World J Surgery* **2001;**25:1408–1411.
122. Karp WB, Grigsby RK, McSwiggan-Hardin M, Pursley-Crotteau S, Adams L, Bell W, Stachura M, Kanto WP. Use of telemedicine for children with special health care needs. *Pediatrics* **2000;**105:843–847.
123. Gray JE, Safran C, Davis RB, Pompilio-Weitzner G, Stewart JE, Zaccagnini L, Pursley D. Baby carelink: Using the internet and telemdicine to improve care for high risk infants. *Pediatrics* **2000;**106:1318–1324.
124. Whitten PJ, Cook D. School-based telemedicine: Using technology to bring health care to inner-city children. *J Telemed Telecare* **1999;**5:S23–25.
125. Williams A, Doolittle GC, Cook D. An estimation of costs for a pediatric telemedicine practice: Results from the TeleKidcare experience. *Telemed e-Health* **2001;**7(2):99.
126. Kofos D, Pitetti R, Orr R, Thompson A. Telemedicine in pediatric transport. *Pediatrics* **1998;**102:5.
127. Crouch R, Patel A, Williams S, Dale J. An analysis of telephone calls to an inner-city accident and emergency department. *J R Soc Med* **1996;**89:324–328.
128. Pert JC, Furth TW, Katz HP. A 10-year experience in pediatric after-hours telecommunications. *Curr Opin Pediatr* **1996;**8:181–187.
129. Roth A, Malov N, Carthy Z, Golovner M, Naveh R, Alroy I, Kaplinsky E, Laniado S. Potential reduction of costs and hospital emergency department visits resulting from prehospital transtelephonic triage—The Shahal experience in Israel. *Clin Cardiol* **2000;** 23:271–276.
130. Scott WW Jr, Bluemke DA, Mysko WK, Weller GE, Kelen GD, Reichle RL, Weller JC, Gitlin JN. Inter-

pretation of emergency department radiographs by radiologists and emergency medicine physicians: Teleradiology workstation versus radiograph readings. *Radiology* **1995;**195:223–229.
131. Eng J, Mysko WK, Weller GE, Renard R, Gitlin JN, Bluemke DA, Magid D, Kelen GD, Scott WW Jr. Interpretation of emergency department radiographs: A comparison of emergency medicine physicians with radiologists, residents with faculty, and film with digital display. *AJR* **2000;**175:1233–1238.
132. Lee JK, Renner JB, Saunders BF, Stamford PP, Bickford TR, Johnston RE, Hsaio HS, Phillips ML. Effect of real-time teleradiology on the practice of the emergency department physician in a rural setting: Initial experience. *Acad Radiol* **1998;**5:533–538.
133. Smith RS. Telemedicine and trauma care. *South Med J* **2001;**94:825–829.
134. Aucar J, Granchi T, Liscum K, Wall M, Mattox K. Is regionalization of trauma care using telemedicine feasible and desirable? *Am J Surg* **2000;**180:535–539.
135. Lambrecht CJ. Telemedicine in trauma care. *Telemed Today* **1998;**6:25.
136. Boulanger B, Kearney P, Ochoa J, Tsuei B, Sands F. Telemedicine: A solution to the followup of rural trauma patients? *J Am Coll Surg* **2001;**192:447–452.
137. Benger J. A review of minor injuries telemedicine. *J Telemed Telecare* **1999;**5:S3:S5–13.
138. Tachakra S, Wiley C, Dawood M, Sivakumar A, Dutton D, Hayes J. Evaluation of telemedical support to a free-standing minor accident and treatment service. *J Telemed Telecare* **1998;**4:140–145.
139. Meltzer B. Telemedicine in emergency psychiatry. *Psychiatr Serv* **1997;**48:1141–1142.
140. Hui E, Woo J, Hjelm M, Zhang YT, Tsui HT. Telemedicine: A pilot study in nursing home residents. *Gerontology* **2001;**47:82–87.
141. Ellis DG, Mayrose J, Jehle DV, Moscati RM, Pierluisi GJ. A telemedicine model for emergency care in a short-term correctional facility. *Telemed J e-Health* **2001;**7:87–92.
142. Chi CH, Chang I, Wu WP. Emergency department-based telemedicine. *Am J Emerg Med* **1999;**17: 408–411.
143. Ljosland M, Weydahl PG, Stumberg S. [Prehospital ECG reduces the delay of thrombolysis in acute myocardial infarction]. *Tidsskr Nor Laegeforen* **2000;**120: 2247–2249.
144. Mobile BAT gets stroke victims to hospital. *Telemed Virtual Real* **1998;**3:36.
145. Houtchens BA, Clemmer TP, Holloway HC, Kiselev AA, Logan JS, Merrell RC, Nicogossian AE, Nikogossian HA, Rayman RB, Sarkisian AE, et al. Telemedicine and international disaster response. Medical consultation to Armenia and Russia via a Telemedicine Spacebridge. *Prehospital Disaster Med* **1993;**8:57–66.
146. Koval T, Dudziak M. MediLink: A wearable telemedicine system for emergency and mobile applications. *Stud Health Technol Inform* **1999;**64:93–107.
147. Schachinger U, Kretschmer R, Neumann C, Nerlich M. NOAH. A mobile emergency care system. Notfall-Organisations-und Arbeitshilfe. *Stud Health Technol Inform* **1999;**64:85–92.
148. Grigsby J, Barron PL, Kaehny MM, et al. *Analysis of expansion and access to care through use of telemedicine and mobile health services*. Denver: Center for Health Policy Research, **1994.**
149. Solheim K. Emergency medicine and telemedicine. *Tidsskr Nor Laegeforen* **1999;**110:936–937.
150. Brennan JA, Kealy JA, Gerardi LH, Shih R. A randomized controlled trial of telemedicine in an emergency department. *J Telemed Telecare* **1998;**4(Suppl 1):18–19.
151. Brennan JA, Kealy JA, Gerardi LH, Shih R, Allegra J, Sannipoli L, Lutz D. Telemedicine in the emergency department: A randomized controlled trial. *J Telemed Telecare* **1999;**5:18–22.
152. O'Connell JM, Stanley JL, Malakar CL. Satisfaction and patient outcomes of a telephone-based nurse triage service. *Manage Care* **2001;**10:55–56, 59–60, 65.
153. Tachakra S, Loane M, Uche CU. A follow-up study of remote trauma teleconsultations. *J Telemed Telecare* **2000;**6:330–334.
154. O'Connell JM, Johnson DA, Stallmeyer J, Cokingtin D. A satisfaction and return-on-investment study of a nurse triage service. *Am J Manage Care* **2001;**7: 159–169.
155. Benger J, Lock A, Cook J, Kendall J. The effect of resolution, colour depth and display modality on the accuracy of accident and emergency telemedicine. *J Telemed Telecare* **2001;**7:1:6–7.
156. Tachakra S. Depth perception in telemedical consultations. *Telemed J e-Health* **2001;**7:77–85.
157. Kollberg H. Cystic fibrosis—An ancient disease with renewed topicality. History and clinical practice. *Lakartidningen* **1999;**96:3324–3329.
158. Hambraeus L, Tylleskar T, Zeisel S, Kollberg H, Fagerlund A. Nutrition in a new millennium. IT—for integrated teaching. *Lakartidningen* **2000;**97:2496.
159. Magrabi F, Lovell NH, Celler BG. IEEE Conference: Methodology for Designing Telecare Systems: A Case Study in Cystic Fibrosis Monitoring, Washington, D.C., 2000
160. Sprauer CD. Letter to the Editor. *Telemed J* **1997;**3:189.
161. Kollberg H, Lidman R. Centralization or more money to health care services? A third way—Use the technology! *Lakartidningen* **2001;**98:855–856.
162. Nakamura K, Takano T, Akao C. The effectiveness of videophones in home healthcare for the elderly. *Med Care* **1999;**37:117–125.
163. Abboud S, Bruderman I. Assessment of a new transtelephonic portable spirometer. *Thorax* **1996;**51: 407–410.
164. Finkelstein J, Hripcsak. Telematic system for monitoring of asthma severity in patients' homes. *Medinfo* **1998;**1:72–276.
165. Tsang MW, Kam G, Jung M, Tang A, et al. Improvement in diabetes control with a monitoring system based on handheld, touch screen electronic diary. *J Telemed Telecare* **2001;**7:47–50.
166. Johnston B, Wheeler L, Deuser J, Sousa KH. Out-

comes of the Kaiser Permanente tele-home health research. *Arch Fam Med* **2000**;9:40–45.
167. Lee RG, Chen HS, Lin CC. Home telecare system using cable television plants—An experimental field trial. *IEEE Trans Inf Technol Biomed* **2000**;4:37–42.
168. Chan WM, Woo J, Hui E, Hjelm NM. The role of telenursing in the provision of geriatric outreach services to residential homes in Hong Kong. *J Telemed Telecare* **2001**;7:38–46.
169. Allen A, Doolittle GC, Boysen CD, Komoroski K, Wolf M, Collins B, Patterson JD. An analysis of the suitability of home health visits for telemedicine. *J Telemed Telecare* **1999**;5:90–96.
170. Roehrig H. Image quality assurance for CRT display systems. *J Digital Imaging* **1999**;12:1–2.
171. Roehrig H, Blume H, Ji TL, Browne M. Performance tests and quality control of cathode ray tube displays. *J Digital Imaging* **1990**;3:134–145.
172. Roehrig H. Image quality control of displays for the PACS environment. In: Lemke HU, Vannier MW, Inamura K, Farman AG, eds. *Computer assisted radiology and surgery '98*. New York, NY: Elsevier, **1998**; 337–342.
173. Kalyanpur A, Neklesa V, et al. Evaluation of JPEG and wavelet compression of body CT images for direct digital teleradiologic transmission. *Radiology* **2000**;217:772–779.
174. Chen, C. Jian, J, et al. Wavelet based compression of pathological images for telemedicine applications. *Proc SPIE Med Imaging* **2000**;3980:113–122.
175. Cabral J, Linker D, Kim, Y. Ultrasound telemedicine system supporting compression of pre-scan converted data. *Proc SPIE Med Imaging* **2000**;3976: 350–358.
176. Marcelo A, Fonetlo P, et al. Effect of image transmission on telepathology: A randomized clinical trial. *Arch Pathol Labo Med* **2000**;124:1653–6.
177. Okumura A, Suzuki J, Furukawa I, Ono S, Ashihara T. Signal analysis and compression performance evaluation of pathological microscopic images. *IEEE Trans Med Imaging* **1997**;16:701–710.
178. Krupinski EA. Practical applications of perceptual research. In: Beutel J, Kundel HL, Van Metter RM, eds. *Handbook of medical imaging: Physics and psychophysics*. Bellingham, WA: SPIE Press, **2000**: 895–929.
179. Kundel HL. Visual search in medical images. In: Beutel J, Kundel HL, Van Metter RM, eds. *Handbook of medical imaging: Physics and psychophysics*. Bellingham, WA: SPIE Press, **2000**:837–858.
180. Krupinski EA. The importance of perception in medical research. *Radiat Med* **2000**;18:329–334.
181. Hirschorn D, Hinrichs C, et al. Impact of a diagnostic workstation on workflow in the emergency department at a level 1 trauma center. *J Digital Imaging* **2001**;14:199–201.
182. Krupinski E, Radvany M, Levy A, et al. Enhanced visualization processing: Effect on workflow. *Acad Radiol* **2001**;8(11):1127–1133.
183. Kayser K, Kayser G. Basic aspects of and recent development in telepathology in Europe, with specific emphasis on quality assurance. *Anal Quant Cytol Histol* **1999**;21:319–328.
184. Lund PJ, Krupinski EA, Pereles S, Mockbee B. Comparison of conventional and computed radiography: Assessment of image quality and reader performance in skeletal extremity trauma. *Acad Radiol* **1997**;4:570–576.
185. Dunn BE, Choi H, Almagro UA, Recla DL, Krupinski EA, Weinstein RS. Routine surgical telepathology in the Department of Veterans Affairs: Experience-related improvements in pathologist performance in 2200 cases. *Telemed J* **1999**;5:323–337.
186. Larson A, Lynch DA, Zeligman B. Accuracy of diagnosis of subtle chest disease and subtle fractures with a teleradiology system. *AJR* **1998**;170:19–22.
187. Kroeker KI, Diamond R, Jennett PA, Johnston RV. Video-capture teleradiology for the after-hours reading of computerized tomography scans. *J Telemed Telecare* **2000**;6:229–232.
188. Oberbarnscheidt P, Hufnagl P, Guski H, Hauptmann S, Dietel M. Analysis of errors in telepathology. *Electronic J Pathol Histol* **2000**;6:109–121.
189. Krupinski EA, Gonzales M, Gonzales C, Weinstein RS. Evaluation of a digital camera for acquiring radiographic images for telemedicine applications. *Telemedicine J e-Health* **2000**;6:297–302.
190. Winokur TS, McClellan S, Siegal GP, Redden D, Gore P, Lazenby A, et al. Prospective trial of telepathology for intraoperative consultation: frozen sections. *Hum Pathol* **2000**;31:781–785.
191. Nodine CF, Mello-Thoms C. The nature of expertise in radiology. In: Beutel J, Kundel HL, Van Metter RM, eds. *Handbook of medical imaging: Physics and psychophysics*. Bellingham, WA: SPIE Press, **2000**: 859–894.
192. Krupinski EA. Medical image perception: Evaluating the role of experience. *Proc SPIE Human Vision Electronic Imaging V* **2000**;3959:281–289.
193. Krupinski EA, Weinstein RS, Rozek LS. Experience-related differences in diagnosis from medical images displayed on monitors. *Telemed J* **1996**;2:101–108.

Address reprint requests to:
Rashid L. Bashshur, Ph.D.
Director of Telemedicine
The University of Michigan Health System
C201 Medinn Building
1500 East Medical Center Drive
Ann Arbor, MI 48109–0825

E-mail: bashshur@umich.edu

Chapter 3

Public Health Applications

Contributors:

Stephen Kopp, Ph.D., Central Michigan University
Robert Shuchman, Ph.D., Altarum, Ann Arbor, Michigan
Victor Strecher, Ph.D., University of Michigan
and
Mamadou Gueye, M.D., University Cheikh Anta Diop, Dakar, Senegal
Jerry Ledlow, Ph.D., Central Michigan University
Tina Philip, MHSA, University of Michigan
Alison Grodzinski, MLIS, Central Michigan University

INTRODUCTION

THIS CHAPTER DESCRIBES telemedicine/telehealth applications in public health, including epidemiologic surveillance, remote sensing, geographic information systems, and health promotion/disease prevention. The work summarized here reflects recent developments in this field at the national and international levels. In addition, suggestions are presented for future research and planning and policy priorities related to dominant, emerging issues in public health.

Information technology has provided the means for integrating and analyzing diverse data sources in a spatial-temporal context. This approach supports the development of predictive models and timely intervention. Online media capabilities and the increasing number of application portals provide opportunities for governments, health care organizations, businesses, and individuals to devise creative solutions to persistent health problems of individuals, communities, nations, and the world.

The realities of differing socioeconomic, educational, cultural, health, and medical care systems, however, must provide the contextual basis for assessing the potential benefits that can be realistically achieved through the use of information technology and the problems of its use. These variations apply to geographic regions and population segments in the United States as they do to various countries. Indeed, the fundamental public health challenge ahead is to transform information, specifically unfiltered and widely available health information, into knowledge that can be used to promote the health and well-being of people globally.

EPIDEMIOLOGIC SURVEILLANCE

Epidemiologic surveillance is advancing rapidly, both in terms of international collaboration through integrated global health networks and through the development of sophisticated monitoring technologies. The growing use of geo-encoded information and geographic information systems (GIS) is transforming spatial analysis and mapping in epidemiology.[1,2] For example, GIS is being used in a variety of research efforts:

1. Geographical distribution and gradients in disease prevalence and incidence.
2. Geospatial and longitudinal disease trends.
3. Identification of differential populations at-risk based on risk factor profiles.

4. Differentiating and delineating risk factors within a population.
5. Population health assessment.
6. Intervention planning; assessment of various intervention strategies and their effectiveness.
7. Anticipating epidemics.
8. Real-time monitoring of diseases, locally and globally.

GIS can be used with new applications to augment planning, monitoring, analysis, and research capabilities in public health. GIS facilitates the standardization and integration of diverse data resources, and it permits the management and convergence of various disease surveillance activities.

Epidemiologic surveillance contains information on the incidence and prevalence of diseases, relevant demographic data, physical environment profiles, geo-referenced acute and chronic disease patterns within a defined population or defined geographic area that, together with a variety of ecological and socioeconomic factors, might account for these trends. These data sets can be amalgamated into a common data set for efficient multivariate analysis, trend analysis, and the search for causes.

A GIS-based method for acquiring, retrieving, analyzing, and managing data differs from traditional modes of disease surveillance and reporting. It facilitates the aggregation and integration of disparate data from diverse sources so it can guide the formulation of public health programs and policy decisions.

As shown in Figure 1, any disease entity can typically be depicted as having multiple etiologies and risk factors, and can point to a multicausal disorder with various health consequences and socioeconomic implications. Possible data sources for such model include existing literature, geo-encoded health status databases, environmental information obtained through GIS, health system utilization patterns, and clinical signs and symptoms, all within a defined population[1,2] or geographic area. In addition, geo-encoded information (not depicted in Fig. 1) from supermarkets, pharmacies, and other relevant retailers, as part of a comprehensive community network, would allow monitoring of purchase patterns for such items as prescription drugs, over-the-counter medications, dietary supplements, food, and other consumables. Aggregating these data with risk factor statistics and other health information could guide strategic community health interventions and planning initiatives. Figure 1 depicts how these complex data sources can be integrated via a multifaceted software "integrator."

A comprehensive surveillance system of this type facilitates the monitoring and tracking of various health risk factors in the population, and it can suggest ways of reducing such risk. The resulting information provides multifactorial evidence to guide decision-making and effective public health strategies.

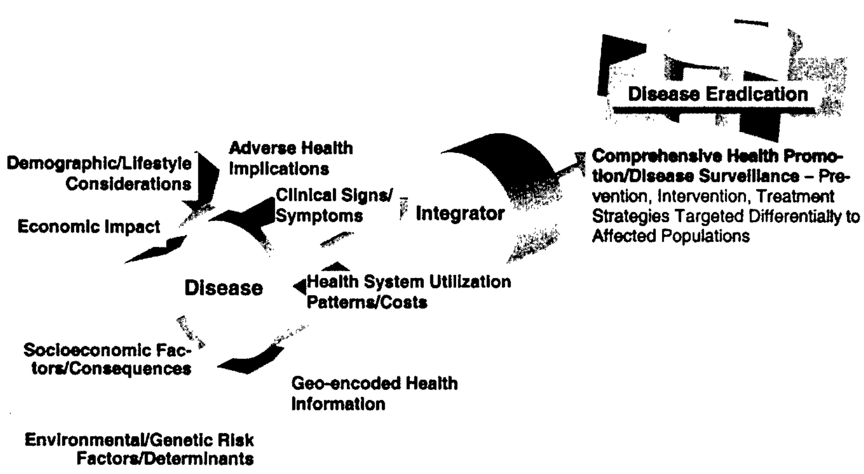


FIG. 1. A hypothetical model for disease surveillance and policy action.

VECTOR-BORNE DISEASE DECISION SUPPORT, GIS, AND REMOTE SENSING

The relationship among environmental factors, such as climatic change and vector-borne disease (VBD) outbreaks, is an area of increasing importance at regional, national, and international levels. Both traditional and emerging infectious diseases continue to pose threats worldwide, at least in part, because of frequent and rapid international travel. Observed and predicted climatic changes, too, have increased the need to understand the relationships between infectious disease and climatic and geographic regimes as changes in vegetation, industrial pollution, and other ecological factors have created or altered habitats for vector borne diseases.

Vector-Borne Disease Decision Support Systems

The basic components of a vector-borne disease decision support systems (VBDDSS) consist of geophysical information derived from remote sensing data and *in situ* sensors, as shown in Figure 2. This system can fulfill several functions:

- Accept remotely sensed data and apply the algorithms for estimating habitat conditions from satellite data.
- Provide the ability to incorporate online sources of information, such as socioeconomic data, other archived data, or data collected in near real-time *in situ*.
- Contain regional baseline environmental GIS databases, as appropriate.

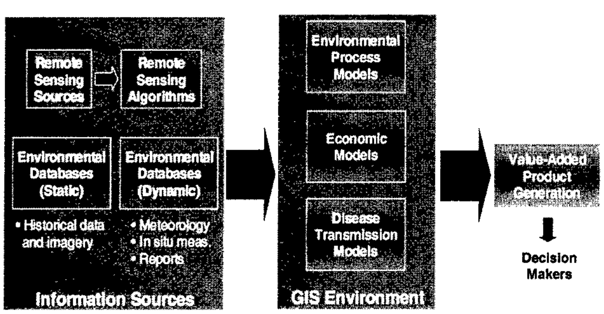


FIG. 2. A vector-borne disease decision support system.

- Use these data and derived parameters as inputs to process models that predict future conditions.
- Integrate the results to generate map-like, value-added products tailored to user requests.

Benefits of this system include facilitating development of cause-and-effect relationships between parameters as well as simulating contingencies.

GIS

GIS provides the basic architecture and analytic tools to perform spatial–temporal modeling of climate, environment, disease transmission, and other factors helpful in understanding the spread of vector borne diseases. Remote sensing provides the environmental input into these models. With a remote sensing component, GIS could significantly improve the management of vector borne disease events by providing:

- Predictive capabilities based on climate and environmental models;
- Remediation measures through rapid and efficient allocation of resources; and
- Preventive methods by providing the ability to evaluate scenarios.

The discussion here focuses on the development of a GIS-based decision support system. Information management has four distinct phases: (1) data collection; (2) information extraction; (3) information synthesis (modeling); and (4) decision support. Data collection involves data acquisition and processing. Data sources can be imagery, *in situ* measurements, and reports or communications from the field regarding prevailing conditions. In the information extraction phase, the data are examined to obtain the desired information, such as geophysical parameters or environmental conditions. This information, in turn, supports and sustains the synthesis or modeling phase. In this phase, decision makers can modify the model parameters and develop alternative scenarios to test and, when necessary, alter or develop better informed action plans.

GIS provides the ability to analyze information in a geographic context by spatially registering data within a single processing environment. Historically, GIS has been used as a "map-maker." However, in recent years, the power of GIS as an analytical tool has grown substantially. Capabilities include interactive visualization, analysis of spatial data, and custom modeling for special applications. The value of GIS for VBD applications is its ability to integrate disparate sets of data. It supports multidisciplinary analysis and enables the prediction of disease outbreaks.

A number of issues must be considered when developing GIS, including data quality, confidentiality, and methodological pitfalls.[3] The currency and completeness of data incorporated into the system must be maintained. The scales of data used must be appropriate for the model or application they support. For example, 1-km imagery will not be appropriate for mapping wetlands and likewise, a 1:5000 land cover GIS is not necessary for climate modeling. Investigators must acquire correct data at appropriate and corresponding scales. Methods must be developed to ensure that no individual will be identified through hospital records or through isolated cases, which allow personal identification.

Remote sensing

Space-based imaging systems are commercially available. Some imagery, such as the Advanced Very High-Resolution Radiometer (AVHRR) sensor carried on the National Oceanic and Atmospheric Administration's orbiting satellites, can be downloaded from the Internet. Others, such as Canada's RADARSAT, must be purchased at a per-scene basis.

The sensors work in different regions of the electromagnetic spectrum—radar, near infrared, through the optical bands. Similarly, the spatial resolutions vary widely—from kilometers (AVHRR) to 4 m and less (1-m images can be obtained from Space Imaging's IKONOS satellite). Unlike satellite-based sensing systems, aerial systems usually offer the benefit of higher spatial resolution (each image pixel represents a smaller piece of the ground). They do this, however, at the expense of less ground coverage and the often-challenging logistics associated with aerial collection.

Development of algorithms for converting remote sensing signatures to physical measurements has been going on since the first satellite sensors were launched in the early 1970s. The algorithms fit into four general categories: (1) direct extraction; (2) time-series analysis; (3) spectral feature analysis; and (4) data assimilation techniques.

Direct extraction involves manual or automated approaches to converting imagery signatures to a geophysical value. For example, multispectral imagery can produce accurate land cover/land use maps using a combination of supervised classification algorithms and manual refinement. Time series analysis involves identifying the change between two images collected over the same area at different times. It can identify changes in land use patterns in an automated manner by looking for cues regarding the cause(s) of the change. Spectral feature analysis is the generation of linear combinations of spectral bands to form intuitive metrics, such as "wetness" and "greenness," rather than simply a radiometric value for a specific optical band. Examples of these techniques include Tasseled Cap[4] and the Normalized Difference Vegetation Index.[5] More recently, the concept of data assimilation has emerged to produce the next generation of algorithms. This iterative process combines imagery with proven process models to estimate geophysical properties.

Many disease vectors cannot be observed directly. However, the presence of the vector, or the conditions under which the vector thrives, can be inferred through such indicators as habitat or habitat change. For example, flooded pastures observed in multispectral or Synthetic Aperture Radar (SAR) imagery may indicate increased potential for mosquito breeding as demonstrated in Kenya.[6]

Remote sensing alone will not provide all the necessary information for detecting or predicting the effects of VBDs, but a number of studies (Table 1) have demonstrated the potential for correlating remotely derived information to VBD outbreaks. For example, Colwell[7] showed significant correlation between sea surface temperature and a cholera outbreak in Bangladesh.

TABLE 1. RESEARCH USING REMOTE SENSING DATA TO MAP DISEASE VECTORS

Disease	*Vector*	*Location*	*Sensor*
Cholera	Water/food supply	USA, Latin America	Ocean Color Scanner (now SeaWiFS)
Cholera	Water/food supply	Bay of Bengal	AVHRR
Dracunculiasis	*Cyclops* spp.	Benin, Nigeria	TM
Eastern equine encephalomhelitis	*Culiseta melanura*	Florida, USA	TM
Filariasis	*Culex pipiens*	Egypt	TM, AVHRR
Leishmaniasis	*Phlebotomus papatasi*	SW Asia	AVHRR
Lyme disease	*Ixodes scapularis*	New York, USA	TM
Lyme disease	*I. scapularis*	Wisconsin, USA	TM
Malaria	*Anopheles albimanus*	Mexico	TM
Malaria	*An. albimanus*	Belize	SPOT
Malaria	*An.* spp.	Gambia	AVHRR, Meteosat
Rift Valley fever	*Aedes* & *Cx.* spp.	Kenya	AVHRR
Rift Valley fever	*Cx.* spp.	Kenya	TM, SAR
Rift Valley fever	*Cx.* spp.	Senegal	SPOT, AVHRR
Schistosomiasis	*Biomphalaria* spp.	Egypt	AVHRR
Trypanosomiasis	*Glossina* spp.	Africa	AVHRR
Trypanosomiasis	*Glossina* spp.	Kenya	TM

AVHRR, Advanced very high resolution radiometer; SAR, Synthetic aperture radar; SPOT, Satellite pour l'observation de la terre (French); TM, Thematic mapper.

AVHRR imagery was used to produce 1-km spatial resolution temperature maps of the Bay of Bengal, and these temperatures were compared with reported cholera cases. Another study[8] demonstrated how landscape elements could be used to predict mosquito abundance and subsequent malaria outbreaks in Mexico. In this study, Landsat imagery was used to produce land cover maps that were correlated with mosquito populations to identify the statistical landscape conditions most likely to have the highest mosquito abundance.

The characteristics of the data source (resolution, revisit time, availability) as well as the maturity of the algorithms (amount of validation), both play a key role in the value of an algorithm for vector borne disease application.

A summary of existing commercial satellite systems is provided in Table 2. This is not a comprehensive list of commercial satellite systems, but rather a list of those that could support the algorithms useful in VBD research.

The rapid development and proliferation of commercial satellite imaging systems is providing new sensors that deliver better resolution and more spectral bands of information. For example, RADARSAT 2 will provide SAR imagery at a nominal resolution of 3 m, versus

TABLE 2. SELECTED EXTANT COMMERCIAL SATELLITE SYSTEMS

Sensor	*First launch*	*Bands*	*Number of spectral bands*	*Nominal spatial resolution*	*Swath size (km)*
Landsat MSS/TM	1972/1987	MS	7	80 m/30 m	185
Landsat ETM+	1999	Pan/MS	7*	13 m Pan/25 M MS	185
SPOT	1986	MS	4*	10 m Pan/20 M MS	60
IRS	1988	MS	4–6*	6 m Pan/23 m MS	148
IKONOS	1999	MS	4*	1 m Pan/4 m MS	11
RADARSAT	1995	C-band SAR	1	10–100 m	45–500
ERS1/2	1991	C-band SAR	1	12/5–100 m	100
SeaWiFS	1997	MS	8	1000 m	2800
AVHRR		MS	4	1100 m	2399
Terra	2000	MS	14	15/30/90 m VNIR/SWIR/TIR	60
MODIS	2000	MS	36	250–1000 m	2330

AVHRR, Advanced very high resolution radiometer.

10 m for RADARSAT, and will be useful for identifying areas of standing water. Forthcoming commercial hyperspectral sensors such as Orb View 4 may provide improved real-time performance of existing multispectral algorithms, and will support new approaches to solving key information requirements related to geology, hydrology, agriculture, and air quality.

The DSS event management system

The decision support system discussed here can be a component of a larger event management system as shown in Figure 3. It comprises four stages: (1) planning, (2) mitigation, (3) response, and (4) recovery/preparedness.

In the planning stage, the DSS provides the ability to monitor environmental conditions and habitats and perform environmental forecasts. If conditions were determined to be conducive to VBD development, the mitigation stage is entered where the DSS will perform a series of modeling activities based on the planning inputs. This will help decision makers develop mitigation plans for a pending outbreak. These plans include not only environmental and health forecasts but also economic and resource forecasts.

Based on the forecasts, decision makers can formulate a response that reduces the impacts of the VBD. In this stage, the infected are cared for, vector elimination programs begin, and the public is alerted to the presence of an outbreak. In the last stage of recovery/preparedness, the environment is restored, potentially harmful material is removed (such as tires in the case of Rift Valley fever), and hospital inventories are stocked with appropriate supplies. This four-stage process is essentially iterative. Through experience and identified shortcomings, the models can be improved, thereby ultimately improving the management of future VBD threats and events.

