Telemedicine Technology and Clinical Applications

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TELEMEDICINE can be broadly defined as the use of telecommunications technologies to provide medical information and services. Although this definition includes medical uses of the telephone, facsimile, and distance education, *telemedicine* is increasingly being used as shorthand for remote electronic clinical consultation. Interest in the field has increased dramatically in the 1990s. State and federal allocations for telemedicine and related technologies are likely to exceed $100 million in fiscal 1994-1995.[1] At least 13 federal agencies, including the US Department of Commerce, Health Care Financing Administration (HCFA), Office of Rural Health Policy, and US Department of Defense, have begun telemedicine research and demonstration programs. Many states are using their own resources to build state-of-the-art telemedicine systems, some with capital investments exceeding $50 million. Faith in this technology is not universal, however. Depending on one's viewpoint, telemedicine may be seen as a valuable tool for providing badly needed specialty care services to underserved areas, a more efficient use of existing medical resources, a way to attract patients living outside a hospital's normal service area, a way of bringing international health care dollars to the United States, or a serious misallocation of increasingly scarce health care dollars.

Clinical telemedicine programs are now under way in at least 40 states, and it is likely that many physicians in the United States will be directly or indirectly involved with clinical telemedicine by the year 2000. At least 35 sites are using or planning to use interactive video consultation, and it is estimated that more than 70 large electronic medical networks are currently under construction.[2] As future users, it is important for physicians to understand the principles of telemedicine, why this field has suddenly emerged from relative obscurity, where it may lead, and what benefits or pitfalls may exist along the way.

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WHAT IS TELEMEDICINE?

Telemedicine is a diverse collection of technologies and clinical applications. The defining aspect of telemedicine is the use of electronic signals to transfer information from one site to another. Telemedicine systems can be characterized by the type of information sent (such as radiographs or clinical findings) and by the means used to transmit it. Many areas of medical practice have potential telemedicine applications. Image transfer is an integral part of radiology and pathology. Clinically oriented specialties can capture and remotely display physical findings, transmit specialized data from tests such as electroencephalograms and electrocardiograms, and carry out interactive examinations or psychiatric interviews. Telemedicine can be useful for situations in which (1) physical barriers prevent the ready transfer of information between patients and health care providers and (2) the availability of information is key to proper medical management.

There are many ways to relay medical data and many ways to use the data (Table 1). Although telemedicine is frequently described in terms of two-way interactive television (IATV), disparate medical problems may have quite different information and transmission requirements. Ordinary telephones are cheap, ubiquitous, and ideal for rapid consultations and some aspects of patient management. Facsimile machines are routinely used to send electrocardiograms and medical records. Transmitted still images are an excellent medium for viewing skin conditions, radiographs, pathology images, and fundoscopic findings.

More complex applications, such as psychiatric examinations and remotely assisted surgery, require one-way or two-way full-motion video. Using the most efficient communications technology for each medical application is important because equipment and communication costs are directly proportional to the amount of information to be transmitted. The carrying capacity, or "bandwidth," needed to transmit a given amount of information within a fixed period of time still serves as a practical limit to the size, cost, and capability of today's telemedicine systems. An uncompressed, full-motion, two-way interactive video communication requires nearly 1300 times more bandwidth than a conventional telephone call.

HISTORICAL PERSPECTIVES

Telemedicine techniques have been under development for nearly 35 years. Wittson and colleagues[3,4] were the first to employ IATV for medical purposes, in 1959, when they used a microwave link for telepsychiatry consultations between the Nebraska Psychiatric Institute in Omaha and the state mental hospital 112 miles away. In the same year, Jutra[5] pioneered teleradiology in Montreal, Quebec, by transmitting telefluoroscopic examinations over coaxial cable. In the 1970s and 1980s, limited telemedicine projects were instituted at several sites in North America and Australia, including the Space Technology Applied to Rural Papago Advanced Health Care (STARPAHC) project of the National Aeronautics and Space Administration (NASA) in southern Arizona, a project at Logan Airport in Boston, Mass, and programs in northern Canada.[6] All of

Table 1.—The Spectrum of Clinical Telemedicine Interactions*

Purpose	Mode of Interaction	Types of Information Transferred	Minimum Bandwidth Requirements†	Typical Applications
Diagnostic or therapeutic consultation	Real-time, one-way or two-way interactive motion video	Voice, sound, motion video images, text, and documents	Moderate to high	Telepsychiatry and mental health applications, remote surgery, interactive examinations
Diagnostic or therapeutic consultation	Still images or video clips with real-time telephone voice interaction	Voice, sound, still video images or short video clips, text	Low to moderate	Multiple medical applications, including dermatology, cardiology, otolaryngology, orthopedics
Diagnostic or therapeutic consultation	Still images or video clips with text information; "store-and-forward," with data acquired and transmitted for review at a later date	Sound, still video images or short video clips, text	Low	Multiple medical applications, including dermatology, cardiology, otolaryngology, orthopedics
Medical education	One-way or two-way real-time or delayed video	Voice, sound, motion video images, text, and documents	Moderate to high	Distance education and training
Case management or documentation	Transfer of electronic text, image, or other data	Text, images, documents, and related data	Low to high	Community health information networks, medical record management

*Omits telemedicine consultations performed using the telephone alone.
†Bandwidth is the transmission capacity of a telecommunication link. Conventional telephone lines have relatively little carrying capacity (low bandwidth). High-capacity lines are required to transmit large amounts of information (such as images) rapidly.

these projects used some form of video (black-and-white television, color television, "slow-scan" transmission) to enhance the most basic unit of telemedicine equipment, the telephone.[7] Grigsby and Kaehny[8] recently reviewed telemedicine activities undertaken prior to 1993.

With the exception of the 20-year old telemedicine program at Memorial University of Newfoundland, St John's, none of the programs begun before 1986 has survived. Although data are limited, the early reviews and evaluations of those programs suggest that the equipment was reasonably effective at transmitting the information needed for most clinical uses and that users were for the most part satisfied.[9-14] However, when external sources of funding were withdrawn, the programs disappeared, indicating that the single most important cause of their failure was the inability to justify these programs on a cost-benefit basis. Other issues, such as limited physician acceptance, played a less definitive role in their demise.[15]

THE POLITICAL AND DIGITAL REVOLUTION

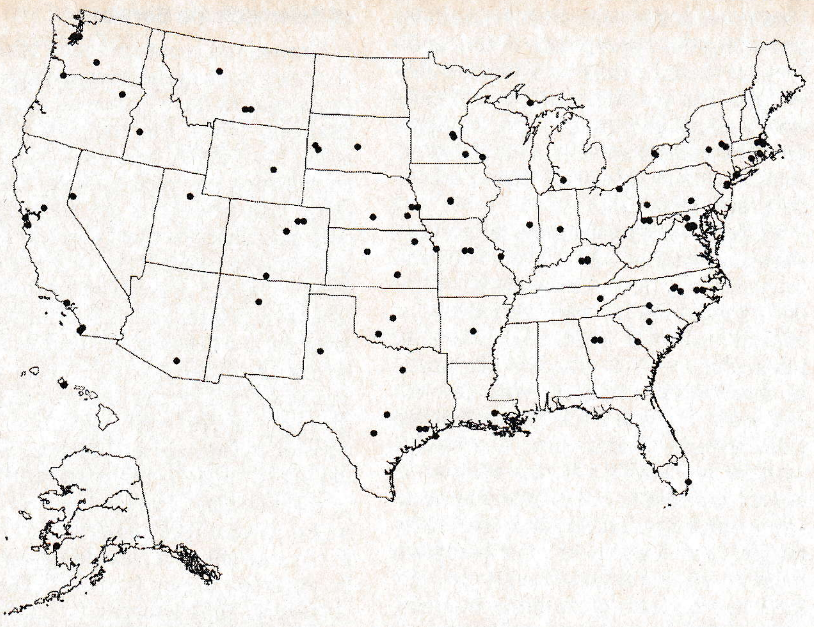
After decades of pilot and demonstration projects, telemedicine moved from relative obscurity to a period of rapid growth in the early 1990s. In a few cases this trend has been precipitated by significant clinical need. For example, the program at the University of Kansas, Kansas City, was proposed by rural practitioners who required access to certain types of medical services.[16] With an area roughly the size of New York State (124 800 km^2), western Kansas currently has no local pediatric subspecialists and only a handful of adult medical and surgical subspecialists. Programs in western Kansas and other remote locations (eg, in Canada or Norway) are based on the premise that telemedicine should improve both access to certain types of specialty care and the overall quality of the care provided.