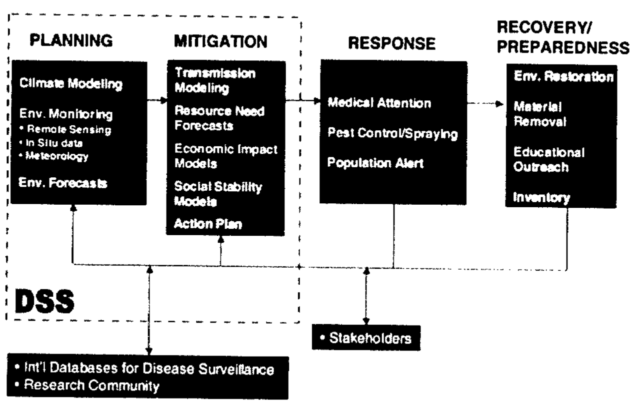


FIG. 3. Decision support systems (DSS) as part of comprehensive event management system.

In brief, effective VBD management requires simultaneous consideration of environmental, socioeconomic, and anthropogenic factors. GIS provides the infrastructure for an end-to-end VBD decision support system for monitoring and responding to the critical phases of VBD. Remote sensing can provide environmental information and support larger scale models. The VBDDSS could significantly enhance the ability of local, national, and international communities and governmental organizations to plan for future outbreaks. A VBDDSS would not only benefit the stakeholder community but would also provide valuable analytic capabilities in other related domains such as biosurveillance and health care forecasting.

INTERACTIVE HEALTH COMMUNICATION FOR HEALTH PROMOTION AND DISEASE PREVENTION

This final section is devoted to the use of information technology to inform, influence, and motivate individuals, populations, and organizations on health, health-related issues, and the adoption of healthy lifestyles. The various approaches and applications can advance and support primary, secondary, and tertiary health promotion and disease prevention agendas. The efficacy, as it relates to the actual value of these applications, however, is yet to be determined.

In general, the design of the various modalities, such as content organization, media support, and methods, is predicated on various cognitive and behavioral theories, models, and evidence. Collectively, these concepts parallel the considerations involved in the genesis of effective distance-education programs, which is a similarly emerging and dynamic field of endeavor.

Health literacy and knowledge are necessary for achieving personal responsibility for health and greater health self-management and empowerment. Whereas access to information is now within reach, people's ability to search, filter and manage health information effectively continues to be a major societal challenge. Figure 4 summarizes and illustrates some of the essential considerations and steps to achieve this objective.[9]

Elevating health knowledge and literacy of the public poses local, national, and international challenges of vast complexity and proportion.[10] An illustration depicting some of the patterns of interactivity and expectations that might be considered in developing interactive communication applications is shown in Figure 5. This diagram brings attention to various factors that are likely to have significant influence over the use and effective deployment of information health communication (IHC) applications, as will be explained.

The potential for IHC applications to influence personal and population health services is substantial. The key areas that should be monitored and studied include the effect on patient care, and patient relationships with clinicians and health care providers, health care systems, and public health systems. The potential for incorporating information-processing programs that can operate autonomously and adapt to the needs of users remains largely undetermined. Similarly, data-mining and expert software systems hold promise that has yet to be fully realized.

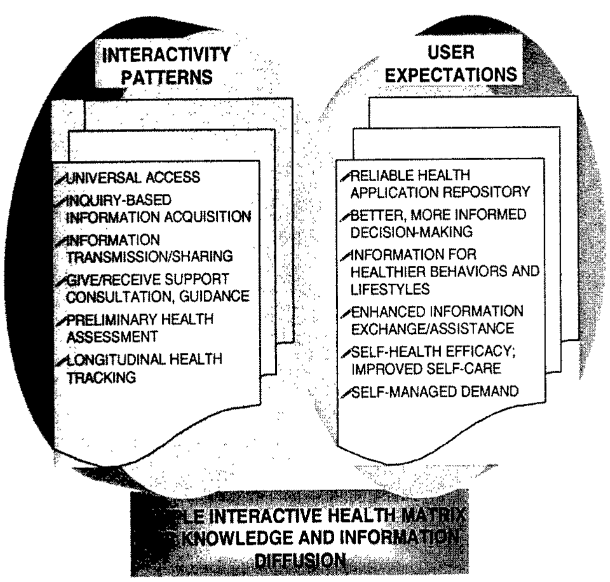


FIG. 4. Interactive Health Communications.

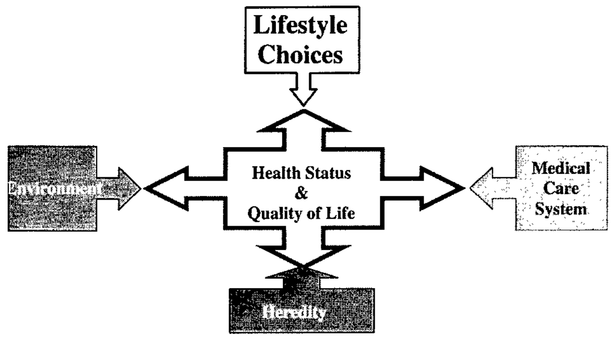


FIG. 5. Relationship between health status and risk factors.

IHC CHALLENGES

The U.S. Science Panel on Interactive Communication and Health[11] prepared a blueprint for addressing the extensive potential that IHC possesses for improving people's health. The scope and breadth of the challenges involved mirror those of distance education and e-learning. They include the design of courseware for Web-based education and the development of interactive health programs that meet the needs of the user. For instance, the demand for customization of learning modules tailored to the way an individual student learns best parallels the demands of the health consumer, who expects applications that address his or her individual needs. And, of course, the cultural and linguistic contexts, not only the type or content of information, represent challenges at the international level.

There is limited research pertaining to the effectiveness of IHC and e-learning applications in the health sector. This precludes informed and definitive conclusions, particularly pertaining to lowering or containing health care costs, predictability, improved health outcomes, and awareness of alternative care decisions. In addition, evaluative norms, benchmarking and comparative approaches between telematics-based applications and approaches that are more traditional remain to be tested.

TABLE 3. INFORMATION HEALTH COMMUNICATIONS SYSTEMS CHARACTERISTICS

Intended major functions	*Factors influencing utilization*	*Major barriers to widespread use*	*Benefits to users*	*Risks to users*
Relay information—individualized health information on demand.	Increasing telecommunication and computing capacity—rapid advances in capacity, power, speed and transmission options present vast opportunity.	Health care provider resistance—perceived threat to professional autonomy and authority.	Improved access to individualized health information—interactive technologies offer potential for customization to support needs of specific groups.	Inappropriate treatment or delays in care—inaccurate/inappropriate information may confound or complicate treatment decisions and delay care.
Enable informed decision-making—applications dealing with health decisionmaking process and/or communication between health care providers and individuals (families, patients, caregivers, etc.) regarding prevention, diagnosis or management of a health condition.	Increasing computer literacy and access—exponential rise in users continues unabated; universal access still remains a destination and not a reality.	Lack of financial incentives to change behavior—without reimbursement providers have little incentive to encourage use of IHC.	Broader choice for users—media design flexibility enables mixing of text, audio, visual modalities tailored to learning style of users.	Damage to patient-provider relationship—inappropriate use of applications or information obtained may undermine trust and prompt conflicts and motivate consumers to seek care from questionable providers.
Promote healthy behaviors—applications promoting adoption and maintenance of positive health behaviors (individual/community).	Increasing consumer demand for health information and shared decision-making—demand fueled by array of factors including greater consumer involvement in medical/health decisions.	Lack of access to infrastructure and inability to utilize applications—barriers to access follow socioeconomic, geographic and other delimiters.	Potential improved anonymity of users—privacy of individuals accessing information can be protected, while improving quality of information.	Violations of privacy and confidentiality—unintended diffusion of sensitive information obtained through IHC interactions may lead to adverse consequences.
Promote peer information exchange and emotional support—examples include online Internet applications that enable individuals with specific health conditions, needs, or issues to communicate with each other, share information and provide/receive peer and emotional support.	Increasing emphasis on primary and secondary prevention—Major component of national health policy strategy; IHC may be effective tool for advancing this agenda.	Substantial implementation and maintenance costs—cost parallels degree of sophistication of the applications.	Greater access to health information and support on demand—applications accessible anywhere, anytime via the Internet.	Wasted resources and delayed innovation—absent cost-effectiveness data, applications may be implemented which drain resources, preventing development of improved systems.

(cont'd)

TABLE 3. INFORMATION HEALTH COMMUNICATIONS SYSTEMS CHARACTERISTICS (CONT'D)

Promote self-care—facilitate self-management of health problems or supplement existing health services by facilitating remote health monitoring and care.	Increasing trend to reduce cost of health care services—implementation of preventative health programming has potential for major cost savings (~90%).	Lack of convincing data on effectiveness—much more data are needed.	Ability to promote greater communication—potential to increase interaction and social support among users and between consumers and health professionals.	Unintended errors—assumptions in the development of more sophisticated applications may prove erroneous leading to unintended errors.
Manage demand for health services—specific information tool kits and other resources to support wellness, self-care and self-efficacy/advocacy to enhance effective utilization of health care services and reduce unnecessary services.	Increasing telecommunication and computing capacity—rapid advances in capacity, power, speed and transmission options present vast opportunity.		Expanded dissemination and currency of information—applications reach ever-increasing audience and updating of information is virtually immediate.	Widening of technology and health gap—failure to achieve universal information and technology literacy and access to Internet will lead to tiered system.

IHC, Information health communication.

Based on theoretical constructs and analysis, and evaluation, nevertheless, extensive opportunities exist in this field for research. Studies of this nature can improve IHC applications on a number of levels and establish the differential impact they can bring to improving personal and population health. Findings will influence the usefulness and efficacy of future generations of IHC applications and minimize the possibility of adverse consequences. In addition, evidence gathered through these processes will define and guide advances in the quality of future applications.

A basic question is whether the new modalities of IHC represent a simple repackaging of existing health-related and surveillance practices but in newer, enhanced media channels, or are they truly enhancing and advancing the practices of associated health profession disciplines. At issue is whether telehealth systems can synergistically integrate multifaceted intervention, prevention, assessment, and treatment to achieve improved personal, as well as local, national, and international community health. Telehealth operations that are confined to specific single purpose (but that share information) contribute to the ultimate health improvement goals.

Synergistic and value-seeking opportunities associated with telehealth require full-spectrum assessment, intervention, and evaluation of health status and outcomes of populations. Using aspects of lifestyle choices and behaviors as an illustrative example (Fig. 5) the question posed involves the extent to which telehealth applications that focus on serving a defined population actually operate across the continuum as contributors, integrators, or transintegrators.

INTERNATIONAL PUBLIC HEALTH

Since 1995, global health networks have given priority to six project areas for testing and advancing the goals of interoperability and standardization of global health networks. The principal project areas identified also have specific countries that are leading the coordination efforts. Table 4 summarizes key aspects of selected international collaboration among developed countries.

Demographic and economic similarities

TABLE 4. SELECTED INTERNATIONAL HEALTH NETWORK APPLICATIONS

Objectives	*Coordinating bodies*	*Targeted goal(s)*
Advance a global public health network	Canada, United States, European Commission, WHO	Improved access for health professionals and institutions to publicly available information pertinent to the outbreak and control of public health hazards and infectious diseases.
Focus on cancer—improve prevention, early detection, diagnosis and treatment through global networks.	Canada, France and the European Commission	Database linkages will be used to facilitate knowledge sharing concerned with best practice for disease prevention, screening, quality control and treatment, while facilitating discussion and consultation concerning strategies and treatment protocols among hospitals and health systems.
Focus on cardiovascular disease—improve prevention, diagnosis and treatment through global networks	Italy	Database linkages will be used to facilitate knowledge sharing concerned with best practice for disease prevention, screening, quality control and treatment, while facilitating discussion and consultation concerning strategies and treatment protocols among hospitals and health centers.
Omnipresent, multilingual telemedicine surveillance and emergency services	France and Italy	Determine feasibility of creating worldwide network of public and private telemedicine centers offering ever-present multilingual services.
Standardize and create fully operational, integrated global health networks	Germany, United Kingdom, European Commission, WHO	Establish requisite approaches to ensure consistent health nomenclature, standards, privacy and security of data and efficient access tools and online translation services.
Advance international use of digitally encoded health data cards (i.e., SMART cards	France and Italy	Assess feasibility of creating portable, interoperable solutions for encoding electronic health records on data cards.

WHO, World Health Organization.
Additional information can be found at www.dfait-maeci.gc.ca/english/geo/europe/medica/report-e.htm#2.2.

among developed nations suggest sets of common challenges that would benefit from collaboration internationally. For instance, the emphasis on national health policy agendas for health promotion and disease prevention makes exceptional sense in most developed countries. There are obvious differences, however, in terms of priorities with the health and disease outbreak challenges faced by developing nations. Therefore, although international collaboration in the development and advancement of global health networks is essential, national priorities and possibilities will vary for the foreseeable future. In addition, the dimensions of health and quality of life that such efforts are attempting to influence may need greater definition. For instance, health-related quality of life indicators encompass an array of determinants ranging from health perceptions, pathology indicators symptoms, and organ system functional capacity to individual preferences, attitudes, and values.[12]

In 1996, the Cooperative Health Information Network (CHIN) initiative followed soon after with the establishment of the first telemedicine networks in Europe. The principal objective was to develop organized, technologically accessible health information networks throughout Europe. The longer term objective was to link these networks to create comprehensive, integrated health tele-informatics systems that would provide broad information services to users.

RECOMMENDATIONS

The topics listed below are intended to serve as points of reference for initiating further analysis and discussion. They encompass various domains, and present an agenda for research and policy action. The basic assumption underlying these recommendations is that increased access to reliable health information from various sources will enable individuals and communities to take effective measures to prevent disease and promote health and well-being. While it is clear that progress has been made on a number of fronts, many of the recommendations presented by Bashshur in 1995[34] concerning the metrics for evaluating the effectiveness and sustainability of telehealth/telemedicine applications are still relevant.

Evaluation

- There is an important need to investigate the effectiveness and efficiency of computerized information and network systems for consumers in relation to their participation in health and health care-related activities.
- Decisions must be made regarding information monitoring, storing and standardization. Standardized protocols should be evaluated and defined when necessary.
- Strategies are needed that address national and international health and information literacy.
- Health self-efficacy, motivation, literacy, and knowledge levels of the general public will be an important determinant of the extent to which the personal responsibility for health becomes a reality. In addition, the determinants or criteria should be used as indicators of progress in this endeavor.
- Cultural differences must be identified pertaining to telemedicine/telehealth use and associated outcomes. Criteria should be established to determine best telehealth and telemedical practices within disparate demographic, cultural, and socioeconomic populations to assure sensitivity and respect for culture, social background, and ethnic differences.
- Health status benchmarks must be established to determine the extent to which telemedicine/telehealth utilization influences health outcomes, reporting (surveillance), interventions, and evaluations of health-related applications.

Cost

- Managing the rising cost of health care and finding ways to contain them continues to be a dominant force shaping the health care system everywhere. Hence, technology-enabled approaches to service delivery must be investigated fully. Indeed, services demanded/expected by consumers must be determined and the telemedicine applications evaluated on a cost/benefit basis.
- Comprehensive cost modeling must include assessment of the costs associated with digital permanence (storage, archiving, retrieval and maintenance of digital assets, i.e., data and consumer-owned information).

Quality

- A consensus operational definition and certification of service quality must be developed and enforced to protect consumers. Certification of network providers is an important consideration for protecting clients, particularly in terms of safety and privacy. Quality parameters are necessary and must be established so consumers can report problems.
- Benefits of telemedicine must be measured against established and tested baseline health indicators and benchmarks. These evidence-based approaches would serve as valuable indicators for the value and quality of service provided by participating networks.

Privacy/legal/security/ethical domains

- The Interdisciplinary Telehealth Standards Working Group has established a set of core standards to guide telemedicine services and resources. The intent of these principles is to protect clients receiving telehealth services, to give health care professions a common ground, and to provide a basis for reviewing professional standards, clinical standards, and the need for telehealth guidelines by professions and by government agencies.[35] They provide a useful context for considering future issues.
- The assumption has been that patient medical records, regardless of form, belong to the patient, yet physicians often retain patient records and charge for copying the record for the patient. Ownership of medical record information poses an interesting and important health policy issue that is distinct from

the issue of privacy. The question of ownership of digital information (created by individuals, either through the use of interactive health communication portals or through their own record keeping) must be resolved. As individuals take a more active role in monitoring their personal health and encode such information in their own health records, the ownership of this information must be resolved.

- Legal and ethical obligations of organizations offering interactive health information applications for the public must be determined and established to meet current and future demands.

Research

- A systematic and comprehensive research agenda must be developed and supported by government agencies and health care professions for the ongoing assessment of telemedical services. Cooperative public and private funding will be necessary to underwrite the scale and duration of research needed.
- Manpower development remains a critical issue and educational programs at colleges and universities must keep pace with the evolution of global health network systems and other telemedicine applications. Increased efforts must be directed at disease prediction and mobilization/intervention before the actual outbreaks of diseases

Technology

- The convergence and compression of data and information sources and resources poses an exceptional challenge. Effective strategies for creating secure network systems and data repositories that provide and protect continuous access and confidentiality must be developed.
- Telemedicine networks must be funded, managed, and administered to provide universal access.

Additional priority areas for consideration

- Telemedicine activity around the world is developing at a rapid pace. Although these projects are being developed in relation to the needs of a specific community, overlapping goals and activities do exist. Identification and indexing of all ongoing projects within the international community is an essential starting point. An international clearinghouse of telemedicine activity needs to be developed to promote and allow for resource sharing and effective collaborative efforts.
- Telemedicine operations and systems that use multidimensional health approaches and disciplines should be identified, and outcomes based on target population goals must be assessed quantitatively and qualitatively.
- Health applications most conducive to telemedicine operations based on providers of care, patients/customers, and employer perceptions and satisfaction variables must be identified.

REFERENCES

1. Richards TB, Croner CM, Rushton G, Brown CK, Fowler L. Geographic information systems and public health: Mapping the future. *Public Health Reports* **1999**;114:359–373.
2. Green J, Escobar F, Waters E, Williamson I. Research Agenda for Geographic Information Systems and Health, 1999. Australian Research Council's Special Research Initiatives Program.
3. Albert DP, Gesler WM, Levergood B, eds. *Spatial analysis, GIS, and remote sensing applications in the health sciences*, Chelsea, MI: Ann Arbor Press, **2000.**
4. Crist E, Cicone R. Application of the tasseled cap concept to simulated thematic mapper data. Photogrammetric Engineering & Remote Sensing **1984**;50: 343–352.
5. Kimes DS, Holben BN, Tucker CJ, Newcomb WW. Optimal directional view angles for remote-sensing missions. *Int J Remote Sensing* **1984**;5:887–908.
6. Pope KO, et. al. Identification of Central Kenyan Rift Valley Fever virus vector habitats with Landsat TM and evaluation of their flooding status with airborne imaging radar. *Remote Sensing of the Environ* **1992**;40: 185–196.
7. Colwell R, et. al., Remote sensing of cholera outbreaks, Center for Health Applications of Aerospace Related Technologies (CHAART), *geo.arc.nasa.gov/sge/health/projects/cholera/cholerarpt1.html*, 2000.
8. Beck LR, Rodríguez MH, Dister SW, Rodríguez AD, Washino RK, Roberts DR, Spanner MA. Assessment of a remote sensing based model for predicting malaria transmission risk in villages of Chiapas, Mexico. Am J Trop Med Hyg **1997**;56:99–106.

9. National Institute for Occupational Health and Safety. *A Model for Research and Training Effectiveness*. Cincinnati, OH: NIOSH, **1999.** DHHS (NIOSH) Publication No. 99–142. Available at: *www.cdc.gov/niosh/99-142.html*. Accessed July 2001.
10. Agency for Health Care Policy and Research. *Consumer Health Informatics and Patient Decision-Making*. Final Report. Rockville, MD: U.S. Department of Health and Human Services, Agency for Health Care and Policy Research, **1997.** AHCPR publication 98-N001.
11. Eng TR, Gustafson DH. *Wired for Health and Well-Being: The Emergence of Interactive Health Communication*. Washington, D.C.: Science Panel on Interactive Communication and Health, U.S. Department of Health and Human Services, U.S. Government Printing Office; 1999. Available at: www.health.gov/scipich/pubs/finalreport.htm. Accessed July 2001.
12. Clancy CM, Eisenberg, JM. Outcomes research: Measuring the end results of health care. *Science*. **1998;** 282:245–246.
13. Tambouris E, Williams MH, Makropoulos C. Co-operative Health Information Networks in Europe: Experiences from Greece and Scotland. J Med Res [serial online]. **2000;**2:e11 Available at: www.jmir.org/2000/2/e11/index.htm. Accessed July 2001.
14. The National Breast and Cervical Cancer Early Detection Program 2001. Available at: www.cdc.gov/cancer/. Accessed July 2001.
15. Association of Telehealth Service Providers. 1999 Report on U.S. Telemedicine Activity. Portland, OR: ATSP; **2000.**
16. Ilioudis C, Pangalos G. A framework for an institutional high level security policy for the processing of medical data and their transmission through the Internet. J Med Internet Res [serial online]. **2001;**3:e14. Available at: jmir.org/2001/2/e14/index.htm. Accessed July 2001.
17. Cancer in Scotland: Action for change 2001. Available at: www.show.scot.nhs.uk. Accessed July 2001.
18. A framework for national surveillance of hospital acquired infection in Scotland. 2001. Available at www.show.scot.nhs.uk. Accessed July 2001.
19. Moore A, Parr G, Logan M, Neely H, Roesner D, Dürer U. Developing a European internet and kiosk-based health information system. J Med Internet Res [serial online]. **2001;**3:e6. Available at: jmir.org/2001/1/e6/index.htm.
20. Beck LR, Lobitz BM, Wood BL. Remote sensing and human health: New sensors and new opportunities. *Emerg Infect Dis* **2000;**6217–227.
21. Malone JB, Bergquist NR, Huh OK, Bavia ME, Bernardi M, EL Bahy MM, Fuentes MV, Kristensen TK, McCarroll JC, Yilma JM, Zhou XN. A global network for the control of snail-borne disease using satellite surveillance and geographic information systems. *Acta Tropica* **2001;**79:7–12.
22. Lovell NH, Celler BG. Information technology in primary health care. *Int J Med Informatics* **1999;**55:9–22.
23. World Health Organization. Integrated disease surveillance. Available at: www.who.int/emc/surveill/index.html. Accessed July 2001.
24. World Health Organization. Strengthening disease surveillance. Available at: www.who.int/emc/healthmap/surveillance.html. Accessed July 2001.
25. Geographical Information Systems (GIS). Mapping for epidemiological surveillance. *Wkly Epidemiol Rec* **1999;**74:281–288.
26. International Activities in Tele-homecare: Background paper. Office of Health and the Information Highway Health Canada. 1998. Available at: www.hc-sc.gc.ca/ohih-bsi. Accessed July 2001.
27. Gray JE, Safran C, Davis RB, Pompilio-Weitzner G, Stewart JE, Zaccagnini L, Pursley D. Baby CareLink: Using the Internet and telemedicine to improve care for high-risk infants. *Pediatrics* **2000;**106:1318–1324.
28. Phillips VL, Temkin A, Vesmarovich S, Burns R, Idleman L. Using telehealth interventions to prevent pressure ulcers in newly injured spinal cord injury patients post-discharge. Results of a pilot study. *Int J Technol Assess Health Care* **1999;**14:749–766.
29. Po YM. Telemedicine to improve patients' self-efficacy in managing diabetes. *J Telemed Telecare* **2000;** 6:263–267.
30. Oki Y, Shiomi T, Sasanabe R, Maekawa M, Hirota I, Usui K, Hasegawa R, Kobayashi T. Multiple cardiovascular risk factors in obstructive sleep apnea syndrome patients and an attempt at lifestyle modification using telemedicine-based education. *Psychiatry Clin Neurosci* **1999;**53:311–313.
31. Zahlmann G, Obermaier M, Mertz M. Real applications of patient-related telemedical services. *Studies Health Technol Informatics* **2000;**79:20–37.
32. Chen H-S, Guo F-R, Chen C-Y, Chen J-H, Kuo T-S. Review of telemedicine projects in Taiwan. *Int J Med Informatics* **2001;**61:117–129.
33. Canada. Department of Foreign and International Trade. Telehealth in Germany. June 1998. Available at: www.dfait-maeci.gc.ca/english/geo/europe/medica/report-e.htm. Accessed July 2001.
34. Bashshur RL. On the definition and evaluation of telemedicine. *Telemed J* **1995;**1:19–30.
35. Report of the Interdisciplinary Telehealth Standards Working Group. Available at: www.arentfox.com/quickguide/businesslines/e-health/e-health_telemed/e-healthnewsalerts/telehlth/telehlth.html. Accessed July 24, 2001. For convenience, the text of the recommended standards is presented verbatim as follows:
i. The basic standards of professional conduct governing each health care profession are not altered by the use of telehealth technologies to deliver health care, conduct research, or provide education. Developed by each profession, these standards focus in part on the practitioner's responsibility to provide ethical and high quality care.
ii. A health care system or health care practitioner cannot use telehealth as a vehicle for providing services that are not otherwise legally or professionally authorized.

iii. Services provided via telehealth must adhere to basic assurance of quality and professional health care in accordance with each health care discipline's clinical standards. Each health care discipline must examine how telehealth impacts and/or changes its patterns of care delivery and how this may require modifications of existing clinical standards.
iv. The use of telehealth technologies does not require additional licensors.
v. Each health care profession is responsible for developing its own processes for assuring competencies in the delivery of health care through the use of telehealth technologies.
vi. Practice guidelines and clinical guidelines in the area of telehealth should be developed based on empirical evidence, when available, and professional consensus among all involved health care disciplines. The development of these guidelines may include collaboration with government agencies.
vii. The integrity and therapeutic value of the client-health care practitioner relationship should be maintained and not diminished by the use of telehealth technology.
viii. Confidentiality of client visits, client health records and the integrity of information in a health care information system is essential.
ix. Documentation requirements for telehealth services must be developed that assure documentation of each client encounter with recommendations and treatments, communication with other health care providers as appropriate, and adequate protections for client confidentiality.
x. All clients directly involved in a telehealth encounter must be informed about the process, attendant risks and benefits, and their rights and responsibilities, and must provide adequate informed consent.
xi. The safety of clients and practitioners must be ensured. Safe hardware and software, combined with demonstrated user competency, are essential components of safe telehealth practice.

Address reprint requests to:

Rashid L. Bashshur, Ph.D.
Director of Telemedicine
The University of Michigan Health System
C201 Medinn Building
1500 East Medical Center Drive
Ann Arbor, MI 48109–0825

E-mail: bashshur@umich.edu

Chapter 4

Telemedicine and Medical/Health Education

Contributors:

Rajesh Mangrulkar, M.D., University of Michigan
and
Brian Athey, Ph.D., University of Michigan
Eileen Brebner, M.S., University of Aberdeen, Scotland
Khalid Moidu, M.D., Ph.D., Medical Center of Boston International
Pablo Pulido, M.D., PAFAMS, Venezuela
James Woolliscroft, M.D., University of Michigan

INTRODUCTION

To date, medical education has not taken full advantage of the advances in information technology, especially the Internet.[1] Except for experimental efforts, the vast majority of learners in the health professions continue to receive most of their training in traditional classrooms, lecture halls, and laboratories. Yet, telemedicine technology has the potential to transform professional medical/health education at all levels: undergraduate, graduate, and professional. Hereafter, the term "medical education" only will be used to simplify the discussion. It can shift the focus from the traditional teacher and classroom to a ubiquitous, learner-centered system.

The need for fundamental change in the context, content, methods, and style of medical education is widely recognized. Indeed, the field is at a crossroads, and those who ignore advances in information technology in the medical education community risk being left behind. Still, educators must select the appropriate context, content, effective methods, and efficient delivery to fit the needs of the largest number of learners (a model of medical education is shown in Fig. 1).

The basic task is how to educate physicians and other health professionals and how to maintain their knowledge and skill throughout their professional life. To be sure, the challenges are daunting, but they must be overcome if we are to improve the quality, breadth, and geographic range of professional medical education.

CONCEPTUAL FRAMEWORK

As it does in many other fields and domains, the Internet offers new opportunities, enhanced capabilities, and alternative formats for medical education. Among its other capabilities, the technology has enabled the creation of Internet learning communities, virtual reality, and problem-based learning environments. Nonetheless, this analysis will be limited to the technologies that mediate the transfer of instructional information across some physical distance. The use of information technology to enhance teaching within the classroom is outside the purview of this chapter.

Nursing, physical therapy, and public health education represent health professional fields that are attempting to improve the learning process and outcome via telemedicine tools. Most of their needs and requirements are similar to those of medical education, and the lessons learned in one field should be applicable to the others.

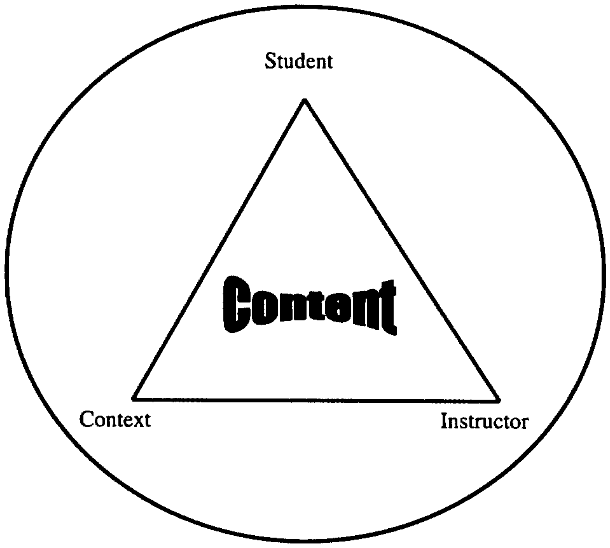


FIG. 1. Model of health professions education.

Traditional medical education consists of two components: basic science and clinical education. Basic science courses include anatomy, physiology, biochemistry, and pharmacology, often taught in lecture format and supplemented by laboratory experience. Clinical education occurs in hospital or ambulatory clinic-based rotations, where students participate in the diagnosis, treatment, and care of patients.

Continuing medical education (CME), once predominantly composed of lectures to large groups of clinicians, is under active revision and reformulation. The aim of the changes being introduced is to find effective ways to keep physicians abreast of scientific and technical developments and to promote their compliance with emerging standards of care in their respective fields.