As with many recent developments in health care, much of the stimulus for rapid change has come from outside the medical profession. In the case of telemedicine, two of the most important driving factors are arguably based on the politics and economics of a managed care approach to health services delivery and the national effort to develop the electronic information highway.

Many of the political imperatives driving telemedicine derive from the anticipated use of managed care incentives to provide accessible, low-cost health care to all Americans. Even in the absence of universal health care legislation, health maintenance organizations (HMOs) and physician-hospital alliances in many parts of the United States are competing for regional contracts on the basis of cost, quality, and access to care.[17] The combination of increased competition, mandated access to care, and increased provider risk with regard to patient outcomes is generating new interest in telemedicine technologies. Telemedicine is seen as a tool that could help manage the medical and financial risks of providing patient care in rural and underserved areas. Providers with telemedicine capabilities are hoping to become more competitive in winning health care contracts, to reduce the economic and medical risks associated with caring for patients in rural areas, and to provide relatively low-cost specialty services to areas where full-time staffing is impractical or uneconomical.

Although demand for telemedicine services appears to be gradually increasing, much of the current enthusiasm for telemedicine is being generated by suppliers of information highway services. Producers of telemedicine equipment and telecommunications carrying capacity (or bandwidth) expect telemedicine to use a significant portion of the so-called *information highway*—the term now used to describe the network of digital signal pathways that is replacing other types of electronic communication.[18] The shift to digital communication technologies in the late 1980s and early 1990s is of enormous importance to long-distance carriers, regional telephone companies, satellite providers, cellular phone systems, cable companies, and the worldwide Internet computer network. Information transmission services formerly provided by separate industries, such as telephone calls, telegrams, image and document transfer, and television programming, become equivalent when converted to digital formats. As a result, most telecommunications companies have seen their own specialty markets merged into a single market in which all providers sell a single commodity: digital bandwidth.

Selling in this new digital market is a daunting task. There are only two ways to increase sales in a commodity market: (1) increase the size of the total market by expanding the demand for bandwidth or (2) increase market share through marketing and product differentiation. Telemedicine can do both. Images, especially relatively expensive two-way interactive video images, use enormous amounts of bandwidth. As a result, major communications carriers have begun to offer and extensively market their products and services for telemedicine applications. The prospect of improved telemedicine services is also being used as an argument for entering new service areas, removing access charges, and obtaining other concessions from government regulators. Manufacturers of video conferencing, imaging, computer, medical, and multimedia equipment have likewise been attracted to the telemedicine market. Commer-



Locations of many of the planned and active consultative telemedicine programs in the United States as of December 1994. Programs limited to teleradiology are not included. Adjacent dots indicate multiple separate projects based in the same city.

cial investment in telemedicine is now being accompanied by major marketing campaigns directed at hospitals, physicians, the military, and, more recently, the general public.

CURRENT STATUS

Until recently, transmission of a high-resolution, full-motion video signal was possible only through the use of expensive or little-available modalities, such as satellite uplinks costing more than $400 per hour or microwave towers. Recent developments in digitization and data-compression technologies allow transmission of the enormous amount of information needed for video with much less bandwidth. Thus, while an undigitized (ie, analog), uncompressed video signal would normally require the equivalent of 90 million bits per second for transmission, roughly the same amount of information can now be transmitted at 384 000 bits per second. The reduction in bandwidth allows affordable transmission of full-motion, moderately high-resolution, color audio-video images over long distances. Transmission costs for these compressed signals are about one tenth the costs of satellite transmission. While the equipment cost for an IATV telemedicine site is now $50 000 to $100 000, decreasing costs of hardware, software, and transmission suggest that high-resolution, full-motion IATV may soon be available to medical clinics and offices at a fraction of that price.

Although telemedicine is often conceived in terms of dynamic, interactive video consultations, "store and forward" technologies are at least as promising. In these systems, static images or audio-video clips are transmitted to a remote data storage device, from which they can be retrieved by a medical practitioner for review and consultation. The advantage of store-and-forward technology is that it obviates the need for simultaneous availability of the consulting parties. The low bandwidth requirements of store-and-forward systems also tend to make them much less expensive. Store-and-forward technology is the basis of at least one major teledermatology research project currently sponsored by the National Library of Medicine, Bethesda, Md.[19]

Radiology and pathology are especially suited to a store-and-forward format. They have some unique requirements, however, most notably for higher-resolution images than are used for most types of clinical consultation. Most teleradiology and telepathology programs are currently separate from the IATV-mediated telemedicine programs. More than 7000 teleradiology systems have been sold to date by two of the largest manufacturers (Image Data, San Antonio, Tex, oral communication, July 15, 1994, and Icon Medical Systems, Campbell, Calif, oral communication, July 15, 1994). In the first 6 months of 1994, approximately 15 interfacility teleradiology programs in North America provided teleradiology services to about 90 remote sites and interpreted approximately 22 000 studies.[20] It is estimated that 60 dedicated telepathology systems are currently in use in the United States (Thomas Arnold, Roche Image Analysis, Elon College, NC, oral communication, December 29, 1994, and John Gerbauer, Sony Medical Division, Montvale, NJ, oral communication, July 15, 1994).

Telemedicine projects of all types are being implemented in the United States at an accelerating rate. In 1990, four telemedicine projects using IATV for patient consultations were active in North America. In December 1993, there were 10, and by December 1994, at least 50 IATV programs were either active or in various stages of planning and implementation. Recent federal funding allocations ensure that at least a dozen new projects will be brought on-line in 1994-1995.

However, the rapid growth and high visibility of these projects masks the fact that relatively few patients are now being seen. In 1993, approximately 2250 patients were seen through interactive (nonradiology) teleconsultation in the United States and Canada.[21] One thousand of these were 3- to 5-minute renal dialysis consultations performed by a physician at a single site in Texas. The remaining 1250 consultations averaged about 35 minutes and were primarily in the specialties of dermatology, psychiatry, neurology, and orthopedics. In the first 6 months of 1994, electronic mental health consultations nationwide totaled approximately 500 patient-practitioner interactions.[22] In almost every telemedicine project, teleconsultation accounts for less than 25% of the use of the system. The majority of on-line time is used for medical education and administration.

Most US telemedicine programs are being funded, at least in part, by state and federal funds. At least 13 different federal grant programs with a total of $85 million in telemedicine funding were approved for fiscal 1994. Some states are sponsoring and building state-of-the-art telemedicine systems with large capital investments of their own. Georgia has allocated approximately $8 million for a program that currently links six sites, with a planned expansion to 40 or more in future years (L. Adams, Medical College of Georgia, Augusta, oral communication, July 20, 1994). Military applications appear to be developing parallel to programs in the civilian sector. Recent appropriations have awarded more than $70 million to military telemedicine programs, including approximately $15 million for teleradiology alone (COL Fred Goerringer, US Army Medical Materiel Agency, Ft Detrick, Md, oral communication, July 15, 1994). The Figure is a map showing most of the active and planned telemedicine programs in the United States as of December 1994.

Table 2.—Some Proposed Applications of Telemedicine Technology

Application	References
Cardiology	27
Dentistry	28-30
Dermatology	31
Electronic medical records	32, 33
Emergency care	34
Endocrinology	35
Home care	36
Managing disabilities	37
Medical education	38
Military and other applications	39-41
Neurology/neurosurgery	42, 43
Obstetrics/gynecology	44
Oncology	45, 46
Ophthalmology	47
Pathology	48-50
Pediatrics	51, 52
Psychiatry	53, 54
Radiology	55-58
Sign-language communication	59
Sports medicine	60
Surgery	61-64
Urology	65
Veterinary medicine	66

In some instances in which federal funding is not involved, telemedicine has become a tool for marketing medical services beyond an institution's normal catchment area. For example, the Massachusetts General Hospital, Boston, has formed a for-profit subsidiary that, for a fee, reads radiographs transmitted from hospitals and clinics in the Middle East.[23,24] The Mayo Clinic, Rochester, Minn, is establishing a $550 000 telemedicine clinic in Amman, Jordan.[25] A multinational venture, the Health Care International Hospital in Glasgow, Scotland, has been designed to function as an electronically integrated hospital capable of providing care via telemedicine to patients anywhere in the world and is targeting international clients from Italy to Saudi Arabia to become part of its network.[26] Other active telemedicine programs have been established in Canada, Europe, and Asia.