Learning theorists have confirmed that learning is maximized when adults act as self-directed, motivated learners, pursuing topics of their own interest in appropriate contexts.[2] These principles are driving the change in medical and continuing medical education to a more interactive, practical self-paced modality, and several authors have suggested the congruence of technology-mediated distance education with these principles.[3,9,33] Indeed, successful educational programs use information technology to achieve: (1) a self-paced process that encourages self-reliance; (2) consistent delivery of subject matter; (3) realistic multimedia simulations within a high-fidelity context; (4) a learning process designed to adapt to learner needs promptly; (5) self-testing with immediate feedback; and (6) learning augmented by delayed or immediate repetition.

DISTANCE LEARNING MODALITIES

The various applications of telemedicine in education have demonstrated a wide range of effects in terms of achieving desired changes in the learner's knowledge, attitude, skill, and behavior. Information about the relative effectiveness of these applications forms the basis for a future dissemination strategy. Where definitive research is lacking, we need to draw on useful lessons from the published literature on similar applications, even though this may be less than optimal.

The review of the effectiveness of educational modalities will be organized by type of technology and by type and level of learner, as shown in Table 1. This table identifies a representative subset of studies on the effectiveness of distance education along these two axes: technology and learners. The technologies include standard videoconferencing, Internet-based systems, and high bandwidth Internet (known as Next Generation Internet [NGI] or Internet2 [I2]). The learners include physicians, nurses, and physical therapists.

VIDEOCONFERENCING

Some of the earliest applications in telemedicine were related to distance education using two-way closed-circuit television or simple audio channels in Nebraska, and the Canadian provinces of Newfoundland,[4] Labrador, and Ontario.[5] The current emphasis is on Internet Protocol (IP) systems because they are relatively inexpensive and nearly universally available. Bidirectional or two-way videoconferencing enables true interaction[6] where faculty and students see and talk with each other as well as transmit and receive slides, images, and documents. The target audience initially was (and continues to be) the general practitioner far removed from a tertiary health center.

Table 1. Representative Studies of the Effectiveness of Distance Education Technologies in Medicine

Technology	*UGME, GME*	*CME*	*UGNE, GNE*	*CNE*	*PTE*
Video conferencing	Brebner, personal communication, presented at symposium.	DeMartines et al.: Surgical teleconferences delivered to European university hospitals. Outcomes: value of advice, accuracy of transmission.[12] Deaton et al.: Surgical telementoring of endovascular aortic grafting. Outcomes: clinical success, "mentoring" success of new procedure.[15]	No significant outcomes-based studies.	Umble et al.: Satellite broadcast of federal immunization education course. Outcomes: knowledge, self-efficacy, adherence to recommendations.[17] Sawada et al.: Videoconferences on respiratory rehabilitation skills to rural nurses. Outcomes: self-reported behavior.[16]	Barden et al.: Teleconferences to remote PT education site on hand-assessment skills. Outcomes: Objective Structured Clinical Exam on standardized patient.[18]
Web-based learning	Fleetwood et al.: Web-based simulated cases for medical students, covering ethical issues. Outcomes: exam scores, standardized patient performance, satisfaction.[36] Bell et al.: Web-based self-study program used by internal medicine and family medicine residents, instructing on post-MI care. Outcomes: amount of study time, exam scores.[34] Grundman et al.: VR module on physical examination of the eye and ear, delivered to medical students. Outcomes: exam scores, satisfaction.	Sargeant et al.: Web-mediated, case-based learning module on medication-induced headaches, delivered to family practitioners in a PBL format. Outcomes: activity on the Web site, satisfaction, and analysis of transcripts of electronic discussions.[40] Chan et al.: Internet-based discussion on depression in the elderly, delivered in a PBL format to family practitioners. Outcomes: satisfaction, exam score.[44]	Soon et al.: Web-based course on Growth and Development, administered to nursing students. Outcomes: satisfaction.[35] Thiele et al.: Internet-based instruction on nursing theory and nursing informatics delivered to first and second year nursing students. Outcomes: Flashlight survey measuring comfort and barriers with Web-based instruction.[34]	No significant outcomes-based studies.	No significant outcomes-based studies.

UGME, Undergraduate Medical Education; GME, Graduate Medical Education; CME, Continuing Medical Education; UGNE, Undergraduate Nursing Education; GNE, Graduate Nursing Education; CNE, Continuing Nursing Education; PTE, Physical Therapist Education; VR, Virtual Reality; MI, Myocardial Infarction; PBL: Problem-Based Learning.

Digital transmission of similar and more refined data by low bandwidth and high bandwidth links, and by satellite that provides better quality at a higher price. The use of this educational technology has increased in other contexts such as infection control,[7] radiology,[8] community health interventions,[9] and postgraduate diplomas for general practitioners.[10] Moreover, the push to develop international standards for the training and practice of medicine has resulted in educational links across countries. One example is Boston University's School of Medicine and the Emergency Hospital in Armenia. These two institutions have forged a low-cost technology protocol delivering continuing medical education teleconferences to Armenia.[11]

THE UNIVERSITY OF ABERDEEN TELEMEDICINE EXPERIENCE

One illustration of the potential of using distance learning is a medical education program at the University of Aberdeen, Scotland. Historically, as the number of medical students in Scotland increased, it became difficult to educate them all in an urban medical center. Hence, all students were required to gain part of their clinical experience at Inverness, 120 miles north of Aberdeen. Still, certain specialties lacked formal educational experiences at this satellite site. These included neurology, plastic surgery, and infectious disease. Specialists in these areas had to travel to Inverness to conduct educational sessions. The distance proved prohibitive, so a two-way, Integrated Service Digital Network (ISDN)-6 connection was used to deliver the material by interactive videoconferencing.

As part of the evaluation, student performance among those receiving instruction face-to-face at Aberdeen was compared with that of students using distance learning in Inverness. In general, knowledge gains (as measured by performance on standardized written examinations) and satisfaction scores were high in both groups, suggesting an equivalency of both methods. However, in-depth analysis of the entire program by the organizing team produced the following insights.

- Using many experts: The successful implementation and management of such a system depended largely on using a multidisciplinary team of specialists. The team included clinicians, technology specialists, and educators skilled in computer-aided instruction, multimedia experts, and faculty trainers who could make use of these tools.
- Faculty development: Ideally, faculty development would precede the implementation of the program. Certain applications were poorly received because the instructor was not comfortable with certain aspects of distance instruction. These objections were either technological or pedagogical in nature.

—Technical issues include familiarity and comfort with the use of cameras, audio controls, and graphics displays.

—Pedagogical issues included speaking style, animation, and the use of graphic material. Some students in Aberdeen reported delays in sound transmission and a failure to feel involved in a dialog. While delayed sound transmission is a technical issue, the feeling of not being involved directly relates to the ability of the facilitator to use distance learning effectively.

Overall, student experiences at Aberdeen and Inverness were equivalent in most respects, and the program proved successful in achieving its mission in terms of acceptability (as measured by learner satisfaction) and effectiveness (as measured by knowledge test scores). It is now an established on-going service.

OTHER STUDIES OF VIDEOCONFERENCING EFFECTIVENESS

A careful review of the literature reveals limited rigor in the evaluations of the effects of videoconferencing on measurable learning outcomes. Often this research has focused on practicing health care physicians, nurses, and physical therapists—and not students and trainees (see Table 1). For example, DeMartines et al.[12] described the European Institute of Telemedicine's link of six university hospitals in four countries that were transmitting weekly surgical teleconferences to all participants. Topics ranged from general surgery to the management of complex cases. The system used six ISDN lines to transmit at a composite rate of 384 kilobytes per second (kbps). Participants reported high satisfaction with educational content, quality of the transmission, and comprehensiveness of material. This study did not, however, measure actual gains in knowledge or skill, not unlike numerous other studies.

The apprenticeship model of medical education is particularly strong in surgical training through telementoring, where trainees "learn by doing" under the guidance of experienced mentors.[13,14] Using this approach, remote clinicians learn about surgical devices, procedures, and techniques. Deaton et al.[15] described how they performed endovascular aortic grafting on seven patients using technology similar to that used in the DeMartines study. No differences were observed in clinical outcomes between the remote patients and those operated on by traditional methods. In addition, surgical personnel felt at ease with the new approach.

Two studies may represent the range of learning outcome studies in continuing nursing education (CNE). Sawada et al.[16] investigated the acquisition of respiratory rehabilitation skills by rural nurses when taught by distance education in Japan. Instructional materials were delivered face-to-face and then, for a subset of nurses, by videoconferences over ISDN lines. No significant differences were observed between the two groups in terms of the frequency in which the acquired skills were used in actual practice. However, the sample was small (32 nurses), participation was low (<50% of eligible nurses), and the outcome measure was self-reported. Another nursing study found no significant differences in recommending vaccinations among public health nurses when given such information in person or remotely.[17]

Overall, studies involving physicians and nurses failed to measure actual changes in skill, performance, or clinical behavior. Rigorous evaluation of the effectiveness of videoconferencing (and all educational interventions, for that matter) must focus on actual learning outcomes. One such study, by Barden et al.,[18] compared videoconferencing, traditional instruction, and self-study for hand-assessment skills by physical therapists. Students in the videoconferencing group and the traditional teaching group acquired more skill than those in the self-study group.

Typically, little or no difference was observed between videoconferencing and traditional teaching methods in CME. Several studies have demonstrated that, regardless of type of technology used, traditional methods of CME (predominantly lecture formats) are not as effective as newer approaches (such as one-to-one mentoring, small group discussions, academic detailing). It seems clear that information technology alone would not be a sufficient replacement for these newer approaches.

Innovative approaches must also be pursued to improve videoconferencing by enhancing interaction, providing small group learning environments, and fostering customized learning.[19] Nonetheless, the lack of demonstrated superiority of this medium is outweighed by its unique benefits in terms of enabling: (1) interaction over a distance, (2) remote access to experts at centralized locations, and (3) the delivery of educational material to exponentially larger audiences.

WEB-BASED LEARNING

Whereas point-to-point videoconferencing has advanced distance education generally, its potential is limited when compared with the rapidly expanding Internet[20] and the accelerating physician interest in online education.[21] The Internet's appeal comes from its availability, its access to vast reservoirs of information, its potential for multimedia streaming, and its low cost. Immediate access to information resources for medical decision-making has also contributed to the lure of this medium as a powerful teaching and learning tool. Still, educators are wondering about the ideal format for Web-based learning. Descriptions of the applications of this medium appear to capitalize on crucial aspects that promote learning, especially (1) the ability to facilitate interaction and (2) the ability to convey complex multimedia material to augment learning. Both are congruent with principles of optimal learning, which encourage learners to participate actively in knowledge acquisition embedded in a meaningful context,[22,23] and they provide realistic, although virtual, representation of the environment and content. (See Table 2 for information on technical demands of the Internet).

INTERACTION

Internet-based education tends to create "learning communities" with access to such information resources as lectures, notes, additional readings, and assignments; interactive self-directed exercises with opportunities for feedback; and discussion areas (electronic "whiteboards") where instructors and students can asynchronously conduct electronic conversations. Applications have been described in Spain in teaching minimally invasive surgical techniques,[24] in Australia with a problem-based learning curriculum,[25] and in the United States using Internet-based learning portfolios for obstetrical residents.[26] Degree programs also take advantage of the interactive nature of the Web to create distance-learning curricula.[27,28]

A recent Internet search using the key words "online CME" and "Web-based CME" revealed more than 1500 unique sites providing CME credit to practicing physicians.[29] The number is increasing rapidly, providing physicians with a dizzying array of choices but with little guidance on quality or credibility. Quality issues surrounding successful Web-based learning sites must be addressed.

MEDICAL EDUCATION IN ONE REGION OF INDIA

The advent of high-speed Internet access in the United States and abroad has shifted the focus from point-to-point videoconferencing to Web-based systems. One example of this is a project that electronically links a network of private and government medical schools in the Indian province of Tamil Nadu. Initially the project was designed to bring the expertise of urban and prestigious hospitals within the province to the other hospitals in the network. However, a secondary goal emerged that established links between Boston and the network in India. Both primary (384 kbps ISDN) and secondary (64 kbps Internet) links were established to facilitate teleconsultation and distance learning. The Web-based learning environment developed by combining video streamed lectures with interactive chat rooms, opportunities for self-education with guided tutorials, and self-evaluation tools.

Organizers of the project derived the following lessons from their experience to date.

TABLE 2. PROFESSIONAL EDUCATION: TECHNICAL DEMANDS OF THE INTERNET

Criteria	*Bandwidth*	*Latency*	*Availability*	*Security*	*Ubiquity*
Importance	+++	++	++	+	+++

Bandwidth:	Data carrying capacity of network; bps that can be transmitted across a particular link or entire network. Greatly important for serving large numbers of people, high frequency of use for teleconferencing, simulations, virtual classrooms, and interactive surgical simulations.
Latency:	Time required for individual pack of data to be transmitted between communicating entities on network (response time = time required for an entire message or file to be transferred across the Internet and acknowledged). High demand for reduced latency in interactive simulations (e.g. surgical techniques) and conferences.
Availability:	Likelihood that network is available for service and is functioning properly. Critical; generally will increase as education becomes more interactive and integrated with patient activities.
Security:	Ability of network to ensure confidentiality and integrity of information transmitted across it. Increasingly important to protect learner confidentiality.
Ubiquity:	Degree of access to a network; constraints imposed by limits on people and limited geographic locations. Great importance to geographical and functional deployment of new learning techniques and tools. Access to Internet crucial to remote practices.

Goal setting

There are several reasons for having clear and explicit goals and objectives: (1) They keep the project focused and on-track; (2) they drive the evaluation of its effects; and (3) when indicated, they spawn secondary objectives, which must be implemented and recognized.

Exploiting the medium

While perhaps restricting the scope and range of personal interactions that can occur in the normal classroom, this medium provides unique teaching and learning opportunities beyond those available in standard instruction. Instructors may be more creative in the format and content of the material they deliver.

Learning preferences

Because students (or learners) are the initiators of various interactions in this system, their learning preferences must be observed, including their choice of material and means of transmitting information whether it be through chat rooms or interactive videoconferencing or through topic selection and sequencing.

MULTIMEDIA

Greater realism is being achieved in multimedia platforms as a result of expansion of bandwidth. Interactive, multimedia, enriched courses can be targeted directly at the adult learner.[30,31] In 1995, for example, Bittorf and colleagues[32] described the development of a searchable dermatological atlas intended for use by practicing physicians worldwide, a remarkable feat at the time. Since then, hundreds of these sites have been developed, using compression technology to deliver both still and moving images for students and practicing physicians for instruction and reference.

THE VISIBLE HUMAN PROJECT

A notable example of advanced delivery of graphical anatomy is the Visible Human of the National Library of Medicine. It provides a realistic, three-dimensional rendition of the human form. Its potential as an educational tool in both medical and surgical simulation is widely regarded as phenomenal.[33] Because of the very large size of these files, their use via the Internet will likely increase with the advent of I2 or NGI.

The Visible Human is a database that has digitally captured the entire male and female human anatomy in exquisite detail, based on two corpses sliced in 1/3- to 1-mm increments. It opens new opportunities for both medical education and research, creating virtual anatomic tools to facilitate interaction with this database by medical students, practicing clinicians, nurses, and anatomists. The digital anatomical database can be transformed into a teaching tool by using the NGI. The NGI will provide much greater speed than the current Internet, at least 1 gigabyte per second, which is nearly 700 times faster than a standard T1 line. Three-dimensional browsers will let students manipulate the anatomical form in ways that have never been possible. In addition, computed tomography (CT) and magnetic resonance imaging (MRI) images can be reconstructed immediately from the anatomical images.

INTERNET-MEDIATED LEARNING

Actual evidence of the teaching effectiveness of various applications must guide the future design of applications in this field. Unlike interactive videoconferencing, Web-based instructional methods have found their way into the published undergraduate and graduate medical education and nursing education, as shown in Table 1. In addition, the specific outcomes and methods by which learning is assessed appear to be substantive and sophisticated.

Three representative studies have used several outcomes to evaluate effectiveness. Bell et al.[34] conducted a randomized, controlled trial among family medicine and internal medicine residents to determine the effect of a Web-based self-tutorial system on the instruction of postmyocardial infarction care. The core content for both the control and the experimental groups included material from printed clinical practice guidelines; the Web-based system, however, let users explore hyperlinks to direct guideline passages and to graphic animations. Using a validated knowledge assessment examination to measure learning, the performance scores of residents in both groups improved. However, the Web-based group showed the same improvement with less exposure to the materials. Both groups showed similar declines in this knowledge over 4 to 6 months.

A second study, by Grundman et al.,[35] assessed differences in knowledge gains induced by an interactive virtual reality (VR), Web-based program on the ear and eye physical examination, compared with using printed materials. Here, students exposed to the Internet materials performed far better than those who used printed materials, but they also required more exposure to the educational intervention to achieve these gains. Indeed, their "time-on-task" was a significant predictor of performance on the examination; thereby suggesting that time of exposure, not simply the Web, produced the desired effect. Students indicated that they clearly preferred the multimedia intervention.

The third study provides a comprehensive outcome assessment of a Web-based learning environment. Fleetwood et al.[36] simulated multimedia cases on the Internet to teach students about two specific ethical issues: patient confidentiality and assisted suicide. No appreciable differences in examination scores, satisfaction with the learning module, or performance on standardized tests were observed between the two approaches.

Evaluation of Web-based learning among nursing students focused on changes in attitudes, rather than on knowledge and skill. Thiele et al.[37] investigated the impact of Web-based courses in a nursing curriculum on attitudes toward technology. They found that students were more likely to collaborate with their peers, accept the new technology, and develop new computer-related skills as a result of participation in Web-based courses, as compared to the traditional classroom approach. Soon et al.[38] used qualitative data and similarly assessed satisfaction with a distance-learning course delivered over the Internet as compared to the classroom.

The evaluation of Web-based learning in continuing medical education has been limited. A notable exception is the analysis of the Internet in so-called problem-based learning (PBL).[39] If Web-based PBL can simulate the important features of traditional PBL in small groups, these modules may be similarly popular, though not necessarily more effective. In Nova Scotia, Sargeant et al.[40] reported that among family physicians, the anticipated roles of the facilitators were fulfilled, but equal participation was difficult to achieve in the asynchronous environment of the Internet. The Internet can remove the traditional barriers to physician interaction with coparticipants. In an outcomes-based, randomized controlled study, Chan et al.[41] found no difference in performance on a knowledge-based examination between this group and those exposed to traditional PBL; that is, no improvement in performance resulted from either intervention.

BARRIERS COMMON TO ALL DISTANCE LEARNING APPLICATIONS

Researchers have investigated impediments to the adoption of new technology by learners.[34,35] These barriers can be classified into three types: learner issues, instructor issues, and overall effectiveness.

LEARNER ISSUES

Learners tend to express different preferences for various components in a teaching module as well as for specific styles of teaching. These preferences, in turn, are influenced by a variety of factors, including familiarity with the subject matter, comfort and familiarity with the technology, and general attitudes toward innovation and technology. An understanding of the socialization to this new environment is crucial for facilitating the adoption of distance-learning. Computer literacy (including familiarity with Web browsers) is not uniformly high among older students and practitioners. Hence, basic information technology (IT) training is important.

Frustration with technology, such as excessive downloading time, poorly designed search engines, unreliable or poor quality audio and video signals, and other inefficiencies are likely to reduce the adoption of distance education. These issues must be overcome or the approach will be defeated. Moreover, if distance learning proves to be effective, institutional leaders could be convinced to invest in it.

TEACHER ISSUES

Not all faculties can take advantage of distance education capabilities. Those who want to use the medium must have appropriate training. The students will notice discomfort or lack of familiarly with the medium, and it may have a negative effect on the learning experience. This, however, can be overcome by improving instructor skills.

EVALUATION

Evaluating the effectiveness of various distance-education/distance-learning modalities is of paramount importance, even though the proof-of-concept has been well documented. Nonetheless, as is typical of health professions education in general, there is a paucity of scientifically rigorous outcome studies. Such evaluation is hampered by four kinds of problems. (1) There is a lack of appropriate and reliable measurement tools, including the measurement of medical expertise or skill. (2) There are few, if any, dedicated researchers and inadequate funding for valid research. (3) Interpreting data from such studies is inherently difficult. For example, failure in some applications can be attributed to certain limitations in technology, such as low bandwidth, poor quality service, or other technical limitation. These limitations can be remedied by better technology that is already available in the marketplace. (4) The final problem is the lack of a systematic approach to consider all the relevant contextual and methodological issues. Issues related to evaluation must be addressed systematically and include an explicit statement of objectives, timing or maturation, specific focus, and methodology.

FUTURE DIRECTIONS

Distance education in the health professions is likely to go forward with or without systematic planning. This is because the benefits of the underlying technology are now widely applied in everyday practice and professionals will continue, if not accelerate, using it in patient care, business transactions, as well as education. Planning provides the unique benefit of guiding the future in ways that maximize the desired benefits, reduce pitfalls and blind alleys, and minimize costs.

ISSUES RELATED TO PROCESS

The success of any program in distance clinical education, or education generally, depends to a large extent on the process that is put in place. In distance education, the process is shaped largely by the technology and the manner in which the capabilities of the technology are exploited. There are significant variations in terms of the quality of graphical design interfaces, bandwidth connections, and multimedia capabilities. The technology must enable the acquisition, delivery, storage, and retrieval of large data files. Both the teacher and the learner must be able to manipulate these data files. Students must have the tools (hardware and software), and they must learn how to open, retrieve, store, and transmit these files.

Institutions may pose substantial barriers to the diffusion and wide use of the technology. Few campuses have sufficient numbers of "smart" classrooms equipped with network connections that permit broadband Internet connections, even though the trend is positive.

Digital technology can transform the process of learning dramatically in four important ways. First, it can guide clinical decision making by giving students and supervising clinicians access to the latest medical literature. Second, it can overcome the constraints of geography and time, giving learners an enriched education in their home communities. Third, multimedia video streaming over the Internet can simulate and model disease processes and conditions to enrich and enhance clinical education. Finally, the technology allows a realistic simulation of surgical techniques and procedures.

OPPORTUNITIES AND CHALLENGES

Whereas distance education in the health professions generally and medicine in particular provides unique opportunities, it also faces significant challenges that must be addressed before its promise becomes reality. Hence, a clarification of both opportunities and challenges is in order.

The technology enables the development of a customized learning environment that is responsive to learner, instructor, and system requirements. In standard learning environments, a feedback loop allows the modification of curricular content based on the needs of learners, the needs of society, and the learner's performance. However, customization may be difficult with large classes. In small groups, content may be modified quickly ("on the fly"). Web-based instruction has the potential to create a high-fidelity, customized learning environment in which feedback is rapid and content modification is possible. In essence, the instruction is adapted to the learner and may be able to change in response to differences in learning preferences, common or uncommon individual learner issues, or even attitudinal differences among students regarding the material.

The successful implementation of distance education for health professionals requires the cooperation of specialists in various fields. The plan to accomplish this must incorporate both design and evaluation features. In the design phase, special efforts must be made to obtain input from multiple stakeholders, including: learners, educators, psychologists, information scientists, providers, policy makers, professional organizations, and universities. Similarly, the evaluation requires a multimodal approach to assess a variety of outcomes. Multiple, converging evaluation approaches must be used to enhance the validity of obtained results. "Hard" outcome measures must be developed, beyond satisfaction and simulated knowledge outcomes. These include behavioral measures, and (if possible) clinical outcomes. Moreover, the evaluation must be longitudinal if it is to assess long-term effects.

In view of the rapid expansion of the Internet, both nationally and internationally, distance education can be provided globally. The availability of the Visible Human and online literature and bibliographic materials from the National Library of Medicine would greatly facilitate international and global collaboration. Indeed, the development of the NGI or I2 will eliminate geographic boundaries for medical education, and international collaboration will naturally follow. Accordingly, the following strategy is proposed.

1. An attempt should be made by health professions educators to create tools and instructional modules for the current and the NGI. Appropriate tools outside of this infrastructure should be moved into the Internet as soon as possible to promote collaboration.
2. Data repositories (such as anatomical, pharmacological, biochemical, genetic repositories) should be closely linked via the Internet. Many such massive projects (e.g., the Human Genome, the Visible Human) have fulfilled this goal, but many smaller ones may not be included because they pass below the radar screen of those with this broad vision. They must be brought on board.
3. Educators must make a concerted effort to develop international glossaries, ontology, and languages that describe all biological phenomenon. This will facilitate communication about ideas that will be shared through this medium.
4. Educators must develop international standards for health professions education and educational technology. The geopolitical barriers that prevent the spread of advanced understanding of disease and health must be eliminated, nor should there be acceptable excuses for variances in the quality of patient care. An international consensus for these standards must be reached, while remaining sensitive to the individual cultural context from which they are derived.

The basic challenges in achieving this potential are multifaceted, revolving around skills and preferences of learners and instructors, curriculum design, technological configurations, cultural contexts, and social and regulatory constraints. Both learners and instructors have to reach a common understanding of not only the teaching objectives and the content of the curriculum but also of the style of interaction and the skills necessary for this type of education. They must also achieve a commitment for scientific evaluation of performance and outcomes for each side.

Equally important is the social and cultural context in which these interactions must occur. Indeed, student behavior is strongly influenced by culture. Institutions wishing to participate in international or global education must assume a shared responsibility for achieving mutual understanding and accommodation in terms of cultural norms, rules of conduct, and interpersonal expectations. In addition, several regulatory issues must be addressed, including accreditation and certification, intellectual property rights, uniform standards and interoperability of hardware and software, business arrangements, and quality assurance.

PROPOSED ACTION PLAN

Whereas the rapid pace of development in information technology has led to increased use of these tools in distance education in health care, these applications remain sub optimal, as they do in various fields. Some institutions have developed their own distance education programs, some with and some without strategic planning. Indeed, there are examples of successful models for implementation that can be emulated. But, these were largely implemented within rather than between educational institutions. Attention must be paid to developing international and global networks that exploit the unique capabilities of this technology.

The evaluation of these programs has been mostly soft, relying on attitudinal measures, perceptions, and satisfaction rather than actual changes in behavior, skill or clinical outcomes. The electronic infrastructure of all Internet-mediated educational tools lets researchers capture important data regarding learning behaviors with minimal effort. This capability must be exploited.

To advance the field, we must revisit all issues related to curriculum content and design, teaching and learning tools, innovative uses of information technology and multimedia to enrich the educational experience, and, ultimately performance and outcome.[40]

REFERENCES

1. National Research Council. *Networking health: Prescriptions for the Internet.* National Academic Press, Washington DC, 2000.
2. Knowles MS. *Andragogy in Action.* 1st ed. San Francisco: Jossey-Bass; 1984.
3. Ward JPT, Gordon J, Field MJ, Lehmann HP. Communication and information technology in medical education. *Lancet* **2001**;357:792–796.
4. House AM, Roberts JM, Canning EM. Telemedicine provides new dimensions in CME in Newfoundland and Labrador. *Can Med Assoc J* **1981**;124:801–804.
5. Lindsay EA. Continuing education through telemedicine for Ontario. *Can Med Assoc J* **1987**;137:503–506.
6. Weber JR, Lawlor AC. Professional nursing series by videoconferencing. *J Cont Ed Nurs* **1998**;29:161–164.
7. Sinkowitz-Cochran RL, Jarvis WR. Evaluation of a satellite education program on the prevention and control of antimicrobial resistance. *Am J Infect Control* **2000**;28:267–268.
8. Tello R, Davison BD, Blickman JG. Delivery of live and recorded continuing medical education material over the Internet. *AJR* **2000**;174:1519–1521.
9. Saeki K, Izumi H, Ohyanagi T, Sugiyama A, Sawada I, Suzuki K, Hatazawa M, Ohuch M. Distance education for health centre staff in rural Japan. *J Telemed Telecare* **2000**;6:67–69.
10. McLachlan-Smith CJ, Tracey JM. Learning by distance for general practitioners: students' experiences of Goodfellow Unit diplomas. *N Z Med J* **2000**;113:187–189.
11. Screnci D, Hirsch E, Levy K, Skawinski E, Der-Boghosian M. Medical outreach to Armenia by telemedicine linkage. *J Med Sys* **1996**;20:67–76.
12. DeMartines N, Mutter D, Vix M, Leroy J, Glatz D, Rosel F, Harder F, Marescaux J. Assessment of telemedicine in surgical education and patient care. *Ann Surg* **2000**;231:282–291.
13. Lee BR, Bishoff JT, Janetschek G. A novel method of surgical instruction: international telementoring. *World J Urol* **1998**;16:367–370.

14. Camara JG, Rodriguez RE. Real-time telementoring in ophthalmology. *Telemed J* **1998**;4:375–377.
15. Deaton DH, Balch D, Kesler C, Bogey WM, Powell CS. Telemedicine and endovascular aortic grafting. *Am J Surg* **1999**;177:75–77.
16. Sawada I, Sugiyama A, Ishikawa A, Ohyanagi T, Saeki K, Izumi H, Kawase S, Matsukura K. Upgrading rural Japanese nurses' respiratory rehabilitation skills through videoconferencing. *J Telemed Telecare* **2000**;6:69–71.
17. Umble KE, Cervero RM, Yang B, Atkinson WL. Effects of a traditional classroom and distance continuing education: A theory-driven evaluation of a vaccine preventable disease course. *Am J Pub Health* **2000**;90:1218–1224.
18. Barden W, Clarke HM, Young NL, McKee N, Regehr G. Effectiveness of telehealth for teaching specialized hand-assessment techniques to physical therapists. *Acad Med* **2000**;75(10 Suppl):S43–6.
19. Chandler GE, Hanrahan P. Teaching using interactive video: Creating connections. *J Nurs Educ* **2000**;39:73–80.
20. The Strategis Group. Us Internet breaks the 100 million mark. **1999**.
21. Sikorski R, Peters R. Tools for change: CME on the Internet. *JAMA* **1998**;280:1013–1014.
22. Pratt DD. *Five perspectives on teaching in adult and higher education*. Malabar, FL: Krieger Publishing Co, **1998**.
23. Ohrn M, vanOostrom JH, vanMeurs WL. A comparison of traditional textbook and interactive computer learning of neuromuscular block. *Anaesth Analg* **1997**;84:657–661.
24. Masero V, Sanchez FM, Uson J. A telemedicine system for enabling teaching activities. *J Telemed Telecare* **2000**;6:86–88.
25. Carlile S, Barnet S, Sefton A, Uther J. Medical problem based learning supported by intranet technology: A natural student-centered approach. *Int J Med Informatics* **1998**;50:225–233.
26. Fung MFK, Walker M, Fung KFK, Temple L, Lajoie F, Bellemare G, Bryson SCP. An Internet-based learning portfolio in resident education: the KOALA muticentre programme. *Med Educ* **2000**;34:474–479.
27. Sherman EC. Using distance education for an MPH degree program for health services administration for physicians. *Acad Med* **1999**;74(5 Suppl):615–616.
28. University of Illinois at Chicago Master's Degree Program in Health Professions Education. URL: www.uic.edu/com/mcme/mhpeweb/Home.html. Accessed August 7, 2001.
29. Google search, www.google.com. Accessed November 7, 2001.
30. Graeber S, Feldmann U. Medical information processing: an interactive course for the Internet. *Int J Med Informatics* **1998**;50:69–76.
31. Seifried SE. Technology-based delivery of PBL curricular elements at JABSOM. *Haw Med J* **2000**;59:240,284.
32. Bittorf A, Krejci-Papa NC, Diepgen TL. Development of a dermatological image atlas with worldwide access for the continuing education of physicians. *J Telemed Telecare* **1995**;1:45–53.
33. The Visible Human Project, funded by the National Library of Medicine. URL: www.nlm.nih.gov/research/visible/. Accessed August 13, 2001.
34. Bell DS, Fonarow GC, Hays RD, Mangione CM. Self-study from web-based and printed guideline materials: A randomized, controlled trial among resident physicians. *Ann Intern Med* **2000**;132:938–946.
35. Grundman JA, Wigton RS, Mickol D. A controlled trial of an interactive, web-based virtual reality program for teaching physical diagnosis skills to medical students. *Acad Med* **2000**;75(10 suppl):S47–9.
36. Fleetwood J, Gracely E, Vaught W, Kassutto Z, Feldman D, Novack D. MedEthEx Online: A computer-based learning program in medical ethics and communication skills. *Teach Learn Med* **2000**;12:96–104.
37. Thiele JE, Allen C, Stucky M. Effects of web-based instruction on learning behaviors of undergraduate and graduate students. *Nurs Health Care Perspec* **1999**;20:199–203.
38. Soon KH, Sook C, Jung CS, IM KM. The effects of Internet-based distance learning in nursing. *Comput Nurs* **2000**;18:19–25.
39. Colliver JA. Effectiveness of problem-based learning curricula: Research and theory. *Acad Med* **2000**;75:259–266.
40. Sargeant JM, Purdy A, Allen MJ, Nadkarni S, Watton L, O'Brien P. Evaluation of a CME problem-based learning Internet discussion. *Acad Med* **2000**;75(10 Suppl):S50–2.
41. Chan DH, LeClair K, Kaczorowski J. Problem-based small-group learning via the Internet among community family physicians: A randomized controlled trial. *MD Comput* **1999**;16(4):May:54–58.

Address reprint requests to:
Rashid L. Bashshur, Ph.D.
Director of Telemedicine
The University of Michigan Health System
C201 Medinn Building
1500 East Medical Center Drive
Ann Arbor, MI 48109–0825

E-mail: bashshur@umich.edu

Chapter 5

Organizational Models of Telemedicine and Regional Telemedicine Networks

Contributors:

Gary Shannon, Ph.D., University of Kentucky
Thomas Nesbitt, M.D., University of California, Davis
and
Richard Bakalar, M.D., Naval Telemedicine Office
Eric Kratochwill, M.H.S.A., University of Michigan
Joseph Kvedar, M.D., Partners Telemedicine
Luis Vargas, Ph.D., University of Pittsburgh

INTRODUCTION

THIS CHAPTER REVIEWS the organizational models in telemedicine including an assessment of their successful attributes. This is followed by a discussion of the concept of regionalization in medical care delivery and its relevance to telemedicine networks, together with a summary of issues pertaining to the planning and implementation of regional, national, and international telemedicine networks. Also included is a select review of telemedicine network developments at the regional, national, and international levels. The chapter concludes with recommendations for research and policy development designed telemedicine networks at all geographical scales of development.

ORGANIZATIONAL MODELS

Over the last 30 years, a variety of organizational models for telemedicine networks has emerged along with the evolution of the field. Predominantly, these organizational models have been generated in response to:

- Interests of funding sources or sponsoring institutions;
- Attempts to meet the unmet health care needs of geographic regions of varying size from a small region to states and entire countries;
- Lack of access to essential medical services (primary care and/or specialty care) in remote areas; and
- Need to provide access to medical care services for selected target populations.

Nevertheless, all telemedicine efforts and related organizational models share the common goal of promoting the transfer of health related expertise over distance to improve the health of a target population. In efforts to achieve this goal, a number of organizational models have been developed. It should also be mentioned that there are few mature and self-sustaining telemedicine systems. This has important implications in determining the relative success of the various models observed, as discussed later in this chapter. Nonetheless, despite the variety and nascent and, in some instances, short-lived nature of many telemedicine networks and projects, it is useful and instructive to attempt a general classification of these models. Such a classification will enhance our ability to evaluate networks and permit objective assessments of their performance and their outcomes pertaining to stated goals. Despite internal variations, most organizational models can be classified into four general, but not mutually exclusive, categories. Within each category, a model may share certain characteristics with models in other categories. We can classify the four models based on:

- Size and complexity of geographic service area, such as regions, states, or countries;
- Target population groups, including rural and inner-city populations, institutionalized populations such as those in long-term care facilities and penal institutions, members of managed care plans, and armed forces members and dependents;
- Single- and multi-purpose medical specialties or disease entities, such as dermatology, diabetes, or comprehensive cardiac care; and
- "Open" or "closed" systems, as defined by a target client population.

Geographically based models provide medical and health services to people residing in a defined geographic region within a state, an entire state, a whole country or a group of countries. At each scale the designated target area may or may not be geographically contiguous. For example, in the United States, the Georgia Statewide Telemedicine Program ostensibly serves the entire State of Georgia. The Arizona Telemedicine Program serves a large portion of the State of Arizona, several correctional institutions in the state and international partners. The Mayo Clinic Telemedicine Program, based in Rochester, Minnesota, has links with affiliated clinics in Jacksonville, Florida, and Scottsdale, Arizona, in addition to international links with Amman, Jordan, and several medically underserved areas of the United States. In Europe, the National Center for Telemedicine serves the northern region of Norway. In Toulouse, France, the Regional Telemedicine Network in Mid-Pyrenees Province serves the Mid-Pyrenees Region, as well as locations in several other countries. The most notable and geographically comprehensive national telemedicine program is that of Malaysia. Here, the government developed a comprehensive program as part of its national health plan to meet the needs of the entire population.

Population-based models are designed to meet the health care needs of a defined population, which typically receives its health services based on entitlement. These include institutionalized populations such as inmates of correctional institutions and residents of long-term care facilities, as well as service groups such as members of the armed forces, and patients enrolled in the Veterans Administration Health Service. The Veterans Health Administration has an active program in its various administrative regions throughout the United States. The U.S. Army has an active telemedicine program together with a high-level research center, the Telemedicine and Advanced Technology Research Center. The Center facilitates development of operational and peacetime telemedicine applications along with advances in medical informatics, such as the high capacity medical record, known as Personal Information Carrier (PIC). The U.S. Navy's Program provides services to its personnel aboard ships on a worldwide basis.

Specialty- or disease-based models use technologies to draw together clinical, research and educational efforts that address a specific clinical or a set of clinical services to assist people with certain illnesses. There are many examples of this type of model and only few are mentioned here as illustrations. In the United States, the Centers for Medicare and Medicaid Services (formerly the Health Care Financing Administration [HCFA]) recently provided funding for a consortium of health care groups and providers to install Internet-based telemedicine technology in homes of hundreds of low-income diabetic patients living in medically underserved areas of New York State. The object of the 2-year project is not only to improve care, but also to determine the cost-effectiveness of the technology.[1] This is a particularly important project because it is designed as a randomized clinical trial.

In Europe, the European Commission (DG XIII Information Society) provided support for the Black Sea Tele Diab system project. The system provides clinicians in countries of the Black

Sea area with a computer-based diabetes health care record system in order to promote the electronic exchange of health care information between clinicians and scientists in these countries.[2,3] The European Commission-DG XIII also sponsored the Remote Diagnosis, Management, and Education in Congenital Heart Disease telemedicine project involving the United Kingdom, Greece, and Portugal. In Italy, the Ministry of Public Health initiated a 3-year pilot project in Trento Province using ISDN technology over a Wide Area Network. The project provided comprehensive oncology services for providers and their patients in seven rural hospitals in the region.[4]

Finally, telemedicine systems may be open or closed. Open systems permit global access to expert health knowledge without the barriers of health professional licensure or conflicting health policy agendas. For example, the Partners Online Specialty Consultation Program provides global access to its specialists through its Web site. Launched on July 1, 2001, the program provided care to 509 patients across the globe in its first 6 months of operation. The Global Grid Telemedicine System (GGTS) is a global telemedicine command and control system that allows telemedical consultations to occur anywhere in the world, regardless of location or transportation modality. The GGTS is unique, as it is software based and not solely reliant on human interaction for consult-requestor linkage.

Typically, programs that offer services to institutionalized or other specified target populations are, by definition, closed systems, because their clients (patients/users) are limited to specific target populations in specified institutions. The most significant barrier met by closed systems has been the lack of appropriate technological infrastructure among its end user clients. Funding sources of closed systems or laws often dictate the terms of entitlement in closed system.

For more examples, see the following Web site: www.ntia.doc.gov/otiahome/top.

SPECIAL CASE CLOSED MODELS

The following brief discussion of what might be termed the "military model" of telemedicine is provided as a special case. Military telemedicine does not face the usual problems seen in the private sector pertaining to licensure, reimbursement, and liability. However, it faces unique challenges in complexity in meeting the needs of its populations from all areas around the globe. Hence, the military telemedicine experience may offer additional insight into the development and success of other types of organizational models. Moreover, in the military sector, there is only one payer, and the service population is constrained in the availability and choice of medical care. In certain respects, military telemedicine is unique in terms of its organization and implementation. It is an example of a "tightly" closed model with a number of special and singular characteristics, and it may not serve as a versatile model beyond the military sector. Nevertheless, important lessons can be learned from this system. In addition, the military has served as an important test bed for new technologies that can be applied in the public and private sectors.

Medical support for United States armed forces involves providing medical care in distant countries. In addition, combat troops are generally "on the move," and the medical facilities that serve them must be mobile as well. Because of the unique conditions of many military operations, the infrastructure requirements—such as transmission speed and ready availability of information—are of paramount importance. During peacetime, military troops increasingly are deployed to many parts of the globe to support humanitarian, peacekeeping, and disaster relief missions. These missions often face significant logistical problems as well as mechanisms for maintaining and making readily accessible large volumes of patient records. In both combat and humanitarian missions, these records must be transmitted so that forward medical personnel have adequate information to treat a casualty, an illness or an injury.[5]

The U.S. Navy Business Office is actively deploying teleradiology capabilities in all ships in the Navy fleet. A similar effort is underway in the U.S. Air Force. The National Aeronautics and Space Administration (NASA) has had a long-standing interest in the applications of telemedicine in medical monitoring of astronauts in space.[6–8] Similarly, correctional institutions have supported the deployment of telemedicine. Experience has demonstrated strong evidence of its cost effectiveness in comparison to traditional modes of providing care to inmates.[9] State and federal correction departments are using telemedicine to deliver health care to inmates to improve quality of care, save on transportation costs, and enhance public safety.[10]

ATTRIBUTES OF SUCCESS

To date, there are few systematic attempts to ascertain the attributes of successful telemedicine programs. Despite the diversity of models and the lack of systematic empirical research, practitioners and observers suggest several basic attributes of successful models. These attributes include the following:

- A clearly articulated mission, which provides direction for the program as well as specific targets/goals to be achieved.
- An accountable governance structure, which creates accountability, as well as an effective decision-making authority structure to facilitate operations and coordinate activities within the organization.
- A well-defined service or target population to determine who gets service and on what basis. The criteria for entitlement could be, but are not necessarily limited to, membership in managed care organizations, residents of a specific region, or patients with a particular disease.
- Identification of the service providers, including their specialties, capabilities, and willingness to participate in the program fully.
- Specification of the services provided and the conditions under which the services would be provided. Ideally, the services would match the needs of the target population.
- Administration of quality assurance mechanisms, as well as meaningful ongoing evaluation of activities and outcomes.
- Detailed procedures and protocols for activities ranging from receiving requests and delivering service, to quality control procedures, and outcome evaluations.
- The appropriate choice of technology is also critical to the success of any program, including the appropriate level of investment in technology. Technology must fit the specific clinical needs of the providers as well as the capabilities of the local communities. It must be reliable and responsive, and it must have an open architecture in order to allow changes and growth.
- Finally, programs must be economically viable and self-sustaining, be based on a sound economic framework, which delivers significant value for the investment.

As explained above, these attributes do not derive from systematic research or comparative analysis of operational programs. They are based largely on views of practitioners in the field and general assumptions about organizational behavior. Their derivation seems serendipitous in view of the dearth of self-sustaining models from which such observations can be made. However, with continued information development and proliferation nationally and globally, the technical barriers to network development will continue to decline. Hence, the need to identify sound organizational models and successful attributes will become even greater. Attention is now directed to an attribute long considered essential to the effective and efficient delivery of medical care, namely, regionalization.

REGIONALIZATION

Historically, regionalization has been hailed as an efficient, effective, and equitable basis for organizing and integrating the delivery of health and medical services to a target population residing in a designated geographic region. Both in theory and practice, regionalization is aimed at coordinating and integrating health resources and facilities within regions to promote both efficiency and equity. Efficiency is achieved by means of: (1) locational efficiency of resources, or the optimal location especially of new facilities and (2) efficient utilization of existing resources. Equity is achieved by enhancing access to the available resources by a population living within the specified region.

The lack of implementation of regionalization in telemedicine networks or planning at the regional level, is likely to result in unnecessary duplication of resources and underutilization/overutilization, or otherwise inefficient utilization of services.[11] However, despite the anticipated benefits, the implementation of regionalization in telemedicine faces serious obstacles related to the difficulties of planning systems in general, especially planning for the coordination and integration of health services in an unstructured environment. To be successful, planning requires political support, citizen participation and detailed information. If not done properly, citizens may not be involved in decision-making; and the planning process may actually lead to increased costs.[12] Moreover, the benefits of regionalization cannot be realized without changes in the resource allocation methods.[13]

With the continued evolution of sound organizational models, telemedicine can offer a fresh new perspective on regionalization that requires serious consideration and attention, since it promises to achieve the desired objectives (1) without having to relocate established facilities, (2) while establishing new facilities at reasonable cost, and (3) causing minimal overall disruption.

The concept of medical care regionalization is not new in the United States, or in many other countries of the world. Considerable efforts have been directed toward organizing medical resources and facilities to improve their geographic redistribution and to overcome disparities in resource availability and people's access to these resources. Today in the United States, major concern is directed toward the differences between rural and urban areas (*Healthy People 2010*).[14] In addition, there is increasing unease at the lack of available and accessible preventative health programs and medical care in large sections of central cities increasingly populated by ethnic minority and poor populations (*Healthy People 2010*). At the global scale, concern is increasingly directed toward the gaps in provision of medical care in developed versus redeveloping and emerging nations.

REGIONAL NETWORKS

Telemedicine networks have the potential to alleviate problems related to geographic isolation and distances that separate patients and health care facilities. Electronic or virtual networks can provide near instantaneous communication links between providers and clients/patients. Indeed, development of comprehensive regional and national networks is key to the substantial reduction in the geographic and time barriers pertaining to medical care availability and access to preventative, therapeutic and health education programs.[15]

Whereas the potential benefits of an integrated regional and national (and international) network for individuals, remote populations, clinical professionals, and health/medical researchers may be obvious, we have yet to realize the necessary and desired seamless, "regionally nested" network hierarchy. Regardless of scale, these networks will not supplant and must be developed and coordinated in conjunction with traditional "in person" medical care systems in situ.

Barriers continue to exist to the development, adoption, implementation, and ultimately the success of telemedicine systems at each level in any proposed regional hierarchy. There are barriers to regionalization at the international level, as well as well as some potential guidelines for development. The following issues were identified by a large sample survey ($n = 350$, from 29 different countries) as general barriers to a "Global Information Society for Health."

- Patient confidentiality and access rights, data protection and security, and consent.
- Clinical risks including quality of practice and malpractice exposure.
- Regulations including reimbursement and licensure.
- Liability for defective telemedical systems and telecommunications network deficiencies.
- Interoperability of work stations, and
- Access to adequate bandwidth.[a,16,17]

SELECTED FINDINGS

There is an extensive literature that describes individual telemedicine initiatives in a variety

[a]It should be noted that the majority of these barriers exist regardless of the scale of the network considered.

of medical and health fields at the regional and national levels. Presented here are few examples to illustrate current findings and provide a basis for further discussion. To date, the most comprehensive effort toward developing a regional (international) hierarchy is concentrated in Europe. Designed for international use, the experiences are both illustrative and instructive for our purposes. For example, under the auspices of the European Union (EU) in cooperation with the G-7/8 countries, a number of regional test beds have been established. Of particular importance is the Global Healthcare Applications Project Theme 8, which aims to demonstrate the potential of telematics in the field of medicine and health care through 10 subprojects covering a wide range of applications and issues. The subprojects ranged from a global public health information network through a global healthcare network with Internet connectivity and concerted international collaboration (www.gip.int/G8/GHAP.htm).

In Europe, the Telematics in Ophthalmology (OPHTEL) project was designed to overcome regional differences in ophthalmology and internal medicine within and between five countries in Europe.[b] The first stage of the project developed a multilingual diagnostic and therapeutic thesaurus in order to create standards for communication and quality control.[18] It was also determined that the scientific quality of transferred ophthalmologic content must be assured.

The Trans European Network for the Provision of Value-Added Services in Telemedicine network project assessed acceptance of telemedical services by end users, the economic viability of telemedicine—especially in an international context, the legal implications of telemedical practice and the regulatory framework within the EU.[19] Results from the study suggested that developing framework agreements between telemedical service providers and "bulk" users, such as insurance companies and public health authorities, would enhance cooperation. Moreover, telecommunications information network "backbones" should be provided over which competing networks could be organized; and, a supranational organization should be organized to operate the international network.

A number of pilot projects have been proposed and undertaken to encourage the growth of telemedicine in underserved regions, including an evaluation of their potential in serving unmet needs and cost-benefit ratios.[20] Such projects could form the basis for developing a national health policy that incorporates telemedicine. At the same time, however, a warning was issued that sponsors of such pilot programs should have a clear plan from the start as to how the project can be sustained when sponsorship terminates.[21] It was also made clear that the rapidly growing interest in telemedicine networks within underserved regions will challenge the medical community and make them reconsider how to provide services and address medical needs in which services are absent or in short supply.[22]

To this end, the EU has sponsored a project in Africa to develop "indigenous" regional telemedicine networks in developing countries connected to European counterparts.[23] For example, the Fundamentals of Modern Telemedicine in Africa (FOMTA) is aimed at preparing the way for the use of broadband technology in Africa. FOMTA was designed to eliminate the lack of a supportive infrastructure by simulating an integrated service digital network. Other pilot projects in Africa and Asia are being carried out under the auspices of the Telecommunication Development Bureau of the International Telecommunications Union.[24]

BARRIERS TO IMPLEMENTATION

The potential of telematics in several areas, including "smart cards," cancer detection, public health information, medical imaging and dentistry has been demonstrated. However, there remain significant barriers to international collaboration and cooperation, including variations in culture, illness behavior, and language as well as incompatibilities in technology, variations in medical practice and requirements for diagnosis and treatment. Other

[b]Denmark, France, Germany, Great Britain, and Italy.

problems in developing and implementing integrated regional projects include:

- Limited volume of utilization to date.
- Lack of clear strategies for promoting wider utilization in particular specialties or geographical areas.
- Lack of uniform standards for health technology assessment.
- Limited dissemination of results based on the experience to date.
- Lack of necessary infrastructure in many remote areas, especially those with greatest needs for medical care and preventative health programs.
- Limited technical resources to assist underserved areas in developing systems.
- Rapid obsolescence of technology and the attendant lack of interoperability.
- Uncertainty about practical and reliable solutions and security of patient data.
- Inconsistent quality assessment.
- Geographic licensure barriers that limit professional privileging across intra- and international boundaries.

A review of the literature that addresses regional and integrated telemedicine network development reveals support for these findings as well as determination of other barriers. The following section describes a few illustrative projects designed to address barriers presented here.

The EU-sponsored Network of Integrated Vertical Medical Services (NIVEMES) was designed to create an international hierarchical network of telemedicine service providers for remote, isolated places for both routine and emergency situations.[25] In conjunction with the project, a variety of new training needs arose. Users had to be instructed in new ways of conducting business, of taking advantage of available services, and even a new way of perceiving health care delivery. In brief, telemedical networks "spawned" in each region had to be coordinated, and the users needed to know where and how to acquire necessary support.

The organizational consequences of regional telemedicine were examined qualitatively among a small cohort of physicians in Norway.[26] Several changes had to be made with regard to the organizational restructuring, patient-flow through the system, job descriptions, and clinical teamwork.[27] Additionally, specific procedures and requirements had to be implemented to ensure the confidentiality and integrity of patient data.

Severe disruption of traditional management and organizational practices was also identified as a derivative of the regionalization of health informatics.[28] Telecommunications and Internet technologies were observed to "render ineffectual" previous external barriers of distance and regional boundaries, while the combination of knowledge bases with information technologies created tendencies towards internal autonomy of organization. From this perspective, telemedicine creates direct and radical challenges to the organizational and national policy control of medical care.

International telemedicine network development also must respect indigenous cultural norms and health care beliefs. Significant questions arise for telemedicine networks, namely, to what extent will international and global telemedicine networks be viewed as a form of "virtual colonialism?" To what extent will and should international and global networks impose a Western model of medicine on culturally distinct populations? What is the price of globalization of telemedicine in terms of loss of diversity? Many national leaders view "global culture as Western culture." The current global information-communication order is seen by some as a principal diffusion agent to serve the market and political needs of the Western world.[29] It is viewed as a form of media or "cultural imperialism" that threatens the cultural integrity of many groups and nations. How can international and global networks avoid imposing a Western medical model and Western philosophy of medicine? Alternatively, perhaps, the question is better framed as, "How can Western medicine be appropriately adapted to indigenous medical cultures and practices through the use of telemedicine?" Acting globally in the Information Society demands cooperation of citizens on a global scale, over different cultures and languages, to an extent not necessary in the past.

The goals and conclusions arrived at in the final report of the G8 Pilot Project Theme 3, Transcultural Education and Training for Language Learning, also addressed this concern.[30] The aim of this project was to develop an international network for language education and training including the cultural dimension required for communicating adequately in another language. Interestingly, one purpose of the project was to help people develop adequate and effective resources to learn better how to communicate—while retaining their cultural and linguistic diversity. Accordingly, this concept of a global information society would give real meaning to citizens. It would enable them to "concretize the vision of technology that supports cultural diversity and richness globally, rather than a uniform monolingual scenario that forces people to adapt to technology instead of technology adapting to people."

RESEARCH AND POLICY CONSIDERATIONS

A review of the literature reveals near universal consensus among scholars, program developers and policy-makers regarding the many issues facing and limiting the full deployment of telemedicine and the exploitation its capabilities regardless of scale, whether regional, national, or international. The burgeoning literature also reveals a plethora of independent, noncoordinated, non-self–sustaining projects at the regional, national, and international scales financed by various combinations of public and private funding. The ultimate success of regional networks remains uncertain, making progress toward a nested hierarchy of regional programs leading to a truly national and ultimately international network all the more demanding. Nonetheless, effective, integrated virtual and traditional regional networks must be developed, deployed and maintained at the regional, national and international levels.

Several questions and issues must be addressed and resolved before an integrated, seamless, nested telemedicine hierarchical network can be realized. Some of these issues are complex and difficult to solve, and some may be addressed in several different ways. However, it is important to start the process without delay.

RECOMMENDATIONS

The development of national and international regionally integrated networks requires an effective and efficient organizational structure to develop guidelines, regulations, licensing procedures, as well as security and privacy protection for patients and providers. The World Health Organization (WHO) is ideally suited for these tasks. Its regional offices could serve as a starting point for the development of a global telemedicine union. The WHO also has official relationships with the United Nations, the European Union, Organization for African Unity, as well as over 150 additional regional, national, and international nongovernmental organizations (NGOs) from the Aga Khan Foundation to the World Veterinary Association. The WHO has also made a commitment to use telecommunications for health and to partner with the United Nations and other organizations to advance the exchange of health information across geographic, temporal, and social boundaries.[31]

The European Union provides another model for this type of international cooperation within one region of the world. Although a supranational organization, it operates in a coordinated manner in the political, economic and medical sectors for (currently) 15 countries.

The development of subnational regional and interregional telemedicine organizations requires close cooperation and coordination among the constituent telemedicine programs. Each region would be self-contained in terms of providing a complete range of primary care and specialty services within its network of providers.

The potential for developing integrated telemedicine/telehealth networks at the regional, national, and international scales depends largely on the existence of an adequate telecommunications infrastructure. Overcoming the "digital divide" that separates areas with and without adequate communications infrastructures will be expensive, but it must be identified as a national and international priority. Regional and national virtual/electronic communication networks must be developed and maintained in order to improve access to quality medical care for people living in medically underserved areas. The new information network will create a new geography of medical care, while retaining some traditional elements of the old system.

Within the United States as well as within and between most countries, there remain many and deep cultural (religious, linguistic, ethnic), socioeconomic, and historically diverse communities. These differences are reflected in the evaluation, interpretation, and treatment of diseases and health conditions and are manifest as barriers to development of a national standard for medical terminology and treatment protocols. The variability of medical/heath resources including technology and personnel also constitutes a formidable barrier to a seamless hierarchy of telemedicine/telehealth networks. Serious and concerted action must be directed at reducing the "digital disparities" between communities, regions, and nations.

While many networks and models are recognized as "successful," little research addresses the measurable and relevant outcomes of successful models beyond anecdotal and subjective evaluations of pilot projects. The key attributes of successful models and the fatal flaws of unsuccessful models merit increased emphasis and study. Consideration should also be given to determine whether smaller, successful models could be scaled to larger populations and regions.

Telemedicine networks cannot be developed entirely separate from the traditional health care networks already in place. There must be coordination and integration between the telemedicine and traditional medical care networks if the entire process is to be successful. Remote expert diagnosis, clinical protocol, and prescription do not help patients in areas lacking appropriately trained personnel and without access to appropriate medical facilities. Telemedicine networks cannot be planned and implemented without taking into consideration the "facts" on the ground. For the foreseeable future of telemedicine, the geography of remote populations, travel distance, and the distribution of remote personnel and facilities will remain fundamental to planning of regional networks, regardless of scale.

In certain areas, for example, teleradiology and telepathology, international standards and terminology have been developed. It is not as simple, however, when clinical diagnosis and treatment are involved. Further study is needed in the development of clinical guidelines for other specialties. This will allow networks to share resources across models more effectively.

REFERENCES

1. Chin T. Diabetes Project Testing Feasibility of Telemedicine. amednews.com April, 2000
2. Pruna S, Dixon R, Harris, N. Black Sea Tele Diab: Diabetes computer system with communication technology for Black Sea Region. IEEE Transactions on Information Technology in Biomedicine **1998**;3:193–196.
3. Pruna S, Pauna S, Harris ND, Stanciu E, Dixon R. Black Sea Tele Diab: A Computer-based Information System for Diabetes itch.uvic.ca/itch2000/PRUNA/PRUNA.htm. Accessed March 2002.
4. Forti S, Graiff A, Visentin R, et al. Telepathology within the Project "Teleoncology over a Wide Area Network in Province of Trento." *Adv Clin Pathol* **1997**;1:2.
5. Gomez E, Poropatich, RK, Karinch, MA et al. Tertiary telemedicine support during global military humanitarian missions. *Telemed J* **1996**;2:201–210.
6. Williams DR, Bashshur RL, Pool SL, Doarn CR, Merrell RC, Logan JS. A strategic vision for telemedicine and medical informatics in space flight. *Telemed J e-Health* **2000**;6:441–448.
7. Nicogossian AE, Pober DF, Roy SA. Evolution of telemedicine in the Space Program and earth applications. *Telemed J e-Health* **2001**;7:1–15.
8. Butler DJ, Simmons SC, Guess TM, Effenhauser RK, Jones JA, McGinnis PJ. The NASA Haughton Mars Project: validation of medical technologies and operations on Devon Island. *Telemed J e-Health* **2001**;7:141.
9. Butler DJ, Simmons SC, Guess TM, Effenhauser RK, Jones JA, McGinnis PJ. The NASA Haughton Mars Project: validation of medical technologies and operations on Devon Island. *Telemed J e-Health* **2001**;7:141.
10. Allen A. UTMB-Galveston: in a league of its own. *Telemed Today* **1995**;3:15–16.
11. Rosenblatt R, Macfarlane A, Dawson A, et al. The regionalization of perinatal care in Wales and Washington State. *Am J Public Health* **1996**;86:1011–1015.
12. Church J, Barker P. Regionalization of health services

in Canada: A critical perspective. *Int J Health Services* **1998**;28:467–486.