UNRESOLVED ISSUES

The implementation of telemedicine programs raises important questions concerning how much we really know about the appropriate use of telemedicine and how it should be incorporated into the nation's health care system. The important unresolved issues revolve around how successful telemedicine can be in providing quality health care at an affordable cost. This depends on (1) clinical expectations, (2) matching technology to medical needs, (3) economic factors, (4) legal and social issues, and (5) organizational factors.

Clinical Expectations and Medical Effectiveness

The clinical problems that are most amenable to telemedicine solutions are largely cognitive in nature, ie, problems in which a decision directly affecting treatment or disposition can be made by providing the appropriate visual, auditory, or written data to a remote consultant. The possible uses for telemedicine technologies range from straightforward radiographic consultations to complex "virtual reality"–based telerobotic surgery (Table 2).[27-66]

With the exception of image-oriented subspecialties, such as teleradiology and telepathology, few clinical studies have documented the accuracy, reliability, or clinical utility of most applications of telemedicine as a primary diagnostic or therapeutic modality. With few exceptions,[67-71] clinical studies evaluating telemedicine to date are descriptive rather than analytic. In the absence of empirical, current data regarding accuracy, reliability, utility, and user satisfaction, the high level of expectation must be viewed with some caution. Efforts are under way to determine the safety, efficacy, and utility of new types of telemedicine systems and services, using both single-site research projects and coordinated multisite collaborative studies.[72]

Matching Technology to Medical Needs

Matching communications technologies to medical needs is important because resources available for medical care are limited; use of more expensive telemedicine technologies will reduce the total number of sites that can be installed nationally. Many well-known projects, such as those of the Mayo Clinic and the Medical College of Georgia, have required relatively elaborate facilities and large capital investments that would be impossible to duplicate in most locations.

While use of the latest and most powerful equipment may seem logical, the early adoption of two-way full-motion video may be an unrealistic "gold standard" for many rural and underserved areas. First, although real-time video may not be necessary for many clinical applications, many of the costs incurred by IATV projects are due to the expense of supporting real-time interactions. Second, the standard television resolutions common to IATV are relatively low for certain types of detailed clinical image data. Third, convenient high-speed links are not available at a reasonable price in most rural and underserved areas. The challenge in choosing telemedicine equipment and services is to match the lowest cost and most accessible technology that will achieve the desired objective with the exact medical needs of the communities to be served.

The Economics of Telemedicine Services

Unresolved reimbursement issues are currently considered to constitute a major barrier to the widespread use of telemedicine. Given the complexity of this issue, the HCFA has been cautious in establishing payment policies. Teleradiology interpretations are currently the only examinations that routinely receive full reimbursement. Several issues are likely to be key in establishing definitive, long-term policies: (1) Is telemedicine cost-effective as a diagnostic, therapeutic, and/or case management tool? There are no published studies that address this issue for many critical care applications using current technology and evaluative techniques. (2) What is the relative utility of a telemedicine consultation compared with a conventional consultation? (3) Even if it is cost-effective, should telemedicine be expected to pay for itself? The most obvious savings associated with telecommunications (lower travel expenses, less time taken from work, etc) are not currently included in the cost accounting of health care. Increasing access to care by use of telecommunications may therefore have the paradoxical effect of actually increasing direct medical expenditures, while the monetary savings accrue to other segments of the economy. (4) Should specific telemedicine training or certification be required? Who should receive how much reimbursement for each examination? Most remote referrals will generate technical, personnel, and professional costs at both ends of the transmission.

Legal and Social Issues

Although many telemedicine interactions are already crossing state and national boundaries, legal precedents for remote liability and licensure are not yet established. When a telemedicine consultation crosses state lines, does the provider have to be licensed in one state, the other, or both? If the community "standard of care" is to be upheld, which community standard applies—rural or urban? If telemedicine services are available and a poor outcome results when they are not used, does this constitute malpractice? Today's patchwork of state regulations, accreditation, and liability is clearly incompatible with the widespread use of electronic medical services. Universal cross-state licensure is already established within the Department of Veterans Affairs and the Indian Health Service.

Social issues are subtler. If access to health care is a right, can telemedicine services reasonably be withheld anywhere there is access to telecommunications? Who will be allowed (or compelled) to provide those services? So far, there has been relatively little discussion of social effects.