13. Williams S, Belcher D, Moscovice I, Inui, T. Regionalization in the Veterans Administration health care system: Rhetoric and realities. *J Health Politics, Policy and Law* **1980**;5:98–119.
14. *Healthy People 2010.* Office of Disease Prevention and Health Promotion, U.S. Dept. of Health and Human Services, November 2000.
15. Skiba D, Springer H. Computer mediated learning experiences spanning the globe: A pilot study between schools of nursing in the United States and the Netherlands. *Medinfo* **1995**;8(Pt 2):1340–1343.
16. Rogers R, Reardon J. *Barriers to a global information society for health: recommendations for international action: report from the project G8–ENABLE.* Amsterdam: IOS Press, Inc.
17. Rogers, R. Overcoming the barriers: National to European to G7. *Int J Med Informatics* **1998**;48:33–38.
18. Mertz M, Mann G, Zalmann G, Obermaier M. Scientific role of German opthalmology in the European telecommunications project OPHTEL [German]. *Opthalmologie* **1997**;96:523–528.
19. Anogianakis G, Maglavera S. Transeuropean network for the provision of added-value services in telemedicine: (VAST-Net). *Studies health technolo informatics* **1997**;39:298–306.
20. Wright, D. Telemedicine and developing countries. A report of study group 2 of the ITU development sector. *J Telemed Telecare* **1998**;4(Suppl 22):1–85.
21. Wright D. Can developing countries afford telemedicine? In: Wootton R, ed. *European Telemedicine.* 1999 London, England: Kensington Publications Ltd., **1999**:35–37.
22. Wright D, Androuchko L. Telemedicine and developing countries. *J Telemed Telecare* **1996**;2:63–70.
23. Adeyinka M. Fundamentals of modern telemedicine in Africa. *Meth Informatics Med* **1997**;36:95–98.
24. Wootton R. The possible use of telemedicine in developing countries. *J Telemed Telecare* **1997**;3:23–26.
25. Samiotakis Y, Anagnostoupoulou S, Alexakis A. A regulated telemedicine system for day to day application in remote areas. *Studies in Health Technol Informatics.* **2000**;57:9224:91–98.
26. Aas I. Telemedical work and cooperation. *J Telemed Telecare* **2001**;7:212–218.
27. Caramella D, Reponen J, Fabbrini F, Bartolozzi C. Teleradiology in Europe. *Euro J Radiol* **2000**;33:2–7.
28. Rigby M. The management and policy challenges of the globalization effect of informatics and telemedicine. *Health Policy* **1999**;46:97–103.
29. Janelle D. Global interdependence and its consequences. 1998.
30. Tel*Lingua (1997) Transcultural education and training for language learning. G8 pilot project theme 3 final report. http://www.gip.int/G8/TelLingua.htm
31. Brundtland G. Speech to the inter-country meeting on telemedicine. Riyadh, Saudi Arabia, 6–9 February 1999.

Address reprint requests to:
Rashid L. Bashshur, Ph.D.
Director of Telemedicine
The University of Michigan Health System
C201 Medinn Building
1500 East Medical Center Drive
Ann Arbor, MI 48109–0825

E-mail: bashshur@umich.edu

Chapter 6

Telemedicine Technology

Contributors:

Michael Ackerman, Ph.D., National Library of Medicine
Richard Craft, M.S., Sandia National Laboratories
Frank Ferrante, M.S.E.E., M.S.E.P.P., Johns Hopkins University
Mary Kratz, M.T., Internet2
Salah Mandil, Ph.D., World Health Organization
Hasan Sapci, M.D., University of Michigan

INTRODUCTION

THIS CHAPTER FOCUSES on the status of the technology and presents an agenda for future development. Whereas information technology has taken giant strides in developing effective and efficient tools for delivering health services to widely dispersed populations, much remains to be done on the parts of both the technology industry and the health system. Indeed, the ultimate success of telemedicine/telehealth depends on how well the health care system exploits the capabilities of advanced information technology. This technology can extend the reach of medical facilities and resources, promoting efficiency, productivity, accuracy in clinical decision-making, coordination, and integration. At the same time, information technology, for its part, will need to redesign network systems to offer quality of service, bandwidth on demand, and a more effective business model—a model that would charge for network connectivity on the basis of data flow and appropriate speed.

The telemedicine industry as a whole has asserted that the technological requirements for telemedicine systems are already available, albeit at various degrees of efficiency and various levels of cost. Telecommunication links are becoming nearly ubiquitous, but they still do not reach all communities, leaving segments of the population unserved. While off-the-shelf devices provide all the necessary hardware and software for operating telemedicine systems, the development of more advanced technology will enable the creation of telemedicine devices to support more applications.

Still, numerous questions can be raised regarding future trends in technology. The following questions only illustrate the range of issues yet to be resolved. Does the future of wireless and broadband offerings imply that we are on the brink of a revolutionary change in health care delivery? Will the cost of these advancements slow progress, or will competitive pricing resulting from better standards and improved interoperability across products accelerate progress? In view of pending privacy regulations, can the security and privacy arrangements now available meet the needs of the medical profession and patients without compromising quality of service? What are the barriers for the future expansion of telemedicine in the home environment and in the community? Will the expansion of broadband networks, such as Internet2, bring benefits equitably to all segments of society and to all countries?

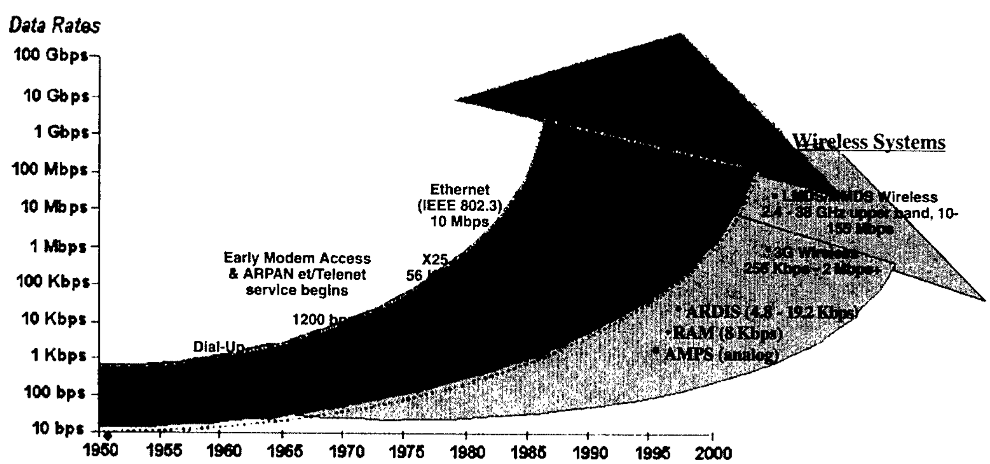
These questions are not necessarily answered in this chapter, and they are beyond its purview. Instead, several equally relevant questions are addressed systematically under the following four topics: technical design, technical applications, interoperability, and security. All these topics are critically important. However, in this report, the discussion will be limited to the first three only. To be sure, security of the data passing through a network or accessible through a network is of vital importance, and risk management must be an integral part of all telemedicine technology.

TECHNICAL DESIGN

Telecommunications support has varied from basic telephone service to broadband Internet, incorporating online diagnostics, remote patient monitoring, and today's virtual touch computer interfaces, referred to as haptics. Figure 1 illustrates the extent of change that has occurred in telecommunications over the past half century. The key item to note is today's multitude of high-speed service offerings that can be used in the design of telemedicine systems.

The asynchronous transfer mode (ATM) is one of the new high-speed offerings available in today's telecommunications market. ATM systems are preferable when high data rate transfers of information are required. When coupled with the resilient synchronous optical network (SONET) configurations, ATM systems offer high-quality and low-delay conditions. Currently, fiberoptic systems are being designed to support data rates as high as 40 gigabytes per second (Gbps) (OC-768) for advanced medical systems.[1–3]

Mobile service for medical applications, such as those encountered in ambulance operations, is critical. As indicated by Casal, et al.,[4] "Mobile communication systems can defined in five groups: cordless, cellular, satellite, paging, and private mobile radio systems. These mobile communication systems will all be included at a common system: the Universal Mobile Telecommunications System, (UTMS)." Prehospital management in emergency care can be essential for patient survival. A portable medical device that transfers patient diagnostic information to physicians at a distant location while in the ambulance has been developed



LEGEND:

- Frequency Band Trends (39-50 MHz, 150 MHz, 400 MHz, 800 MHz, 700 MHz, 2.5 GHz, 5 GHz, 28GHz, 38 GHz)
- Local/Multichannel Multipoint Distribution System (LMDS/MMDS)
- Wireless; Analog/Digital Cable Technology (unlicensed - 2.4–2.5 GHz bands; licensed -24–38 GHz bands with data rates in the 1.5 to 155 Mbps range)
- RAM - Radio Analog Mobile Service
- ARDIS - Advanced Radio Data Information Service
- AMPS - Analog Mobile Paging System

FIG. 1. Evolving telecommunications complexity. (Source: Author Frank Ferrante.)

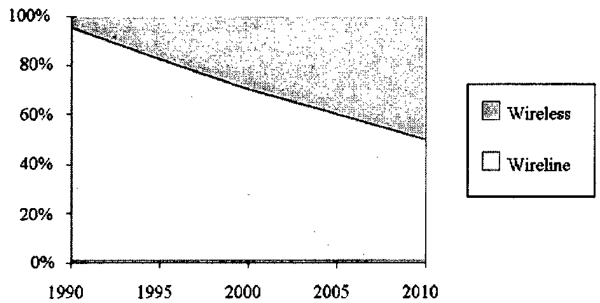


FIG. 2. Growth in wireless vs. wireline. (Source: MITRE Corporation.)

and evaluated.[5] Figure 2 illustrates the recent and predicted future trends in wireless growth.

Wireless systems are defined as first and second generation (1G and 2G or 2.5 G). These network designs offer services for analog voice as well as digital services up to 38 kbps. The next generation of wireless (3G) incorporates broadband, multimedia mobile operations with digital services ranging from 144 kbps across all environments and from 384 kbps pedestrian outdoors up to 2 mbps indoors.[6] As the next generation digital cellular network will have faster and larger transmission capabilities, more complex medical services can be delivered reliably and without degradation of quality.[7]

The concept of intelligent "mobile agents" to support telemedicine applications was described by various authors.[8–10] Essentially these are software agents that can analyze large data sets and retrieve specific information relevant for clinical decision making.

The range and complexity of telecommunications technology requirements vary with specific medical or health applications. However, generically defined digital medical devices impose the telecommunications performance requirements. Table 1 illustrates a sampling of several of the more common digital medical devices used in telemedicine. Figure 3 illustrates the image sizing determination for the devices listed in Table 1. Except for the last few items contained in the table (starting with ultrasounds and running through full-motion video), the majority of vital sign medical devices require relatively low data transmission rates. Capabilities currently offered by these systems, even 1G and 2G wireless and basic telephone connections, would support the transfer of information provided error free or as "error detecting and correcting" processes.

Tradeoff must be considered when choosing a telecommunications system for high data intensive services, as illustrated in Figure 4. This example assumes digital radiography requiring 2048 × 2048 pixels for quality and 12 bits per pixel. In this example, it would take almost 30 minutes to compete the transfer of a single image when using a modem and a speed of 28.8 kbps. This is clearly unacceptable given that several views of a single patient must be transmitted in a single episode. However, the newest telecommunications offerings reduce the time per view to less than a second per view (at OC-768).

In the following section, a few demonstration projects from several countries are briefly described to illustrate the range of applications.

TABLE 1. DATA RATES OF TYPICAL DEVICES USED IN TELEMEDICINE

Digital device	*Data rate required*
Digital Blood Pressure Monitor (sphygmomanometer)	<10 kilobits of data per second (kbps) (required transmission rates)
Digital thermometer	<10 kb of data (required transmission rates)
Digital audio stethoscope and integrated electrocardiogram	<10 kb of data (required transmission rates)
Ultrasound, Angiogram	256 kilobytes (KB) (image size)
Magnetic resonance image	384 KB (image size)
Scanned x-ray	1.8 megabytes (MB) (image size)
Digital radiography	6 MB (image size)
Mammogram	24 MB (image size)
Compressed and full motion video (e.g., nasopharyngoscope, ophthalmoscope, proctoscope, episcope, ENT scope)	384 kbps to 1.544 Mb/s (speed)

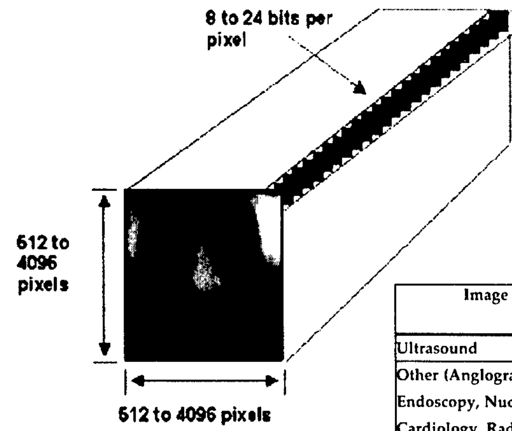


Image Type	Image Resolution		Image Size
	Spatial	Contrast	
Ultrasound	512x512	x8	256 Kbytes
Other (Anglography, Endoscopy, Nuclear Med., Cardiology, Radiology)	512x512	x8	256 Kbytes
Computed Tomography	512x512	x12	384 Kbytes
Magnetic Resonnance Imaging	512x512	x12	384 Kbytes
Digitized (Scanned) X-ray	1024x1250	x12	1.8 Kbytes
Digital Radiography	1024x1024	x8	1 Kbytes
	2048x2048	x12	6 Kbytes
Mammography	4096x4096	x12	24 Kbytes

FIG. 3. Teleradiology imaging applications. (Source: Author Frank Ferrante.)

The first is a collaborative model system developed by Mitre Corporation (McLean, VA). It used two ATM high-speed switching units to support concurrent transfer of voice, data, and video between several medical facilities. Images from this system are shown in Figure 5 (Mitre Corporation, 1995). This system demonstrated a practical application of ATM systems using real-time microscopic image transfers, concurrent with magnetic resonance imaging (MRI) images, live video and audio, and collaborative capabilities between research facilities.

A novel emergency telemedicine system based on wireless communications, AMBULANCE[5] demonstrated a successful wireless telemedicine system at four different sites in Europe. The goal of the project was to transmit medical information from an emergency ambulance to distant medical facilities for consultation. The project reported less than 10% interruptions in communication, and only 5% of wireless connections were actually lost.

A digital wireless system, referred to as the global system for mobile (GSM) communica-

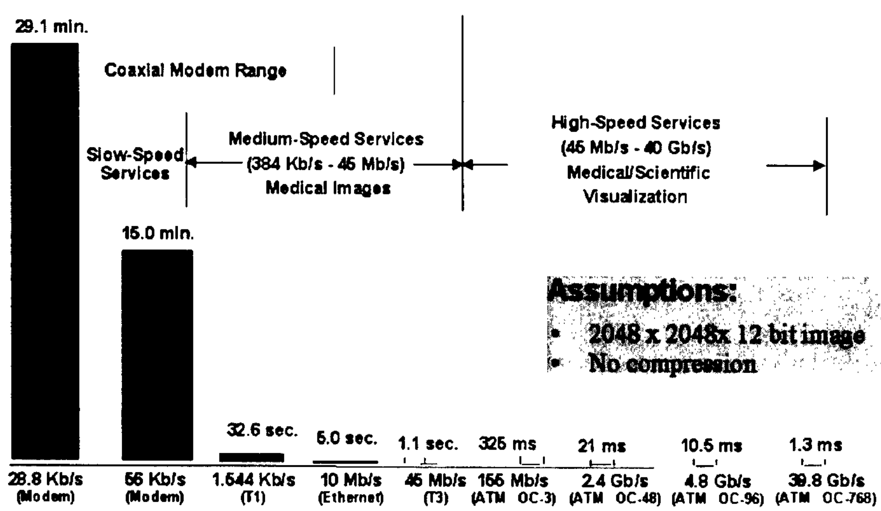


FIG. 4. Image transmission times.

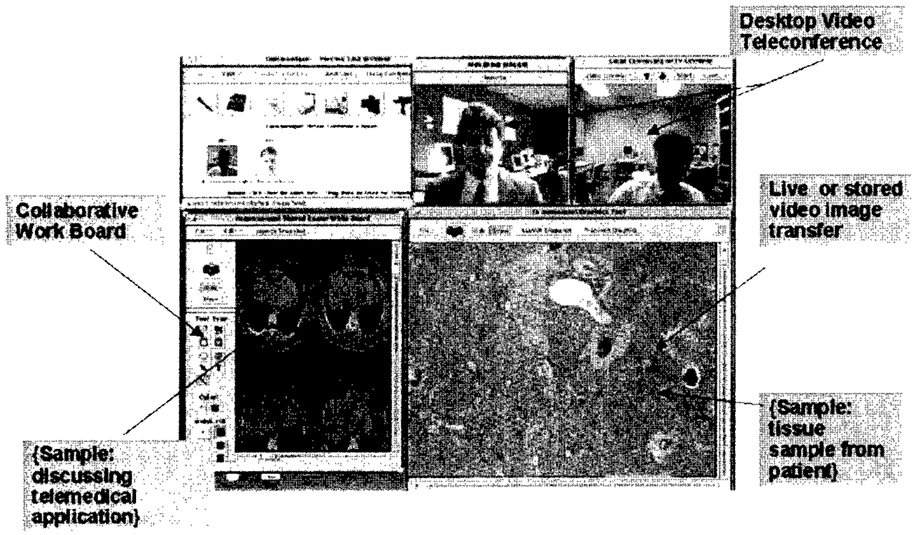


FIG. 5. Asychronous transfer mode (ATM) collaborative computing in a telemedicine application. (Source: MITRE Corporation, 1995).

tions, the system used for cell phones proved more than capable of meeting the minimum thresholds of medical data transfer rates. Generally, GSM was employed in cases where the emergency site was on average 40 minutes away from a medical facility. In some instances, myocardial infarctions (MIs) were treated with thrombolytic therapy before the patient was transported to the hospital.

In a "Home Telecare System Using Cable Television Plants: An Experimental Field Trial," Lee[12] describes an ongoing demonstration in Taiwan using hybrid fiber coaxial cable (HFC). Integrated service digital network (ISDN) and ATM configurations as well as basic "twisted pair" telephone service were also considered before settling on HFC as the most cost-effective solution. These services included a three-channel electrocardiogram (ECG), blood pressure, and live video and audio service. ECG transmissions were successfully completed.

INTEROPERABILITY

To date, much of the engineering work in telemedicine has consisted of integrating off-the-shelf components to enable various clinical applications. As a result, these systems can be costly and inflexible. While they perform well in terms of their intended functions, adding new features can be costly and time consuming. Moreover, the "closed" designs of these systems means that the telemedicine stations from one vendor may not be able to communicate with those produced by another vendor.

To address these shortcomings, the telemedicine community needs a three-level approach to telemedicine system interoperability. First, stations developed by independent vendors must be able to interact with each other. Second, medical devices and other "peripherals" connected to one vendor's station must be able to interact with stations created by other vendors. Finally, it should be possible to create individual stations in plug-and-play fashion from components developed by multiple vendors. The first level of interoperability can be implemented with only limited change in existing systems, and the second level does not necessarily require the first. Reaching consensus on the third level will require substantial effort but will be rewarded by equally substantial benefits.

At the first level, a station wanting to interact with other stations advertises its existence in a "registry server"—a public resource that contains both address and attribute data describing various telemedicine stations. The station wanting to find a specific station or a certain type of station queries the registry server and is provided with the address of at least one station that fits the query. Using this address, the station contacts the desired station and inquires about the specific medical devices and other resources installed at the host station. Subsequently, the requesting station reserves specific resources and a proposed quality of service and security parameters to be used during the session. If the host station responds positively, the two stations negotiate with the network to establish the quality of service requirement for the session. Once a session is established, the requesting station interacts with the resources that it has "leased" from the host station as if these resources were local at the requesting station. This is the simplest form of interoperability.

To address the second level requires standardizing the interfaces of devices (e.g., medical instruments or patient record cards) that attach to a station. It also requires that the station be able to monitor when devices have been added or removed, and that other components in the station be able to explore and employ devices dynamically attached in this way. One approach to achieving this would be through the use of a "station registry," which maintains descriptions of all the components that make up the station and is able to alert other station components when a given kind of device has been added. If implemented, this level of interoperability makes it possible for end users to create, in plug-and-play fashion, a range of stations to meet a diverse collection of healthcare delivery needs.

The third level requires the creation of systems that are based on shared, distributed resources. For instance, in the future, this might allow medical peripherals and software to be added to a home's existing computing and communications infrastructure to create a home-based telemedicine station.

RECOMMENDATIONS

The agenda for technology development and deployment would necessarily require closer coordination between industry and the health care sector to design more efficient systems and to exploit the capabilities of these systems more fully to deliver remote health care. The following areas require special attention.

Middleware

Hardware manufacturers and software developers typically try to design and develop proprietary systems. Successful proprietary systems are highly rewarded in the marketplace because they limit competition and assure a certain market share with a lock on their product. (One distressing feature about standards is the fact that there are so many to choose from.) The most pressing engineering need in telemedicine is middleware, an area that falls between software engineers and network engineers.

Interoperability

Whereas interoperability can be achieved at different levels through standardization and integration, some of these levels may not be achievable in the foreseeable future. Indeed, in the short term, we are not likely to develop fully interoperable telemedicine stations that can interact with each other and make use of each other's devices. Hence, the most pressing need is for middleware (the area between software and network engineering), in both forms hardware and software. Middleware will be the glue that renders incompatible standards interoperable, and it is feasible in the short term.

Perhaps the first step in reaching interoperability is to streamline or create interoperability between seemingly divergent policies. Often, policies and regulations drive the development of technology. This is especially true for technologies that will be required to implement the security and privacy regulations mandated by the Health Insurance Portability and Accountability Act of 1996 (HIPAA). Once final agreement is reached on a set of compatible HIPAA-mandated policies, hardware and software development can proceed and implement these policies. The opportunity for compatibility between various policies and regulations should not be missed.

Portability will also need to be assured through portable medical devices and smart cards. These portable devices must include all systems, including biosignal monitoring, image acquisition and display devices and nomadic computing.[11]

MEMS

Micro Engineer Machine Systems (MEMS) and other forms of nano-technology represent new opportunities for telemedicine. MEMS can take different forms, including MEMS robots in noninvasive arthroscopic surgery, MEMS-encapsulated cameras that can be swallowed to provide detailed images of the digestive tract, and so on. Similarly, wearable wireless sensors can monitor physiological functions in various environments. Work must continue in this highly promising area.

Human/machine interface

Whereas output requires proper displays, input requires better sensors. The quest for designing optimal machine/human interface is ongoing. It is prompted by the need for better, more natural displays and for better, less invasive sensors. Indeed, the optimal design of a human/machine interface may be doubly important in telemedicine because every telemedicine episode requires two interfaces, one at the patient or remote provider site and the other on the consultant side. The interface renders certain pieces of equipment usable or not usable, and the use of telemedicine desirable or not desirable.

The ultimate and most natural human/machine interface is natural language. The development of a human-to-machine natural language would have an especially substantial impact on the home telemedicine market. Research in this area must be a high priority.

Knowledge robots

The development of intelligent medical robots, called "know-bots," will be critical for the future of telemedicine. Each person would have his/her own intelligent avatar that lives on the Internet as well as the person's electronic health record. The know-bot would understand spoken natural language and could respond to inquiries for medical information on the Internet relevant to a person's medical history. The know-bot could also act as a monitor to alert its owner about unhealthy trends in the health record and for inconsistencies in the record.

The medical know-bots could decrease medical errors or enhance quality of care. They could provide relevant and timely information for health promotion, disease prevention, and clinical decision making. Unfortunately, this technology is not likely to appear in resource-constrained countries or isolated rural areas. The challenge here is economic and not technological.

Data integrity and validation

Security systems must be built into every telemedicine network. These systems must be able to ascertain a "real" image and derived images and to authenticate the source.

Technology transfer

The information technology that supports telemedicine is being developed in a variety of settings for a variety of purposes and applications. Much of this developmental work is occurring outside the health care field. Technology transfer, or borrowing, must become a high priority. The network infrastructure for future telemedicine is likely to be public and not private. Hence, it is important to encourage the use of digital video, H. 323 (or Internet Protocols), Health Level 7 (HL7), as well as an open source for software. The ultimate goal is to guarantee end-to-end connectivity. Technology transfer between resource rich and resource poor countries must be a high priority.

REFERENCES

1. Fowler TB. Optical networking: A tutorial and outlook. Telecommunications Review, Mitretek Systems. **2000.**
2. Faraydon K, Nguyen A, Dey S, Rao R. On-Chip Communications Architecture for OC-768 Network Processors. DAC 2001 Conference, **2000.**
3. Held G. On the Road to OC-768. *ITProfessional Magazine*, **2001**;2.
4. Casal CR, Schoute F, Prasad R. Evolution Towards Fourth Generation Mobile Multimedia Communication. Ubiquitous Communications: *hhtp://www.ubicom.tudelft.nl/MMC/MMCstatDocuments.asp*
5. Pavlopoulos S. A novel emergency telemedicine system based on wireless communication technology. Ambulance. *IEEE Trans Inf Technol Biomed.* **1998;** 2:261–267.

6. Agrawal P, Cormac C, Sreenan J. Get Wireless: A Mobile Technology Spectrum. *ITProfessional Magazine.* **1999**;1:18–23.
7. Miaou SG. Huang CY. A next-generation mobile telemedicine testbed based on 3G cellular standard. IEEE Computers in Cardiology Conference, Rotterdam, The Netherlands, Paper #194, September 23–26, 2001.
8. Bui T, Sankaran S. Group decision and negotiation support in telemedicine: An application of intelligent mobile agents as non-human teleworkers. *Proceedings of the 30th Hawaii International Conference on System Sciences* **1997**;4:120–129.
9. Lange DB. *Programming and Deploying Java Mobile Agents with Aglets.* Boston: Addison Wesley, **1998.**
10. Smith KD, Paranjape RB. Mobile Agents for Web-Based Medical Image Retrieval. *J. Telemed & Telecare* **2000**;6(4)Suppl2:53–55.
11. Pavlopoulos S, Kyriacou E, Berler A, Dembeyiotis S, Koutsouris D. A novel emergency telemedicine system based on wireless communication technology-AMBULANCA. *IEEE Trans Infor Technol Biom* **1998**;2:261–267.
12. Lee RG, Chen HS, Lin CC, et al. Home telecare system using cable television plants, an experimental field trial. *IEEE Transactions on Information Technology in Biomedicine* **2000**;4(1):37–44.

Address reprint requests to:
Rashid L. Bashshur, Ph.D.
Director of Telemedicine
The University of Michigan Health System
C201 Medinn Building
1500 East Medical Center Drive
Ann Arbor, MI 48109–0825

E-mail: bashshur@umich.edu

Chapter 7

The Diffusion of Telemedicine

Contributors:

Jim Grigsby, Ph.D., University of Colorado
Michael Rigby, B.A., F.S.S., Keele University
and
Amy Hiemstra, M.P.H., University of Michigan
Max House, M.D., Government of Newfoundland
Silas Olsson, M.Sc., European Commission
Pamela Whitten, Ph.D., Michigan State University

INTRODUCTION

THIS CHAPTER DESCRIBES general trends in the growth and diffusion of telemedicine worldwide. It begins with a description of the diffusion in the United States, and is followed by examples from a range of other countries. A theoretical model is then presented that contains factors that affect the adoption of new technologies, particularly in a free market economy and with a high degree of professional autonomy. Attention is then focused on the analysis of important factors slowing the spread of telemedicine on several different levels.

Analyzing the diffusion of telemedicine and telehealth is complicated by virtue of the complexity and inclusiveness of the field. Although telemedicine or telehealth refers to the delivery of medical or health services at a distance, there is no single and uniform telemedicine or telehealth service as such. As well, there is no specific, fixed, or uniform technology that enables telemedicine or telehealth. Instead, telemedicine and telehealth encompass a full range of diagnostic, clinical, and educational services and activities aimed at the promotion of health, the prevention of disease, and the treatment of illness. The technology of telemedicine also is variable; design configuration, transmission, and equipment are all developing quickly, with much of it becoming obsolete almost as quickly. Hence, it is neither possible nor perhaps appropriate to postulate a target or desirable rate for the diffusion of telemedicine as a whole, in isolation from a host health care system, the specific applications of telemedicine, or the alternative means of providing the same services.

In addition to its inherent complexity, the major difficulty in assessing global diffusion of this field derives, in large part, from the fact that health care systems, health care technologies, and the availability of health care vary enormously between nations and even among developed industrialized nations.[1,2] As expected, many developing nations are economically disadvantaged to such an extent that even basic public health systems are either lacking entirely or overwhelmed by the aggregate burden of poverty, unemployment, limited education, the double weight of infectious and chronic diseases, and disabilities. Hence, a discussion of the areas in which the majority of the world's population lives may involve a very different set of considerations and hierarchies of need than those of its counterpart.

A further complication—but one that can also be an enriching factor—is that telemedicine, by definition, can cross national boundaries and indeed circle the globe. Hence, the patient and the referring health professional can be in one health system and economic environment, and the expert in another. This can bring new expertise to areas in need of it. But it also has the risk of destabilizing or bringing new priorities to local settings.[3,4] It may be difficult to determine when such external influences are beneficial or when they are inappropriate because of opportunity cost, inequity, or distortion that can only be determined by applying local values.[5] Thus, global diffusion is a significant issue in its own right.

Most discussions of diffusion of technology assume an economic base that would permit the purchase, maintenance, and operation of the requisite infrastructure and the ability of patients or payers to purchase the services it might provide. Because of the complexity and differences of economies and health care systems from one nation to another, the economic issues underlying the differential diffusion of telemedicine on a global basis (intranationally or internationally) will not be discussed here. They represent a separable set of issues that is best handled independently.

GROWTH AND DIFFUSION OF TELEMEDICINE

Telemedicine had its beginnings in the United States in the 1960s[6] as a means of providing specialty consultation using closed circuit interactive television. The idea of telemedicine, however, was decades ahead of the limited quality, availability, and affordability of the technologies then available. Consequently, the development of this modality for providing health services continued to be slow and sporadic. By the early 1990s, dramatic improvements in information and communications technology heralded the dawn of a new era for telemedicine.

It is 10 years since the resurgence of interest in telemedicine. The technology has undergone considerable development: the cost of equipment and communications has declined substantially; a wide range of applications has been deployed; telemedicine has been used in a variety of unique and extreme environment[7,8]; the quality of the published literature on telemedicine has improved; administrators have more realistic ideas about how to plan and use the technology, tempered by years of uphill struggle; and slow progress has been made in the areas of coverage and payment. Yet, apart from the notable exception of teleradiology, the overall diffusion of telemedicine is below the expectations of its proponents.

Data from the Association of Telemedicine Service Providers (ATSP) Annual Survey of Telemedicine reveal a positive trend of growth in the number of programs and providers (Table 1). However, the aggregate statistics mask the uneven distribution of growth. In 1998, fully 30% of nonradiology activity occurred in a handful of state prisons; 20% of all encounters involved mental health services.[9] In the 132 programs in the 1999 sample, only 15 reported more than 1000 teleconsultations a year, suggesting uneven regional distribution

TABLE 1. GROWTH IN NORTH AMERICAN TELEHEALTH ACTIVITY

	1994[a]	*1995*[b]	*1996*[c]	*1997*[d]	*1998*[e]	*1999*[f]
Number of programs identified	24	49		132	157	179
Number of teleconsultations	2,11 0	6,138	21,732	41,740	52,223	74,828[g]
Avg. teleconsults/responding program	88	125	253	316	428	608
Total number of facilities reported				747	1,345	1,521
Avg. number of facilities per program				8.3	10.3	11.1

[a]Allen and Allen, 1995.[10]
[b]Allen and Scarbrough, 1996.[11]
[c]Grigsby, 1997.[9]
[d]Grigsby and Brown, 1998.[43]
[e]Grigsby and Brown, 1999.[44]
[f]Excludes teleradiology activity.
[g]Projected growth, based on first quarter report of 18,706.

of services. Distribution by clinical specialty also showed a handful of high-volume specialties (mental health, orthopedics, neurology, dermatology, and cardiology). The number of physicians who reported participating in telemedicine in 1999 was less than 4,000, and the annual average number of teleconsultations per site for 1998 was less than 40.

TELEMEDICINE DIFFUSION IN OTHER COUNTRIES AND SETTINGS

Presented here are illustrative examples of the adoption of telemedicine in countries outside North America. These examples are not fully inclusive, nor do they present a complete picture of telemedicine diffusion in the respective countries. They do demonstrate, however, the variations in scale and nature of telemedicine diffusion across the international scene, largely as a result of differences in influences, driving forces, and opportunities.

Malaysia

As Malaysia seeks to develop its economic position and improve the quality of life of its citizens, the government of Malaysia has seen the potential of telecommunication services to modernize a range of infrastructure and public services. Because a healthy economy requires a healthy population, a key part of this national strategy for development is the transition from "industrial age medicine to information age medicine."

This strategy has a wide range of ambitious but carefully interlinked components in a cohesive strategy, the "Telemedicine Blueprint," harnessing an information superhighway to make health care resources more accessible to the population. This is coupled with a change to a culture of wellness. Telecommunication-based health records and the application of appropriate telemedicine services will be enabled by an integrated framework that supports the technology, operating standards, staff development skills, and legal framework, with key components being electronically held, such as "Lifetime Health Records" and personal "Lifetime Health Plans."[12,13]

The role envisaged for telemedicine includes personal self-help with health problems and choices for a health-promoting lifestyle through availability of sound information and virtual health services. Telemedicine is also expected to redress imbalances in the distribution of physical health services.

South Africa

The newly democratized South Africa realized that it had immense challenges in modernizing its services in rural areas, not the least of which was to increase the number of doctors and nurses in these underserved regions. Telemedicine has been seen as a way of spreading health care skills equitably and efficiently. In many countries any move toward a distributed virtual health system requires major organizational and behavioral change. Given the paucity of traditional health services in large parts of rural South Africa, there was a blank canvas on which to produce a totally new picture. Significant investment is needed, but there are no existing health resources in many areas to modify, with all their traditional inertias and change management issues.

Consequently, a strategic framework has been published, and a development strategy is being applied. Funding has been specifically considered as part of the guidelines for development.[14] This example shows how telemedicine can be used as a backbone for a health system in the 21st century. It also shows how the investment cost of the technical infrastructure will be offset by more cost-effective use of the scare and expensive health resources. This is, of course, significantly different from telemedicine diffusion in a long-established health sector.

Australia

As a large country with a widely dispersed population and developed economy, Australia might be considered a classic location for telemedicine applications. It has a long history of remote health care, including the Radio Doctor and the Flying Doctor services, which exemplified how telecommunications can become part of normal health care delivery. Modern telemedicine is widespread in Australia, with individual applications being developed according to local need and appropriateness. This is facilitated by the recent development of specialist professional expertise and specialist university departments that facilitate research and teaching in telemedicine. In this context, the Commonwealth government has seen the importance of an overall framework and standards and has invested in rigorous collation of evidence and knowledge.[15,16]

Special populations

Telemedicine services have particular attractions for dealing with special populations that are not easily reached. These include penitentiary programs,[17] scattered rural populations,[18,19] and passengers and crew of ocean-going vessels[20,21] and airplanes in long distance travel.[20] We have yet to determine the cost effectiveness of telemedicine in all these situations, as compared with traditional face-to-face consultation. But, it is not as expensive or cumbersome as the alternatives (escorting prisoners, extensive escorted ambulance or air journeys, air-sea rescue services, or emergency landings).

Military telemedicine

Military telemedicine presents a special situation. The military has an essential need for acute secondary and tertiary health care that is normally divorced from local health services, and it has access to expensive, advanced telecommunications. Among the active users of military telemedicine are the United States and British armed forces.[22,23] In terms of general implementation, military telemedicine differs significantly from its civilian counterpart. It normally has high political support, a clear line of command, including direction to follow agreed procedures and technologies, and considerable technological investment resources. In addition to being an important arena of telemedicine diffusion in its own right, military telemedicine serves as an important generic telemedicine learning environment.

Integrated specialist services

Telemedicine can be a powerful vehicle for creating integrated virtual services for special patient populations that depend on specialist clinical expertise, which is necessarily concentrated in tertiary care centers of large catchment areas. For example, in Trentino, Italy, a pilot project has been initiated to provide an integrated service for patients of the regional oncology service. Telemedicine and secure Internet-based integrated records have been used to integrate primary care and local hospitals with the tertiary specialist service.[24] After tertiary care assessment and determination of therapeutic plans, patients can avoid long journeys for regular treatments by receiving their regular treatments at their local hospital. Real-time telemedicine links, coupled with access to a shared virtual record that includes treatment plans and parameters, mean that the local clinician has readily available support from the specialists. This reduces the need for ill patients to travel to receive straightforward individual procedures within a prescribed treatment plan; makes optimal use of clinical skill-mix; and still ensures a seamless standard of safety and surveillance by creating a virtual therapeutic environment.

Preventive telehealth

Telehealth can be applied successfully in preventive health settings, as was demonstrated by the Volta River onchocerciasis prevention project.[25] In this international program, environmental monitoring identifies increases in environmental causal risk factors (e.g., variations in stream flow and water level), and triggers targeted preventive measures (e.g., pesticide application) to avoid epidemics of this vector-borne disease. The expensive administration of pesticides and use of other scarce resources is targeted to the times and locations of need, where they can be most effective, and this targeted use also minimizes adverse health effects.

A THEORY OF DIFFUSION OF INNOVATION

With notable exceptions, the process of adopting innovative technology is seldom rapid or linear. Many technical, economic, social, political, and psychological factors affect the rate and pattern of diffusion. Those relevant to the diffusion of telemedicine will be discussed here under four headings: economic, societal, institutional, and individual.

The extent to which a new technology is adopted by its intended users varies as a function of the nature of the technology, the nature of the users, and the setting for which its use is contemplated. Various factors that have a general effect on diffusion have been studied for nearly a hundred years,[26,27] but the increasing pace of technological innovation of all types, especially since the 1970s, has led to considerable interest in a comprehensive model of the process. Rogers[28,29] had already developed such a model. Its relevance to telemedicine is discussed here.

For Rogers,[30] diffusion is "the process by which an **innovation** is **communicated** through certain channels over time among the members of a **social system**" [the basic elements highlighted for emphasis]. A thorough discussion of this model is well beyond the scope of this report; instead, attention is drawn to the components most relevant to the spread of telemedicine technology.

Rogers suggested that innovations do not necessarily benefit all adopters. For example, whereas increased access to care may be a socially desirable benefit of telemedicine, payers may view it as a potential threat in terms of increasing their expenditures. A tertiary care center may derive substantial benefits from a heavy investment in information technology that can be used for various purposes (administration, education, and clinical services), but the same investment for a rural critical access hospital may represent a large expenditure with little gain.

At the provider level, a consulting specialist may stand to expand his or her practice and increase revenues by offering remote consultation. For a busy primary care physician, however, there may be no compelling reason to refer patients for teleconsultation. The financial gain from such a referral is likely to occur only if the physician participates in the consult—and the benefits from participating exceed the cost. In short, different parties in telemedicine are likely to have very different incentives to use, or not use, the technology. Even if there may be obvious advantages for a given provider or organization (e.g., retention of patients in a rural hospital), those advantages "are not always clear-cut."[30]

A list of the factors affecting the diffusion of new technologies is presented in Table 2. These factors relate to the four different aspects of the diffusion process and may be manifested at the level of the health care system, the organization, the technology, the institution, or the individual provider. The left-hand column of the table contains a list of factors that influence the adoption of innovative technologies (taken from the work of Scott[31] and Rogers,[30] while the right-hand column lists the significance of these factors for the diffusion of telemedicine.

The health care context: international variety

Global and national diffusion of telemedicine will be faster and easier where there is a strategic environment that supports it. Of course, health care environments vary globally by type (structured and regulated, or free market); form (centralized or decentralized); financing (public, private, or a combination); and other ways as well. In addition, there are also significant variations in terms of the economic and developmental status of any particular country, including the telecommunications infrastructure, as discussed earlier.

In all these contexts, early identification of the potential beneficial use of telemedicine, together with a framework in which it can be applied, enhances the diffusion of telemedicine in appropriate ways. At the same time, drawbacks and potential problems must be anticipated and, as far as possible, controlled. And, the costs must be estimated so cost-benefit ratios can be analyzed.

The integration of telemedicine systems into the local health sector can facilitate its effective diffusion and use. A number of examples from around the globe are cited here.

Small islands. Providing health care to small islands can be challenging. Trauma services or specialist diagnosis of referred symptoms can require sea or air evacuations. These are expensive, often cause delay, and are often inconvenient to the patient and the family. Not surprisingly, in a number of locations, telemedicine is being used to link the island to the

TABLE 2. INFLUENCES ON THE DIFFUSION OF TELEMEDICINE IN INDUSTRIALIZED NATIONS

Factor	*Relevance to telemedicine*
Authoritarian decision-making	Adoption fastest when the decision to adopt is made by an individual with authority to enforce the decision
Improvement in efficiency	Little increase in efficiency for many applications—especially using videoconferencing—because of inconvenience
Cost of the technology	Relative cost to institution varies by site; absolute costs declines but is excessive for small/rural facilities
Organizational/social structure	Diffusion facilitated by hierarchical, authoritarian systems, and hampered by loosely organized systems
Return on investment	Revenue is minimal, but this varies by application, size of facility, and geographic location
Risk or uncertainty	Payment for services is questionable, as is the issue of whether providers will use the service
Communication channels	Information dissemination most effective if done by peers with similar interests and concerns
Consistency with social norms	Greater likelihood of adoption when an innovation is close to the professional/organizational mainstream
Effect on quality of services	Quality probably comparable to in-person care; possible improvement associated with increased access
Role of opinion leaders	Mainstream, charismatic individuals are likely to influence their peers to adopt new technology
Complexity of skills required	Reasonable learning curve, but requires acquisition of new habits associated with providing care
Social approval	Moderately high appeal to general public and news media, but many providers remain skeptical
Compatibility with status quo	Significant systemic changes may be required in the way care is provided
Capable of pilot test	Depending on technology and application, there may be sufficient opportunity for pilot testing
Organizational change required	Some degree of change may be required, but not necessarily disruptive to ordinary processes of care
Significance of research data	Important for early adopters, but less important than interpersonal channels involving professional peers

From Scott 1990,[31] and Rogers, 1995.[30]

mainland to provide both initial triage and advice on trauma management and secondary care diagnosis for less common illnesses. Examples include linking Easter Island with mainland Chile, Gozo with Malta, and Guadaloupe with Bordeaux (the islands of the French Caribbean being classified as a department of mainland France). In each of these settings, the driving force has been the ethic of equity within one health care system, with telemedicine the appropriate technology to reduce the time and financial barriers of distance.

Isolated populations. A similar driving force for telemedicine diffusion occurs with remote and isolated populations within individual health provider catchment areas, an application pioneered in a number of locations including Newfoundland.[19] In other settings, telemedicine now reduces the number of long and uncomfortable ambulance or private journeys in settings as far apart as the Grampian region of Scotland, southwest Ireland, and outback Australia. In Norway, telemedicine is part of the national strategic approach to tertiary referral, with a specialist support resource in Tromsø.

Locally integrated services. The Andalusia region of Spain invested in modernization of information and communications environments in health care as well as in direct service delivery. The region has a history of innovative partnering with the information technology sector. It has recently integrated emergency, outpatient, and primary care clinical communication systems. This effort is being led by a private sector company contracted to provide the emergency ambulance service. An investment in mobile telemedicine ensued, and the region became an active innovator in a European Union Research and Development project.[20] The 24-hour, managed telemedicine communication system has had a capacity added for wider emergency, outpatient, and primary care telemedicine communication.[32]

Integration into a national clinical hierarchy. The Kingdom of Saudi Arabia developed a hierarchical system for targeted distribution of clinical skills. It is important to develop sound and appropriate clinical skills at the local level and to ensure that they have backup in the event of more difficult cases. At the same time, tertiary skills that may not be available at the national level need access to global knowledge. The country has, therefore, developed a tiered telemedicine structure. This is focused on the King Faisal Specialist Hospital, which provides a referral service within the country, and a nodal point for selective consultations for advanced cases with selected partners in the United States.

GENERIC HEALTH SYSTEM ISSUES

In health systems with less governmental involvement, the financial framework plays a significant role in the diffusion process, whereas the role of government may be directed toward quality, client safety, and confidentiality. Consideration of the diffusion of telemedicine should, therefore, be specific to the contextual setting. It must be based on the following clearly articulated set of criteria:

- Demonstrable need
- Explicit statement of anticipated benefits
- Detailed methodology for implementation
- Sound methodology for evaluation
- Service delivery policy and protocols.

VARIABLES AT DIFFERENT LEVELS OF ANALYSIS AFFECTING TELEMEDICINE DIFFUSION

The variables that influence the rate of telemedicine diffusion are manifested at different levels of the health care system. These variables may include aspects of the technology itself, the reaction of different individuals (providers, clients, and others) to the technology; the integration of the technology into other technologies and into organizational processes; the effects of the technology on other components of an organization; and institutional, regulatory, or social policies, among others. The effects of some of these may be felt across providers, provider groups, institutions, and networks because they are associated with policies and regulations at the national, regional, or provincial or state level.

Nonetheless, all variables influencing diffusion can be classified into four categories: economic, societal, organizational, and individual.

Economic variables: information technology and productivity

Economic productivity is the amount of output per unit of input. It is most commonly defined in terms of the cost of labor (labor productivity), or of all input variables (total factor productivity). When we examine the effects of information technology on economic productivity, we find that not all service industries have benefited from the introduction of information technology in the same way or to the same extent. One sector of the economy in which information technology has apparently yielded significant gains is manufacturing. In this sector, computerization and industrial robots have permitted increased production and lower labor costs. Likewise, the economy, finance, insurance, and real estate portions of the service sector have also benefited from information technology. Many derivative investment instruments owe their existence to the development of computing power and the ability to relay large amounts of information around the world in real time. These industries, however, can experience negative effects on productivity as a consequence of any number of unanticipated changes or hidden costs. It has been estimated, for example, that in some organizations the obvious and hidden costs of supporting a client-server computer network may range from $5,000 to as high as $20,000 per personal computer (PC) per year.[33,34]

While many manufacturing processes can be automated, it is not yet possible to automate the work done by physicians, nurses, and the other highly educated and well-paid individuals who make up the health care labor force. Health care is labor-intensive. Moreover, health care management does not have the same degree of control over its labor, as does management in other industries. Physicians have a certain degree of independence, and they tend to dominate management. Even when lower physician charges have been negotiated, the negotiations have not been easy.

In health care, there is little solid evidence that information technology had a significant effect on productivity from 1973 and through the 1990s. However, this finding may not stand scrutiny. The lack of evidence may be due, at least in part, to the difficulty of measuring productivity in health care[35–38] On the other hand, Roach[37] suggested that the time input variable in productivity may be underestimated because during the past decade or so people in the United States have worked an increasing number of hours (estimated at 25% more). This increase in hours may be the result of blurring the lines between home and office work as a result of heavy use of information technology.

In short, the introduction of telemedicine into health care systems may have been done in ways that counter improvements in productivity. In some cases, providers must spend more time to accomplish the same amount of work, as, for example, has been the case with the introduction of many electronic medical record systems. There may well be a trade-off between the quality of the patient experience, and the use of clinical time (a familiar conundrum in a new guise). For instance, in a Swedish pilot telemedicine environment, there was strong support for telemedicine as it led to quicker referral, fewer and shorter patient journeys, and greater participation in case discussion and treatment setting by the referring clinician. However, it required more clinician time (and discipline when keeping appointments) since clinicians were involved simultaneously at each end of the link.[39]

When a technology is not at least as convenient as the process it is intended to replace, productivity suffers. The failure of a technology to improve economic productivity may be felt both at the institution's bottom line and by providers who find themselves putting in more work for the same outcome. If there are other gains, as indicated above, they need to be explicitly identified as the corporate gain, justified against the identified resource loss.

The societal level: health care systems and government policy

In the United States, it is customary to attribute what appears to be the slow diffusion of telemedicine to such societal barriers as lack of a widely accepted coverage and payment policy, restrictive interstate licensure issues, inadequate human factors design, lack of uniform engineering standards, and concerns over confidentiality, security, and liability.[40–47] These commonly cited barriers operate primarily at a broader level than individual institutions or providers, and hence they affect most providers in similar ways.

Coverage, licensure, and related issues have been dealt with at length elsewhere.[40–42,47] They are not trivial matters, but they will not be examined here.

The institutional level: health care organizations

Bashshur[40] addressed the diffusion of telemedicine, noting "when technological innovations are not accepted or implemented properly, generally the failure may be traced to a poor fit between the nature of the innovation and the vested interests, resources, and expectations of its major gatekeepers." He listed 16 variables identified by Scott[31] as intrainstitutional factors influencing the process of adoption of new technologies. These included: initial or continuing cost of the innovation; returns on investment; improved efficiency; effect on quality of services; risk or uncertainty; testability in a pilot project; social approval and recognition; consistency with existing procedures and values; extent to which other changes in the organization are required; ability to implement a part of the program on a trial basis; potential for modification if necessary; ease of explaining changes; extent to which new and complex skills are required to use the technology; clarity of results; social desirability; and origin of the innovation (inside or outside the organization). Previously, Kaluzny and Veney[49] investigated the relative importance of these variables and found the following three as the most significant: anticipated payoff, rate of recovery of investment, and social approval.

It is important to note that the adoption of telemedicine at the institutional level is influenced by the structure of authority behind it, and the degree to which management is able to mandate the use of the technology. This would explain the relatively higher activity levels of adoption in prison programs, the Veterans Administration, and Department of Defense,[9] all of which have a significant degree of institutional control over both physicians and patients.

One fruitful way to consider the effects of institutional structure on the diffusion of telemedicine is through the perspective of the neo-institutional school of thinking in sociology. According to this theoretical paradigm, an institution can be thought of as "an organized, established, procedure,"[50] essentially, a set of habits at the level of a group of people. Often, institutions are resistant to change.[51] Health care professionals and organizations are significantly institutionalized as a consequence of tradition, organizational complexity, and the existence of structured processes, some of which are incremental developments over time, and others of which are carefully designed controls to ensure quality and safety. The adoption of telemedicine necessitates significant changes to this status quo. Consequently, institutions resist such change.

Three types of influence on organizational behavior, relevant to a change such as adoption of telemedicine, have been hypothesized.[52] These reflect the rules and norms that characterize the organizational fields (in this case, health care), rather than reflect responses to market conditions. They are:

1. Coercive isomorphism entails external pressure, which could be exerted on organizations (e.g., federal regulations regarding reimbursement, by grant funding agency guidelines dictating specifics of how telemedicine networks should be constructed and operated), or by cultural expectations within society. Cultural expectations might include pressure from consumer groups to make telemedicine services more broadly available, from physician groups, or from common assumptions about technology innovation as a technical or supply problem. Coercive isomorphism increases in importance with the degree of dependence of the organization on the entities exerting external pressure.
2. Mimetic isomorphism is a process of mimicry in which one organization, especially in an uncertain institutional environment (e.g., in telemedicine, where cost effectiveness is often unknown or ambiguous), may model another. The degree of competitiveness within the health sector may lead organizations to invest in telemedicine and telehealth networks not because of perceived clinical need or comparative market advantage, but because their competitors have telemedicine programs. Mimetic isomorphism may be one explanation for the preponderance of "hub-and-spoke" telehealth network models.
3. Normative isomorphism is a process derived from professionalization. An example of this is the creation or changing of physician attitudes about technology through medical school curricula or through activities or materials generated by professional society subsections (the active telehealth subsection of the American Psychiatric Association is a prime example; whether it is in any way responsible for the high levels of mental health activity within telemedicine is an empirical question). This is more likely to have an effect within organizational fields where the professional class has a relatively high degree of potential influence, as is the case with telemedicine.

Neo-institutional theory yields two important insights. First, organizations and institutions can exhibit habitual behaviors just as individuals can. These behaviors can, under the proper circumstances, become quite resistant to change (i.e., they become institutionalized). Second, the organizational outcome of interest (here, telemedicine networks) is often not the product of rational, market-driven forces. The extent to which networks are born out of coercion or institutional copying (i.e., rather than being internally driven by clinical and organizational need) may affect their prospects for long-term sustainability.

The individual level

At the level of the individual provider, early adopters of a new technology are more likely to be influenced by the scientific literature than are those who are slower to embrace innovation. The latter group is more likely to be influenced by the experience of peers. The technology itself (complex equipment with a steep learning curve or equipment that either decreases or fails to enhance efficiency) may be less likely to be adopted because it is relatively inconvenient and time consuming.

Many other variables are intrinsic to individual providers or small provider groups. These represent significant impediments to more rapid diffusion of telemedicine, and their influence is felt at the individual level. These variables may be thought of as psychological in nature.

For example, much of economic theory is predicated on the assumption that humans make rational choices about the things that are important to them. While this assumption may facilitate economic theory building, it runs counter to prevailing thinking in both cognitive psychology and cognitive neuroscience (for a readable review of cognitive psychology.[53] People do not necessarily make rational decisions. In fact, as a rule they tend not to do so. Instead, human reasoning relies on rapid pattern recognition (whether the patterns are truly there or not, as in racial stereotyping), and on a number of shortcuts in thinking that psychologists refer to as heuristics. For example, McNeil et al.[54] demonstrated "framing errors" among a sample of American physicians; that is, the physicians responded differently depending on how a question was framed. They were told either that a certain procedure was associated with a 7% mortality rate over five years, or that there was a 93% survival rate over 5 years. When the statistics were presented in terms of a survival rate, physicians said they would be significantly more likely to recommend the procedure to their patients than when the outcomes were presented in terms of mortality, despite the fact that these rates mean exactly the same thing. This is only one of a number of such heuristics.[55]

Cognitive neuroscientists have likewise shown that people tend not to make deliberate, conscious decisions about their behavior. Instead, they tend predominantly to act on the basis of habit—behaviors performed automatically and nonconsciously, learned through the procedural learning system (which is specialized for skills, processes, and habits) as opposed to the declarative learning system, which is specialized for the retention of information and facts.[56] This is advantageous in that habits are frequently efficient, require little thought, and in an emergency could be much more adaptive than having to deliberate over a course of action.[57,58] This efficiency comes at a cost, however, in that novelty may not be well received, in large part because a new way of thinking about or doing things requires deliberate conscious effort until it eventually becomes habitual. In other words, it may be inconvenient.

There are several difficulties associated with these findings. First, people tend not to do things because it is rational to do so; instead, they tend to do them because they are habitual. Second, habits, once established, may persist over a lifetime unless the habit is disrupted by some external force, or one makes a deliberate, conscious, effortful attempt to disrupt the behavior in question. Third, the memory system specialized for learning habits and skills is relatively independent of the system specialized for acquiring knowledge (information). This means that giving providers information will not necessarily change their behavior—something providers see repeated again and again among patients with diseases that are associated with lifestyle.

If we apply these findings to telemedicine, we can formulate the hypothesis that, absent a strong motivating influence or disruptive external force, providers are unlikely to be persuaded to use telemedicine technology on the basis of information (e.g., research findings) alone. Their ordinary habitual mode of practice is generally efficient, they are usually busy, and to do things significantly differently may well require too great an investment of time and energy, not to mention some opportunity cost. This may be the case even when one is able to argue with them that their choice is not entirely rational. In fact, they are likely to have an immediate and plausible (even if not quite accurate) explanation for their habitual (albeit irrational) behavior.[59]

In short, providers' habits represent a strong inertial force which must be considered if we are to alter behavior and promote the adoption of new technologies. This is especially true when there is no compelling, intrinsic motivation to do so; when the new technology involves inconvenience or a steep learning curve; and when they are already satisfied with the status quo.

Diffusion of MRI: a comparison with telemedicine

The case of nuclear magnetic resonance imaging (MRI) represents an important contrast to telemedicine. MRI is now commonplace in North America. Most urban hospitals in the United States have at least one magnet, and many are purchasing a second or third, often of greater field strength. MRI is widely used, and the number of scanners operating in both Canada and the United States has increased markedly in recent years. Yet in the mid-1980s, there were significant questions about the rate of diffusion of MRI. A study of the diffusion of MRI was published in 1986, about the time the Health Care Financing Administration (now Center for Medicare & Medicaid Services) and many private insurers had decided to cover most clinical uses of the machines.[60] Data were collected, however, prior to the availability of coverage. According to the authors,

> HCFA did not allow reimbursement for Medicare patients. With a few exceptions, Blue Cross/Blue Shield plans refused to pay for MR scans. Many private insurers were just receiving their first claims for MR scans and were still establishing a policy. The grounds for refusal were universally that MR scanning was still an experimental procedure of unproven diagnostic value and was not yet a part of accepted medical practice (p. 47).

This may sound eerily familiar to anyone involved with telemedicine in the United States. Hillman et al.[60] further reported,

> At the time of our interviews, there was (and there continues to be) considerable uncertainty about the ultimate clinical value of MR and about which technological embodiment of basic MR principles will ultimately prove most successful. Not surprisingly, these uncertainties figured prominently in decisions about acquiring MR. Few respondents believed that MR's current capabilities were in themselves sufficient to justify the high costs of the new technology. Uncertainty about the ultimate clinical utility of MR was compounded by uncertainty about the future reimbursement regime: Would important third-party payors recognize sufficient value in MR to reimburse its use? (p. vi)

By 1995–1996, there were approximately 16 magnets per million people in the United States, second only to Japan (at 18.8 scanners per million), and well ahead of Germany, which ranked third at 5.7 per million. In Canada the corresponding figure was 1.3 per million.[1]

There is obviously considerable variation in the organization, quality, and availability of health care in different nations. Yet, even within countries, changes in a single variable may produce significant effects throughout the health care system. For example, Baker[61] reported that the increase in the market share of health maintenance organizations (HMOs) in the United States in the decade between 1983 and 1993 was associated with slower diffusion of MRI into hospitals. HMOs were also associated with lower availability and use of MRI in the mid- and later 1990s.[61]

As was true with MRI, the United States government has on the one hand invested heavily in the development and deployment of telemedicine technology, and on the other it has attempted to control health care costs by placing significant constraints on coverage and payment.

The situation for MRI in the early 1980s was similar in certain fundamental respects to the current situation for telemedicine. One important difference, however, is that MRI became established as an important clinical tool relatively quickly and for a large range of potential diagnostic uses. Moreover, for many purposes it yielded images that were clearly superior to those of computed tomography or standard radiography. With telemedicine, it is more difficult to make an equally compelling case for its clinical utility. Nevertheless, it may be the case that telemedicine is passing through an unavoidable phase in its evolution and diffusion. It is still primarily the innovators and early adopters[30] who now use the technology and encourage its use.

THE MEASURED PACE OF TELEMEDICINE DIFFUSION: SLOW OR TO BE EXPECTED?

The slow pace of telemedicine diffusion is a problem for those who have invested their time, money, and energy in developing programs and applications, and who struggle to promote this modality of care. Yet, from a more reflective perspective, perhaps this slow pace of development is to be expected. A brief review of some of the factors influencing its diffusion suggests numerous reasons why it may be unrealistic (and indeed inappropriate) to expect faster growth.

A number of the variables influence the rate of diffusion of telemedicine in North America, especially in the United States, and these are likely to be relevant on a wider basis. These include economic, social, organizational, and psychological issues. Economically, for example, it is unclear whether telemedicine and related technologies have had (or could have) a clear and beneficial effect on economic productivity, and hence on organizational profitability. Theoretical models of the diffusion of innovative technology generally help to illuminate the problems faced by those who attempt to promote telemedicine. A focus on the issues (such as uncertainty on the part of providers about the technology and its effect on quality of care, fears of rapid obsolescence, inefficiency, inadequate return on investment) may clarify the directions that need to be taken by organizations that offer telemedicine services. Moreover, it is instructive to note that in the mid-1980s, there was considerable uncertainty about the future of MRI, a technology that seems—at least until it is superseded by a more advanced technology—to be firmly established.

Habit and normal human cognitive functioning are major influences on the behavior of individual providers. People tend—as individuals, and in organizations—to behave in ways that are relatively automatic and nonconscious. These habits make much of our activity more efficient, although they may interfere with an individual's ability to react flexibly to novel situations. Habits, especially those that allow efficient patterns of practice, take some time to establish and may take even longer time (and considerable conscious effort) to alter. In the absence of some strong intrinsic motivation or coercive external forces, the inertia of habit is likely to interfere with change.

Therefore, in current health care behavioral and financial contexts, there may be little stimulus to expand telemedicine use rapidly, and indeed powerful inhibiting factors can be identified. This may be highly appropriate; as with any new technology in health, too rapid an uptake may create risks ranging from lack of development of appropriate clinical skills and of control and quality assurance systems to rapid technical obsolescence. The development of experience, education, and health sector policies and infrastructures appropriate for telemedicine delivery, matched by evaluation and organizational learning, should ensure safe and steady development and expansion, rather than a premature deployment.

The role of government

The role of the government in influencing the pace of telemedicine diffusion varies considerably, at least in relation to type of health care system. In the United States, the government has an interest in ensuring access to quality health care at a reasonable cost, but it also is interested in controlling costs, and controlling the spread of technologies that might increase costs. In essence, the United States government encourages health care organizations to invest in technologies for which it is, at the same time, unwilling to pay.

The problem is compounded by the fact that to influence the development and future direction of a technology, governments must establish policy early. Unfortunately, this is typically at a time when the clinical and economic outcomes of the diffusion of the technology cannot be predicted because too little is known about the technology, its cost, and its utility.

The situation in the United States is not dissimilar from the situation in the United Kingdom, where telemedicine is advocated as a means of avoiding greater capital expenditure, without guidance or consideration of the deeper issues, both of which are needed in the context of a public health service. In contrast, Finland has approved a virtual hospital, but the hospital has been required to conform exactly to the licensing and regulating procedures for any other, physical hospital. The United States and United Kingdom's approaches also contrast with the integrated approaches adopted in Malaysia and South Africa (described elsewhere in this report).