Organizational Factors

In contrast to busy programs like that at the University of Tromsø in Norway, which performed 546 IATV consultations in 1993 (S. Pedersen, electronic mail, May 5, 1994), virtually all US telemedicine programs have historically low rates of utilization. There is increasing evidence that managerial and administrative issues may play an important role in both the effectiveness and utilization of all types of telemedicine services.[73] Critical studies that examine the influence of leadership, organizational, and training factors on the success or failure of modern telemedicine programs have not been performed.

THE FUTURE

Clinical use of telemedicine in the United States is still limited. With substantial investments under way, now is the time to establish a telemedicine plan to minimize wasted or duplicated effort, misallocated resources, and dashed expectations. Five considerations may serve as starting points in the endeavor to provide remote medical services during the 1990s and beyond.

First, goals must be defined early. The first question asked in planning any local, regional, or national telemedicine project must be, "Exactly what services are currently lacking, and can they reasonably be provided by simply moving images and data?" If the answer is yes, there is reason to consider telemedicine technologies. Only after these needs are fully defined should the types of equipment and electronic services required be brought into the planning process.

Second, data collection, evaluation, and accountability are key technology management tools. Telemedicine has a substantial potential impact on the type, quality, and patterns of care offered. For example, preliminary results for cases in which telemedicine was used in the Texas prison system suggest that 70% to 80% of patients do not require additional referral to the outside community.[74] The ultimate effect of telemedicine on conventional medical practice is unknown, and its impact may vary substantially in different clinical settings. Ongoing evaluation is needed to determine whether investments made or approaches taken have been worth the effort, especially as telemedicine technology continues to grow and change.

Third, adherence to communications standards is the only way to ensure access to the telemedicine marketplace. Communication via telemedicine requires common standards and protocols. Incompatible equipment can prevent rural medical centers from communicating with the widest possible choice of secondary or tertiary medical centers in a regional, national, or even international market. Standards will be enforced by end users voting for compatibility by means of their purchasing budgets. The American College of Radiology has recently adopted standardization guidelines for plain film teleradiology.[75]

Fourth, licensing and reimbursement policies should foster efficient and technology-neutral use of resources. Telemedicine is a means to an end, not an end in itself. In making decisions about whether to use telemedicine, in-person consultation, or any other form of diagnosis and treatment, physicians should choose the method that can provide the desired clinical outcome at the most reasonable cost. Reimbursement policies should favor desired outcomes rather than specific processes. Although the process of evaluating reimbursement for telemedicine has just begun, state-specific requirements for medical licensure need to be reconsidered in light of rapidly changing medical technologies.

Fifth, goals and accomplishments should be reevaluated periodically. The emerging field of telemedicine is inherently dynamic. Goals, technologies, and practice patterns that make sense today may not make sense tomorrow. Evaluation and reevaluation of goals and accomplishments is the only way to ensure that the needs of users are being met and that appropriate choices will be made in the future.

CONCLUSION

Rapid changes in technology and health care make it difficult to predict the role of telemedicine in future practice. Technology trends suggest that, within the next few years, health care providers will be able to see patients at remote sites by using a desktop workstation or laptop computer in a mobile, wireless configuration. Clinicians will be able to select interactive video and store-and-forward modes as needed. Simple, intuitive software shells will allow seamless access to pertinent patient records, radiographs, pathology slides, pharmacy information, and billing records. Instant access to on-line libraries of medical information, diagnosis and treatment algorithms, and patient instructional materials will be available. Referral to specialists and allied health personnel will be done by computer-based scheduling. Patient information will be stored in archives that can be accessed by authorized medical personnel anywhere in the world. Privacy and security will be provided by encrypting data and restricting user access by means of passwords.

The medical community should treat telemedicine as both a means of communication and a new diagnostic or therapeutic modality. Proper skepticism and caution should be matched by decisive implementation when there are well-defined opportunities to serve distressed populations. Research into safety, efficacy, cost-effectiveness, and satisfaction must be a high priority, and providers should be kept up to date with telemedicine developments. Using the lowest cost and most conventional technology that will meet clearly identified needs also seems prudent. Finally, decisions about large-scale implementation should be based on the services to be provided rather than the technology used. Telemedicine systems are simply one more method of providing needed medical services to patients and other medical care consumers.

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