Toward a telemedicine enablement policy

Separate from, but a key basis for, a telemedicine enablement policy is establishing an appropriate health information infrastructure. There have already been calls for this kind of vehicle in the United States—not a public sector-dominated system or database, but a set of agreed standards, policies, and, when necessary, essential technologies to ensure effective and safe communication of data and other electronic health information.[62–64] Although individual point-to-point telemedicine systems, or hub-and-spoke systems within an individual state, can occur under present circumstances, a federal information infrastructure would facilitate safe and effective telemedicine diffusion. A strategic investment policy in both public and private sectors is necessary for the effective diffusion of telemedicine. In 1997, the United States General Accounting Office (GAO) called for a federal telemedicine strategy to enable effective investment in telemedicine[65]; this was an encouraging step.

Research priorities

The only way to ensure the development of an effective body of knowledge on the impact of telemedicine, to demonstrate its benefits, to ensure that there are no adverse effects that cannot be managed, and to ensure that risks can be adequately controlled and managed, is the development of an objective evaluation program. This has already been argued for in the context of the harnessing of modern information technologies in health. In 1998 the President's Information Technology Advisory Committee argued, "if, as a Nation, we are to fully capture the promise of the new technologies we develop, it is important to include within that program a research agenda to address the social and economic implications of information technologies adoption and diffusion."[66] This is especially appropriate for telemedicine.

Any development, particularly novel technology-based services, must ensure quality and reliability and control known risks. This is particularly pertinent given the current focus on avoidable adverse incidents in current health care systems.[67] A European-led study has shown that there are issues in ensuring reliability and safety in telemedicine, particularly when it crosses international boundaries.[68] Governments must develop appropriate quality control requirements for telemedicine services within their own national boundaries. They must also come together to support international principles, standards, and agreements to ensure the safe mutual trust and dependence on telemedicine services that are intended to make the most efficient use of international expertise but for that may put citizens and local health care professionals at risk from incompetent or even malicious activity.[68]

The role of government is neither to manage telemedicine nor to instigate complex bureaucratic approval or control mechanisms. However, one of the strongest potential barriers to the appropriate diffusion of telemedicine is the concern of individuals and organizations that neither quality nor adverse outcomes are adequately monitored.

Therefore, the development of an appropriate, impartial evaluation mechanism and knowledge base and agreement on regulatory standards and frameworks seems essential. While excessive governmental control in any setting is liable to stifle telemedicine diffusion, so too is government inaction or abnegation of responsibilities likely to have a similar effect by failing to provide the climate in which telemedicine can grow and develop safely and with mutual trust. An evidence-based support to appropriate mechanisms, and a similarly evidence-based set of quality requirements, are essential enablers of the diffusion process.

Conventional wisdom points to financial, technical, and institutional barriers as reasons for telemedicine's slow and uneven growth. While these may represent important problems, some of them are beyond the ability of single institutions or networks to address. Telemedicine networks may comprise multiple organizations, may rely on physicians only loosely affiliated with the facilities, and in general may represent complex combinations of individuals and organizations. In some cases, networks may be nothing more than congeries of organizations, in some cases including potential competitors, brought together to take advantage of federal funding opportunities. There is a fair amount of "social engineering" required to ensure that incentive structures reflect the needs and constraints of various participants. Solving technical and financial problems is no guarantee of participant satisfaction, efficacy, or high utilization.

Theoretical models of the diffusion of innovative technology help to illuminate the problems faced by those who attempt to promote telemedicine. In fact, a brief review of these issues suggests that we should not be surprised at the current pace of telemedicine adoption. A focus on these issues (e.g., uncertainty on the part of providers about the technology and its effect on quality of care, fears of rapid obsolescence, inefficiency, minimal return on investment) may clarify the directions that need to be taken by organizations that offer telemedicine services.

Finally, we should not ignore the influence of habit and normal cognitive functioning on the behavior of individual providers. In the absence of some strong intrinsic motivation or coercive external forces, the inertia of habit is likely to interfere with change.

RECOMMENDATIONS

- National governments should develop a comprehensive policy framework to enable the safe and effective practice of telemedicine, to include technical and practice standards, and quality assurance best practice. Scientific research must be required in all funded projects.
- A database of telemedicine evidence must be established that extends beyond a mere listing and description of current applications, so as to include evaluative material. This would be compiled in a structured way so as to indicate type of health system and economic context. Above all, it would have a classification of the strength of the evidence, derived from the principles of evidence-based medicine.
- It is important for the World Health Organization (WHO) to identify the focal point of expertise in telemedicine within its organizational structure in order to serve as an international resources for all countries seeking help in designing and developing their telemedicine systems. The WHO can compile and regularly update a comprehensive bibliography and knowledge base of descriptive and evaluative literature, to be available to those wishing to consider potential telemedicine applications. This would be compiled in a structured way so as to indicate type of health system and economic context.
- It is also recommended that the WHO initiate, in conjunction with other relevant organizations such as the International Telecommunication Union and the World Trade Organization, an international scientific forum and resultant international conventions on principles, standards, and underlying reciprocal legal ratification thereof, to ensure safety and public protection in health care delivery by telemedicine across international boundaries.

REFERENCES

1. Anderson GF. *Multinational comparisons of health care.* New York: The Commonwealth Fund, **1998.**
2. Tjam FS. *Technology assessment and transfer for district health systems.* Geneva: WHO, **1994.**
3. Rigby M. The management and policy challenges of the globalisation effect of informatics and telemedicine. *Health Policy* **1999;**46:97–103.
4. Rigby M, Birch K, Roberts R. Key issues in taking health telematics safely and ethically into the 21st century. In: Rigby M, Roberts R, Thick M, eds. *Taking health telematics into the 21st century.* Radcliffe Medical Press, Abingdon, **2000;**173–186.
5. Rigby M. Impact of telemedicine must be defined in developing countries. *B Med J* **2002;**324:47–48.
6. Benschoter R. Multipurpose television. *Ann NY Acad Sci* **1967;**142:471–478.
7. Angood PB, Satava R, Doarn C, Merrell R, and the E3 Group. Telemedicine at the top of the world: The 1998 and 1999 Everest Extreme Expeditions. *Telemed e-Health J* **2000;**6:315–325.
8. Nicogossian AE, Pober DF, Roy SA. Evolution of telemedicine in the space program and earth applications. *Telemed e-Health J* **2001;**7:1–15.
9. Grigsby B. 1997 *Report of U.S. telemedicine activity.* Portland, OR: Association of Telemedicine Service Providers, **1997.**
10. Allen A, Allen D. Telemedicine programs: 2nd annual review reveals doubling of programs in a year. *Tel Today* **1995;**3(1):10–16.
11. Allen A, Scarborough M. Third annual program review. *Tel Today* **1996;**4:10–17; 34–38.
12. Government of Malaysia. *Malaysia's telemedicine blueprint—Leading healthcare into the information age.* Kuala Lumpur: Ministry of Health of Malaysia, **1997.**
13. Government of Malaysia. *Telemedicine Standards.* Kuala Lumpur: Ministry of Health of Malaysia, **1997.**
14. Telemedicine Task Team. *Establishment of a telemedicine system for South Africa: Strategic outline.* Pretoria: Department of Health, **1998.**
15. National Health Information Management Advisory Council. *Health online. A health information action plan for Australia.* Canberra: Department of Health and Aged Care, **1999.**
16. Mitchell J. From telehealth to e-health: The unstoppable rise of e-health. Canberra: National Office for the Information Economy. Department of Communications, Information Technology and the Arts, **1999.**
17. Viegas SF, Dunn K, Calhoun JH, Angelo JG. *Telemedicine: Practicing in the information age.* Philadelphia: Lippincott-Raven, **1998.**
18. Computer Science and Telecommunications Board, National Research Council. *Networking Health.* Washington D.C.: National Academy Press. **2000.**
19. Elford R. Telemedicine activities at Memorial University of Newfoundland: A historical review, 1975–1997. *Telemed J* **1998;**4:207–224.
20. www.sadiel.es/europa/Hector/default.htm
21. Iakovidis I, Maglavera S, Trakatellis A. A convincing case for the provision of telemedicine services to ocean going vessels—the MERMAID paradigm. Studies in Health Tech and Informatics **1998;**56: 101–107.
22. Navein J, Hamann J, Ellis J. Telemedicine in support of peacekeeping operations overseas: An audit. *Telemed J* **1997;**3:299.
23. Ritchie C. British Army establishes telemedicine unit in Bosnia. *Lancet* **1998;**352:9121.
24. Demichelis F. Design and initial implementation of a tele-oncology project. *J Telemed Telecare* **2000;**6(Suppl 1):116–118.
25. Arunachalam S. Informatics in clinical practice in developing countries: Still early days. *BMJ* **1999;**319:1227.
26. Ryan B, Gross NC. The diffusion of hybrid seed corn in two Iowa communities. *Rural Sociology* **1943;**8:15–24.
27. Tarde G. *The laws of imitation.* Trans. by EC Parsons. Chicago: University of Chicago Press, **1969.**
28. Rogers EM. *Diffusion of innovations.* 1st ed. **1962.**
29. Rogers EM, Shoemaker FF. Communication of innovations: A cross-cultural approach, 2nd ed. New York: Free Press, **1971.**
30. Rogers EM. *Diffusion of innovations.* 4th ed. New York: Free Press, **1995.**
31. Scott WR. Innovation in medical care organizations: A synthetic review. *Med Care Rev* **1990;**72:165–192.
32. www.epes.es/proyectosid/technologicos.asp
33. Garner R. Unsupportable costs. *UNIX World: Open Computing.* February **1994.**
34. Woods WW. Information technology costs and productivity gains. *Drug Information* **1998;**32:947–953.
35. Brouwer WBF, Koopmanschap MA, Rutten FFH. Productivity costs measurement through quality of life? A response to the recommendation of the Washington Panel. *Health Economics* **1997;**6:253–259.
36. Jensen GA, Morrisey MA. Medical staff specialty mix and hospital production. *J Health Economics* **1986;** 5:253–276.
37. Roach SS. No productivity boom for workers. *Iss Sci Technol* **1998;**19:49–56.
38. Webb RH. National productivity statistics. *Federal Reserve Bank of Richmond Economic Quarterly* **1998;**84: 45–64.
39. Malmquist G, Hannson U, Qvarnström Å, Carlsson G. Health practice by remote expert: A case study from mid-Sweden. In: Rigby M, Roberts R, Thick M, eds. *Taking health telematics into the 21st century.* Abingdon: Radcliffe Medical Press, **2000.**
40. Bashshur RL: Telemedicine and the health care system. In: Bashshur RL, Sanders JH, Shannon GW eds. *Telemedicine: Theory and practice.* Springfield, IL: Charles C Thomas, **1997;**5–35.
41. Gilbert F. How to minimize the risk of disclosure of patient information used in telemedicine. *Telemed J* **1995;**1:91–94.
42. Granade PF. Malpractice issues in the practice of telemedicine. *Telemed J* **1995;**1:87–89.
43. Grigsby B, Brown N. *1998 Report on U.S. telemedicine activity.* Portland, OR: Association of Telehealth Service Providers, **1998.**

44. Grigsby B, Brown N. 1999 *Report on U.S. telemedicine activity*. Portland OR: Association of Telehealth Service Providers, **1999.**
45. Perednia D, Grigsby J. Telephones, telemedicine, and a technologically neutral coverage policy. *Telemed J* **1998;**4:145–152.
46. Physician Payment Review Commission: *Annual report to Congress*. Washington, DC: Physician Payment Review Commission, **1995.**
47. Shannon GW. The Atlantic Rim Telemedicine Summit. *Telemed J* **1997;**3:269–296.
48. Bashshur RL, Puskin D, Silva J, eds. Conference report: Second invitational consensus conference on telemedicine and the National Information Infrastructure. *Telemed J* **1995;**1:321–375.
49. Kaluzny AD, Veney JE. Attributes of health services as factors in program implementation. *J Health Soc Behav* **1973;**14:124–133.
50. Jepperson R. Institutions, institutional effects, and institutionalism. In: Powell W, DiMaggio P eds. *The new institutionalism in organizational analysis*. Chicago: University of Chicago Press, **1991;**143–163.
51. Zucker L. The role of institutionalization in cultural persistence. In: Powell W, DiMaggio P eds. *The new institutionalism in organizational analysis*. Chicago: University of Chicago Press, **1991;**83–107.
52. Powell W, DiMaggio P. The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields. In: Powell W, DiMaggio P eds. *The new institutionalism in organizational analysis*. Chicago: University of Chicago Press, **1991;**63–82.
53. Piattelli-Palmarini M. *Inevitable illusions: How mistakes of reason rule our minds*. New York: Wiley and Sons, **1994.**
54. McNeil BJ, Pauker SG, Sox HC Jr., Tversky A. On the elicitation of preferences for alternative therapies. *N Engl J Med* **1982;**306:1259–1262.
55. Kahneman D, Tversky A. On the psychology of prediction. *Psychol Rev* **1973;**80:237–251.
56. Cohen NJ, Squire LR. Preserved learning and retention of pattern-analyzing skill in amnesia: Dissociation of "knowing how" and "knowing that." *Science* **1980;**210:207–209.
57. Grigsby J, Stevens D. *Neurodynamics of personality*. New York: Guilford Publications, **2000.**
58. Shallice T. *From neuropsychology to mental structure*. Cambridge, UK: Cambridge University Press, **1988.**
59. Gazzaniga MS, LeDoux, JE. *The integrated mind*. New York: Plenum Press, **1978.**
60. Hillman BJ, Neu CR. Winkler JD, Aroesty J, Rettig RA, Williams AP. *Diffusion of magnetic resonance imaging into clinical practice*. Santa Monica, CA: RAND (pub. R-3392–HHS), **1971.**
61. Baker LC. Managed care and technology adoption in health care: Evidence from magnetic resonance imaging. Working paper 8020 (www.nber.org/papers/w8020). Cambridge, MA: National Bureau of Economic Research, **2000.**
62. Detmer DE. Information technology for quality health care: A summary of United Kingdom and United States experiences. *Qual Health Care* **2000;**9:181–189.
63. President's Information Technology Advisory Committee. Transforming Health Care Through Information Technology. www.ccic.gov/pugs/pitac_hc_9feb91.pdf
64. National Committee on Health and Vital Statistics. *Toward a national health information infrastructure: Interim report*. nchvs.hhs.gov/NHII2kReport.htm. **2000.**
65. General Accounting Office. Telemedicine: Federal Strategy is Needed to Guide Investments (Report NSIAD/HEHS-97-67)(14 February 1997); General Accounting Office, Washington DC. **1997.**
66. President's Information Technology Advisory Committee. *Interim report to the President*. Washington D.C.: PITAC, **1998.**
67. Kohn LT, Corrigan JM, Donaldson MS. *To err is human: Building a safer health system*. Washington D.C.: National Academy Press. **1999.**
68. Rigby M, Forsström J, Roberts R, Wyatt J. Verifying quality and safety in health informatics services. *BMJ* **2001;**323,7312,552–556.

Address reprint requests to:
Rashid L. Bashshur, Ph.D.
Director of Telemedicine
The University of Michigan Health System
C201 Medinn Building
1500 East Medical Center Drive
Ann Arbor, MI 48109–0825

E-mail: bashshur@umich.edu

Chapter 8

Executive Summary

RASHID L. BASHSHUR, Ph.D.,[1] SALAH H. MANDIL, Ph.D.,[2]
and GARY W. SHANNON, Ph.D.[3]

INTRODUCTION

IN AUGUST 2001, more than 200 participants, from North and South America, Africa, Europe, and Asia, took part in an International Symposium on the State-of-the-Art in Telemedicine/Telehealth in Ann Arbor, Michigan. The University of Michigan Health System and World Health Organization cosponsored the gathering with additional support from a number of other entities.[a] The goals of the symposium were to: (1) assess the state-of-the-art in telemedicine/telehealth (hereafter referred to as telemedicine) and (2) develop a set of recommendations for research and policy to advance the field at the regional, national, and international levels. After a brief discussion of the role of telemedicine in health care, this report provides a summary of the assessments and recommendations produced by the symposium on the following topics: clinical applications, public health, medical education, organizational models, technology and diffusion.

The symposium adopted a broad definition of telemedicine to incorporate the remote delivery of health services and health information via information technology, and telemedicine systems to consist of integrated networks offering such services.

TELEMEDICINE AND HEALTH CARE

In 1981 and again in 1994, the World Health Assembly identified the need for equity of access to essential health care services as a desideratum in national and international health policies. Accordingly, available health resources should be equitably distributed so that no one would be denied access to essential health care. In *Healthy People 2010*, the U.S. Department of Health and Human Services identified several action areas, each containing concise goal statements and specific objectives, all aimed at improving health.

The promise of telemedicine lies in its potential to enhance accessibility to care for remote, isolated, and confined populations by reducing the need for travel to specialty centers, and by reducing appointment waiting times. Simultaneously, telemedicine technology can contain medical care cost inflation by effective substitutions and possible reductions in the intensity of care, and by enabling more patients to receive appropriate care in their home communities. The ready availability of specialty care, information, and resources via telemedicine can also improve the distribution of quality by according remote providers ready access to specialist colleagues at tertiary care centers and up-to-date information, and con-

[1]Director of Telemedicine, University of Michigan Health Center, Ann Arbor, Michigan.
[2]Director, HIT, World Health Organization, Geneva.
[3]University of Kentucky, Lexington, Kentucky.
[a]National Aeronautic and Space Administration, National Library of Medicine, Office for the Advancement of Telehealth, Agency for Health Care Research and Quality, Department of Commerce Technology Opportunity Program, US Army Telemedicine and Advanced Technology Research Center, RGK Foundation, Salinas Valley Memorial Health System, Internet2, and Environmental Research Institute of Michigan (now Altarum)

tinuing education. Finally, the equitable distribution of telemedicine can bridge the medical care "divide" between countries and promote the globalization of health care, thereby contributing positively to improving access to health care for people everywhere and the global goal of "health for all."

Despite its remarkable promise, definitive research necessary to substantiate the role of telemedicine is still considered incomplete. This situation derives from a number of problems, including: (1) short-term funding for projects without plans for long-term sustainability; (2) lack of mature telemedicine programs and associated comprehensive, scientific evaluations; (3) limited acceptance by practitioners and administrators; and, in the United States particularly, (4) state-based protectionism and inconsistent federal policies and financing regulations.

CLINICAL APPLICATIONS OF TELEMEDICINE

Whereas telemedicine has been applied in practically all areas of clinical medicine, the vast majority of applications are represented in the following fields: radiology, pathology, psychiatry, dermatology, cardiology, ophthalmology, surgery, pediatrics, and emergency medicine. This group of clinical applications varies by "maturity," defined on the basis of the quantity and quality of related research, development of standards and protocols, and acceptance by the profession. The order of their presentation here is based largely on these criteria. Subsequently, each clinical application is assessed in terms of published research pertaining to performance attributes such as technical feasibility; diagnostic accuracy, sensitivity and specificity; clinical outcome; and, cost effectiveness.

Teleradiology and telepathology are the most mature specialties due, in large part, to: (1) The fact that these specialties rely heavily on imaging rather than direct patient contact; (2) explicit standards for quality assurance have been established in these areas, and they are accepted by the professions; (3) there is a wealth of national and international scientific evidence demonstrating their clinical effectiveness and potential cost effectiveness. In addition, these services are reimbursable under U.S. government rules, all of which consequently led to greater professional acceptance and diffusion.

Improvement in teleradiology and telepathology can be made in terms of developing new and user-friendlier equipment. In telepathology specifically, there is a need to develop additional protocols, methodologies, and technology for remote image-field assessment, and to improve the quality of static-image transfer.

Telepsychiatry, teledermatology, telecardiology, and teleophthalmology

Despite the large amount of research and development in each of these specialties, there has not been a commensurate degree of acceptance by the respective professions. This may be caused, in part, to a perception of limited evidence and definitive cost-benefit evaluations, which are often precluded by the constrained funding for research projects.

Telepsychiatry is among the most commonly used applications involving real-time consultations. Research has consistently demonstrated a high degree of concordance in diagnostic reliability between telepsychiatric and in-person consults. Moreover, some studies reported some cost savings in telepsychiatry as compared to in-person care.

Because of the inherent nature of this practice, telepsychiatric consultations require real-time synchronous links with higher bandwidth. Psychiatrists have to be able to observe emotional and behavioral manifestations of clients for diagnostic and treatment purposes. The higher costs associated with the technological requirements for effective telepsychiatry and the limited scope and duration of many projects precluded definitive conclusions regarding its cost-effectiveness.

Teledermatology relies heavily on visual imagery and high-quality images have assisted in the development of this specialty. Research in this field has demonstrated a high level, although not perfect, trend of diagnostic concordance between teledermatology and in-person consultation. In several studies, diagnoses were not significantly different between teledermatology and conventional dermatology, especially when performed by experienced clinicians. Problems identified in this application pertained to increased length of synchronous clinical examinations due to the time necessary for capturing transmissible images and difficulty in evaluating dark-skinned individuals.

The critical importance of timely diagnosis, and the high prevalence of morbidity and mortality related to heart disease make telecardiology especially appropriate. A substantial body of national and international literature points to successful transmission of echocardiograms and cineaortography (angiograms). Remote sphygmomanometry (blood pressure reading) is prompted by the potential to install home monitoring devices for the control of hypertension and reduction in cardiovascular morbidity and mortality. Several studies reported small rates of misdiagnosis, on the order of 5% or less, but more timely diagnosis, considerable savings derived form reductions in patient travel, and prompt transfer of patients requiring surgery. In at least one instance, enhanced image display resulted in a more effective blood flow analysis and lesion identification when compared to conventional cardiac care.

Teleophthalmology seems well suited because optical and imaging devices provide the basis for ophthalmic evaluations, and ophthalmologists tend to rely on diagnostic images in assessing, diagnosing, and treating eye disease. Several studies have demonstrated the clinical feasibility and effectiveness of teleophthalmology. Generally, agreement between diagnosis by means of teleophthalmology and conventional diagnosis has been high. Considerable efforts in Europe and the United States have focused on detecting diabetic retinopathy in adults and children.

Telesurgery, telepediatrics, and emergency medicine

This last group of specialties is classified as emerging in that efforts in each are relatively recent; pertinent research is limited, as is professional acceptance.

Interest in telesurgery is probably spurred by the success of laparoscopic and arthoscopic surgical procedures, miniaturization, and robotic technology. Telesurgery subsumes both telementoring and actual remote surgery. The former involves surgical specialists directing remote providers in surgical procedures, while the latter involves the actual performance of surgery by a surgeon remote from the site of the operation. Despite obvious interest in telesurgery, definitive research remains scarce. Studies have been largely descriptive and somewhat anecdotal. Questions of patient safety, provider liability, and cost of robotic equipment/instruments are currently limiting the definitive investigation and proliferation of telesurgery.

Interest in telepediatrics, as in other specialties, derives largely from a geographic imbalance in the distribution of qualified providers. Telepediatrics, to date, has focused on care for chronically ill children and those with special health care needs. As with telesurgery, the majority of the literature is largely descriptive and emphasizes patient/family/provider attitudes and perceptions. Nevertheless, in a randomized clinical trial, Internet videoconferencing led to substantial cost reductions related to shortened hospital stays for very low birthweight infants. Telepediatric care has been demonstrated to be both feasible and acceptable to parents of children who are poor, uninsured and/or live in remote areas where these issues were explored.

As recently as 1994, emergency telemedicine was recognized for its potential to contain emergency medical costs and improve patient management in trauma care. Telemedicine has been used successfully in several areas of emergency medicine including "off-hours" interpretation of radiographs and computed tomography (CT) scans, remote mentoring and consultative services for onsite trauma centers, and follow-up care for trauma patients returned to their communities after initial stabilization and management in tertiary care centers. In addition, in-transit (prehospital) emergency medical services comprise an essential component of emergency telemedicine. Despite the considerable potential embodied in the emergency telemedicine concept, its diffusion has been slow.

Among problems identified is the need for timely coordination of equipment and personnel at both remote and consulting sites at unpredictable times and of unknown duration. Technology requirements for remote assessment of various types of trauma are considerable, as are reliable transmission modes.

Scientific research in clinical emergency telemedicine is especially lacking. However, in the only randomized clinical study, no significant differences were observed between experimental and control groups in terms of return visits, need for additional care, physician-patient interaction and overall patient satisfaction.

Rare diseases. While not included in the list of clinical applications considered here, mention should be made of using of telemedicine to provide services for patients with rare diseases, defined generally in the United States as diseases afflicting 200,000 people or less. For many people suffering from diseases such as cystic fibrosis, sickle cell anemia, and Addison's disease, treatment is often complex and requires specialist care. Often, access to such specialists is problematic. Telemedicine could assist in medical diagnosis, treatment, and maintenance programs, thereby coordinating the delivery of care as well as reducing the need for travel.

Homecare. Finally, mention is made here of "telehome care," which refers to the provision of care electronically in the home. It is spurred by the aging of the population, reduced length of hospital stays, and increased outpatient procedures. Telemedicine can provide new opportunities for more comprehensive and monitored health care in the home environment, which includes remote monitoring of blood pressure, electrocardiogram (ECG), glucose, forced vital capacity, and other vital data. The potential for telemedicine to contribute to cost containment and cost savings is considerable.

Recommendations

Clinical applications hold considerable promise for improving access and quality, as well as containing cost containment across the spectrum of clinical applications. Teleradiology and telepathology are already well established, mature applications that have demonstrated their value and are being widely accepted into the mainstream of medical care. It is in the other clinical specialty areas that research and action agendas must be engaged in order to provide the necessary scientific evidence for a reasoned, merit-based deployment of telemedicine. These recommendations are organized by topical areas.

Technology

- Appropriate extant technologies should be adapted/adopted in clinical applications, and they should be continually monitored and updated as new products and services become available.
- Standards and protocols, such as those for teleradiology and telepathology, must be developed by appropriate professional societies and implemented by each clinical specialty.
- A repository of technology research literature should be established in order to ensure the efficient development of specific technologies and synergistic research development.

Human factors

- Research must assess the human-technology interface for each clinical application in an effort to reduce technology-based barriers for providers and patients.
- Research must be conducted in each clinical specialty to determine the extent to which telemedicine technology is appropriate, suitable, and productive in improving patient outcomes.

Research

The following strategies represent some of the most pressing action necessary to facilitate progress:

- Determination of research priorities in clinical applications including clinical effectiveness and safety.
- Support for large-scale, multi-institutional, comprehensive and long-term research utilizing randomized clinical trials, large data sets and/samples.
- Cost sharing, when necessary, among funding agencies for large-scale research among a consortium of research institutions.
- Development of guidelines regarding:
  - Patient safety
  - Provider proficiency, certification
  - Clinical protocols
  - Continuous monitoring for quality assurance
- Integration of clinical applications into medical school curricula.
- Establishment of clinical telemedicine boards within professional societies for the purpose of overseeing research development, pro-

mulgation of research findings, development of appropriate protocols, guidelines, and curricula for medical schools and continuing medical education.

- Development, testing, and implementation of successful organizational (infrastructure) models appropriate to support teleclinical activities within and between provider institutions, and within regional telemedicine networks.
- Efforts must be directed toward enlarging and extending the research base through:
  - Expanding cooperative and coordinated multi-institutional research efforts.
  - Providing funding for long-term broad-based scientific research efforts in order to aggregate the volume of research necessary for rational public policy decisions.
  - Clinical research must proceed from initial "proof of concept" research to that which promulgates evidence-based guidelines for implementation.
  - Research must be conducted that demonstrates the safety and efficacy of clinical applications.
  - Professional societies must be directly involved in development of their respective applications as well as with interrelated developments in other clinical specialties.
  - In addition to sponsored research, funding agencies should support training grants and fellowships in clinical applications.

PUBLIC HEALTH APPLICATIONS

Public health applications of telemedicine range from epidemiologic surveillance through the development of appropriate geographic information systems and deployment of remote sensing technology to health promotion/disease prevention. The development, deployment, and evaluation of these applications must take into account the wide variation in contextual factors, including the socioeconomic, educational and cultural environments where these systems are implemented. The challenge here is to obtain, transform, and transmit knowledge to promote the health and well-being of people at the local, national and international levels.

Epidemiological surveillance is growing rapidly, in part, because of the development of geographic information systems (GIS) and remote sensing technologies. GIS technology provides for the spatial-temporal analysis of disease related information by spatially registering data within a single processing environment. Recent advances in interactive visualization and custom modeling have increased the utility of GIS in disease surveillance. Also, space-based remote imaging and sensing systems are capable of providing high-resolution data for small or large areas. Multispectral imagery produces accurate land cover/land use maps for epidemiologic analysis.

Taken individually and together, GIS and remote sensing/imaging permit the management and convergence of various disease surveillance activities in the public health sector. They provide data on the geospatial and temporal trends in disease incidence and prevalence; risk areas for potential epidemics; and, the corresponding populations at risk. Most importantly, these technologies permit intervention planning and assessment of prevention strategies. Hence, they constitute an important source of information to guide and formulate public health policy and intervention program.

Vector-borne diseases remain a serious threat at the regional, national, and international levels. Therefore, it is important to assess the complex relationships between environmental factors, such as changes in climate, vegetation, hydrography, and land use patterns and the emerging vector-borne infectious diseases. Remote sensing and GIS technologies use aggregate multiple data sets from a variety of sources to assist the development of predictive climatic environmental models. The models, in turn, provide a variety of risk scenarios and remediation measures for rapid and efficient allocation of resources. A number of studies already have demonstrated the potential of these models in specific risk-environments.

Essential to the success of these efforts is development of a decision support management system. Such a system comprises four elements, namely (1) planning (environmental monitoring, modeling, and forecasting); (2) mitigation (resource need forecasts, economic impact models, social stability models, and action plans); (3) response (medical attention, vector control, population alert/education), and (4) recovery/preparedness (restoration of environment, elimination of toxic/disease material, educational outreach, inventory of resources).

Health promotion/disease prevention

Information technology can also be used effectively to inform, influence and motivate individuals, groups, and organizations to adopt healthy lifestyles. Interactive health information can be valuable insofar as health literacy and knowledge are required for assuming personal responsibility for health and greater health "self-management." Established interactive health communication (IHC) systems can: (1) provide access to individualized health information on demand; (2) enable informed judgments and health decisions and communication between providers and patients/families; (3) promote adoption of healthy lifestyle; (4) facilitate informed self-management of chronic health problems and supplement existing health resources through remote monitoring; and (5) enhance effective and appropriate utilization of health resources.

The success of IHC systems would ultimately depend on the appropriate utilization, identification of user benefit/cost ratios, and the reduction of barriers to broad acceptance. Enabling factors include: continued expansion in telecommunications capacity (power, speed, options); increasing computer literacy and universal access; promotion of consumer demand for health information and acceptance of shared-decision making with providers; and increased emphasis on prevention. Major barriers to general acceptance and use of IHC systems include: resistance from professional providers; limited reimbursement incentives; lack of individual/group access because of socioeconomic, educational, and cultural factors and lack of sufficient data demonstrating IHC system effectiveness. The potential benefits of IHC systems must be weighed against certain costs or risks. The latter may include inappropriate, inaccurate, or misleading information; delay in necessary treatment; damage to provider-patient relationship; breaches of privacy and confidentiality; misdirection in the development of resources; unintended errors; and, the possible introduction of a multitiered health system.

The research to date precludes definitive conclusions pertaining to cost containment and improved health outcomes sufficient for informed decisions. Evaluative norms, benchmarking, and research that compare IHC systems to traditional arrangements are lacking in this field. Therefore, in large part, the potential opportunities and benefits of IHC systems for health promotion/disease prevention remain as theoretical propositions waiting to be tested.

Promoting international public health

Since 1995, development of global health networks have focused on the goals of interoperability and standardization. At the same time, national and international health agencies have established health policy agendas that focused on disease prevention/health promotion. For the most part, however, international cooperation in this domain has been limited to developed countries, and considerable gaps remain between developed and emerging/reemerging countries. These gaps can be filled only through international collaboration and the advancement of global health networks.

Among developed countries, the United States, Canada, France, Germany, Italy, and other countries of the European Union, have engaged in a number of collaborative projects over the past decade. These projects focused on prevention, early detection, diagnosis and treatment of cancer, cardiovascular disease, emergency services, and so-called "smart (encoded health data) cards."

Recommendations

The recommendations pertaining to development of public health applications can be grouped into five categories: research/evaluation, cost, quality, legal regulatory issues and technology.

Research and evaluation

- Effectiveness and efficiency of epidemiological surveillance and IHC systems must be determined and defined.

- National and international information technology literacy must be addressed.
- Benchline and quantitative measures of progress in promoting health literacy, motivation, and health knowledge levels among the public must be developed and applied.
- Cultural differences in health practices and the potential role of information technology generally and telemedicine particularly must be determined and incorporated into the development of national and international networks.
- Systematic and comprehensive research agenda must be developed and supported.
- An international repository of data on all previous and ongoing telemedicine projects must be developed to promote resource sharing and encourage effective collaborative efforts.
- Suitability of telemedicine applications for specific health/disease sectors must be determined in order to establish the proper proportionate responsibility.

Cost

- Cost modeling must include assessment of the costs associated with storage, archiving, retrieval, and maintenance of digital assets, including consumer owned information.
- Benefit/cost analysis must provide public health policy makers with adequate economic data to allow informed policy and programmatic decisions.

Quality

- Quality must be operationally defined and an enforcement system established.
- Baseline quality indicators and measures must be applied to assess benefits.
- Appropriate educational programs in telemedicine must be introduced into medical school curricula.

Legal/regulatory issues

- Standards, such as those developed by the Interdisciplinary Telehealth Standards Working Group, devised to protect patients and health providers must be established for each telemedicine application.
- "Ownership" of medical records must be defined to provide guidelines and protection for both patient and provider.

Technology

- Development of technology to create secure network systems that provide continuous access, protect confidentiality, and adequate firewalls must be supported.
- Organizational/administrative frameworks and strategies must be developed to support and oversee national and international networks.

MEDICAL EDUCATION

Advanced information technology has the potential to transform medical and health education at the undergraduate, graduate, and professional levels. Some suggest that health education generally, and medical education in particular, is at a "crossroad" in terms of incorporating advanced information technology into the content and context of medical education.

The focus here is on those technologies that provide for the transfer of medical knowledge to remote medical students and professionals, so-called "distance education." Distance medical education has been facilitated by videoconferencing, Internet-based systems, and high bandwidth Internet (Next Generation Internet or Internet2).

At the undergraduate level, science education consists of classroom lecture/laboratory format, whereas clinical education extends to hospitals or ambulatory clinic-based rotations where students actively participate in diagnosis, treatment and follow-up care of patients. Continuing Medical Education (CME) is aimed at keeping physicians abreast of scientific and technical advances, promoting compliance with emerging standards of care, and assuring quality medical care.

Evidence suggests, particularly in CME, that learning is maximized in self-directed situations where physicians actively pursue topics of interest to them in appropriate contexts. Information technology can help create these situations and environments directly through providing (1) self-paced programs; (2) realistic multimedia simulations; and, (3) custom-designed learning processes that include self-testing with immediate feedback and augmented learning opportunities.

Two-way interactive videoconferencing enables interaction between geographically separated faculty and students. In this setting, faculty and students see and communicate with one another in an environment where images and documents can be viewed and transmitted from place to place. This electronic interactive mode has been used in other contexts as well, such as infection control, radiology, and community health interventions. Indeed, there has been considerable international emphasis on developing international standards for this mode of training and practice of medicine. Several studies have demonstrated an "equivalency" between in-class and remote videoconferencing and telementoring in terms of student performance on standardized examinations, conformity with clinical protocols, as well as the convenience and efficiency of distance education. Significantly, distance CME has been judged to provide a "better" learning experience than that provided in the traditional format.

There is some evidence, however, that "remote" students were not fully "involved in dialogue" with the faculty, and that the success of this modality depended on the presentation of programs by a multidisciplinary team. Ideally, the team would consist of trained competent clinicians who are comfortable with the requisite technology, technology specialists, and distance learning education specialists. The team approach enhances the benefits of videoconferencing by providing remote access to specialists at centralized locations and expanding medical education to larger student populations.

Web-based learning

The advantage of Internet or Web-based medical education lies primarily in the increased access relative to the point-to-point structure of videoconferencing. The ubiquity of the Internet with its vast reservoir of information, potential for multimedia streaming and low cost adds to its appeal for medical education. Remote access to information sources including lectures, notes, and assignments; interactive self-directed exercises; access to related Internet sites; "chat rooms" that provide for synchronous as well as asynchronous discussion between faculty and students and among students, characterize Internet-based or "virtual" medical education communities, regardless of level. Recent advances in multimedia platforms have been made possible by the Next Generation Internet's expanded bandwidth. This, coupled with compression technology, has contributed to development and delivery of high quality and advanced imagery such as the National Library of Medicine's Visible Human Project. Several studies have demonstrated the equivalency of Web-based learning relative to traditional modalities. Perhaps more important, however, are several studies that demonstrated medical students' preference for Internet-based multimedia over printed materials. It should come as no surprise that students exposed to Internet materials performed much better than those using printed materials, although the length of exposure to the Internet materials was necessarily greater.

Generally, impediments to adoption of new educational technologies can be classified into three types: learner issues, instructor issues, and overall effectiveness. It is necessary to understand learners' familiarity with the requisite technology. Appropriate training in the use of this technology can facilitate the adoption of Web-based education. The technology must also be user-friendly, high quality, reliable, and effective. Many, if not all, of the same issues can be related to instructors using information technology. They must be experienced in and comfortable with the technology. This, in turn, will improve the likelihood of student acceptance of the modality.

Recommendations

Evaluation is paramount. To date, the "proof-of-concept" has been demonstrated, but there is a paucity of scientifically rigorous outcome studies. Evaluation is hampered primarily by the lack of adequate and reliable measurement tools, limited funding for systematic research and the dearth of research specialists in this area. As with most evaluation strategies, research into videoconferencing and Web-based education technologies suffer from inherent limitations and generality stemming from variability in the level of applied technology.

Advanced information technology has the potential to enhance, facilitate, expand, and improve distance medical education in all areas and at all stages. Hence, it can provide unique opportunities for the improvement of medical education at the regional, national, and international scales. Several challenges lay ahead, including skills and preferences of instructors and students, curriculum design, technological configurations, cultural context, social and regulatory constraints. These challenges can be met only in conjunction with development and support for ongoing, systematic, comprehensive scientific evaluation programs to demonstrate the efficiency and effectiveness of the information technology in medical education.

ORGANIZATIONAL MODELS AND REGIONAL NETWORKS

Organizational models and regional networks constitute some of the essential building blocks in the development of telemedicine systems. Hence, it is of some import to determine the key attributes of these networks and the requirements for their success.

To date, there are few mature and self-sustaining telemedicine systems to ascertain the requirements for "successful" organizational models and networks. Nevertheless, telemedicine organizational models have been based on one or more of the following variables: geography, target or service population, and/or specific disease or medical specialty. In addition, telemedicine networks can operate either as open or closed systems.

Geographically based models provide medical and health services to people residing in a defined geographic area. Population-based models target the health care needs of a defined population, which receives health services on the basis of some type of entitlement, such as membership in the armed services, residents of institutions, or membership in health care plans. These populations may be geographically discontinuous or located in a specific target area that helps define them, such as medically underserved areas. Specialty or disease-based models bring together clinical, research, and educational expertise to assist people with certain illnesses. Finally, some networks operate as open systems permitting global access to their services, and some operate as closed system limiting access to them.

Observers have identified some of the basic requirements for successful telemedicine networks, regardless of type. These include:

- A clearly articulated mission, with specified program objectives.
- Ongoing, systematic evaluation of processes and outcomes for quality assurance.
- Identification of service providers and specification of services to be provided to meet needs of targeted area and/or population.
- Development and deployment of technology appropriate to meet the needs of the program.
- Built-in organization/technology flexibility to adopt new technologies when available and appropriate.

As information technology continues to evolve, sound organizational models and their attributes must be identified, described and presented to potential telemedicine network developers, institutions incorporating telemedicine, and public policy makers.

At both the national and international levels, concern is being directed toward the geographic imbalance in access to quality health care among national regions and between countries, respectively. In both theory and practice, the creation of regional medical care systems is aimed at coordinating and integrating health resources and facilities within areas to promote both efficiency and equity. Efficiency is achieved by maximizing the locational efficiency of resources. Equity is achieving by giving people greater access to health resources. The appropriate development of telemedicine may achieve both efficiency and equity by obviating the need to relocate existing facilities, establishing new facilities at minimal cost, and creating flexible virtual regions that rise above traditional geographic constraints.

The European Union and G7/8 countries are cooperating in developing several regional telemedicine test beds, but the most comprehensive efforts toward developing (international) regional hierarchical telemedicine networks can be found in Europe. Moreover, both developed and lesser-developed countries, including medically underserved areas of sub-Saharan Africa and Asia have organized such networks. At the same time, variations in information technology infrastructure, the culture of health, illness, and medical care, and language have hampered further development of these international networks.

Attempts to develop regional telemedicine networks have encountered other problems in applying the regionalization concept, including organizational control and national policy. "Virtual colonialism" may emerge as an issue if more developed countries try to control lesser-developed ones. Global regionalization in this case must acknowledge and accommodate the indigenous medical values and systems.

Recommendations

The ultimate success of regional telemedicine networks depends on making progress toward a nested hierarchy of regional programs that lead to national and ultimately international regionalized telemedicine networks. In order to make this progress, the following are recommended:

- National and international organizations should develop guidelines, regulations, licensing procedures as well as security and privacy protection for patients and providers, especially in emerging networks.
- Regional national and international networks should develop mechanisms for ensuring cooperation and coordination among extant and future telemedicine programs.
- Efforts must be made to increase equity and efficiency in the distribution of infrastructures in various countries with the aim of overcoming the "digital divide" within and between countries.
- International collaboration must be based on the principles of cultural diversity as well as variations in socioeconomic factors, and medical systems.
- Support must be provided for long-term development of large scale "test beds" to ascertain the true attributes of successful/unsuccessful regionalization models.
- Standards, protocols, and guidelines that are mutually acceptable to all members of proposed regional telemedicine networks must be developed.

TECHNOLOGY

Technology constitutes an essential feature of telemedicine, and it has been a driving force behind its development and evolution. Indeed, the ultimate success of telemedicine may depend on how well the various sectors of the health and medical care systems capitalize on and tie into the ever-expanding capabilities of advanced information technology. Among the many facets of technology and its development, technical design, technical applications, interoperability are critically important.

Technical design

Over the past 5 decades, information technology has changed considerably, and has been introducing a vast array of technical capabilities at an accelerating pace. Of particular relevance is the current multitude of high-speed service offerings applicable in the design of telemedicine systems. The Asynchronous Transfer Mode (ATM) is one of the new high-speed offerings available in today's telecommunications market. ATM systems are preferable when high data rate transfers are required. When coupled with the Synchronous Optical Network (SONET) configurations, ATM systems offer high-quality and low-delay conditions. Currently, fiberoptic systems are being designed to support data transmission rates as high as 40 gigabytes per second (Gbps) suitable for advanced telemedicine medical systems.

Currently, wireless systems are expanding at a fast pace, and their use in everyday communication has already surpassed wired systems. Wireless system can be classified as first or second generation. These network designs offer services for analog voice as well as digital services up to 38 kbps. The next generation of wireless systems incorporates broadband, multimedia mobile operations with digital services ranging from 144 kbps across all environments and from 384 kbps pedestrian outdoors up to 2 Mbps indoors. Because the next generation digital cellular network will have faster and larger transmission capabilities, more complex medical services can be delivered reliably and without degradation of quality.

Technical applications

The range and complexity of telecommunications technology requirements vary with specific medical/health applications. As the next generation digital cellular network will have faster and larger transmission capabilities, more complex medical services can be delivered reliably and without degradation of quality.

With the exception of digital devices ranging from blood pressure monitors through compressed and full-motion video, the majority of vital sign medical devices require relatively low data-transmission rates. Capabilities currently offered by these systems, including first and second-generation wireless and basic telephone connections, would support the transfer of information provided error free or as "error detecting and correcting" processes.

Interoperability

Most of the early engineering work supporting telemedicine consisted of integrating "off-the shelf" components to specific clinical applications. Currently, several firms now provide customized telemedicine components. While efficient for the specific setting and purpose, systems comprising these components can be costly and inflexible. Adding, modifying or otherwise restructuring custom designed systems can be costly and time consuming. Moreover, most of these designs are configured as a single vendor system, and communication between vendors may be problematic. There is an increasing need to develop interoperable systems. The term "interoperability" refers the compatibility and ease of communicating between individual telemedicine systems and between nodes in a single telemedicine network. There are three levels of interoperability to be considered: (1) interaction between stations; (2) interaction between devices connected to a station's platform with that platform; and (3) interaction between components that constitute the platform with one another.

Interoperability in a complete system implies the integration and standardization of four kinds of devices available at each station, namely, those involving:

- User interface
- Medical process
- Patient record
- Communications

Recommendations

Any action agenda pertaining to telemedicine technology is based on the premise of closer cooperation between the information technology and health/medical care sectors. This cooperation is critical to the development of telemedicine systems to deliver health and medical care more fully, effectively, and efficiently, regardless of the type or scale of application being considered.

- Efforts should be directed toward developing fully interoperable telemedicine stations that interact with and make use of one another's devices. Essential to this development is merger of policies and regulations and the development and promulgation of industry standards.
- The development of "middleware" is essential. Middleware engineering links the work of software and network engineers.
- Research into the human (patient/provider)–machine interface must be a high priority. There is a need for better displays that are more natural and for better and less invasive sensors.
- Development of "intelligent" medical robots may be critical to the future of some telemedicine sectors. Research should be directed toward the development of these robots, which could decrease medical errors and enhance the quality of care.
- Security systems must be built into every telemedicine network.

- Technology transfer, exchange and cooperative development must be a high priority. The ultimate goal is to guarantee end-to-end connectivity. It is essential that technology transfer between "resource rich" and "resource poor" become a high priority.

DIFFUSION

The ultimate measure of the success of telemedicine, whether it be in clinical or public health applications, or medical education, is the extent to which it is integrated into the mainstream, or its diffusion. The assessment of telemedicine diffusion is complicated by its many forms and the inclusiveness of the field. One obvious conclusion drawn from previous sections in this report is that various applications of telemedicine have developed or diffused at different rates. Overall, the exceptional promise of telemedicine has yet to be matched by a corresponding level diffusion.

Adoption/diffusion process

The adoption process is at the base of observed rates of all innovation diffusion, variously defined as "the process by which an innovation is communicated through certain channels over time among the members of a social system" or the change in geographic/functional distribution of a phenomenon over time. The adoption process related to telemedicine involves a series of stages including awareness, interest, evaluation, trial, and finally adoption or rejection. For most innovations including telemedicine, it is not sufficient that the innovation simply match the value of the technology in place. Generally, the innovation must overcome inertia of the current technology/practice by being demonstrably superior. Also, in the case of telemedicine, there are a number of different actors in the adoption process, including providers, administrators, institutions, funding agencies, and the public.

The overall diffusion process can vary considerably between these groups. In each group, we may find gatekeepers, innovators, early acceptors, late acceptors, and laggards. This too, leads to differential rates of diffusion, as does the recency of the innovation. The current generation of telemedicine is barely one decade old. Finally, external environmental factors can limit or facilitate the diffusion of telemedicine. For example, the presence or lack of appropriate communication technology infrastructure, the ability to implement information received, and the social, economic, and cultural milieu related to health and illness behavior can significantly alter the rate of diffusion. All this must be considered against a backdrop of the consistent evolution of the technology of telemedicine and improved affordability over short periods.

Growth and diffusion of telemedicine

Apart from the notable exception of teleradiology and, to a much lesser extent, telepathology, the overall diffusion of telemedicine is below expectation. Whereas aggregate statistics reveal a consistently positive trend in the number of providers, programs, and consultations, growth is unevenly distributed across various applications and regions. Several states in the United States have developed comprehensive state-wide systems, while other states have few, small and geographically restricted efforts. In 1999, an estimated 4000 physicians in the United States participated in telemedicine (out of an active nonfederal physician supply of almost 700,000). However, in a recent sample survey, the American Medical Association reported that more than 9 of 10 physicians use computers in their practices, and a majority of them use the Internet for medical research, legal and regulatory updates, and e-mail communication. Nevertheless, the average number of teleconsultations per telemedicine site was less than 40. Among a sample of 132 programs, only 15 reported more than a 1000 teleconsultations per year.

A cursory assessment of the diffusion of telemedicine in other countries also illustrates wide variability in terms of scale, driving forces, opportunities, and geographic landscape. In Australia, for example, with a widely dispersed population, a developed economy and a history of providing health care for remote populations, telemedicine is relatively widespread. Emphasis placed on telemedicine in university medical departments has helped propel the diffusion.

Malaysia also has a dispersed population, with West Malaysia located on the southern portion of the Malay Peninsula and East Malaysia on the northern one third of the island of Borneo. The nation is separated by water for a distance of 640 km. Here, a concerted government-sponsored effort is underway to incorporate and rely heavily on telemedicine to bring health care to its population.

The situation in South Africa is one in which there is a paucity of traditional health services in many parts of the country, especially rural areas. Telemedicine is viewed as a way of spreading health and medical care equitably and efficiently to these areas. However, this cannot be accomplished without significant investment in an information infrastructure and training of health professionals to serve in the remote areas.

Thus, the situation facing telemedicine diffusion varies substantially country by country and region by region. The diffusion of telemedicine depends on addressing and adapting to the special needs of each country, and overcoming the obstacles faced in each environment.

The complexity of assessing the telemedicine diffusion as presented above is matched by the number of influences on the diffusion process, and includes: the structure of decision-making; role of opinion leaders; availability of significant research data; improvement in efficiency; impact on quality of service; cost of technology; organizational/social structure; risk or uncertainty; consistency with social/cultural norms; compatibility with in situ care; organizational change required; and learning curve of providers and patients.

Enhancing the diffusion of telemedicine

Regardless of context, early identification and substantive demonstration of the potential benefits of telemedicine and significant cost/benefit ratios will enhance the acceptance and diffusion of telemedicine by various actors in the adoption process. A suitable framework, including necessary technological and educational infrastructure must be established for the introduction and utilization of telemedicine. Telemedicine must be integrated into the local/regional health sector and adapt to the social and cultural health and medical milieu.

Consideration of and prospects for the diffusion of telemedicine must be based, therefore, on the following clearly articulated set of criteria:

- Demonstrable need
- Explicit statement and demonstration of anticipated benefits
- Understanding of distributive impact of telemedicine
- Detailed methodology for implementation
- Sound methodology for evaluation
- Service delivery policy and protocols

Recommendations

It has been stated, "When technological innovations are not accepted or implemented properly, generally the failure may be traced to a poor fit between the nature of the innovation and the vested interests, resources and expectation of its major gatekeepers." Nonetheless, the proponents of telemedicine must provide convincing evidence of the benefits of telemedicine vis-à-vis traditional medical and health care modalities. This can only be done on the basis of scientifically sound experimentation and evaluation. Concern over a target or a desirable rate of diffusion may be misdirected. In many ways, this generation of telemedicine is in its infancy. And, it may be argued that because of a lack of data from long-term, large-scale projects and test beds that demonstrate the effectiveness of each telemedicine application, the relatively slow pace of diffusion is not only to be expected, but fitting. The highest priority should be given to funding appropriate, long-term large-scale telemedicine projects by national and international agencies. Positive results from these types of undertakings will expedite the rate of diffusion.

Address reprint requests to:
Rashid L. Bashshur, Ph.D.
Director of Telemedicine
The University of Michigan Health System
C201 Medinn Building
1500 East Medical Center Drive
Ann Arbor, MI 48109–0825

E-mail: bashshur@umich.edu

List of Participants

Ackerman, Michael, Ph.D.	USA
Ade, Alex	USA
Aladjam, Silvio	USA
Alessi, Norman, M.D.	USA
Anderson, Frank J., M.D.	USA
Archer, Frank, M.D.	Australia
Athey, Brian, Ph.D.	USA
Bahabri, Sultan, M.D.	Saudi Arabia
Bakalar, Richard, M.D.	USA
Balch, David, M.A.	USA
Bashour, Tail, M.D.	Lebanon
Bashshur, Noura, M.H.S.A.	USA
Bashshur, Rashid L., Ph.D.	USA
Belard, J. Louis, M.D.	USA
Bennett, John, M.D.	USA
Bergman, Dale	Canada
Biermann, J. Sybil, M.D.	USA
Biggs, Deborah, J.D.	USA
Billi, John, M.D.	USA
Boucha, Kathe	USA
Brebner, Eileen, M.S.	Scotland
Brebner, John, M.D.	Scotland
Brock, Elaine, J.D., M.H.S.A.	USA
Bujnowska-Fedak, Maria-Magdalena, M.D., Ph.D.	Poland
Butcher, Laura, M.D.	USA
Calhoun, Judith, Ph.D.	USA
Capone, Antonio, Jr., M.D.	USA
Castillo, Fernando	Panama
Christensen, Bill, Prof.	USA
Clyburn, Conrad	USA
Cochran, Keith	USA
Cohn, Vicki	USA
Craft, Richard, M.S.	USA
Crandall, Ken	USA
Crump, John, M.D.	USA
Darkins, Adam, M.D., M.P.H., F.R.C.S.	USA
DeBakey, Michael, M.D.	USA
Deering, Mary Jo, Ph.D.	USA
Doarn, Charles, M.B.A.	USA
Douglass, Alan, M.D.	USA
Downs, Stephen J.	USA
Durand, Kate	USA
Durka-Pelok, Geri	USA
Ecken, Brenda	USA
Ehrenberger, Heidi, Ph.D., RN	USA
Ellis, Charles, M.D.	USA
Ellis, David	USA
Fernández, Eduardo Garcia	Brazil
Ferrante, Frank E., M.S.E.E., M.S.E.P.P.	USA
Ferrara, Alane, R.N.	USA
Filler, Robert, M.D.	Canada
Fraker, Nancy, M.S.W.	USA
Freer, James, M.D.	USA
Friedewald, Vincent	USA
Frost, Renee Woodten	USA
Gist, Nat	USA
Goldberg, Alan S, J.D.	USA
Goldsmith, Aaron J., M.S.W.	USA
Grigsby, Jim, Ph.D.	USA
Grodzinski, Alison, M.L.I.S.	USA
Guindi, Sally, J.D.	USA
Hacker, Thomas	USA
Hague, R. Daniel	USA
Haig, Andrew, M.D.	USA
Haig, Daniel	USA
Halman, Marc	USA
Hammer, Peter, J.D.	USA
Hammoud, Maya	USA
Hanson, Deborah	USA
Haveman, James K., Jr.	USA
Heffelfinger, Mary, M.D.	USA
Henny, Geoffrey, Ph.D.	USA
Hiemstra, Amy, M.P.H.	USA
Hiss, Roland, Ph.D.	USA
Hoffart, Marita	USA
Holevinski, Tom, Ph.D.	USA
Hollenbeck, Ann, J.D.	USA
Hooberman, Amy, M.H.S.A.	USA
Hopp, Faith, Ph.D.	USA
House, Maxwell, M.D.	Canada
Jacobs, Lloyd, M.D.	USA
Jacobson, Peter, J.D.	USA
Johnson, Oryema, M.D.	Canada
Jordan, Steven	USA
Juan Ramon, Arosemena, M.D.	Panama
Kahl-Shulz, Vanessa, M.B.A.	USA
Kamil, Leslie, M.S., J.D.	USA
Katz, Jana, M.P.H.	USA
Kaushik, Raval, M.D.	USA
Kessler, Marc, Ph.D.	USA
Khoury, Osama, M.H.S.A.	USA

Kinlaw, Jerome	USA
Kipa, S. George, M.D.	USA
Koelling, Todd	USA
Kollberg, Hans, M.D.	Sweden
Kopp, Stephen, Ph.D.	USA
Kratochwill, Eric, M.H.S.A.	USA
Kratz, Mary, M.T.	USA
Kvedar, Joseph, M.D.	USA
Kwankam, S. Yunka, M.D.	Switzerland
Lacerna, Mario, M.D.	USA
Lacroix, Andre, M.D.	Canada
Lareng, Louis, M.D.	France
Latouff, Omar, M.D.	USA, Egypt
Lay, Michael	USA
Ledlow, Jerry, Ph.D., M.H.A.	USA
Leonard, Gregory	USA
Levine, Robert, M.D.	USA
Lichter, Allen, M.D.	USA
Linkous, John, M.A.	USA
Lobo, Manuel, M.D.	Panama
Lowry, Julie, Ph.D.	USA
Luqman, Nike	USA
Luxenberg, Steven, M.D.	USA
Mandil, Salah, Ph.D.	Switzerland
Mangurlkar, Rajesh, M.D.	USA
Mansour, Sherine	Canada
Marciscano, Ivette, R.N.	Panama
Marscellas, Susan	USA
Marsh, Lon	USA
Massa, Ricardo, M.D.	Mexico
McCarthy, Joseph, M.B.A., M.S.	USA
McGee, James, M.D.	England
Mehta, Ameet	USA
Meixner, Walter	USA
Mellow, Alan, M.D., Ph.D.	USA
Mercier, Karen	USA
Merrell, Ronald, M.D.	USA
Moidu, Khalid, M.D.	USA
Morales, Jorge Ramon, M.D.	Brazil
Morales, Joseph, M.S., M.B.A.	USA
Morris, Harper, M.D.	USA
Nemana, Ravi	USA
Nesbitt, Thomas, M.D., M.P.H.	USA
Nicogossian, Arnauld, M.D.	USA
Nugent, Clark, M.D.	USA
Nypaver, Michele, M.D.	USA
O'Connell, Vincent	USA
Oh, Michelle, M.B.A.	South Korea
Olson, Suzan, Ph.D.	USA
Olsson, Silas, M.Sc.	Belgium
Orlov, Oleg, M.D.	Russia
Palma-Davis, Lavaugh, M.A.	USA
Patel, Vimal	India
Paterson, Amber, Ph.D.	USA
Perednia, Douglas, M.D.	USA
Philip, Tina, M.H.S.A.	USA
Pomerantz, Stuart	USA
Pool, Sam L., M.D.	USA
Poropatich, Ronald, M.D.	USA
Pulido, Pablo, M.D.	Venezuela
Puskin, Dena, Sc.D.	USA
Rahman, Sam	USA
Randles, Ted, Ph.D.	USA
Reardon, Tim, M.S.	USA
Rigby, Michael, B.A.F.S.S.	UK
Rockoff, Maxine L., Ph.D.	USA
Ross, Linda, J.D.	USA
Safwat, Rihab, M.D.	USA, UAE
Sanders, Jay H., M.D.	USA
Sapci, Hasan, M.D.	Turkey
Satava, Richard, M.D.	USA
Schmidt, Steven, M.D.	USA
Schneider, Lisa	USA
Schrank, Gordon, M.D.	USA
Schwartz, John J.H., M.D.	USA
Sessions, Rufus, Ph.D.	USA
Shay, Kenneth, D.D.S., M.S.	USA
Shihadeh, Muaiad, M.D.	USA
Short, Tina, M.P.A.	USA
Shuchman, Robert, Ph.D.	USA
Smith, Robert W.	USA
Smith, Dean, Ph.D.	USA
Sood, Sanjay P.	India
Stachura, Max E., M.D.	USA
Strecher, Victor, M.D.	USA
Suleiman, Abu Bakar, M.D.	Malaysia
Szetela, Maciej, M.S.	Poland
Tawakkol, Nader, M.D.	Syria
Taylor, Andre, M.D.	USA
Teitelbaum, Daniel, M.D.	USA
Terrell, Jeffrey, M.D.	USA
Treloar, David, M.D.	USA
Turgeon, D. Kim, M.D.	USA
Vander Werf, Mark, M.H.S.A.	USA
Vargas, Luis, M.D.	USA
Vega, Silvio, M.D.	Panama
Vivian, Wes, Ph.D.	USA
Von Lubitz, Dag	USA
Walker, Deborah, M.D.	USA
Warren, Larry, M.A.	USA
Watts, Charles M., M.D.	USA
Weinstein, Ronald S., M.D.	USA
Whitten, Pamela, Ph.D.	USA
Williams, Lisa	USA
Woolliscroft, James, M.D.	USA
Yeo, Matthew, J.D.	USA
Younas Janjua, Muhammad Mobeen	Pakistan
Youssef, Zakhour, Ph.D., M.P.H.	USA
Zakir, Sikder, M.D.	Bangladesh
Zurita, Beatriz, M.D., Ph.D.	Mexico